EARTH SCIENCE

CK-12 Foundation
CK12

Default Text

This text is disseminated via the Open Education Resource (OER) LibreTexts Project (https://LibreTexts.org) and like the thousands of other texts available within this powerful platform, it is freely available for reading, printing, and "consuming."

The LibreTexts mission is to bring together students, faculty, and scholars in a collaborative effort to provide an accessible, and comprehensive platform that empowers our community to develop, curate, adapt, and adopt openly licensed resources and technologies; through these efforts we can reduce the financial burden born from traditional educational resource costs, ensuring education is more accessible for students and communities worldwide.

Most, but not all, pages in the library have licenses that may allow individuals to make changes, save, and print this book. Carefully consult the applicable license(s) before pursuing such effects. Instructors can adopt existing LibreTexts texts or Remix them to quickly build course-specific resources to meet the needs of their students. Unlike traditional textbooks, LibreTexts' web based origins allow powerful integration of advanced features and new technologies to support learning.



LibreTexts is the adaptable, user-friendly non-profit open education resource platform that educators trust for creating, customizing, and sharing accessible, interactive textbooks, adaptive homework, and ancillary materials. We collaborate with individuals and organizations to champion open education initiatives, support institutional publishing programs, drive curriculum development projects, and more.

The LibreTexts libraries are Powered by NICE CXone Expert and was supported by the Department of Education Open Textbook Pilot Project, the California Education Learning Lab, the UC Davis Office of the Provost, the UC Davis Library, the California State University Affordable Learning Solutions Program, and Merlot. This material is based upon work supported by the National Science Foundation under Grant No. 1246120, 1525057, and 1413739.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation nor the US Department of Education.

Have questions or comments? For information about adoptions or adaptions contact info@LibreTexts.org or visit our main website at https://LibreTexts.org.

This text was compiled on 03/29/2026

TABLE OF CONTENTS

Licensing

1: The Nature of Science

- 1.1: Scientific Explanations and Interpretations
- 1.2: Scientific Method
- 1.3: Developing Hypotheses
- 1.4: Testing Hypotheses
- 1.5: Correlation and Causation
- 1.6: The Nature of Science- Challenge 1
- 1.7: Observations and Experiments
- 1.8: Theories
- 1.9: Evolution, Plate Tectonics, and Climate Change
- 1.10: Scientific Models
- 1.11: Scientific Community
- 1.12: The Nature of Science- Challenge 2

2: Introduction to Earth Science

- 2.1: Branches of Earth Science
- 2.2: Earth Science Field Work
- 2.3: Uniformitarianism
- 2.4: Location
- 2.5: Direction
- 2.6: Elevation
- 2.7: Introduction to Earth Science- Challenge 1
- 2.8: Maps
- 2.9: Map Projections
- 2.10: Topographic and Geologic Maps
- 2.11: Seafloor
- 2.12: Introduction to Earth Science- Challenge 2
- 2.13: Telescopes
- 2.14: Study of Space by the Electromagnetic Spectrum
- 2.15: Satellites, Shuttles, and Space Stations
- 2.16: Introduction to Earth Science- Challenge 3

3: Planet Earth

- 3.1: Atoms and Molecules
- 3.2: Earth's Shape
- 3.3: Earth's Magnetic Field
- 3.4: Earth's Rotations
- 3.5: Earth's Revolutions
- 3.6: Coriolis Effect
- 3.7: Seasons
- 3.8: Planet Earth- Challenge 1
- 3.9: Eclipses
- 3.10: Solar Eclipses

- 3.11: Lunar Eclipses
- 3.12: Lunar Phases
- 3.13: Planet Earth- Challenge 2
- 3.14: Earth's Interior
- 3.15: Earth's Outer Layers
- 3.16: Earth's Inner Layers
- 3.17: Earth's Crust
- 3.18: Earth's Mantle
- 3.19: Earth's Core
- 3.20: Lithosphere and Asthenosphere
- 3.21: Planet Earth- Challenge 3

4: Earth's Minerals and Rocks

- 4.1: Minerals
- 4.2: Mineral Groups
- 4.3: Mineral Identification
- 4.4: Mineral Formation
- 4.5: Earth's Minerals and Rocks- Challenge 1
- 4.6: Rocks
- 4.7: Rock Cycle Processes
- 4.8: Igneous Rocks
- 4.9: Intrusive and Extrusive Igneous Rocks
- 4.10: Igneous Rock Classification
- 4.11: Earth's Minerals and Rocks- Challenge 2
- 4.12: Sedimentary Rocks
- 4.13: Lithification of Sedimentary Rocks
- 4.14: Sedimentary Rock Classification
- 4.15: Metamorphic Rocks
- 4.16: Metamorphic Rock Classification
- 4.17: Earth's Minerals and Rocks- Challenge 3

5: Plate Tectonics

- 5.1: Continental Drift
- 5.2: Wegener and the Continental Drift Hypothesis
- 5.3: Magnetic Polarity Evidence for Continental Drift
- 5.4: Bathymetric Evidence for Seafloor Spreading
- 5.5: Magnetic Evidence for Seafloor Spreading
- 5.6: Seafloor Spreading Hypothesis
- 5.7: Plate Tectonics- Challenge 1
- 5.8: Earth's Tectonic Plates
- 5.9: Tectonic Plate Motions
- 5.10: Theory of Plate Tectonics
- 5.11: Divergent Plate Boundaries in the Ocean
- 5.12: Divergent Plate Boundaries
- 5.13: Transform Plate Boundaries
- 5.14: Plate Tectonics- Challenge 2
- 5.15: Ocean-Continent Convergent Plates
- 5.16: Ocean-Ocean Convergent Plate Boundaries
- 5.17: Continent-Continent Convergent Plate Boundaries

- 5.18: Continental Margins
- 5.19: Supercontinent Cycle and Pangaea
- 5.20: Intraplate Activity
- 5.21: Plate Tectonics- Challenge 3

6: Geological Activity and Earthquakes

- 6.1: Geological Stresses
- 6.2: Principle of Horizontality
- 6.3: Folds
- 6.4: Faults
- 6.5: Mountain Building
- 6.6: Geological Activity and Earthquakes- Challenge 1
- 6.7: Earthquakes
- 6.8: Earthquake Zones
- 6.9: Earthquakes at Transform Plate Boundaries
- 6.10: Earthquakes at Convergent Plate Boundaries
- 6.11: Intraplate Earthquakes
- 6.12: Seismic Waves
- 6.13: Tsunami
- 6.14: 21st Century Tsunami
- 6.15: Geological Activity and Earthquakes- Challenge 2
- 6.16: Measuring Earthquake Magnitude
- 6.17: Locating Earthquake Epicenters
- 6.18: Earthquake Magnitude Scales
- 6.19: Predicting Earthquakes
- 6.20: Earthquake Damage
- 6.21: Earthquake Safe Structures
- 6.22: Staying Safe in an Earthquake
- 6.23: Geological Activity and Earthquakes- Challenge 3

7: Geological Activity and Volcanoes

- 7.1: Volcanoes
- 7.2: Volcanoes at Plate Boundaries
- 7.3: Volcanic Hot Spots
- 7.4: Magma Composition
- 7.5: Explosive Eruptions
- 7.6: Effusive Eruptions
- 7.7: Predicting Volcanic Eruptions
- 7.8: Geological Activity and Volcanoes- Challenge 1
- 7.9: Types of Volcanoes
- 7.10: Supervolcanoes
- 7.11: Volcanic Landforms
- 7.12: Hot Springs and Geysers
- 7.13: Geological Activity and Volcanoes- Challenge 2

8: Earth's Fresh Water

- 8.1: Distribution of Water on Earth
- 8.2: States of Water

- 8.3: The Water Cycle
- 8.4: Uses of Water
- 8.5: Water Distribution
- 8.6: Safety of Water
- 8.7: Conserving Water
- 8.8: Earth's Fresh Water- Challenge 1
- 8.9: Streams and Rivers
- 8.10: Ponds and Lakes
- 8.11: Flooding
- 8.12: Glaciers
- 8.13: Earth's Fresh Water- Challenge 2
- 8.14: Groundwater
- 8.15: Groundwater Aquifers
- 8.16: Springs and Geysers
- 8.17: Earth's Fresh Water- Challenge 3
- 8.18: Groundwater Depletion
- 8.19: Groundwater Pollution
- 8.20: Water Pollution
- 8.21: Protecting Water From Pollution
- 8.22: Cleaning Up Groundwater
- 8.23: Earth's Fresh Water- Challenge 4

9: Earth's Oceans

- 9.1: Importance of the Oceans
- 9.2: Seawater Chemistry
- 9.3: Ocean Zones
- 9.4: Earth's Oceans- Challenge 1
- 9.5: Wind Waves
- 9.6: Tides
- 9.7: Surface Currents
- 9.8: Ocean Currents and Climate
- 9.9: Deep Currents
- 9.10: Earth's Oceans- Challenge 2
- 9.11: Coastal Pollution
- 9.12: Ocean Garbage Patch
- 9.13: Oil Spills
- 9.14: Earth's Oceans- Challenge 3

10: Atmospheric Processes

- 10.1: Importance of the Atmosphere
- 10.2: Composition of the Atmosphere
- 10.3: Pressure and Density of the Atmosphere
- 10.4: Temperature of the Atmosphere
- 10.5: Atmospheric Processes- Challenge 1
- 10.6: Troposphere
- 10.7: Stratosphere
- 10.8: Mesophere
- 10.9: Thermosphere and Beyond
- 10.10: Atmospheric Processes- Challenge 2

- 10.11: Electromagnetic Energy in the Atmosphere
- 10.12: Solar Energy on Earth
- 10.13: Thermal Energy Transfer in the Atmosphere
- 10.14: Heat Budget of Planet Earth
- 10.15: Solar Energy and Latitude
- 10.16: Greenhouse Effect
- 10.17: Atmospheric Processes- Challenge 3
- 10.18: Circulation in the Atmosphere
- 10.19: Local Winds
- 10.20: Global Wind Belts
- 10.21: Atmospheric Processes- Challenge 4
- 10.22: Air Quality
- 10.23: Types of Air Pollution
- 10.24: Effects of Air Pollution on the Environment
- 10.25: Causes of Air Pollution
- 10.26: Acid Rain
- 10.27: Ozone Depletion
- 10.28: Reducing Air Pollution
- 10.29: Atmospheric Processes- Challenge 5

11: Weather

- 11.1: Introduction to Weather
- 11.2: Humidity
- 11.3: Clouds
- 11.4: Fog
- 11.5: Precipitation
- 11.6: Air Masses
- 11.7: Fronts
- 11.8: Weather- Challenge 1
- 11.9: Thunderstorms
- 11.10: Tornadoes
- 11.11: Cyclones
- 11.12: Hurricanes
- 11.13: Blizzards
- 11.14: Heat Waves and Droughts
- 11.15: Weather- Challenge 2
- 11.16: Collecting Weather Data
- 11.17: Predicting Weather
- 11.18: Weather Maps
- 11.19: Weather- Challenge 3

12: Climate

- 12.1: Weather vs. Climate
- 12.2: Effect of Latitude on Climate
- 12.3: Effect of Atmospheric Circulation on Climate
- 12.4: Effect of Continental Position on Climate
- 12.5: Effect of Altitude and Mountains on Climate
- 12.6: Climate- Challenge 1
- 12.7: Climate Zones and Biomes

- 12.8: Tropical Moist Climates
- 12.9: Dry Climates
- 12.10: Temperate Climates
- 12.11: Continental Climates
- 12.12: Polar Climates
- 12.13: Climate- Challenge 2
- 12.14: Climate Change in Earth History
- 12.15: Short-Term Climate Change
- 12.16: Carbon Cycle and Climate
- 12.17: Global Warming
- 12.18: Causes and Effects of Global Warming
- 12.19: Impact of Continued Global Warming
- 12.20: Reducing Greenhouse Gas Pollution
- 12.21: Climate- Challenge 3

13: Weathering and Soils

- 13.1: Weathering and Erosion
- 13.2: Mechanical Weathering
- 13.3: Chemical Weathering
- 13.4: Influences on Weathering
- 13.5: Weathering and Soils- Challenge 1
- 13.6: Soil Characteristics
- 13.7: Soil Formation
- 13.8: Soil Horizons and Profiles
- 13.9: Types of Soils
- 13.10: Soil Erosion
- 13.11: Avoiding Soil Loss
- 13.12: Weathering and Soils- Challenge 2

14: Erosion and Deposition

- 14.1: Erosion by Streams
- 14.2: Deposition by Streams
- 14.3: Erosion by Groundwater
- 14.4: Deposition by Groundwater
- 14.5: Erosion and Deposition- Challenge 1
- 14.6: Erosion by Waves
- 14.7: Deposition by Waves
- 14.8: Protecting Shorelines
- 14.9: Erosion by Wind
- 14.10: Deposition by Wind
- 14.11: Erosion and Deposition- Challenge 2
- 14.12: Erosion by Glaciers
- 14.13: Deposition by Glaciers
- 14.14: Landforms from Erosion and Deposition
- 14.15: Erosion and Deposition- Challenge 3

15: Understanding Earth's History

- 15.1: How Fossilization Creates Fossils
- 15.2: Types of Fossilization
- 15.3: Earth History and Clues from Fossils
- 15.4: Understanding Earth's History- Challenge 1
- 15.5: Principles of Relative Dating
- 15.6: Determining Relative Ages
- 15.7: Correlation Using Relative Ages
- 15.8: Geologic Time Scale
- 15.9: Understanding Earth's History- Challenge 2
- 15.10: Tree Rings, Ice Cores, and Varves
- 15.11: Radioactive Decay as a Measure of Age
- 15.12: Radiometric Dating
- 15.13: Age of Earth
- 15.14: Understanding Earth's History- Challenge 3

16: Earth's History

- 16.1: Formation of the Sun and Planets
- 16.2: Formation of Earth
- 16.3: Formation of the Moon
- 16.4: Early Atmosphere and Oceans
- 16.5: Earth's History- Challenge 1
- 16.6: Precambrian Continents
- 16.7: Paleozoic Plate Tectonics
- 16.8: Paleozoic and Mesozoic Seas
- 16.9: Mesozoic Plate Tectonics
- 16.10: Cenozoic Plate Tectonics
- 16.11: Earth's History- Challenge 2

17: Evolution and Populations

- 17.1: Modern Biodiversity
- 17.2: Characteristics and Origins of Life
- 17.3: Metabolism and Replication
- 17.4: Adaptation and Evolution of Populations
- 17.5: Theory of Evolution by Natural Selection
- 17.6: Population Size
- 17.7: Extinction and Radiation of Life
- 17.8: Evolution and Populations- Challenge 1
- 17.9: Growth of Human Populations
- 17.10: Agriculture and Human Population Growth
- 17.11: Revolutions in Human Population
- 17.12: Overpopulation and Over-Consumption
- 17.13: Future Human Population Growth
- 17.14: Sustainable Development
- 17.15: Evolution and Populations- Challenge 2

18: Ecosystems

- 18.1: Biological Communities
- 18.2: Roles in an Ecosystem
- 18.3: Flow of Energy in Ecosystems
- 18.4: Flow of Matter in Ecosystems
- 18.5: Nitrogen Cycle in Ecosystems
- 18.6: Ecosystems- Challenge 1
- 18.7: Fresh Water Ecosystems
- 18.8: Types of Marine Organisms
- 18.9: Marine Food Chains
- 18.10: Ocean Ecosystems
- 18.11: Ecosystems- Challenge 2

19: History of Life on Earth

- 19.1: Evolution of Simple Cells
- 19.2: Evolution of Eukaryotes to Multicellular Life
- 19.3: Life of the Phanerozoic Eon
- 19.4: History of Paleozoic Life
- 19.5: History of Mesozoic Life
- 19.6: History of Cenozoic Life
- 19.7: Human Evolution
- 19.8: Life and the Geologic Time Scale
- 19.9: History of Life on Earth- Challenge

20: Earth's Energy

- 20.1: Energy Resources
- 20.2: Obtaining Energy Resources
- 20.3: Energy Conservation
- 20.4: Renewable vs. Nonrenewable Energy Resources
- 20.5: Earth's Energy- Challenge 1
- 20.6: Fossil Fuel Formation
- 20.7: Coal Power
- 20.8: Petroleum Power
- 20.9: Natural Gas Power
- 20.10: Fossil Fuel Reserves
- 20.11: Nuclear Power
- 20.12: Earth's Energy- Challenge 2
- 20.13: Solar Energy
- 20.14: Hydroelectric Power
- 20.15: Wind Energy
- 20.16: Geothermal Energy
- 20.17: Biomass Energy
- 20.18: Earth's Energy- Challenge 3

21: Earth's Materials

- 21.8: Preventing Hazardous Waste Problems
- 21.1: Materials Humans Use
- 21.2: Renewable vs. Nonrenewable Resources

- 21.3: Ore Deposits
- 21.4: Ore Mines
- 21.5: Ore Extraction
- 21.6: Earth's Materials- Challenge 1
- 21.7: Environmental Impacts of Mining
- 21.8: Hazardous Waste
- 21.10: Earth's Materials- Challenge 2
- 21.11: Availability of Natural Resources
- 21.12: Natural Resource Conservation
- 21.13: Earth's Materials- Challenge 3

22: The Solar System

- 22.3: Outer Layers of the Sun
- The Solar System: Challenge 1
- 22.1: Sun
- 22.2: Interior of the Sun
- 22.4: Surface Features of the Sun
- 22.6: Planets of the Solar System
- 22.7: Planet Orbits in the Solar System
- 22.8: Gravity in the Solar System
- 22.9: The Solar System- Challenge 2
- 22.10: Inner vs. Outer Planets
- 22.11: Mercury
- 22.12: Venus
- 22.13: Moon
- 22.14: Mars
- 22.15: The Solar System- Challenge 3
- 22.16: Jupiter
- 22.17: Saturn
- 22.18: Uranus
- 22.19: Neptune
- 22.20: The Solar System- Challenge 4
- 22.21: Exoplanets
- 22.22: Asteroids
- 22.23: Comets
- 22.24: Meteors
- 22.25: Dwarf Planets
- 22.26: The Solar System- Challenge 5

23: Beyond the Solar System

- 23.1: Star Constellations
- 23.2: Star Power
- 23.3: Star Classification
- 23.4: Star Formation
- 23.5: Beyond the Solar System- Challenge 1
- 23.6: Main Sequence Star Lives
- 23.7: Red Giants and White Dwarfs
- 23.8: Supergiants and Supernovas
- 23.9: Neutron Stars and Black Holes

- 23.10: Beyond the Solar System- Challenge 2
- 23.11: Star Clusters
- 23.12: Galaxies
- 23.13: The Milky Way
- 23.14: Universe
- 23.15: Expansion of the Universe
- 23.16: Big Bang
- 23.17: Dark Matter
- 23.18: Beyond the Solar System- Challenge 3

Index

Glossary

Detailed Licensing

Licensing

*A detailed breakdown of this resource's licensing can be found in **Back Matter/Detailed Licensing**.*

CHAPTER OVERVIEW

1: The Nature of Science

1.1: Scientific Explanations and Interpretations
1.2: Scientific Method
1.3: Developing Hypotheses
1.4: Testing Hypotheses
1.5: Correlation and Causation
1.6: The Nature of Science- Challenge 1
1.7: Observations and Experiments
1.8: Theories
1.9: Evolution, Plate Tectonics, and Climate Change
1.10: Scientific Models
1.11: Scientific Community
1.12: The Nature of Science- Challenge 2

This page titled 1: The Nature of Science is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

1.1: Scientific Explanations and Interpretations

What is a fact?

Science is different from other ways of thinking. It is based on facts. Gravity is a fact. If you let go of a ball, it will fall to the ground. Can you tell a fact from an opinion? Can you tell when an idea follows logically from a fact? Basing ideas on facts is essential to good science.

Facts, Observations, Opinions

Science is a set of facts, and it is also a set of explanations that are based on those facts. Science relies on facts to explain the natural world.

Scientists usually begin an investigation with facts. A **fact** is a bit of information that is true. Facts come from data collected from observations. Facts can also come from experiments that have been run. **Data** is factual information that results from an investigation. Facts and data are not subject to opinion or bias. An opinion is someone's subjective view or position on a subject.

What is a fact? Look at the following list. Identify if the statement is (1) a fact (from observation or prior experiments), (2) an opinion, or (3) a combination.



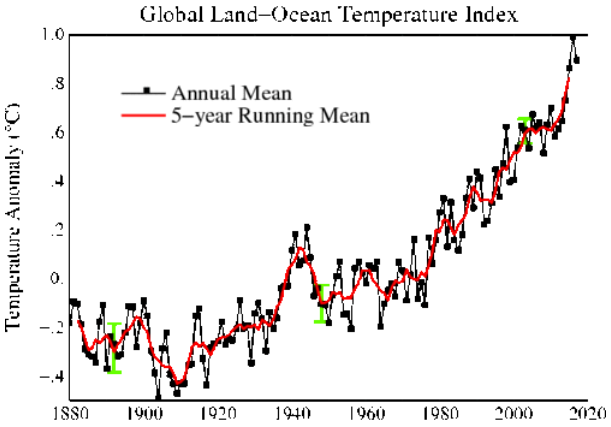
Can you be sure from the photo that Susan has a cold?

1. Susan (**Figure** above) has black hair.
2. Susan is sneezing. She has a cold.
3. Colds are caused by viruses.
4. Echinacea is an herb that prevents colds.
5. Jeff Bezos is the smartest man in the United States.
6. People born under the astrological sign Leo are fiery, self-assured, and charming.
7. Average global temperature has risen since 1900.

An Analysis

The following is an analysis of the statements above:

1. This is a fact. The fact comes from observation.
2. The first sentence is a fact from observation. The woman is sneezing. The second sentence is an opinion. She might have a cold, or she might have allergies or the flu. Tests could be done to see what is causing her illness. This opinion could become fact if the tests show that she actually has a cold, or it could be proven wrong.
3. This is a fact. Many, many scientific experiments have shown that colds are caused by viruses.
4. This statement sounds like a fact. However, the scientific evidence is mixed. One reputable study published in 2007 showed a decrease in colds of 58% in people who used echinacea. Several other studies have shown no beneficial effect.
5. Jeff Bezos is the wealthiest man in the United States; that's a fact. However, there's no evidence that he's also the smartest man; this is an opinion.
6. This sounds like a fact, but it is not. There must be data to support the statement. How would you test it? Gather together a large number of subjects, each with a friend. Have the friends fill out a questionnaire describing the subject. Match the traits against the person's astrological sign. Do the astrological predictions fit? Are Leos actually more fiery, self-assured, and charming? Tests like this have not supported the claims of astrologers. However, astrologers have not modified their opinions.
7. This is a fact. The following graph shows the temperature anomaly since 1880 (**Figure** below). There's no doubt that average global temperature has risen since 1880. The largest rise has been since the late 1970s.



Global average annual temperatures are rising. This graph shows temperature anomaly relative to the 1951-1980 average (the average is made to be 0). The green bars show uncertainty.

Summary

- Facts are true. Data, gathered correctly, is factual. Facts and data are not subject to opinion or bias.
- Facts can be determined by observations or experiments.
- Some statements that appear to be facts are not.
- All scientific explanations and interpretations are based on facts.

Review

1. What is a fact? What is data? What is an opinion? How can you tell them apart?
2. Why are facts and data important to science?
3. How might a fact be disproved? Are there some facts that will never be disproved?

Explore More

Use this resource to answer the questions that follow.



1. How do we use science every day?
2. What is science?
3. What is the scientific process?
4. Define science.
5. What are the rules of science?

This page titled 1.1: Scientific Explanations and Interpretations is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

1.2: Scientific Method



How many angels can dance on the head of a pin?

This is a question that has been pondered over the centuries. Can it be answered using the scientific method? Is it a scientific question?

The Goal of Science

The goal of science is to answer questions about the natural world. Asking (and answering) questions is integral to the process of science. Scientific questions must be testable. Which of these two questions is a good scientific question and which is not?

- What is the age of our planet Earth?
- How many angels can dance on the head of a pin?

The first is a good scientific question. It can be answered by age-dating rocks and by using other techniques. The second question cannot be answered using data. It is not a scientific question.

Scientific Method

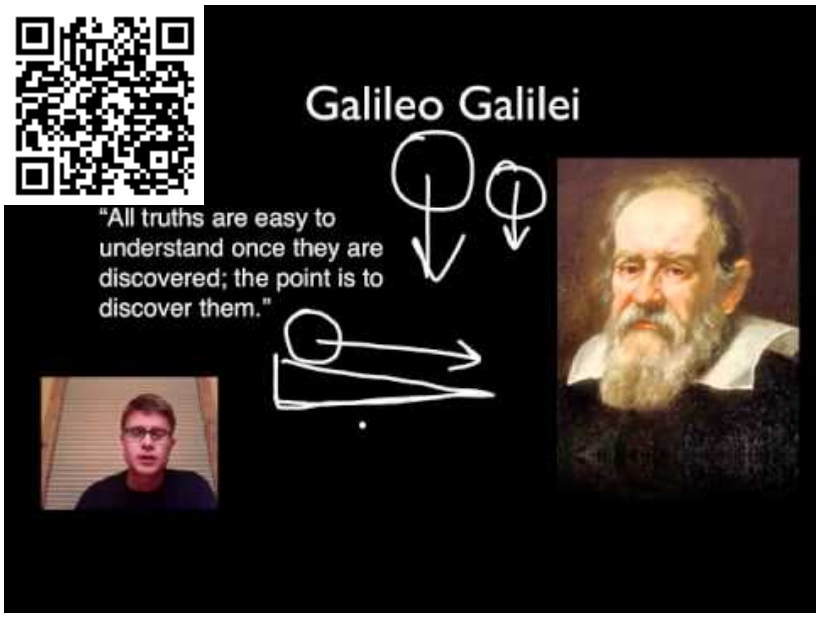
Scientists use the **scientific method** to answer questions. The scientific method is a series of steps. These steps help scientists (or even just people!) investigate a question.

Often, students learn that the scientific method goes from step to step to step in a specific order, like so:

- Ask a question. The question can be based on one or more observations or on data from a previous experiment.
- Do some background research.
- Create a hypothesis. Use your imagination and reasoning skills.
- Conduct experiments or make observations to test the hypothesis.
- Gather the data.
- Use logical reasoning to formulate a conclusion.

In reality, however, the process doesn't always go in a straight line. A scientist might ask a question and then start doing some background research. During his research, he may discover that his original question needed to be asked in a different way, or that an entirely different question should be asked. As a result, he is brought back to the first step of the scientific method.

LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



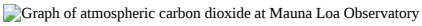
Ask a Question

Now, let's ask a scientific question. Remember that it must be testable.

We learned in the previous concept, "Scientific Explanations and Interpretations," that the average global temperature has been on the rise. Scientists know that carbon dioxide is a **greenhouse gas**. Greenhouse gases trap heat in the atmosphere. This leads us to a question:

Question: Is the amount of carbon dioxide in Earth's atmosphere changing?

This is a good scientific question because it is testable.



According to data collected at the Mauna Loa Observatory in Hawaii, atmospheric carbon dioxide has been increasing since record keeping began in 1958. The small ups and downs of the red line are due to seasonal changes in the winter and summer. The black line traces the annual average.

How has carbon dioxide in the atmosphere changed since 1958 (**Figure** above)? The line on the graph is going up so carbon dioxide has increased. About how much has it increased in parts per million?

So we've answered the question. We used data from research that has already been done. Fortunately, scientists have been monitoring CO_2 levels over the years. If they hadn't, we'd have to start these measurements now.

Because this question can be answered with data, it is testable.

Summary

- Scientific questions must be testable.
- Scientists use the scientific method to answer questions about the natural world.

Review

1. What feature does a question need to have in order to be a good scientific question?
2. Create a question that is a good scientific question. Create a question that is not a good scientific question.
3. Look at the graph of atmospheric CO_2 measured at the Mauna Loa Observatory over time (**Figure** above). How much has the atmospheric CO_2 content risen since 1958?

Explore More

Use this resource to answer the questions that follow.

403 ERROR

The request could not be satisfied.

Request blocked. We can't connect to the server for this app or website at this time. There might be too much traffic or a configuration error. Try again later, or contact the app or website owner.
If you provide content to customers through CloudFront, you can find steps to troubleshoot and help prevent this error by reviewing the CloudFront documentation.

```
Generated by cloudfront (CloudFront)
Request ID: KGe_qAERp-ure4cSeH43qAQVC6KSmGoXU8RoMxOTRrJLSiPGjb_CFQ
```

1. What is the first rule of writing scientific questions?
2. What is the second rule?
3. What type of questions should NOT be used?
4. What is the third rule?
5. Write a good scientific question that follows the three rules.

This page titled 1.2: Scientific Method is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

1.3: Developing Hypotheses

What is a hypothesis?

An educated guess? Is that what you learned a hypothesis is? Lots of people have learned that, but it's not exactly right. So what is a hypothesis? There are two hypotheses listed below. They address a question about carbon dioxide in the atmosphere. Check out what those hypotheses are. Then we'll see what to do with them next.

Asking a New Question

First, we need to find a question that we want to answer. Let's start with the fact that atmospheric CO_2 has been increasing since 1958. This leads us to ask the following: why is atmospheric CO_2 increasing?

Possible Answers to the Question

A **hypothesis** is a reasonable explanation for a small range of phenomena. A hypothesis is limited in scope; it attempts to explain a single event or a fact. A hypothesis must be **testable** and **falsifiable**. In other words, we must be able to test it, and we must be able to disprove it.

Back to answering the question. Let's say we do some background research to learn the possible sources of carbon dioxide in the atmosphere. We discover that there are at least two (there are actually many more):

- CO_2 is released into the atmosphere by volcanoes when they erupt.
- CO_2 is released when fossil fuels are burned.

From these two facts, we can create two hypotheses; we will have **multiple working hypotheses**. We can test each of these hypotheses. We can prove either or both of these hypotheses false. In this case, it's even possible that both are true.

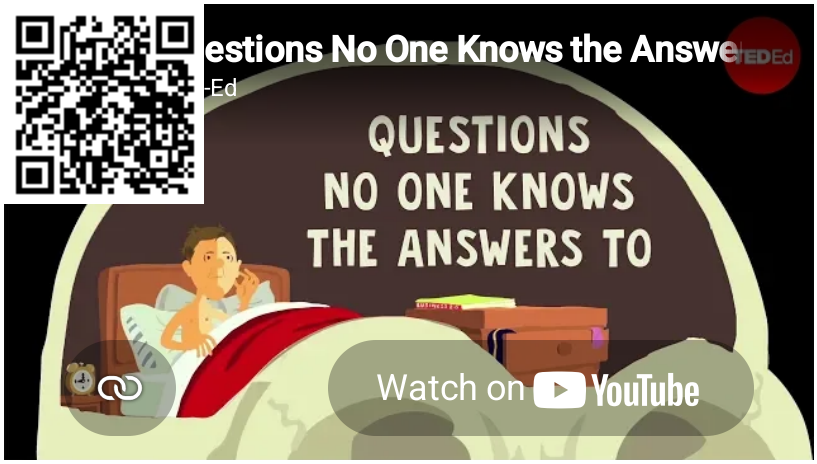
Hypothesis 1

Atmospheric CO_2 has increased over the past five decades because the amount of CO_2 gas released by volcanoes has increased.

Hypothesis 2

The increase in atmospheric CO_2 is due to the increase in the amount of fossil fuels that are being burned.

Usually, testing a hypothesis requires making observations or performing experiments. In this case, we will look into existing scientific literature to see if either of these hypotheses can be disproved, or if one or both can be supported by the data.



Summary

- A hypothesis is a reasonable explanation for a small range of phenomena.
- A scientific hypothesis must be both testable and falsifiable.
- If two or more hypotheses are being tested, they are called multiple working hypotheses.

Review

1. How is a hypothesis "a reasonable explanation”? Why is that a better definition than “an educated guess”?
2. What if a hypothesis is shown to be wrong: Is the question the scientists are trying to answer a bad question?
3. What are multiple working hypotheses? What are the two hypotheses proposed to answer the question in this concept?

Explore More

Use the resource below to answer the questions that follow.



1. What is a hypothesis?
2. Why is it important to have a specific hypothesis?
3. How can you test a scientific hypothesis?
4. Write an example of a hypothesis, and explain how you would test it.

This page titled 1.3: Developing Hypotheses is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

1.4: Testing Hypotheses

How can I show that my hypothesis is wrong?

Many young scientists learn that a good scientist tries to disprove her hypothesis. This is the best way to be sure that your hypothesis is getting a rigorous test. Why do you think established scientists tell students this? Why is it a good idea?

Testing Hypotheses

How do you test a hypothesis? Often you need scientific tools, perhaps a microscope or a magnetometer. You need to know how to analyze the data that come from those tools. Often computers are needed to gather, analyze, and interpret the data.

In this example, we will look into the scientific literature to find data. These studies were done using scientific method. The scientists used the necessary tools and computers. To test a new hypothesis, we would need to do the experiments ourselves.

We will test the two hypothesis that we developed to explain this fact: Atmospheric CO_2 has increased over the past five decades.

Testing Hypothesis 1

Hypothesis 1: Atmospheric CO_2 has increased over the past five decades because the amount of CO_2 gas released by volcanoes has increased.

To test Hypothesis 1, we need to see if the amount of CO_2 gas released by volcanoes over the past several decades has increased.

There are two ways volcanoes could account for the increase in CO_2:

- There has been an increase in volcanic eruptions in that time.
- The CO_2 content of volcanic gases has increased over time globally.

Our research tells us that 50-70 eruptions occur every year. We see that the number of volcanic eruptions is about constant. We learn from different scientific papers that volcanic gas compositions have not changed over time. Different types of volcanoes have different gas compositions. However, the gases overall are the same. Another scientific paper states that major volcanic eruptions for the past 30 years have caused short-term cooling, not warming!

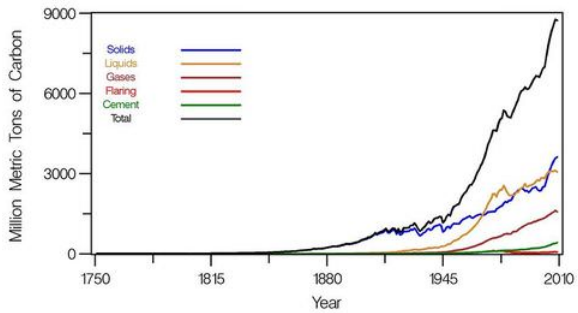
Hypothesis 1 is wrong! Volcanic activity is not able to account for the rise in atmospheric CO_2. Remember that science is falsifiable. We can discard Hypothesis 1.

When a hypothesis is wrong, often much has been learned anyway. Rarely is the pursuit of a hypothesis a total loss!

Testing Hypothesis 2

Hypothesis 2: The increase in atmospheric CO_2 is due to the increase in the amount of fossil fuels that are being burned.

To test hypothesis 2, we need to see if the amount of CO_2 gas released by fossil fuels over the past several decades has increased. We look into the scientific literature and find the following graph (**Figure** below).



Global carbon dioxide emissions from fossil fuel consumption and cement production. The black line represents all emission types combined. The colored lines show emissions from individual fossil fuels.

Fossil fuels have added an increasing amount of carbon dioxide to the atmosphere since the beginning of the Industrial Revolution in the mid 19th century. Hypothesis 2 appears to be at least partly true!

It is very important when testing hypotheses to eliminate any bias. A biased researcher may miss important factors that do not match his bias. It actually is good to try to disprove your own hypothesis! Having other researchers involved will also help to eliminate bias.

Summary

- Science is falsifiable. An incorrect hypothesis is discarded.
- Carbon dioxide levels in the atmosphere are increasing. Fossil fuel burning is increasing. The rise in fossil fuel burning is increasing the CO_2 in the atmosphere.
- More than one hypothesis can be tested at a time. This is called multiple working hypotheses.

Review

1. Could there be other reasons that CO_2 has been increasing in the atmosphere for the past several decades? Could there be more than one reason?
2. At this moment, can we say that the increase in fossil fuel burning is causing the increase in CO_2 in the atmosphere?
3. At this moment, can we say that the increase in fossil fuel burning is causing the rise in average global temperature?
4. What do we need to do next to address the last two questions?

Explore More

Use the resource below to answer the questions that follow.



1. How are they using the word "theory" in this video? What word would be more accurate for them to use in this context?
2. What is the hypothesis they are testing?
3. How do they test the hypothesis?
4. What were their results?
5. Is their hypothesis absolutely, certainly correct? If so, explain your reasoning. If not, what can they do to further narrow down whether the hypothesis is correct?

This page titled 1.4: Testing Hypotheses is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

1.5: Correlation and Causation



Sugar consumption is up. Global temperatures are up. Is one causing the other?

Is the rise in sugar consumption in America causing the average global temperature to rise? Are rising temperatures causing people to eat more sugar? Both of these factors are rising, but how are they related? Are they related by correlation, causation, or both?

Correlation

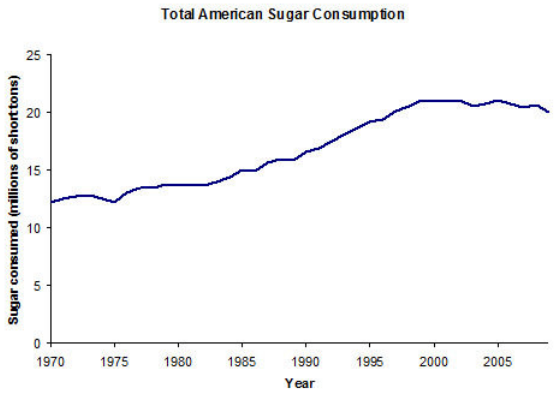
We made a few discoveries so far in this concept:

- Average global temperature has been rising for the past several decades.
- Atmospheric carbon dioxide levels have been rising for the past several decades.
- Carbon dioxide emissions into the atmosphere from fossil fuel burning have been rising for the past several decades.

A **correlation** is the mutual relationship between two or more things. We see here a correlation between three things: (1) CO_2 emissions from fossil fuel burning are rising (2) atmospheric CO_2 levels are rising, and (3) average global temperatures are rising. These three things exhibit **positive correlation**. They are all going in the same direction. If one factor rises while another sinks, they have **negative correlation**. For example, the amount of forest land is decreasing. This factor has a negative correlation with global temperature.

Causation

But correlation does not necessarily indicate causation. **Causation** refers to the factor that is producing the effect. If I push a toy car, I will cause it to move. To explain the difference between correlation and causation, let's look at an example. Sugar consumption in the United States has been rising for decades (**Figure** below). There is a positive correlation between sugar consumption and rising average global temperatures.



American consumption of sugar, 1970-2009.

https://k12.libretexts.org/@go/page/5313

Is the rise in sugar consumption causing the rise in global temperatures? Is the rise in global temperatures causing the rise in sugar consumption? These two things aren't impossible, but they are extremely unlikely. There's no **mechanism** for one to increase the other. Here there is correlation, not causation. To establish causation we need to know how one would cause the other.

Fossil Fuel Burning Causes Temperatures to Rise

Here is a brief outline of the way an increase in CO_2 can increase global temperatures. This is a logical step-by-step argument. There is no part of this explanation that goes beyond the evidence.

- Greenhouse gases in the atmosphere trap heat. CO_2 is a greenhouse gas.
- Burning fossil fuels releases CO_2 into the atmosphere.
- The more greenhouse gases there are in the atmosphere, the more heat can be trapped.
- The more heat that's trapped, the warmer average global temperatures are.

Because carbon dioxide is a greenhouse gas, increased CO_2 in the atmosphere causes average global temperatures to rise. We found one cause for rising global temperatures. There are also others. Climate change science is dealt with extensively in the chapters *Atmospheric Processes* and *Weather and Climate*.

Summary

- Correlation is a comparison of two factors within a population. Correlation does not imply causation.
- If one factor is responsible for the change in another factor, there is causation.
- Establishing causation requires a mechanism to show how one factor can influence the other.
- Burning fossil fuels releases CO_2 into the atmosphere. That CO_2 traps heat, which causes global temperatures to rise.

Review

1. Describe correlation. Describe causation.
2. Sugar consumption has been rising in the U.S. for decades. Can you think of something this might be positively correlated with? Could one be causal of the other?
3. Outline the logical steps that link fossil fuel emissions to rising average global temperature.

Explore More

Use the resources below to answer the questions that follow.



1. Why did people fear polio?
2. Why did people think there was a correlation between ice cream and polio?



3. Why are there more police in Washington, D.C. than in Denver? Where is there more crime? Do police cause crime? Then why are there more police in Washington, D.C.?
4. Explain why people often confuse correlation and causation.

This page titled 1.5: Correlation and Causation is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

1.6: The Nature of Science- Challenge 1

1. Facts and data are objective, while an opinion is ___.

subjective

2. All science is based on facts and ___.

data

3. ___ are factual information that results from an investigation.

Data

4. A series of steps that help to investigate a scientific question is ___.

the scientific method

5. After finding out that carbon dioxide is increasing in the atmosphere, what would be a good question to try to answer with an experiment?

The following or similar questions are valid: What is causing the increase in carbon dioxide in the atmosphere? Which other greenhouse gases are increasing in
the atmosphere? What is the effect of increasing atmospheric carbon dioxide on the atmosphere?

6. There are several steps for solving a problem: recognizing and identifying, forming a hypothesis, analyzing data, and testing a hypothesis. What is the correct order of these steps?

Recognizing and identifying (1), forming a hypothesis (2), testing a hypothesis (3), and analyzing data (4)

7. A scientist uses information about a phenomenon to formulate a reasonable, testable explanation called a ___.

hypothesis

8. A hypothesis is discarded when ___.

data contradict the hypothesis.

9. A ___ is based on observations and must be testable and falsifiable.

hypothesis

10. The rise of fossil fuel burning, such as coal, is increasing the amount of ___ in the atmosphere.

carbon dioxide

11. Why does a hypothesis have to be falsifiable?

It must be possible to show that it is wrong.

12. If data contradict an existing hypothesis, then ___.

an analysis must be done to see if the hypothesis should be modified or abandoned

13. A ___ is the mutual relationship between two or more things.

correlation

14. ___ is when one thing is responsible for another thing happening.

Causation

15. Carbon dioxide in the atmosphere is a ___ gas that traps heat, causing the global average temperature to rise.

greenhouse

This page titled 1.6: The Nature of Science- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

1.7: Observations and Experiments



How do you test a hypothesis?

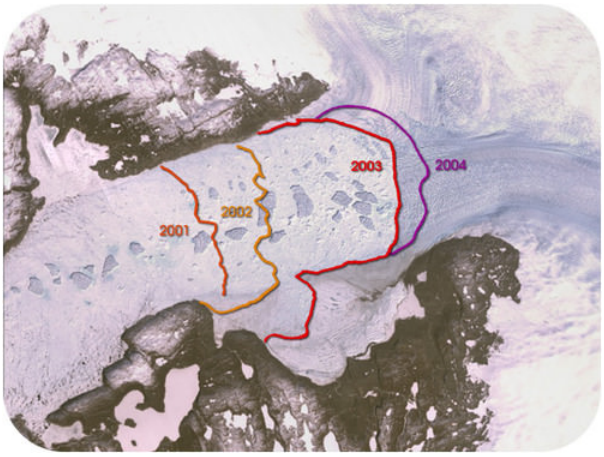
When you test a hypothesis, you must make observations or perform experiments. So far in this concept we have used scientific papers that were published. The papers were available because scientists collected that data using scientific method. If we asked a new question, we would need to do the testing ourselves. How might you do the testing yourself?

Testing Hypotheses

To test a hypothesis you need data. How do you collect data? By making observations or running experiments.

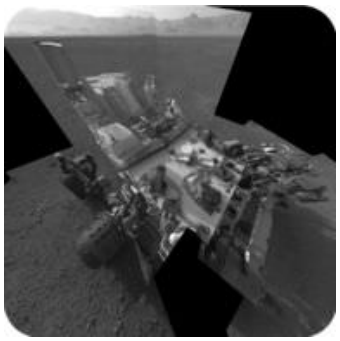
Observations

Observations can happen on many scales. You can use a microscope to observe tiny things. You can use a telescope to observe distant things in space. To learn about the effects of climate change, you could observe Earth's surface. How would you make observations of Earth's surface? You could do this from the land surface or from space. Many important observations are made by orbiting satellites. These satellites have a bird's eye view of how the planet is changing (**Figure** below).



This satellite image shows the retreat of the Jakobshavn Isbrae Glacier in Greenland from 2001-2004.

Observations are made when it is not possible to do experiments. Scientists send devices to make observations in dangerous places. They send devices to places that are difficult for people to go. For example, many rovers have been to Mars (**Figure** below). There will probably be many more before the first human gets there.



Portrait of the Curiosity rover that landed on Mars on August 5, 2012.

Experiments

Answering some questions requires **experiments**. An experiment is a test that may be performed in the field or in a laboratory. An experiment must always be done under controlled conditions. The goal of an experiment is to test a hypothesis. The data from the experiment will verify or falsify the hypothesis.

Variables

In an experiment, it is important to change only one factor. All other factors must be kept the same.

- **independent variable**: The factor that will be changed.
- **dependent variable**: The factors that depend on the independent variable.

An experiment must have a **control group**. In the control group, nothing is changed. It is not subjected to the independent variable. For example, say you want to test if Vitamin C prevents colds. You gather a large number of people to be your sample group. Then you divide your sample group up. Some receive Vitamin C and some do not. Those who do not receive the Vitamin C are the control group. Vitamin C is the independent variable.

Why should an experiment manipulate only one variable? Imagine a woman who eats a diet heavy on junk food. She is low on energy and says she just doesn't feel right. She decides to change her diet. She cuts out dairy products, wheat, meat and refined sugar. She also cuts out junk food. She feels better! She insists that the cause of her new well-being is the lack of dairy, wheat, meat, and sugar. But it's also possible that she feels better because she eliminated junk food. In other words, she doesn't know what made her feel better. Is it possible that it was eliminating junk food that made her feel better? Is it possible it was eliminating wheat? Meat? Maybe she's lactose intolerant and it was milk. Of course, it could have been any of those things. She doesn't know what it is that made her feel better because she changed too many variables. How could she be more scientific about understanding exactly what it was in her diet that was making her feel bad?

Experimental Error

Scientists make many measurements during experiments. Humans and equipment can make mistakes. Errors are often unavoidable. This is called **experimental error**. Errors may be due to the equipment being used. In this case, the numbers may be always skewed in one direction. For example, a scale may always measure one-half of an ounce high. People can also make errors. A measurement may not be made precisely. For example, a stopwatch may be stopped too soon or too late. But probably not always in the same direction. To correct for this, many measurements are taken. The measurements are then averaged. Experiments always have a margin of error associated with them.

Summary

- Testing a hypothesis requires data. Data can be gathered by observations or by experiments.
- Observations can be done simply by looking at and measuring a phenomenon. Observations can also be done by using advanced technology.
- Experiments must be well-designed. They must be done under controlled conditions. Only one variable should be manipulated.
- Errors are always possible in human endeavors. Scientists have ways to reduce the effects of errors on their data.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Review

1. When would a scientist test a hypothesis using observations?
2. When would a scientist test a hypothesis using experiments?
3. What is the difference between an independent variable and a dependent variable in an experiment?

Explore More

Use the resource below to answer the questions that follow.

403 ERROR

The request could not be satisfied.

Request blocked. We can't connect to the server for this app or website at this time. There might be too much traffic or a configuration error. Try again later, or contact the app or website owner.
If you provide content to customers through CloudFront, you can find steps to troubleshoot and help prevent this error by reviewing the CloudFront documentation.

```
Generated by cloudfront (CloudFront)
Request ID: B65zNDnwmV7rQuBmQ6AueqL5ymngWITTom6XoB57x4YW
```

1. What is an observation?
2. What is an inference?
3. For each picture in the slideshow (slides 14 to 24), list an observation and then an inference. How can you tell the difference?

This page titled 1.7: Observations and Experiments is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

1.8: Theories



Do you have a theory about why this batter can't hit?

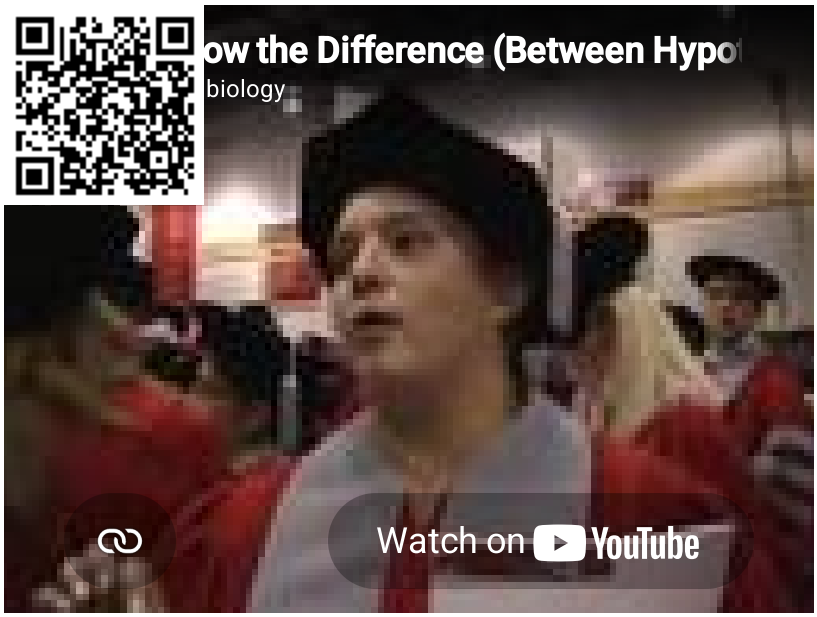
This batter hasn't hit a ball in his last 20 at bats. His coach has a theory: it's because he needs glasses. The idea is a good one, although it is not a theory. In common speech, the word theory is often misused. It is often misused when referring to scientific ideas as well. What would be a better word to use?

Theory

Scientists collect evidence to test a hypothesis. The evidence may refute the hypothesis. In that case, it will be thrown out. The evidence may support the hypothesis. The scientists will then gather more evidence. The scientists will accept the hypothesis if: (1) There is no significant evidence to refute the hypothesis. (2) There is an enormous amount of evidence to support the hypothesis. The hypothesis may then become a theory.

A scientific **theory** is supported by many types of evidence. It is a synthesis of evidence from many experiments and observations. A theory has no major inconsistencies. A theory is a simple model of reality. It is simpler than the phenomenon itself. A theory explains a phenomenon. Scientists can use a theory to make predictions.

A theory is constantly tested. If some data does not agree with the theory, the theory can be revised. If the theory cannot match the data, it is thrown out. That being said, sometimes a theory is well-established; it has a lot of evidence to back it up. A well-established theory is unlikely to be overthrown. It may just need to be modified a bit. But science does not prove anything beyond a shadow of a doubt.

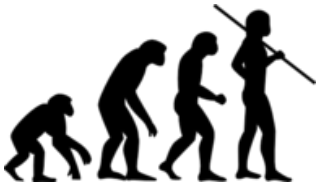


Three Essential Theories

The three theories below are essential in Earth science. Each accounts for an enormous amount of data. Each is supported by many lines of evidence. All can be used to make predications. As new evidence arises, any of these theories may need to be altered. But none of these three are likely ever to be disproved. They are accepted by nearly all of the credible scientists in their fields.

The Theory of Evolution

Evolution means change over time. Darwin's theory of **evolution** says that organisms change over time (**Figure** below). Evolution is seen in the fossil record. It is seen in the way organisms develop. Evolution is evident in the geographic locations where organism are found. It is evident in the genes of living organisms. Evolution has a mechanism called **natural selection**. The organism that is best suited to its environment is most likely to survive.



The theory of evolution maintains that modern humans evolved from ape-like ancestors.

The Theory of Plate Tectonics

Plate tectonics theory says that slabs of continents move around on Earth's surface. The mechanism for that movement is seafloor spreading. Plate tectonics explain many things about Earth: (1) geological activity, why it happens where it does; (2) natural resources, why many are found where they are; and (3) the past and future, what happened in the past and what will happen in the future. The theory of plate tectonics will be explored in the chapter *Plate Tectonics*.

The Theory of Climate Change

The theory of climate change is very new. In fact, scientists don't even call it a theory. But it meets the requirements. These are the things we know: (1) average global temperatures are rising, (2) greenhouse gases trap heat in the atmosphere, (3) CO_2 is released into the atmosphere when fossil fuels are burned, (4) CO_2 is a greenhouse gas, (5) more CO_2 in the atmosphere traps more heat so global temperature is rising. No information contradicts this theory, although some details have not been worked out. The theory is very effective at predicting future events, which are already taking place. This idea will be explored in detail in the chapter *Atmospheric Processes*.

Laws

Many people think that any idea that is completely accepted in science is a law. But that is not true. In science, a **law** is something that always applies under the same conditions. A law explains a fairly simple phenomenon. A theory is much more complex: it tells you why something happens. A law only tells you that it happens. For example, if you hold something above the ground and let go, it will fall. This phenomenon is recognized by the law of gravity (**Figure** below). Some people say that evolution is "just a theory." But for a complex explanation like evolution, theory is the right word.



Skydiving is possible because of the law of gravity.

Summary

- A theory is an explanation of a complex phenomenon. A theory tells why something happens.
- A theory can be used to predict future events.
- A law describes something that always happens under the same set of circumstances. A law does not say why it happens. But even laws do not always hold.

Review

1. Compare and contrast hypothesis, theory, and law.
2. Can a hypothesis become a theory?
3. Which of these, if any, is most important in science: hypothesis, theory, or law?

Explore More

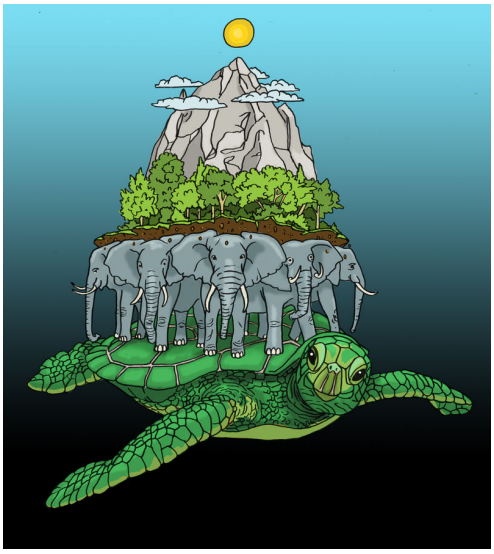
Use the resource below to answer the questions that follow.



1. What is a scientific theory?
2. What can be done with a theory?
3. What is a law?
4. Why is the phrase "only a theory" misleading?

This page titled 1.8: Theories is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

1.9: Evolution, Plate Tectonics, and Climate Change



How do you know this isn't what the world is like?

The natural world wouldn't make much sense without the theories scientists have developed to explain the things that happen or that we observe. Without science, we might think that the world was on the back of an elephant that rested on a tortoise (an inquisitive person would then wonder what the tortoise is resting on). With science, we have theories. Some are essential for earth science.

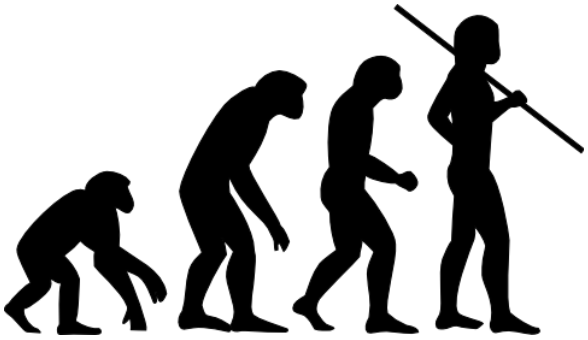
Three Essential Theories

Scientific theories are sometimes thrown out when the data shows them to be wrong. Before plate tectonics theory was accepted, people thought that fossil organisms had spread around using land bridges. Although a land bridge across the Atlantic seemed a bit far-fetched, there was no better idea. Most scientists were relieved when they could toss that theory out.

But some theories account for so many phenomena and are so broadly supported by so many lines of evidence that they are unlikely ever to be disproved. Additional scientific evidence may reveal problems and scientists may need to modify the theories. But there is so much evidence to support them and nothing major to refute them that they have become essential to their fields of science.

The Theory of Evolution

Darwin's theory of **evolution** has been under attack ever since Darwin proposed it. But nearly all biologists accept the theory and recognize that everything they learn about life on Earth supports the theory. Evolution is seen in the fossil record, in the developmental paths of organisms, in the geographic distribution of organisms, and in the genetic codes of living organisms. Evolution has a mechanism, called **natural selection**. People often refer to natural selection as "the survival of the fittest." With natural selection, the organism that is best adapted to its environment will be most likely to survive and produce offspring, thus spreading its genes to the next generation.



The theory of evolution maintains that modern humans evolved from ape-like ancestors.

The Theory of Plate Tectonics

The **theory of plate tectonics** is the most important theory in much of earth science. Plate tectonics explains why much geological activity happens where it does, why many natural resources are found where they are, and can be used to determine what was happening long ago in Earth's history. The theory of plate tectonics will be explored in detail in later concepts.

The Theory That Climate is Changing Due to Human Activities

The **theory of climate change** is a much newer theory than the previous two. We know that average global temperatures are rising. We even know why: Carbon dioxide is released into the atmosphere when fossil fuels are burned. Carbon dioxide is a greenhouse gas. In the atmosphere, greenhouse gases trap heat. This is like putting an extra blanket over Earth. Since more heat is being trapped, global temperature is rising.

There is very little information that contradicts the theory that climate is changing due in large part to human activities. Unless some major discrepancy is discovered about how the atmosphere works, the theory is very likely to stand. So far, the evidence that is being collected supports the idea, and global warming can be used to predict future events, which are already taking place. This idea will be explored in detail in later concepts.

Summary

- Since scientific ideas must be testable and falsifiable, theories are sometimes tested and shown to be wrong.
- Many theories have held up against most tests over many decades. These theories may need to be modified but they are solid at their core.
- Three essential theories for Earth Science are the theory of evolution, the theory of plate tectonics, and the theory that human activities are altering Earth’s climate.

Review

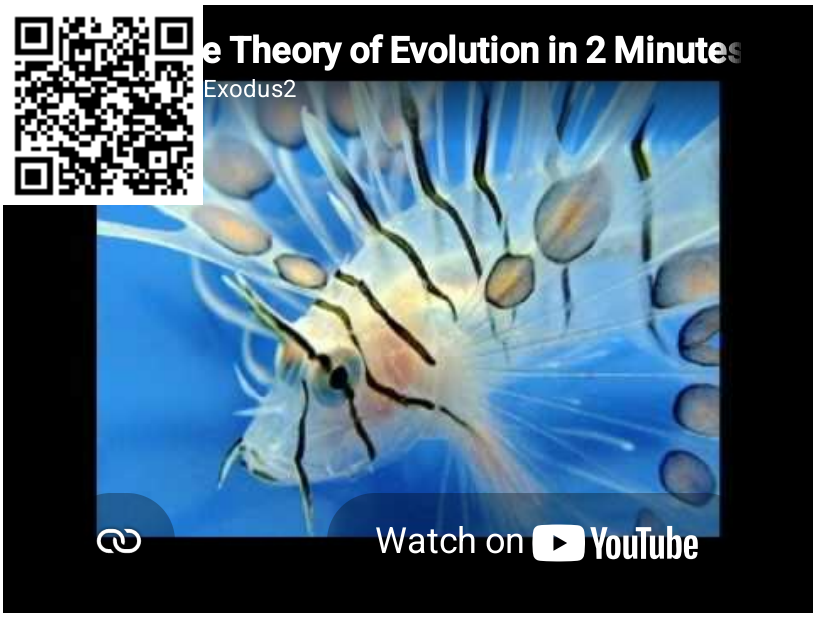
1. Scientists are reluctant to say that any theory is absolutely true. Why do you think that is?

2. What reasons do people have outside science to think that a theory is incorrect? Are these valid scientific arguments?

3. What are the three essential theories in Earth science as stated here?

Explore More

Use these resource to answer the questions that follow. Note that plate tectonics will be described in great detail in coming concepts.



1. Briefly explain the theory of evolution.
2. Why is evolution by natural selection called the unifying theory of biology?
3. How many experiments have been done that show evolution not to be true?
4. Is it likely that scientists will unearth something that will show the theory of evolution to be false?
5. How does the process of evolution differ from the theory of evolution?



6. Briefly explain the theory of climate change as mentioned here.
7. What evidence is there for this theory?
8. Most people, including scientists, do not call this a theory. Why not? Do you think it should be called a theory? Would calling it a theory saddle it with the same air of uncertainty that follows the theory of evolution?

This page titled 1.9: Evolution, Plate Tectonics, and Climate Change is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

1.10: Scientific Models



Why do scientists need models?

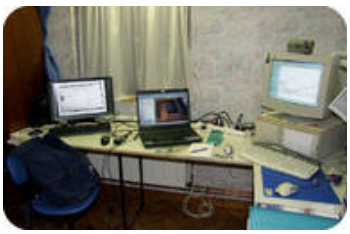
Scientists work with models because reality is complex and difficult. Earth's climate is an example of a system that is both difficult and complex. Many factors influence climate: clouds, snow cover, ocean mixing, sequestration of carbon in the oceans, etc. In fact, there are many more factors than can be dealt with all at once. Models are necessary in science. However, you must always remember that a model is a model and not the real thing.

Models are Useful Tools

Scientific models are useful tools for scientists. Most of Earth's systems are extremely complex. Models allow scientists to work with systems that are nearly impossible to study as a whole. Models help scientists to understand these systems. They can analyze and make predictions about them using the models. There are different types of models.

- Physical models are smaller and simpler representations of the thing being studied. A globe or a map is a physical model of a portion or all of Earth.
- Conceptual models tie together many ideas to explain a phenomenon or event.
- Mathematical models are sets of equations that take into account many factors to represent a phenomenon. Mathematical models are usually done on computers.

Many models are created on computers (**Figure** below). Only computers can handle and manipulate such enormous amounts of data. Many scientists now work with climate models. An unimaginable number of factors affect Earth’s climate. Many factors are dependent on one another. A reasonably accurate climate model needs the most powerful computers. Still, no computer has yet been developed that can work with the entire system. So scientists create models that represent parts of the system.



Many scientists use computers to model complicated processes.

Models Can be Used to Test Ideas

Scientists must test their ideas. It's much easier to work with a model than with a whole system. A scientist may want to understand how rising CO_2 levels will affect climate. In this case, it will be easier to model a smaller portion of that system. For example, the scientist may model how higher levels of CO_2 affect plant growth and the effect that will have on climate.

Models Can be Used to Make Predictions

Models can be used to predict the future. The best ones take into account the most factors. How do scientists know if a model will predict the future accurately? One way is to use a time in the past as the starting point. Then run the model to see if the model can

accurately predict the present. A model that can successfully predict the present is more likely to be better at predicting the future. For example, climate models are very useful for trying to determine what types of changes we can expect as carbon dioxide in the atmosphere rises.

Models Have Limitations

Since models are simpler than real objects or systems, they have limitations. A model deals with only a portion of a system. It may not predict the behavior of the real system very accurately. But the more computing power that goes into the model and the care with which the scientists construct the model can increase the chances that a model will be accurate.

Summary

- A model is a representation of a more complex system. Models can be manipulated more easily than the system.
- Models can be used to make predictions.
- Models may be physical, conceptual, or mathematical.

Review

1. Why do scientists use models?
2. Describe the types of models mentioned.
3. Why are computers often used to make models?

Explore More

Use the resource below to answer the questions that follow.



1. What is a model?
2. How do scientists create models?
3. How are models checked for accuracy?
4. How did Dr. Hansen check his model?
5. What are the challenges associated with modeling?

This page titled 1.10: Scientific Models is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

1.11: Scientific Community



Can only a genius be a scientist?

Of course not! Scientists come from all backgrounds. They have many interests and talents. Scientists have many different reasons for pursuing science. Most scientists are intelligent, creative, and logical people. They are open to new ideas but require evidence to accept them. Women and racial minorities are becoming scientists more than ever before. Diversity brings in more ideas and more ways of solving problems. This makes science stronger.

Funding Science

Scientific research is expensive. So the scientific community controls the type of research that is done. They do this by allotting money. Scientists must write a proposal to an agency or private organization. Two examples are the National Science Foundation and the National Aeronautics and Space Administration (NASA). The scientists outline their project and list what they need in equipment, supplies, and salaries. Scientific proposals are evaluated by other scientists in that field of science. In many fields, the funding rate is low. The money goes only to the most worthy research projects. Once the scientists get the money, they can do their research.

Working Environment

Scientists may work in colleges and universities. They may work in research institutions or government agencies. Businesses and industries hire scientists in a variety of fields. There are many opportunities for well-trained scientists.

Scientists may work together on a project. One reason is that they can share equipment and personnel. Another reason is that they can share ideas. Scientists may also work separately. Even then, they use each other's data and interpretations. When one scientist publishes a paper, others will replicate the work to make sure they get the same result. If they do, the work is valid. If they don't, someone needs to find the source of the problem. Scientists openly communicate with each other on their results. They also discuss and sometimes disagree on their interpretations. If scientists do disagree, they will look for evidence so that they may resolve the disagreement.

Sharing Results

A hypothesis will not be fully accepted unless it is supported by the work of many scientists. Although a study may take place in a single laboratory, a scientist must present her work to the community of scientists in her field.



CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Participants share their results at a scientific conference.

The scientist may present her data and conclusions at a scientific conference (**Figure** above). She will talk with many other scientists to see what they think of her work. Scientists will openly discuss and criticize the work. The scientist may need to gather more data to resolve the problems. Later, she will write a paper to be published in a scientific journal. Several scientists will review the paper. This process is called **peer review**. They will make sure the researcher used scientific method. They will make sure her interpretations follow logically from the data. The scientists may then recommend that she does further work. Or they may deny the paper for publication. Once the paper is published, other scientists will use her results in their own work.

Scientific ideas are advanced after many papers on a topic are published.

The Outcomes of a Scientific Study

Sometimes a study will support an idea. This may bring the idea closer to acceptance in the scientific community. Sometimes new methods or procedures may be developed for a study to be performed. This may assist other scientists with their investigations. Any of these things may lead to new investigations and new data.

Scientific Integrity

The scientific community monitors scientific integrity. During their training, students learn how to conduct good scientific experiments. They learn not to fake, hide, or selectively report data. They learn how to fairly evaluate data. They learn how to interpret the work of other scientists. Scientists who do not have scientific integrity are strongly condemned by the scientific community. Sometimes scientists are hired by private companies to do studies. Often these scientists find what the company wants them to find. These studies should be evaluated very carefully before the results are used. However, often the studies are taken seriously by the media. It is important to know who funded the research to know how to evaluate the results of a study.

Nothing is perfect, and science isn't either. Still, considering all the scientific research that is done, there are few incidences of scientific dishonesty. When they do occur, they are often reported with great vehemence by the media. This may cause the public to mistrust scientists in ways that are unwarranted.

Summary

- If science is done well, other scientists who replicate the same work will get the same results.
- Scientists peer review a scientific paper before it is published. This is done to be sure the work was done using the scientific method.
- There are lots of controls in science. Scientists communicate and replicate each other's work. The scientific community has control of the projects that get funded.
- The checks and balances assure that nearly all scientists operate with a great deal of integrity.

Review

1. How do scientists keep quality control high in scientific research?
2. How does funding keep quality high in scientific research?
3. What procedures are present in science to ensure scientific integrity?

Explore More

Use the resources to answer the questions that follow.



1. Why aren't scientists infallible? How are scientists different from theologians or other experts?
2. What is peer review?
3. What is the importance of peer review?
4. What makes a person a scientist?
5. Why must science be reviewed by people who are trained in that science?

This page titled 1.11: Scientific Community is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

1.12: The Nature of Science- Challenge 2

1. If I want to do an experiment to test whether vitamin C helps prevent colds, the control group must ___.

not be given vitamin C

2. In an experiment to test whether vitamin C prevents getting a cold or not, the sample population is divided into two groups so that one group receives the vitamin C dose and one group does not. Which of these is a control group?

The group that doesn't receive vitamin C.

3. An experiment is conducted to check the effect of migraine pills on people. Out of 100 people, 50 were given migraine pills. What is the control group in this case?

People who didn't receive migraine pills.

4. A ___ can become a theory if it is thoroughly tested and passes all tests, ensuring that there are no lingering problems with it.

hypothesis

5. Scientists can use theory to ___.

offer reliable explanations

6. What is the relationship between a theory and a hypothesis?

If a hypothesis is supported by multiple lines of evidence, it may become a theory.

7. Natural selection is often described as ___.

survival of the fittest

8. A fast-acting insecticide was sprayed on a large population of cockroaches. Some cockroaches that are resistant to this insecticide survived. This is an example of ___.

survival of the fittest

9. ___ may have been present during times of low sea level.

Land bridges

10. What are some limitations of scientific models?

Models show only a portion of a system.

11. Manipulation of a model ___.

can be done far more easily than the system it represents

12. A model ___.

deals with only a portion of a system

13. Scientists engage in ___ review to make sure that work is of high quality prior to publication.

peer

14. ___ is an evaluation of work conducted by qualified people in a field before the work is published.

Peer review

15. Scientists who are part of a peer review can ___.

recommend or deny a paper for publication

This page titled 1.12: The Nature of Science- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

2: Introduction to Earth Science

2.1: Branches of Earth Science
2.2: Earth Science Field Work
2.3: Uniformitarianism
2.4: Location
2.5: Direction
2.6: Elevation
2.7: Introduction to Earth Science- Challenge 1
2.8: Maps
2.9: Map Projections
2.10: Topographic and Geologic Maps
2.11: Seafloor
2.12: Introduction to Earth Science- Challenge 2
2.13: Telescopes
2.14: Study of Space by the Electromagnetic Spectrum
2.15: Satellites, Shuttles, and Space Stations
2.16: Introduction to Earth Science- Challenge 3

This page titled 2: Introduction to Earth Science is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

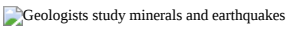
2.1: Branches of Earth Science

What is Earth science?

Earth scientists seek to understand the beautiful sphere on which we live. Earth is a very large, complex set of systems. So most Earth scientists study one aspect of the planet. Researchers work together to answer complicated questions. The major branches of Earth science are described below.

Geology

Geology is the study of the solid Earth. Geologists study how rocks and minerals form. The way mountains rise up is part of geology. The way mountains erode away is another part. Geologists also study fossils and Earth's history. There are many other branches of geology. There is so much to know about our home planet that most geologists become specialists in one area. For example, a mineralogist studies minerals (**Figure** below).

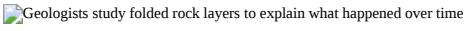

Geologists study minerals and earthquakes

(left) Mineralogists focus on all kinds of minerals. (right) Seismographs are used to measure earthquakes and pinpoint their origins.

Some volcanologists brave molten lava to study volcanoes. Seismologists monitor earthquakes worldwide to help protect people and property from harm (**Figure** above). Paleontologists are interested in fossils and how ancient organisms lived. Scientists who compare the geology of other planets to Earth are planetary geologists. Some geologists study the Moon. Others look for petroleum. Still others specialize in studying soil. Some geologists can tell how old rocks are and determine how different rock layers formed. There is probably an expert in almost anything you can think of related to Earth!

Geologists might study rivers and lakes, the underground water found between soil and rock particles, or even water that is frozen in glaciers. Earth scientists need geographers who explore the features of Earth's surface. They work with cartographers, who make maps. Studying the layers of rock beneath the surface helps us to understand the history of planet Earth (**Figure** below).

Geologists ask a lot of questions. They wonder what they need to know about earthquakes to be able to predict them in time to evacuate a region. They ask what will happen to shorelines as sea level rises. Some even wonder what would happen if the magnetic field reverses!

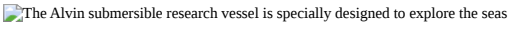

Geologists study folded rock layers to explain what happened over time

These folded rock layers have bent over time. Studying rock layers helps scientists to explain these layers and the geologic history of the area.

Oceanography

Oceanography is the study of the oceans. The word oceanology might be more accurate, since "ology" is "the study of." "Graph" is "to write" and refers to map-making. But mapping the oceans is how oceanography started.

More than 70% of Earth's surface is covered with water. Almost all of that water is in the oceans. Scientists have visited the deepest parts of the ocean in submarines. Remote vehicles go where humans can't (**Figure** below). Yet much of the ocean remains unexplored. Some people call the ocean "the last frontier."


The Alvin submersible research vessel is specially designed to explore the seas

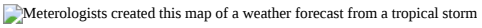
The Alvin research vessel is specially designed to explore the seas.

There are many branches of oceanography. Physical oceanography is the study of water movement, like waves and ocean currents. Physical oceanographers ask when or if a tsunami will hit a shoreline. Marine geologists look at rocks and structures in the ocean basins. These scientists ask how new ocean crust forms. Chemical oceanographers study the natural elements in ocean water. Chemical oceanographers might be concerned with where carbon dioxide goes in the oceans. Marine biologists look at marine life. There are lots of questions to ask about marine life!

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Meteorology and Climatology

Meteorologists don't study meteors—they study the atmosphere! The atmosphere is a thin layer of gas that surrounds Earth. The word "meteor" refers to things in the air. **Meteorology** includes the study of weather patterns, clouds, hurricanes, and tornadoes. Meteorology is very important. Using radars and satellites, meteorologists work to predict, or forecast, the weather (**Figure** below). Meteorologists are getting better at predicting the weather all the time. Meteorologists wonder how to better predict weather. They wonder what the effects of rising water vapor in the atmosphere will be on weather.


Meterologists created this map of a weather forecast from a tropical storm

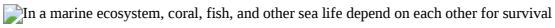
Meteorologists forecast the weather a region can expect from a tropical storm.

Climatologists also study the atmosphere. These scientists work to understand the climate as it is now. They also study how climate will change in response to global warming. There are lots of questions to ask about our changing climate.

Environmental Science

Environmental scientists study the effects people have on their environment. This includes the landscape, atmosphere, water, and living things. These scientists ask all sorts of questions about how Earth systems are changing as a result of human actions. They try to predict what changes will come in the future.

Ecologists study life forms and the environments they live in (**Figure** below). They try to predict the chain reactions that could occur when one part of the ecosystem is disrupted.


In a marine ecosystem, coral, fish, and other sea life depend on each other for survival

In a marine ecosystem, coral, fish, and other sea life depend on each other for survival.

We hope to find better ways of living that can help the environment.

Astronomy

Astronomy is the study of outer space and the physical bodies beyond planet Earth. Astronomers use telescopes to see things far beyond what the human eye can see. Astronomers help to design spacecrafts or satellites that travel into space and send back information about faraway places (**Figure** below).


The Hubble Space Telescope

The Hubble Space Telescope.

Astronomers ask a wide variety of questions. How do strong bursts of energy from the Sun, called solar flares, affect communications? How might an impact from an asteroid affect life on Earth? What are the properties of black holes? Astronomers ask bigger questions too. How was the Universe created? Is there life on other planets? Are there resources on other planets that people could use for space travel? Astronomers use what Earth scientists know about our planet to make comparisons with other planets.

Summary

- The study of Earth science includes many different fields, including geology, meteorology, oceanography, and astronomy.
- Each type of Earth scientist investigates the processes and materials of the Earth.
- Like other scientists, Earth scientists ask questions.

Review

1. What do geologists study? Oceanographers? Meteorologists? Climatologists? Environmental scientists? Astronomers?
2. Ask a question that is relevant to each of the fields of Earth science.
3. Why is Earth science made up of all of these fields?

This page titled 2.1: Branches of Earth Science is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

2.2: Earth Science Field Work

Do Earth scientists work in the field?

Yes! Many geologists do field work to better understand Earth. Many others go on field trips to learn about certain types of geology. In Glacier National Park, a geologist could learn about mountain building. They could learn about how glaciers modify landscapes. He could take photos to assist him in teaching a class. He could just have a great time in a geologically fascinating area!

Field Work

Many Earth scientists collect data in the field, called **field work**. The data may be from observations or measurements. The scientists may create a geological map of the area. They might write detailed descriptions of the rocks and their relationships. They may collect samples to analyze in the lab. They may do a combination of all of these! Earth science laboratories contain high-tech equipment. That equipment can reveal the chemistry or age of a rock sample. Geologists do field work to look for resources. They may study a region for environmental cleanup. There are many other reasons for going in the field. One common reason is just to understand the region better.

Field Trips

To really understand geology and some of the other branches of Earth science, it's best to go out in the field! Geology students in many colleges and universities go on a lot of **field trips**. Some of the concepts presented in this text can be illustrated by features seen in the field. Where possible, photos are provided to illustrate concepts. So we can get some of the benefit of going on a field trip! Some of the places that are featured in this text are described below.

California



California has a lot of different environments and a complex geologic history. California is a great place to study geology!

In the satellite image above (**Figure** above), it is possible to identify the major geographic (physical) features of California.

- The Coast Range runs the length of the state along the Pacific coast. A tremendous amount of rain falls in the northern part of the range, so the region is heavily forested. There is less rainfall and vegetation further south.
- The Central Valley is made up of the Sacramento and San Joaquin river valleys. The Central Valley runs through about half of the central part of the state. The valley is located between the mountains of the Coast Range and the Sierra Nevada. The Central Valley is one of the most important agricultural regions in the world.

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

- The Sierra Nevada Mountain range lies east of the Central Valley. In the winter, the mountains are covered by snow. In this image, there is little to no snow, and the bare rocks of the high peaks are showing. Yosemite National Park lies within the Sierra Nevada.
- East of the Sierra Nevada and into the state of Nevada, the climate is very arid. Death Valley, the driest spot in the United States, is found there.
- Mt. Shasta, at the north end of the Sierra Nevada, is the southernmost remaining volcanic cone in the Cascades Range.

Nevada

East of the image of California is Nevada. Very different from California, Nevada is extremely arid. The Basin and Range province consists of a set of mountains and valleys. You can see the ranges as dark brown rocky regions and the valleys as lighter brown.

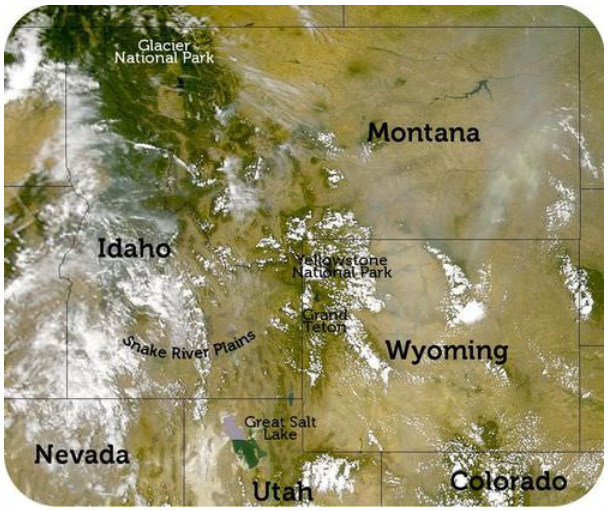
Pacific Northwest



North of California along the Pacific Coast is Oregon, Washington, and then British Columbia in Canada. This region is similar to California in having a coastal range, a central valley (at least in part of Oregon), and very arid lands east of the high Cascades mountains.

The Cascades are a chain of volcanoes that run through Oregon and Washington, and into British Columbia (**Figure** above). Some of them are easily spotted on this image as white spots in the midst of the green forests of the Cascades Range.

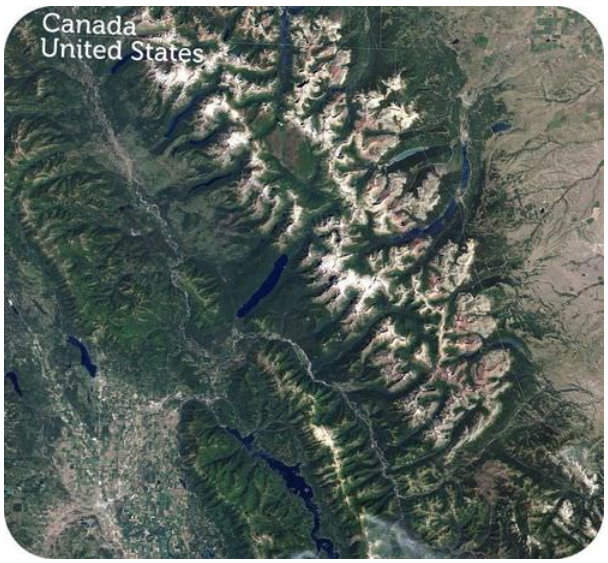
Idaho, Montana, Wyoming



This image shows the states of Idaho, Montana, and Wyoming. The northern part of Idaho and northwestern Montana is mountainous and forested. Arid lands lie to the east.

The states of Idaho, Montana, and Wyoming are located east of the Pacific Northwest. The landscape ranges from mountainous forests to deserts (**Figure** above).

Glacier National Park



This satellite image of Glacier National Park in the summer shows snow-capped peaks and glacial valleys, many of which are now lakes.

Glacier National Park in the northwestern part of Montana (**Figure** above) reaches to the Canadian border. Glacier National Park (**Figure** above) was established in 1910 to preserve the wild lands and wildlife. But less precipitation and higher summer temperatures has decimated most of the glaciers. Glacier National Park is a fantastic place to see glacial features, beautiful scenery, and wildlife (**Figure** below).



Naturalists enjoy the hike to Iceberg Lake in Glacier National Park.

Yellowstone National Park



Grand Prismatic Spring is one of the spectacular features of Yellowstone National Park.

Yellowstone National Park (**Figure** above) is in the northwestern corner of Wyoming. Yellowstone is best known for its incredible geysers. The park also has gorgeous mountain scenery and fantastic wildlife, including herds of bison (**Figure** below). The best known feature is Old Faithful. This geyser is not the highest, largest, or most beautiful, but it is the most reliable.



Bison are just some of the amazing creatures that roam around Yellowstone.

Southwest



The Southwest is home to mountains, canyons, valleys, and flat lands. Many features discussed in the concepts presented in this text can be seen in the Southwest.

The Southwestern United States (**Figure** above) is a great place to study geology. The region is so arid that in most locations rocks and structures are easily seen. In several concepts we will visit parts of the Southwest to view geology in the field.

Grand Canyon

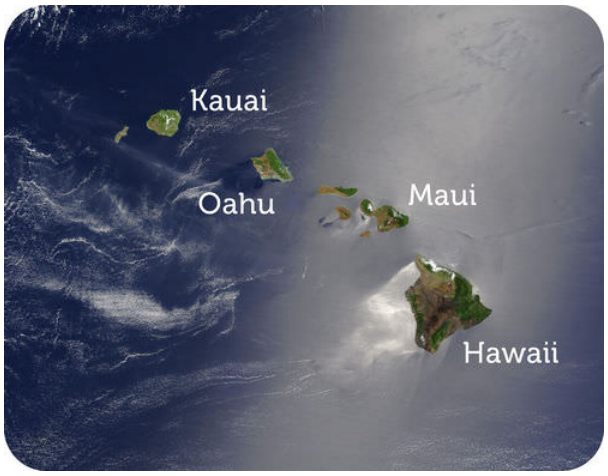


From the rim, the Grand Canyon gives a sense of the vastness of geologic time and the immensity of the planet.

Geologists say that the Grand Canyon (**Figure** above) has "layer cake geology." This is because the rock strata are in layers. They are extremely easy to see. Sedimentary rocks are like a book that tells the story of the environment in which they formed. Rock units can be traced across large expanses. Looking down into the Grand Canyon, you get a sense of the vastness of space and of time.

Hawaiian Islands

https://k12.libretexts.org/@go/page/5323



The Hawaiian Islands from space.

The Hawaiian Islands (**Figure** above) are in the central Pacific Ocean. The islands are volcanoes that increase in age from southeast to northwest. The youngest island is the Big Island of Hawaii at the southeast end of the chain. The volcanoes get older through Maui, Kahoolawe, Lanai, Molokai, Oahu, Kauai, and Niihau Islands through the northwest. The Kilauea volcano on Hawaii has been erupting almost continuously since 1983. There are also eruptions at an underwater volcano called Loihi seamount. Loihi is the youngest volcano. Hawaii is a fantastic place to see volcanic eruptions and features.

Summary

- Earth scientists learn about many aspects of their disciplines by going out into the field.
- Field trips are an important part of the education of a geology student.
- The western United States is a great place to see examples of many types of geological phenomena.

Review

1. Describe the geography of California. What features can you see in this state?
2. Where are the arid lands in the western United States? Why are arid lands important for understanding geology?

Explore More

Use the resources below to answer the questions that follow.



1. How large is Yellowstone?
2. What is Yellowstone?
3. How often has Yellowstone erupted in the past? What does this mean?
4. What heats the geysers and supervolcano of Yellowstone?



5. How many islands make up Hawaii?
6. How long has Kīlauea been continuously erupting?
7. Explain how Hawaii formed.
8. What is the Big Island of Hawaii?

This page titled 2.2: Earth Science Field Work is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

2.3: Uniformitarianism

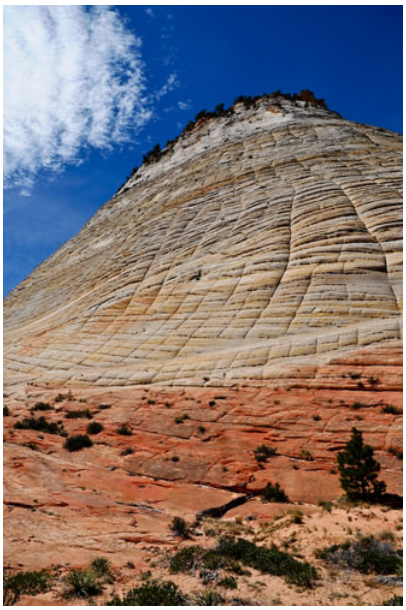


What does this mean: "The present is the key to the past"?

How can this photo help you to figure out what happened in Earth's history? You see the molten lava. You see what the rock looks like when the lava cools. What if you see that type of rock in an outcrop? You can assume that it formed from molten lava. This is the best tool for understanding Earth history. Earth scientists use what they know about Earth in the present to figure out what happened in the past.

Ask a Question: Earth History

The outcrop in **Figure** below is at Checkerboard Mesa in Zion National Park, Utah. It has a very interesting pattern on it. As a geology student you may ask: how did this rock form?



Checkerboard Mesa in Zion National Park, Utah.

If you look carefully at the rock, you will see that it’s made of sand. This rock formation is called the Navajo sandstone. Does knowing that the rock is sandstone tell you how it formed? No, although it limits the possibilities. The next thing to do is to make observations now and apply them to this rock that formed long ago.

Uniformitarianism

James Hutton came up with this idea in the late 1700s. The present is the key to the past. He called this the **principle of uniformitarianism**. It works like this: we understand a geological process that happens now. We see the outcome of that process,

say a rock. Then we find evidence that same process happened in the past, like a similar rock. We can assume that the process operated the same way in the past.

Let's go back to that outcrop. What would cause sandstone to have layers that cross each other, a feature called cross-bedding?

Answer a Question: Earth History

In this photo of this sand dune in Coral Pink Sand Dunes State Park, Utah (**Figure** below), we see that wind can cause cross-bedding in sand. Cross-bedding is due to changes in wind direction. There are also ripples caused by the wind waving over the surface of the dune.



Sand dune in Coral Pink Sand Dunes State Park, Utah.

This doesn't look exactly like the outcrop of Navajo sandstone, but if you could cut a cross-section into the face of the dune it would look very similar.

Since we can observe wind forming sand dunes with these patterns now, we have a good explanation for how the Navajo sandstone formed. The Navajo sandstone is a rock formed from ancient sand dunes. The rock shows that the ancient wind direction changed from time to time.

This is just one example of how geologists use observations they make today to unravel what happened in Earth's past. Rocks formed from volcanoes, oceans, rivers, and many other features are deciphered by looking at the geological work those features do today.

Science Friday: Tar Noir: Paleoforensics at the La Brea Tar Pits

The La Brea Tar Pits contain a massive collection on animals. But how did all these animals die, and how did they get there? In this video by Science Friday, researchers explain how these processes occurred and what the La Brea Tar Pits tell us about Los Angeles thousands of years ago.



Summary

- You may need to apply what you know about the present to determine what happened in the past.
- The idea that the present is the key to the past was recognized by James Hutton in the late 1700s.
- If you see something forming by a process today and then find the end results of that process in the rock record, you can assume that the the process operated the same way in the past.

Review

1. What does an Earth scientist often need to answer a question about something that happened in Earth's distant past?
2. James Hutton is sometimes called the father of geology. Why does he deserve that title?
3. How can you use the principle of uniformitarianism to figure out how a lava rock formed?

This page titled 2.3: Uniformitarianism is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

2.4: Location



How could you locate this feature?

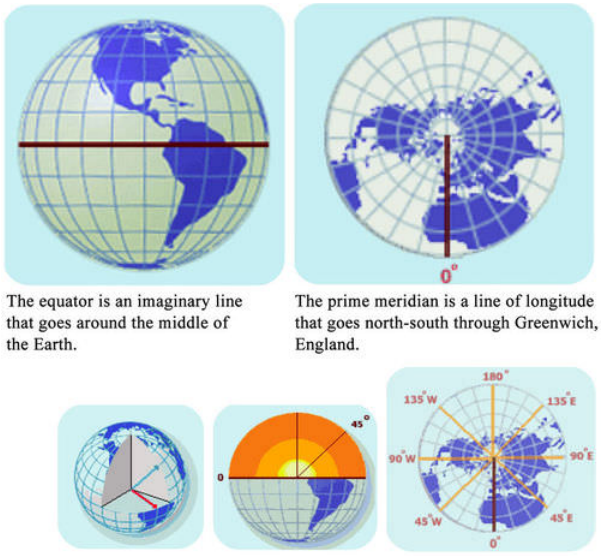
Geologists, hikers, and many other people need to be able to say where they are. Or where they want to go. They need to be able to mark a location on a map. The opening photo is of Old Faithful Geyser in Yellowstone National Park. It is located at 44°30'N and 110°150'W. Let's explore what that means.

Location

To describe your location, you could use a coordinate system. To do this you need two points. For example, you could use streets. Maybe you are at the corner of Maple Avenue and Main Street. Or you could use a point of reference, a distance and an angle for direction. If you want to meet up with a friend, you could tell him "I am two blocks due north of your apartment." Can you identify the point of reference, the distance, and the angle?

Map Coordinates

Most maps use a grid of lines to help you to find your location. This grid system is called a geographic **coordinate system**. Using this system you can define your location by two numbers, latitude and longitude. Both numbers are angles between your location, the center of Earth, and a reference line (**Figure** below).



The equator is an imaginary line that goes around the middle of the Earth.

The prime meridian is a line of longitude that goes north-south through Greenwich, England.

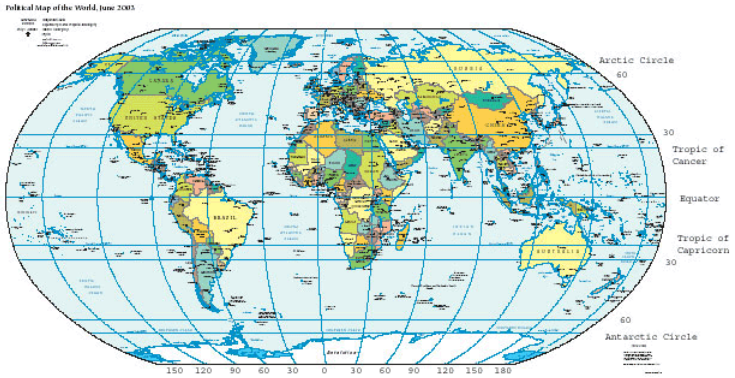
Lines of latitude start with the Equator. Lines of longitude begin at the prime meridian.

Latitude

Lines of **latitude** circle around Earth. The **Equator** is a line of latitude right in the middle of the planet. Latitude is divided into degrees: 90° north of the Equator and 90° south of the Equator. One degree is subdivided into 60 minutes. One minute is subdivided into 60 seconds. The Equator is at 0°. The Equator is an equal distance from both the North and South Poles. If you know your latitude, you know how far you are north or south of the Equator.

Longitude

Lines of **longitude** are circles that go around Earth from pole to pole, like the sections of an orange. Longitude is also measured in degrees, which are subdivided into minutes and seconds. Lines of longitude start at the Prime Meridian, which is 0°. The **Prime Meridian** is a circle that runs north to south and passes through Greenwich, England. Longitude tells you how far you are east or west from the Prime Meridian (**Figure** below). On the opposite side of the planet from the Prime Meridian is the International Date Line. It is at 180°. This is the place where a new day first arrives.



Lines of latitude and longitude form convenient reference points on a map.

You can remember latitude and longitude by doing jumping jacks. When your hands are above your head and your feet are together, say longitude (your body is long!). When you put your arms out to the side horizontally, say latitude (your head and arms make a cross, like the “t” in latitude). While you are jumping, your arms are going the same way as each of these grid lines: horizontal for latitude and vertical for longitude.

Using Latitude and Longitude on a Map

If you know the latitude and longitude of a place, you can find it on a map. Simply place one finger on the latitude on the vertical axis of the map. Place your other finger on the longitude along the horizontal axis of the map. Move your fingers along the latitude and longitude lines until they meet. For example, say the location you want to find is at 30°N and 90°W. Place your right finger along 30°N at the right of the map. Place your left finger along the bottom at 90°W. Move your fingers along the lines until they meet. Your location should be near New Orleans, Louisiana, along the Gulf coast of the United States. Now can you locate Old Faithful, 44°30'N and 110°150'W, on a map?

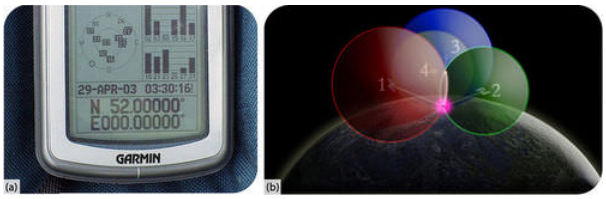
What if you want to know the latitude and longitude of your location? If you know where you are on a map, point to the place with your fingers. Take one finger and move it along the latitude line to find your latitude. Then move another finger along the longitude line to find your longitude.

Global Positioning System

In order to get latitude, longitude, and elevation you need several instruments. What if you could do the same thing with only one instrument? A **Global Positioning System (GPS)** receiver is all that is needed to locate your position on the Earth’s surface in many places.

By 1993, the United States military had launched 24 satellites to help soldiers locate their positions on battlefields. This system of satellites was called the Global Positioning System (GPS). Later, the United States government allowed the public to use this system. Here’s how it works.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



(a) You need a GPS receiver to use the GPS system. (b) It takes signals from four GPS satellites to find your location precisely on the surface.

You must have a GPS receiver to use the system. You can buy many types of these in stores. The GPS receiver detects radio signals from nearby GPS satellites. There are precise clocks on each satellite and in the receiver. The receiver measures the time for radio signals from satellites to reach it. The receiver uses the time and the speed of radio signals to calculate the distance between the receiver and the satellite. The receiver does this with at least four different satellites to locate its position on the Earth's surface (**Figure** above). GPS receivers are now being built into many items, such as cell phones and cars.

You can use a GPS meter to tell you how to get to Old Faithful.

Summary

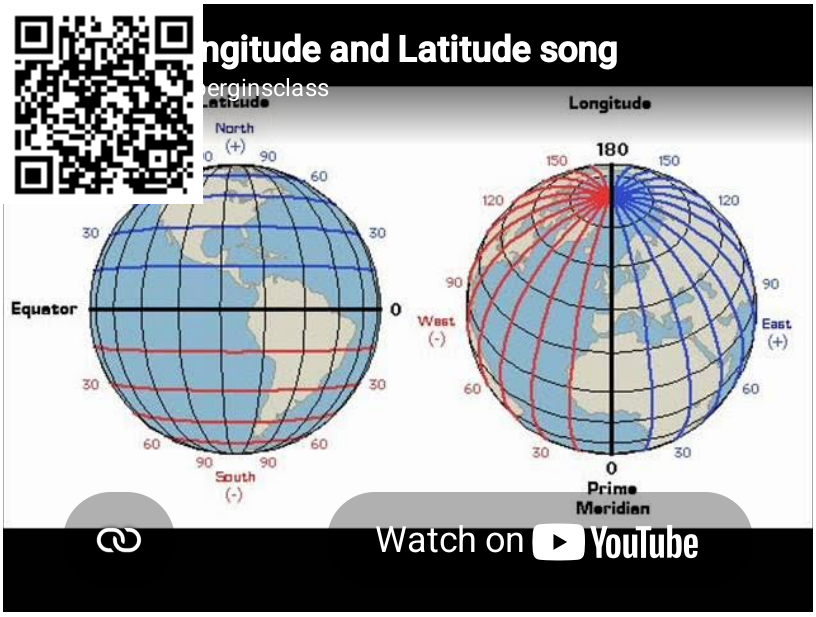
- Latitude is the distance north or south of the Equator. It is expressed as a number between 0° and 90° north or south.
- Longitude is the distance east or west of the Prime Meridian. It is expressed as a number between 0° and 180° east or west.
- The global positioning system uses satellites to display very accurate location information on a special receiver.

Review

1. What would a latitude number in the Southern Hemisphere look like?
2. Define latitude and longitude.
3. Why are GPS devices so accurate?

Explore More

Use the resource below to answer the questions that follow.



1. What is latitude and what does a measurement of latitude give?
2. What is longitude and what does a measurement of longitude give?
3. By looking at the latitude image, tell where the vertex of the latitude lines is?
4. Where is the 90-degree North latitude line?
5. How many longitude lines go through the South Pole?

https://k12.libretexts.org/@go/page/5325

6. Is the United States in the Eastern or Western Hemisphere? What about India?

This page titled 2.4: Location is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

2.5: Direction



How do you indicate which way the wind blows?

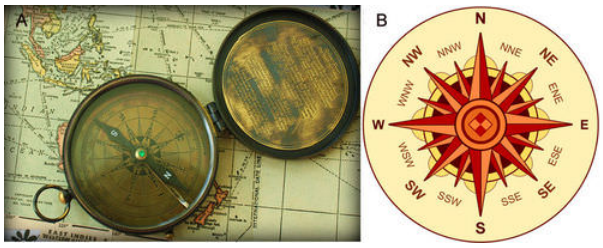
When an object is moving, it is not enough to describe its location. We also need to know direction. For example, a wind blows a storm over your school. Where is that storm coming from? Where is it going? Direction is also needed to indicate where two points are relative to each other on a map.

Direction

To connect two points accurately you need a direction. This occurs when you need to go from point A to point B. It also happens if you want to describe where something is going. If you are walking across a field, for example, you might say you're going north 20° east.

Compass

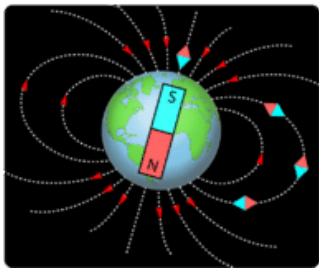
The most common way to find direction is by using a **compass**. A compass is a device with a floating needle (**Figure** below). The needle is a small magnet that aligns itself with the Earth's magnetic field. The compass needle always points to magnetic north. If you have a compass and you find north, you can then know any other direction. See the directions, such as east, south, west, etc., on a **compass rose**.



(a) A compass is a device that is used to determine direction. The needle points to Earth's magnetic north pole. (b) A compass rose shows the four major directions, plus intermediates between them.

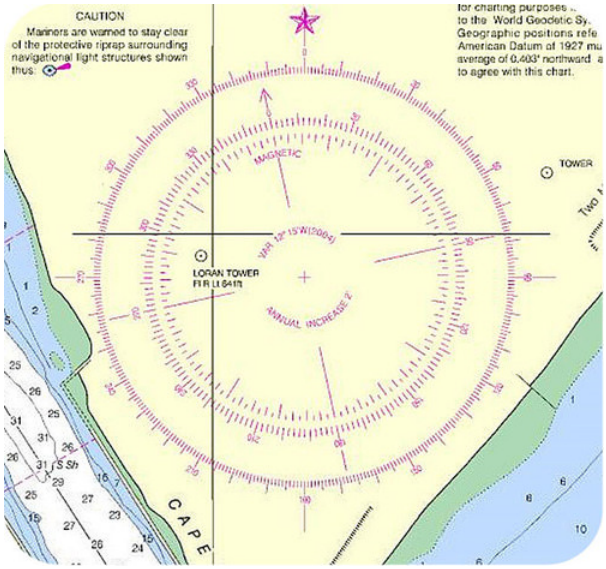
A compass needle lines up with Earth's magnetic north pole. This is different from Earth's geographic north pole, also called true north. The geographic north pole is the top of an imaginary line. This line is the axis around which Earth rotates. The geographic north pole is much like the spindle of a spinning top. The location of the geographic north pole does not change. However, the magnetic north pole shifts in location over time. Depending on where you live, you can correct for the difference between the two poles when you use a map and a compass (**Figure** below).

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



Earth's magnetic north pole is about 11 degrees offset from its geographic north pole.

Some maps have a double compass rose. This allows users to make the corrections between magnetic north and true north. An example is a nautical chart that boaters use to chart their positions at sea (**Figure** below).



Nautical maps include a double compass rose that shows both magnetic directions (inner circle) and geographic compass directions (outer circle).

Polar Coordinate System

You can also use a polar coordinate system. Your location is marked by an angle and distance from some reference point. The angle is usually the angle between your location, the reference point, and a line pointing north. The distance is given in meters or kilometers. To find your location or to move from place to place, you need a map, a compass, and some way to measure your distance, such as a range finder.

Suppose you need to go from your location to a marker that is 20°E and 500 m from your current position. You must do the following:

- Use the compass and compass rose on the map to orient your map with north.
- Use the compass to find which direction is 20°E.
- Walk 500 meters in that direction to reach your destination.

Polar coordinates are used in a sport called orienteering. People who do orienteering use a compass and a map with polar coordinates. Participants find their way along a course across wilderness terrain (**Figure** below). They move to various checkpoints along the course. The winner is the person who completes the course in the fastest time.



A topographic map like one that you might use for the sport of orienteering.

Summary

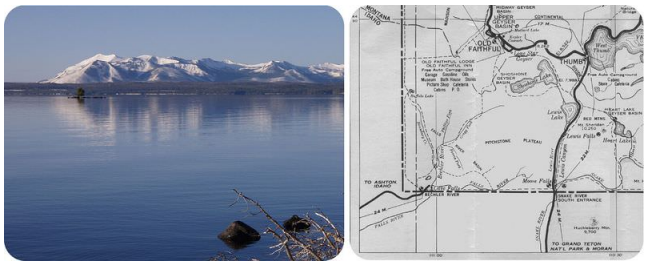
- Direction is expressed as north, south, east, or west, or some gradation between them.
- A compass can be used to indicate direction. A compass rose shows direction on a map or chart.
- To find your location or to move from place to place, you need a map, a compass, and some way to measure your distance.

Review

1. How does a compass work?
2. What is a polar coordinate system?
3. How does someone do orienteering?

This page titled 2.5: Direction is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

2.6: Elevation



Where are you in the third dimension?

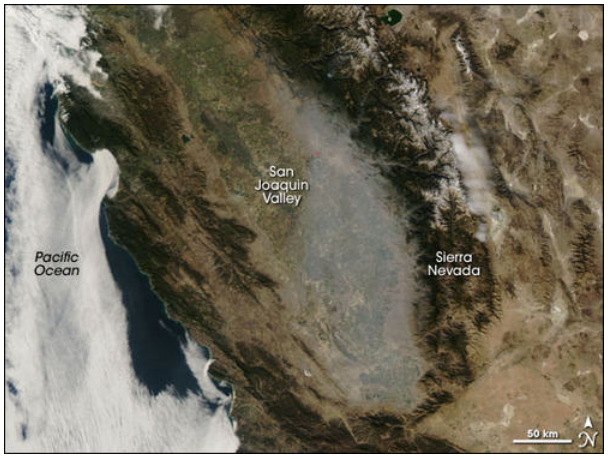
Mt. Sheridan in Yellowstone National Park is higher above sea level than most locations. It is at 10,250 ft (3,124 m). When you're up at that elevation, you definitely think about the third dimension. It is, of course, elevation, or height above sea level. You can see Mt. Sheridan in the opening image and on the map.

Elevation

As you know, the surface of Earth is not flat. Some places are high, and some places are low. For example, mountain ranges like the Sierra Nevada in California or the Andes in South America are high above the surrounding areas. An accurate location must take into account the third dimension. **Elevation** is the height above or below sea level. **Sea level** refers to the height of the ocean's surface. This is the midpoint between high and low tide. Sea level can vary from place to place, but scientists base their elevation measurements on the average, or mean, sea level to make sure they have a standard reference point.

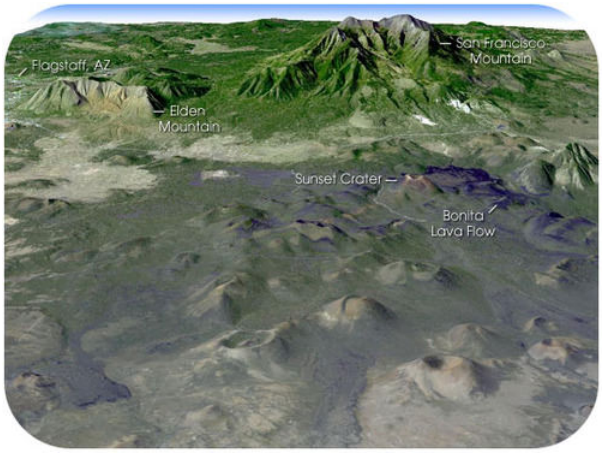
Topography

We can describe the **topography** of a region by measuring the height or depth of that feature relative to sea level (**Figure** below). You might measure your height relative to your classmates. When your class lines up, some kids make high "mountains," while others are more like small hills!



This is a satellite image of California. The highs, like the Sierra Nevada mountains, are rocky looking. During the winter, the peaks are capped with snow. The lows, like the San Joaquin Valley, are lighter and smoother. Green indicates forest.

Relief, or terrain, includes all the landforms of a region. For example, the image below shows the San Francisco Peaks in northern Arizona (**Figure** below). Features on the map include mountains, hills, and lava flows. You can recognize these features from the differences in elevation.



This image was made from data of the Landsat satellite. It shows the topography of the San Francisco Peaks and surrounding areas.

Summary

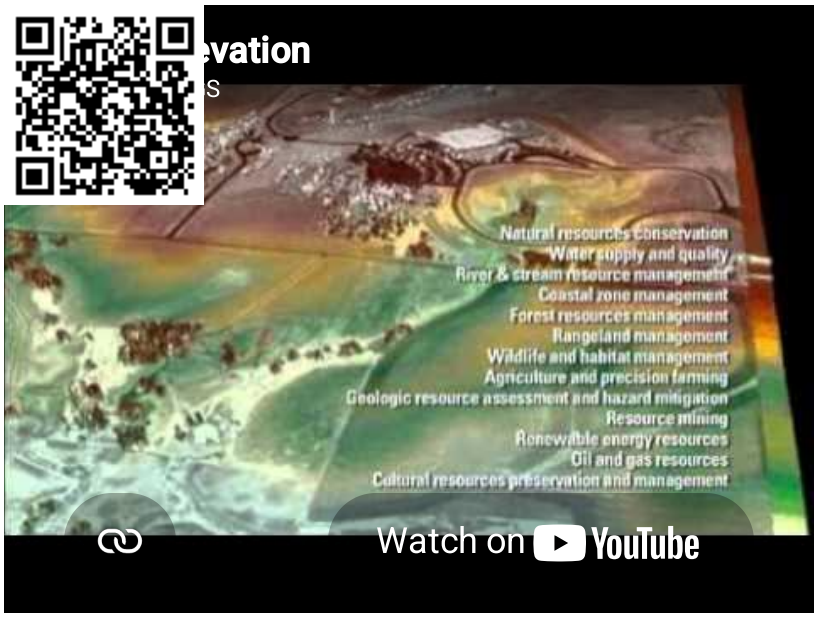
- Elevation refers to height above average sea level.
- The topography of a region describes its highs and lows.
- Sea level is the midpoint between high and low tide. It can vary around Earth.

Review

1. What is elevation, and what is its reference point?
2. How is topography different from relief?
3. Why is the average, or mean, sea level used as a reference point?

Explore More

Use the resource below to answer the questions that follow.



1. Why is elevation important?
2. What is digital elevation data used for?
3. What is the NED?
4. What is the primary source of the NED's new elevation data?
5. What else is LIDAR used for?

6. Why is the continued funding of this project important?

This page titled 2.6: Elevation is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

2.7: Introduction to Earth Science- Challenge 1

1. ___ are scientists who study outer space and the celestial bodies beyond Earth, often using telescopes, spacecrafts, and satellites.

Astronomers

2. If meteorologists study weather patterns, who studies longer-term atmospheric phenomena like climate?

Climatologists

3. ___ are scientists that study space and everything in it.

Astronomers

4. Geologists say that the Grand Canyon has "layer cake geology" because ___.

the rock strata are easy to see

5. Which mountain range is made by volcanoes that run California, Oregon, Washington, and British Columbia?

Cascades

6. The Sierra Nevada Mountains run along the eastern part of the state of ___ and have a desert to their east. The state has the Pacific Ocean on its west coast.

California

7. The principle of uniformitarianism states that processes operate ___.

the same way at present as they did in the past

8. Cross-bedding on sand is due to ___.

changes in wind direction

9. Hutton came up with the principle of ___, which is crucial to our ability to understand Earth's past.

uniformitarianism

10. On the opposite side of the planet from the Prime Meridian is the ___.

International Date Line

11. ___ devices use at least four satellites to identify the latitude, longitude, and elevation of something or someone.

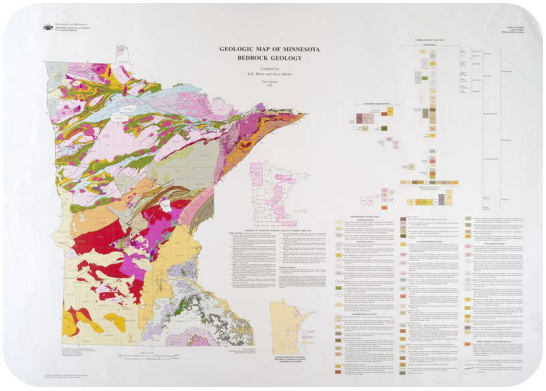
GPS

12. You would find 45°S in the ___ hemisphere.

southern

This page titled 2.7: Introduction to Earth Science- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

2.8: Maps



What information does a map show?

Maps can convey a lot of different types of information. They can tell you where you are, or they can tell you something about a location. Maps can display the relief of an area. They can indicate something about the society that lives in the area. Different types of maps show many different types of things.

Maps as Models

Imagine you are going on a road trip. Perhaps you are going on vacation. How do you know where to go? Most likely, you will use a map. A **map** is a picture of specific parts of Earth's surface. There are many types of maps. Each map gives us different information. Let's look at a road map, which is the probably the most common map that you use (**Figure** below).



A road map of the state of Florida. What information can you get from this map?

Map Legends

You can see the following on this road map of Florida (**Figure** above):

- The boundaries of the state show its shape.
- Black dots represent the cities. Each city is named. The size of the dot represents the population of the city.

- Red and brown lines show major roads that connect the cities.
- Blue lines show rivers. Their names are written in blue.
- Blue areas show lakes and other waterways: the Gulf of Mexico, Biscayne Bay, and Lake Okeechobee. Names for bodies of water are also written in blue.
- A line or scale of miles shows the distance represented on the map; an inch or centimeter on the map represents a certain amount of distance (miles or kilometers).
- Look for the legend on the top left side of the map. The legend explains other features and symbols on the map.
- It is the convention for north to be at the top of a map. For this reason, a compass rose is not needed on most maps.

You can use this map to find your way around Florida and get from one place to another along roadways.

Types of Maps

There are many other types of maps other than road maps. Some examples include:

- Political or geographic maps show the outlines and borders of states and/or countries.
- Satellite view maps show terrains and vegetation: forests, deserts, and mountains.
- Relief maps, also called contour maps, show elevations of areas. They are usually on a larger scale, such as the whole Earth, rather than a local area.
- Topographic maps show detailed elevations of features on the map.
- Climate maps show average temperatures and rainfall.
- Precipitation maps show the amount of rainfall in different areas.
- Weather maps show storms, air masses, and fronts.
- Radar maps show storms and rainfall.
- Geologic maps detail the types and locations of rocks found in an area.

These are but a few types of maps that various Earth scientists might use. You can easily carry a map around in your pocket or bag. Maps are easy to use, because they are flat or two-dimensional. However, the world is three-dimensional. So, how do mapmakers represent a three-dimensional world on flat paper?

403 ERROR

The request could not be satisfied.

Request blocked. We can't connect to the server for this app or website at this time. There might be too much traffic or a configuration error. Try again later, or contact the app or website owner.
If you provide content to customers through CloudFront, you can find steps to troubleshoot and help prevent this error by reviewing the CloudFront documentation.

```
Generated by cloudfront (CloudFront)
Request ID: FipQjrwdQKTtFdKQBrH2eXdZ3APHVB0W9jmaBvAqD0_AR518zBPrUw==
```

Summary

- Maps are two-dimensional representations of a surface, usually Earth's.
- Maps use symbols and have legends. This is so they can display the most amount of information in the least amount of space.
- There are many types of maps. They can show social and political information; they can show scientific information.

Review

1. Using the road map of Florida (**Figure** above), in what direction would you go to get from Fort Lauderdale to Tampa?
2. Why do most maps begin with a portion of Earth's surface? When might they use something different as their base?
3. What types of maps are most useful to Earth scientists?

Explore More

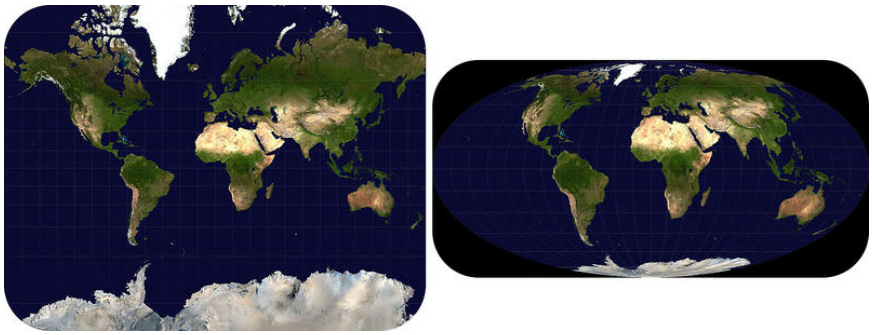
Use this resource to answer the questions that follow.



1. What does a geologic map show?
2. How does a geologist (who, BTW, can also be female) begin to create a geologic map?
3. What is a topographic map?
4. How does a geologist make a geologic map from a topographic map?
5. What are aerial photographs? Why does a geologist use two of the same photographs side by side?
6. What do each of the colors on a geologic map represent?

This page titled 2.8: Maps is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

2.9: Map Projections

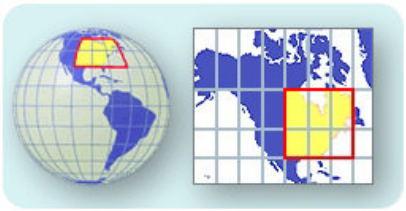


How does Greenland change size?

Greenland does not change size! Different map projections make Greenland appear to be a different size. The Mercator projection makes everything that is near the polar areas appear too large. The Mollweide projection distorts the size of the polar regions much less. To see the actual size of Greenland, look at a globe.

Map Projections

Earth is a round, three-dimensional ball. In a small area, Earth looks flat, so it is not hard to make accurate maps of a small place. When mapmakers want to map the round Earth on flat paper, they use projections. What happens if you try to flatten out the skin of a peeled orange? Or if you try to gift wrap a soccer ball? To flatten out, the orange peel must rip, and its shape must become distorted. To wrap a round object with flat paper requires lots of extra cuts and folds. A **projection** is a way to represent Earth's curved surface on flat paper (**Figure** below).



A map projection translates Earth's curved surface onto two dimensions.

There are many types of projections. Each uses a different way to change three dimensions into two dimensions.

There are two basic methods that mapmakers use in projections:

- The mapmaker "slices" the sphere in some way and unfolds it to make a flat map. This is like flattening out an orange peel.
- The mapmaker can look at the sphere from a certain point and then translate this view onto a flat paper.

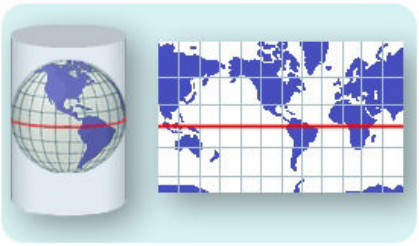
Let's look at a few commonly used projections.

Mercator Projection

In 1569, Gerardus Mercator (1512-1594) (**Figure** below) figured out a way to make a flat map of our round world. This is called the Mercator projection.

Imagine wrapping the round, ball-shaped Earth with a big, flat piece of paper. First you make a tube or a cylinder. The cylinder touches Earth at the Equator. The poles are the farthest points from the cylinder. Now shine a light from the inside of your model Earth out to the cylinder. The image projected onto the paper is a Mercator projection. Where does the projection represent Earth best? Where is it worst? Your map would be most correct at the Equator. The shapes and sizes of continents become more stretched out near the poles. Early sailors and navigators found the Mercator map useful because most explorations were located near the Equator. Many world maps still use the Mercator projection.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



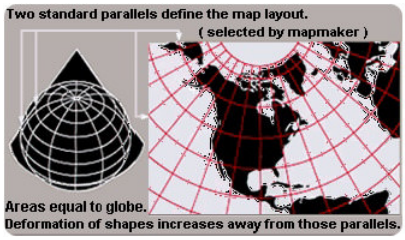
A Mercator projection translates the curved surface of Earth onto a cylinder.

The Mercator projection is best within 15° north or south of the Equator. Landmasses or countries outside that zone get stretched out of shape. The further the feature is from the Equator, the more out of shape it is stretched. For example, if you look at Greenland on a globe, you see it is a relatively small country near the North Pole. But look at the Mercator projection above. Greenland looks almost as big the United States. Because Greenland is closer to the pole, the continent's shape and size are greatly increased. The United States is closer to its true dimensions. Why is this true?

In a Mercator projection, all compass directions are straight lines. This makes it a good type of map for navigation. The top of the map is north, the bottom is south, the left side is west and the right side is east. However, because it is a flat map of a curved surface, a straight line on the map is not the shortest distance between the two points it connects.

Conic Projection

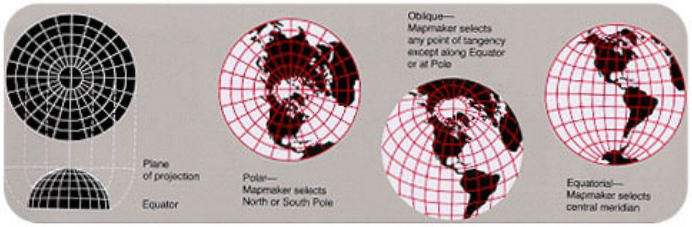
Instead of a cylinder, you could wrap the flat paper into a cone. Conic map projections use a cone shape to better represent regions near the poles (**Figure** below). Conic projections are best where the cone shape touches the globe. This is along a line of latitude, usually the Equator.



A conic map projection wraps Earth with a cone shape rather than a cylinder.

Gnomonic Projection

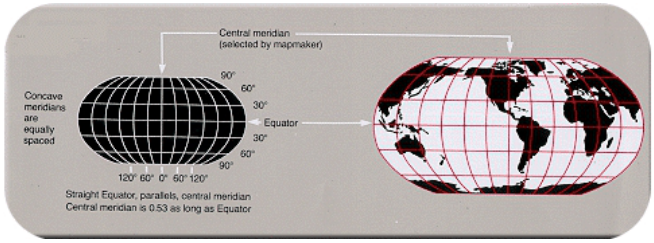
What if you want a different approach? Let's say you don't want to wrap a flat piece of paper around a round object. You could put a flat piece of paper right on the area that you want to map. This type of map is called a gnomonic map projection (**Figure** below). The paper touches Earth only at one point. The sizes and shapes of countries near that point are good. The poles are often mapped this way to avoid distortion. A gnomic projection is best for use over a small area.



A gnomonic projection places a flat piece of paper on a point somewhere on Earth and projects an image from that point.

Robinson Projection

In 1963, Arthur Robinson made a map with more accurate sizes and shapes of land areas. He did this using mathematical formulas. The formulas could directly translate coordinates onto the map. This type of projection is shaped like an oval rather than a rectangle (**Figure** below).



A Robinson projection better represents the true shapes and sizes of land areas.

Robinson's map is more accurate than a Mercator projection. The shapes and sizes of continents are closer to true. Robinson's map is best within 45° of the Equator. Distances along the Equator and the lines parallel to it are true. However, the scales along each line of latitude are different. In 1988, the National Geographic Society began to use Robinson's projection for its world maps.

Summary

- A map projection is a way to show a three-dimensional figure in two dimensions.
- All map projections have some distortion. Different types have distortions in different locations and of different amounts.
- Robinson's project is different from the rest because it uses mathematical formulas. Other projections are best at one point.

Review

1. Why does a map projection distort Earth's features? Where does it distort the features most?
2. Which type of projection is best for someone interested in studying Greenland? The worst?
3. Why would the Mercator projection have been okay for use in the 16th century?

Explore More

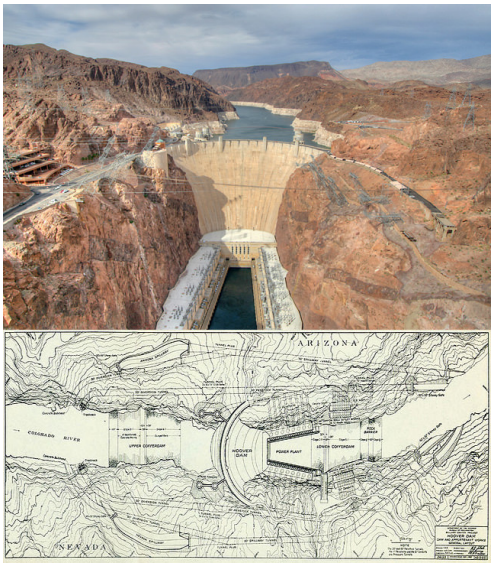
Use the resource below to answer the questions that follow.



1. How is making a map of Earth like trying to flatten an orange peel? What problems occur when making a map of Earth?
2. What is the choice you need to make when you create or use a map of the world?
3. In a Mercator Projection, what is accurate and what isn't? What was a Mercator map made to be able to do?
4. In Lambert's Cylindrical Projection, where is the distortion greatest? What is good? What is distorted?
5. In the Winkel Tripel Projection, what are the three things that need to be compromised?
6. What is a Dymaxion Projection good at showing and what is it commonly used for?
7. What is the best type of map?

This page titled 2.9: Map Projections is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

2.10: Topographic and Geologic Maps



Can a map help you understand a place even if you've never been there?

Hills, streams, valleys, and snowfields all show up on some types of maps. With practice, people can look at a topographic map and see what the landscape is really like. Of course, it's not the same as being there! But a topographic map can give you a good feel for an area before you go. It can also help you to identify features once you are there. What does this map tell you about the region? Can you identify features that appear in the photo on the map?

Topographic Maps

The topography of a region can be shown on a map. **Topographic maps** represent geographical features, such as hills and valleys. Topographic maps use contour lines to show geographical features. A **contour line** is a line of equal elevation. If you walk along a contour line, you will not go uphill or downhill. Topographic maps are also called contour maps. The rules of topographic maps are:

- Each line connects all points of a specific elevation.
- Contour lines never cross. After all, a single point can have only one elevation.
- Every fifth contour line is bolded and labeled.
- Adjacent contour lines are separated by a constant difference in elevation (such as 20 feet or 100 feet). The difference in elevation is the **contour interval**. The contour interval is indicated in the map legend.
- Scales indicate horizontal distance and are also found on the map legend.

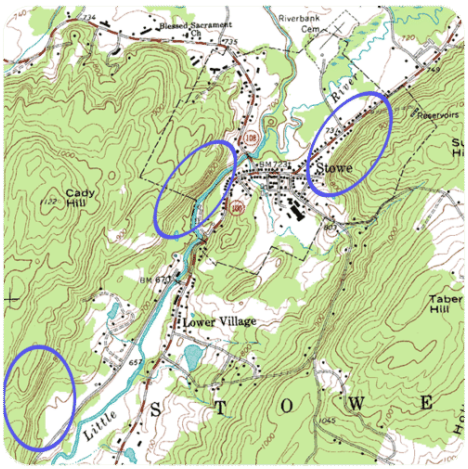
Interpreting Contour Maps

How does a topographic map tell you about the terrain? Let’s consider the following principles:

1. **The spacing of contour lines shows the slope of the land**. Contour lines that are close together indicate a steep slope. This is because the elevation changes quickly in a small area. Contour lines that seem to touch indicate a very steep slope, like a cliff. When contour lines are spaced far apart, the slope is gentle. So contour lines help us see the three-dimensional shape of the land.

Look at the topographic map of Stowe, Vermont (**Figure** below). There is a steep hill rising just to the right of the city of Stowe. You can tell this because the contour lines there are closely spaced. The contour lines also show that the hill has a sharp rise of about 200 feet. Then the slope becomes less steep toward the right.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



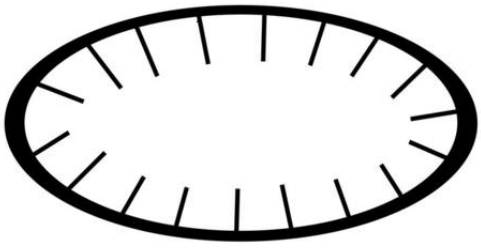
Portion of a USGS topographic map of Stowe, VT.

2. **Concentric circles indicate a hill**. Pictured below is another side of the topographic map of Stowe, Vermont (**Figure** below). When contour lines form closed loops, there is a hill. The smallest loops are the higher elevations on the hill. The larger loops encircling the smaller loops are downhill. If you look at the map, you can see Cady Hill in the lower left and another, smaller hill in the upper right.



Portion of a USGS topographic map of Stowe, VT. Cady Hill (elevation 1122 feet) is shown by concentric circles in the lower left portion of the map. Another hill (elevation ~ 960 feet) is on the upper right portion of the map.

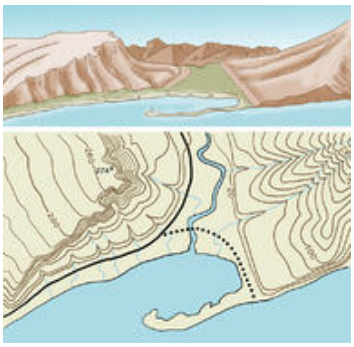
3. **Hatched concentric circles indicate a depression**. The hatch marks are short, perpendicular lines inside the circle. The innermost hatched circle represents the deepest part of the depression (**Figure** below). The outer hatched circles represent higher elevations.



On a contour map, a circle with inward hatches indicates a depression.

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

4. **V-shaped portions of contour lines indicate stream valleys**. The "V" shape of the contour lines point uphill. There is a V shape because the stream channel passes through the point of the V. The open end of the V represents the downstream portion. A blue line indicates that there is water running through the valley. If there is not a blue line, the V pattern indicates which way water flows. Below, you can see examples of V-shaped markings (**Figure** below). Try to find the direction a stream flows.



Illustrations of three-dimensional ground configurations (top) and corresponding topographic map (bottom). Note that the V-shaped markings on the topographic maps correspond to drainage channels. Also, the closely-spaced contour lines denote the rapid rising cliff face on the left side.

5. **Like other maps, topographic maps have a scale so that you can find the horizontal distance**. You can use the horizontal scale to calculate the slope of the land (vertical height/horizontal distance). Common scales used in United States Geological Service (USGS) maps include the following:

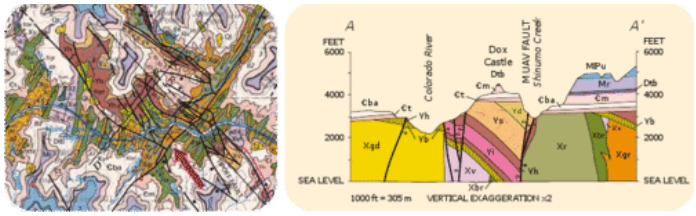
- 1:24,000 scale – 1 inch = 2000 feet
- 1:100,000 scale – 1 inch = 1.6 miles
- 1:250,000 scale – 1 inch = 4 miles

Including contour lines, contour intervals, circles, and V-shapes allows a topographic map to show three-dimensional information on a flat piece of paper. A topographic map gives us a good idea of the shape of the land.

Geologic Maps

A geologic map shows the different rocks that are exposed at the surface of a region. The geology is often put on a contour map. Rock units are shown in a color identified in a key. On the geologic map of the Grand Canyon, for example, different rock types are shown in different colors. Some people call the Grand Canyon "layer cake geology" because most of the rock units are in layers. Rock units show up on both sides of a stream valley.

A geologic map looks very complicated in a region where rock layers have been folded. Faults are seen on this geologic map cutting across rock layers. When rock layers are tilted, you will see stripes of each layer on the map. There are symbols on a geologic map that tell you which direction the rock layers slant. Often there is a cut away diagram, called a **cross section**. A cross section shows what the rock layers look like below the surface. A large-scale geologic map will just show geologic provinces. They do not show the detail of individual rock layers.



A portion of the geologic map of the Grand Canyon, Arizona.

Summary

- Topographic maps reveal the shape of a landscape. Elevations indicate height above sea level.
- Contour lines are lines of equal elevation. Contour intervals are the difference in elevation between two contour lines.

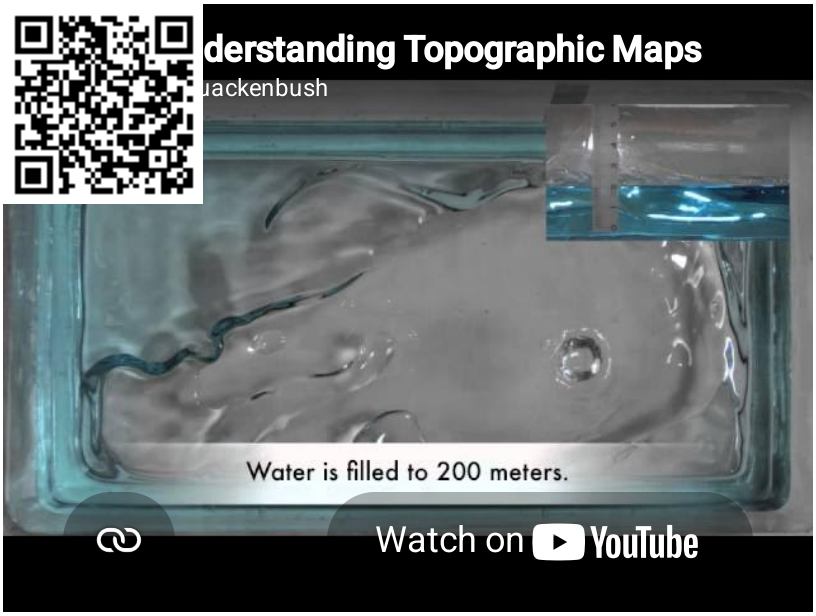
- Geologic maps show rock units and geologic features, like faults and folds.

Review

1. What is a contour line? What is a contour interval?
2. What will a hill look like on a topographic map? How will a basin look different from a hill?
3. How do contour lines indicate a steep slope? How do they indicate a stream?
4. Why might a geologic map be useful to geologists?

Explore More

Use the resource below to answer the questions that follow.



1. What is sea level?
2. How far apart are topographic lines?
3. What do the contour lines represent?
4. How do you know that there's a crater at the top of the volcano rather than a peak?
5. What is the purpose of a topographic map?

This page titled 2.10: Topographic and Geologic Maps is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

2.11: Seafloor



Is it true that we know more about the dark side of the Moon than we do about the oceans?

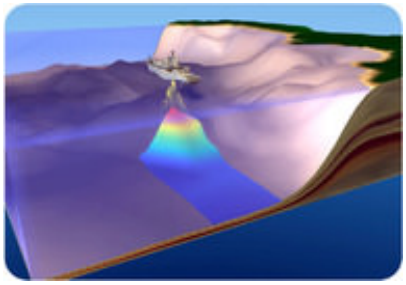
It's true! Why do you think so? The oceans are deep, dark, and frigid. All but the very top surface is under extraordinarily high pressure. It's hard to imagine an environment that's less hospitable to human life! Yet, as you will see, we know quite a bit about the oceans. This is due mostly to technology. Rovers, like the one pictured above, allow scientists to remotely visit places that are too inhospitable for human life.

Studying the Seafloor

Scuba divers can only dive to about 40 meters. When they dive deep, they cannot stay down for very long. Therefore, scuba divers can only observe the organisms and ecosystems very near a coast. Most oceanic research requires accessing greater depths.

Seafloor Bathymetry

How do scientists create bathymetric maps? Early explorers mapped the seafloor by painstakingly dropping a line over the side of a ship. They measured the length of the line when it touched bottom. With this method, they could measure the depth, one tiny spot at a time. During World War II, battleships and submarines carried **echo sounders**. Echo sounders were developed to locate enemy submarines. Early echo sounders had a single beam. The beam bounced off the nearest object and then returned to the ship. Scientists know the speed of sound in seawater. They can then calculate the distance to the object based on the time it takes for the wave to make a round trip. This allowed them to create a line of depth measurements. Modern echo sounders produce sound waves that travel outward in all directions (**Figure** below).

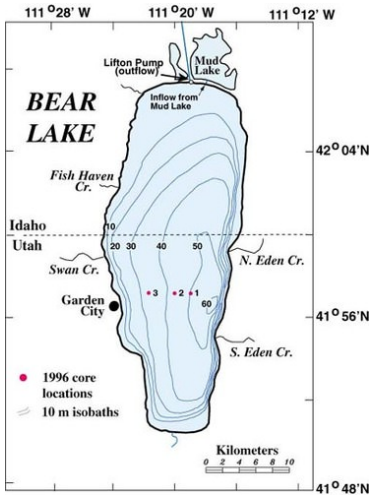


This echo sounder has many beams and creates a three dimensional map of the seafloor.

Bathymetric Maps

Topographic maps that show water depths are called **bathymetric maps**. An example of one is pictured below (**Figure** below). Bathymetric maps can represent any body of water, including lakes and oceans. On these maps, the contour lines represent depth below the surface. Therefore, high numbers are deeper depths and low numbers are shallow depths.

Bathymetric maps are made from depth soundings or sonar data. They help oceanographers understand the shape of bottoms of lakes, bays, and the ocean. This information also helps boaters navigate safely.



Bathymetric map of Bear Lake, Utah.

Water Sampling

Scientists need to sample seawater (or lake water) from different depths. To sample seawater, bottles are placed along a cable at regular depths (**Figure** below). When they are in position, a weight is dropped down the cable. This closes the bottles. The water trapped in the bottle can be analyzed in a laboratory. This allows scientists to understand ocean or lake chemistry.

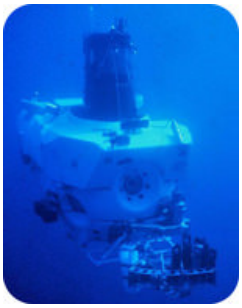


A Niskin bottle being deployed off the side of a research ship.

Scientists also collect rock and sediment samples from the seafloor. A dredge is a giant rectangular bucket that is dragged along behind a ship. The dredge picks up loose rocks lying on the seafloor. Gravity corers are metal tubes that fall to the seafloor. They slice into the sediments to collect a sample. The research vessel, the *Joides Resolution*, drills deep into the seafloor to collect samples of the sediment and ocean crust. Scientists analyze the samples for chemistry and their magnetic properties.

Submersibles

Samples of seawater and rocks can be collected directly by scientists in a **submersible**. These subs can take scientists down to make observations. The subs have arms for collecting samples. The human operated vehicle, Alvin can dive up to 4,500 meters beneath the ocean surface and has made more than 5,000 dives since 1964 (**Figure** below).



Alvin allows two people and a pilot to make a nine hour dive.

Remotely Operated Vehicles

Sending humans to the seafloor is expensive and dangerous. Having to return humans safely to the surface limits what a mission can do. **Remotely operated vehicles**, or ROVs, allow scientists to study the deep without going to the seafloor. These small vehicles carry cameras and scientific instruments. ROVs were used to study inside the *Titanic*. This would have been far too dangerous for a manned sub to enter. Scientists control ROVs electronically with sophisticated operating systems.

Summary

- Scientists have developed amazing technologies so that they can understand the oceans.
- Echo sounders use sound waves to make bathymetric maps of water bodies.
- Submersibles and ROVs allow scientists to view otherwise inhospitable regions.

Review

1. How does an echo sounder work?
2. Why is an ROV better for some tasks than a submersible?
3. How do marine geologists collect rock and sediment samples?

Explore More

Use the resource below to answer the questions that follow.



1. What is the only truly uncharted area of Earth?
2. How were soundings taken in the past?
3. List the advantages of using multi-beam sonar.
4. How is texture captured?
5. What is groundtruthing, and why is it necessary?
6. Why is this project important?

This page titled 2.11: Seafloor is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

2.12: Introduction to Earth Science- Challenge 2

1. Zack is a hiker who plans to climb to the top of Falcon Peak, a mountain near his home. Using a topographic map, what can Zack determine about his location?

The difference in elevation between his home and Falcon Peak

2. A topographic map can be used to determine the ___ of the peak of a mountain

height

3. Topographic maps use ___ to show different elevations.

contour lines

4. What type of projection is best for someone studying Greenland?

Robinson

5. A projection in which the point of contact between the ___ and the ___ is at Greenland would be best for someone studying Greenland.

globe; paper

6. Which type of projection is the worst for accurately representing the size of the areas closest to the north and south poles?

Mercator

7. When a stream crosses terrain, the contour lines are shaped like the letter ___ that points uphill.

V

8. A ___ has closed loop contour lines that which increase in elevation as they move towards the center. The smallest loops are the highest elevation.

hill

9. What do hatched circles on a topographic map indicate?

a depression

10. What is the name of the equipment used to map the ocean floor?

Echo sounders

11. ___ geologists collect rocks with dredges and submersibles, because humans can't travel to the ocean floor.

Marine

12. ___ has taken scientists 4,500 meters deep and has made over 4,000 dives since 1964.

Alvin

This page titled 2.12: Introduction to Earth Science- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

2.13: Telescopes



What would Galileo think of the things we can see through a telescope?

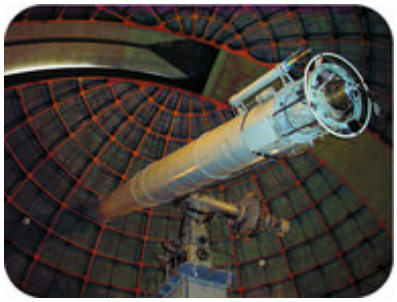
Galileo's telescopes could see about as much as a regular pair of binoculars today. Galileo could see four moons of Jupiter. This was four more than could be seen with the naked eye. But we now know that there are 69 moons. Galileo would be astonished to see all of Jupiter's moons. And imagine what he would think of the galaxies!

Types of Telescopes

Humans have been making and using magnifying lenses for thousands of years. The term "telescope" was coined by the Italian scientist and mathematician Galileo Galilei (1564–1642). Galileo built the first telescope in 1608. His telescope used two lenses to make distant objects appear both nearer and larger. He subsequently made many improvements to telescope design.

Optical Telescopes

Telescopes that use lenses to bend light are called **refracting telescopes**, or refractors (**Figure** below). The earliest telescopes were all refractors. Many amateur astronomers still use refractors today. Refractors are good for viewing details within our solar system. Craters on the surface of Earth's Moon or the rings around Saturn are two such details.



Refracting telescopes can be very large.

Around 1670, Sir Isaac Newton built a different kind of telescope. Newton's telescope used curved mirrors instead of lenses to focus light. This type of telescope is called a **reflecting telescope**, or reflector.

It's much easier to precisely make mirrors than to precisely make glass lenses. Mirrors are also much lighter than heavy glass lenses. For these two reasons, mirrors can be made larger than lenses. This is important because a reflecting telescope can be made much larger. Larger telescopes can collect more light. This means that they can study dimmer or more distant objects. The largest optical telescopes in the world today are reflectors. Telescopes can also be made to use both lenses and mirrors.

Radio Telescopes

Radio telescopes collect radio waves. These telescopes are even larger telescopes than reflectors. Radio telescopes look a lot like satellite dishes. In fact, both are designed to collect and focus radio waves or microwaves from space.

The largest single radio telescope in the world is at the Arecibo Observatory in Puerto Rico (**Figure** below). This telescope is located in a natural hole in the ground. This telescope would collapse under its own weight if it were not supported by the ground.

There is a big disadvantage to this design. What do you think it is? The telescope can observe only the part of the sky that happens to be overhead at a given time.



The radio telescope at the Arecibo Observatory in Puerto Rico.

A group of radio telescopes can be linked together with a computer. The telescopes observe the same object. The computer then combines the data from each telescope. This makes the group function like one single telescope. An example is pictured below (**Figure** below).



The Very Large Array in New Mexico consists of 27 radio telescopes.

Space Telescopes

Telescopes on Earth all have one big problem: incoming light must pass through the atmosphere. This blocks some wavelengths of radiation. Also, motion in the atmosphere distorts light. You see this when you see stars twinkling in the night sky. Many observatories are built on high mountains. There is less air above the telescope, so there is less interference from the atmosphere. **Space telescopes** avoid problems from the atmosphere completely since they orbit outside the atmosphere.

The Hubble Space Telescope (**Figure** below) is the best known space telescope. Hubble began operations in 1994. Since then, it has provided huge amounts of data. The telescope has helped astronomers answer many of the biggest questions in astronomy.



The Hubble Space Telescope has opened up the Universe to human observation.

The National Aeronautics and Space Administration (NASA) has placed three other major space telescopes in orbit. Each uses a different part of the electromagnetic spectrum. The James Webb Space Telescope will launch in 2020. The telescope will replace the aging Hubble.



Stars in the star cluster appear as points of light. Observations like these must be made with a space telescope.

Summary

- Refracting and reflecting telescopes are optical telescopes that use lenses to gather light.
- Radio telescopes collect radio waves and are sometimes used in large arrays.
- Space telescopes can see much more than Earth-bound telescopes, since the atmosphere doesn't affect their information.

Review

1. What type of telescope was the first to be developed? Why was it the first?
2. Why are most telescopes refracting telescopes?
3. Why do scientists need space telescopes?

Explore More

Use this resource to answer the questions that follow.



1. Where were telescopes developed?
2. What did Galileo do for the telescope?
3. What was the old belief about the Moon and other celestial bodies?
4. List Galileo's discoveries with the telescope.
5. Explain Galileo's conflict with the Roman Catholic Church.

This page titled 2.13: Telescopes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

2.14: Study of Space by the Electromagnetic Spectrum



How do scientists learn about space?

Many scientists can touch the materials they study. Most can do experiments to test those materials. Biologists can collect cells, seeds, or sea urchins to study in the laboratory. Physicists can test the strength of metal or smash atoms into each other. Geologists can chip away at rocks and test their chemistry. What can astronomers use to study space? Light and other electromagnetic waves, of course. This is the Andromeda Galaxy as it appeared 2.5 million years ago. Why is the light so old?

Electromagnetic Spectrum

Earth is just a tiny speck in the Universe. Our planet is surrounded by lots of space. Light travels across empty space. Light is the visible part of the **electromagnetic spectrum**. Astronomers use the light and other energy that comes to us to gather information about the Universe.

The Speed of Light

In space, light travels at about 300,000,000 meters per second (670,000,000 miles per hour). How fast is that? A beam of light could travel from New York to Los Angeles and back again nearly 40 times in just one second. Even at that amazing rate, objects in space are so far away that it takes a lot of time for their light to reach us. Even light from the nearest star, our sun, takes about eight minutes to reach Earth.

Light-Years

We need a really big unit to measure distances out in space, because distances between stars are so great. A **light-year**, 9.5 trillion kilometers (5.9 trillion miles), is the distance that light travels in one year. That's a long way! Out in space, however, it's actually a pretty short distance.

Proxima Centauri is the closest star to us after the Sun. This near neighbor is 4.22 light-years away. That means the light from Proxima Centauri takes 4.22 years to reach us. Our galaxy, the Milky Way Galaxy, is about 100,000 light-years across. So it takes light 100,000 years to travel from one side of the galaxy to the other! It turns out that even 100,000 light-years is a short distance. The most distant galaxies we have detected are more than 13 billion light-years away. That's over a hundred-billion-trillion kilometers!

Looking Back in Time

When we look at stars and galaxies, we are seeing over great distances. More importantly, we are also seeing back in time. When we see a distant galaxy, we are actually seeing how the galaxy used to look. For example, the Whirlpool Galaxy is about 23 million light-years from Earth (**Figure** below). When you see an image of the galaxy what are you seeing? You are seeing the galaxy as it was 23 million years ago!

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

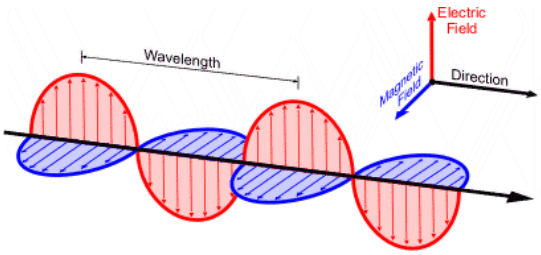


The Whirlpool Galaxy as it looked 23 million years ago.

Since scientists can look back in time, they can better understand the Universe's history.

Electromagnetic Waves

Light is one type of **electromagnetic radiation**. Light is energy that travels in the form of an electromagnetic wave. Pictured below is a diagram of an electromagnetic wave (**Figure** below). An electromagnetic (EM) wave has two parts: an electric field and a magnetic field. The electric and magnetic fields oscillate up and down, which makes the wave.



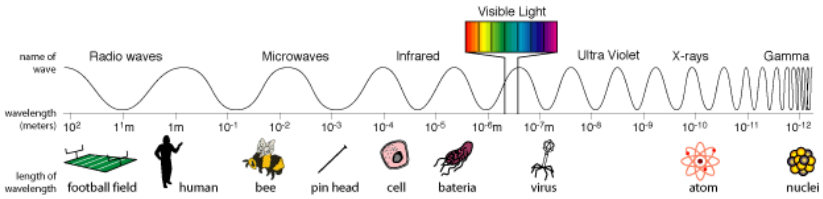
An electromagnetic wave has oscillating electric and magnetic fields.

The **wavelength** is the horizontal distance between two of the same points on the wave, like wave crest to wave crest. A wave's **frequency** measures the number of wavelengths that pass a given point every second. As wavelength increases, frequency decreases. This means that as wavelengths get shorter, more waves move past a particular spot in the same amount of time.

The Electromagnetic Spectrum

Visible light is the part of the electromagnetic spectrum (**Figure** below) that humans can see. Visible light includes all the colors of the rainbow. Each color is determined by its wavelength. Visible light ranges from violet wavelengths of 400 nanometers (nm) through red at 700 nm.

Visible light is only a small part of the electromagnetic spectrum. There are parts of the electromagnetic spectrum that humans cannot see. This radiation exists all around you. You just can't see it! Every star, including our Sun, emits radiation of many wavelengths. Astronomers can learn a lot from studying the details of the spectrum of radiation from a star.



The electromagnetic spectrum from radio waves to gamma rays.

Many extremely interesting objects can't be seen with the unaided eye. Astronomers use telescopes to see objects at wavelengths all across the electromagnetic spectrum. Some very hot stars emit light primarily at ultraviolet wavelengths. There are extremely hot objects that emit X-rays and even gamma rays. Some very cool stars shine mostly in the infrared light wavelengths. Radio waves come from the faintest, most distant objects.

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

Summary

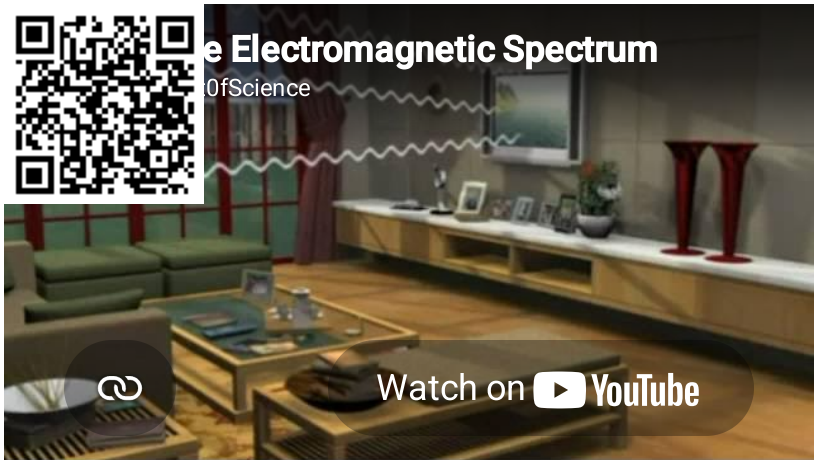
- Electromagnetic radiation is energy transmitted as waves with different wavelengths. This makes up the electromagnetic spectrum.
- Light travels very fast but still takes a long time to get across space. A light-year is the distance light can travel in one year.
- From longest wavelengths to shortest wavelengths the electromagnetic spectrum is: radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays.

Review

1. Why do astronomers use light-years as a measure of distance?
2. In the electromagnetic spectrum, which wavelengths are shorter than visible light? Which are longer than visible light? Which are relatively cooler? Which are relatively hotter?
3. Why does light we see today tell us something about what happened earlier in the history of the Universe?

Explore More

Use the resource below to answer the questions that follow.



1. What is the electromagnetic spectrum?
2. What type of waves have the shortest wavelengths?
3. What type of waves have the longest wavelengths?
4. What do electromagnetic waves transmit?
5. Define wavelength.
6. Define frequency.
7. What type of waves have the lowest frequency?
8. What is the visible light region?
9. How is color produced?
10. What do scientists use the electromagnetic spectrum for?

This page titled 2.14: Study of Space by the Electromagnetic Spectrum is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

2.15: Satellites, Shuttles, and Space Stations



Why are satellites important?

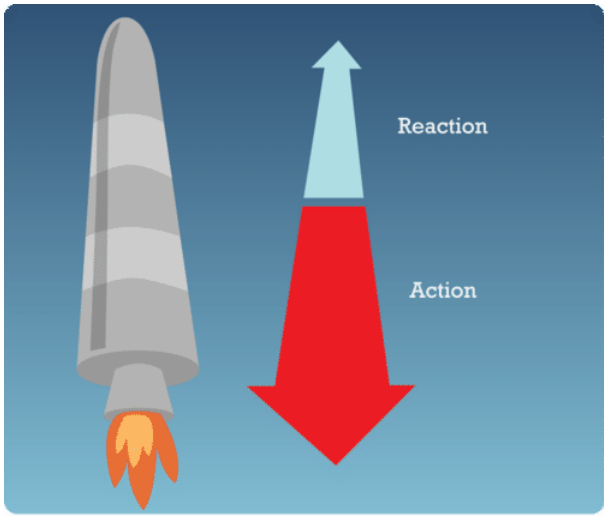
In 1900, a category 4 hurricane devastated Galveston, Texas. It claimed the lives of between 6,000 and 12,000 people. By contrast, the death toll from Hurricane Katrina was about 1,800 people. Why the difference? Although Hurricane Katrina (and Harvey and Maria and others) was a modern tragedy, it would have been much worse without the advance warning of many weather satellites.

Rockets

Humans did not reach space until the second half of the 20th century. They needed to somehow break past Earth's gravity. A **rocket** moves rapidly in one direction. The device is propelled by particles flying out of it at high speed in the other direction.

How Rockets Work

Rockets were used for centuries in wars and for fireworks before anyone could explain how they worked. In 1687 Sir Isaac Newton developed his Laws of Motion. The third law says: To every action there is an equal and opposite reaction. In other words, when a rocket's propulsion pushes in one direction, the rocket moves in the opposite direction (**Figure** below).



A rocket pushes in one direction so that it moves in the opposite direction.

For a long time, many people believed that a rocket wouldn't work in space. There would be nothing for the rocket to push against. But they do work! Fuel is ignited in a chamber. The gases in the chamber explode. The explosion creates pressure that forces the gases out of one side of the rocket. The rocket moves in the opposite direction (**Figure** below). The force pushing the rocket is called **thrust**.



This Space Shuttle launch shows how the thrust of the rocket pushes the shuttle upward into the sky.

A Rocket Revolution

For centuries, rockets were powered by gunpowder or other solid fuels. These rockets could travel only short distances. Around the turn of the 20th century, liquid fuel rockets were developed. Liquid fuel gave the rockets enough power to escape Earth's gravity. By using multiple stages, empty fuel containers could drop away. This reduced the mass of the rocket so that it could fly higher.

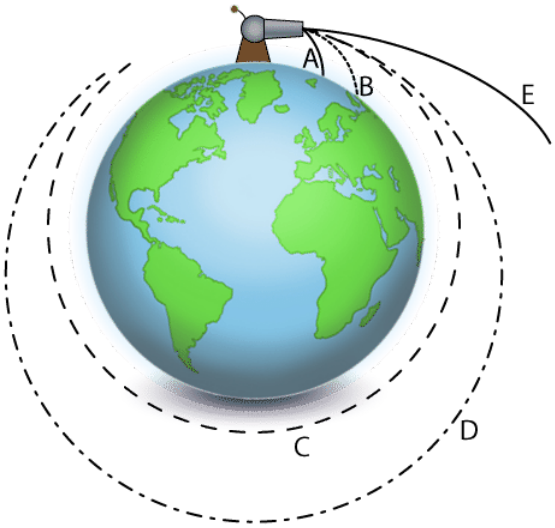
Satellites

One of the first uses of rockets in space was to launch satellites. A **satellite** is an object that orbits a larger object. An **orbit** is a circular or elliptical path around an object. Natural objects in orbit are called natural satellites. The Moon is a natural satellite. Human-made objects in orbit are called artificial satellites.

How a Satellite Stays in Orbit

Newton's law of universal gravitation describes how an object can orbit a planet. Every object in the Universe is attracted to every other object by gravity. Gravity also keeps you from floating away into the sky. Why doesn't gravity cause satellites to crash into Earth?

Newton used an example to explain how gravity makes orbiting possible. Imagine a cannonball launched from a high mountain (**Figure** below). If the cannonball is launched at a slow speed, it will fall back to Earth. This is shown as paths (A) and (B). If the cannonball is launched at a fast speed, Earth curves away at the same rate that the cannonball falls. The cannonball then goes into a circular orbit, as in path (C). If the cannonball is launched even faster, it could go into an elliptical orbit (D). It might even leave Earth's gravity and go into space (E).



Isaac Newton explained how a cannonball fired from a high point with enough speed could orbit Earth.

Unfortunately, Newton's idea would not work in real life. A cannonball launched at a fast speed from Mt. Everest would burn up in the atmosphere. However, a rocket can launch straight up, then steer into orbit. It won't burn up in the atmosphere. So a rocket can carry a satellite above the atmosphere and then release the satellite into orbit.

Satellite Orbits

Satellites have different views depending on their orbit. Satellites may be put in a low orbit. These satellites orbit from north to south over the poles. These satellites view a different part of Earth each time they circle. Imaging and weather satellites need this type of view.

Satellites may be placed so that they orbit at the same rate the Earth spins. The satellite then remains over the same location on the surface. Communications satellites are often placed in these orbits.

Types of Satellites

The first artificial satellite was launched just over 50 years ago. Thousands are now in orbit around Earth. Satellites also orbit the Moon, the Sun, Venus, Mars, Jupiter, and Saturn. Satellites have many different purposes. There are satellites for communications and navigation. There are satellites for taking pictures of a planet's surface.

Dozens of satellites collect data about Earth. NASA's Landsat satellites make detailed images of Earth's continents and coastal areas. Other satellites study the oceans, atmosphere, polar ice sheets, and other Earth systems. This data helps us to monitor climate change. Other long-term changes in the planet are also best seen from space. Satellite images help scientists understand how Earth's systems affect one another. Different satellites monitor different wavelengths of energy.

Space Stations

Humans have a presence in space at the International Space Station (ISS) (**Figure** below). Modern space stations are constructed piece by piece to create a modular system. The primary purpose of the ISS is scientific research, especially in medicine, biology, and physics.



A photograph of the International Space Station was taken from the space shuttle Atlantis in June 2007.

Space Shuttles

Craft designed for human spaceflight, like the Apollo missions, were very successful. They were also very expensive and could not carry much cargo. They could be used only once. To outfit the ISS, NASA needed a space vehicle that was reusable. It needed to be able to carry large pieces of equipment. The cargo might include satellites, space telescopes, or sections of a space station. The resulting spacecraft is called a **space shuttle** (**Figure** below).



Atlantis on the launch pad in 2006. Since 1981, the space shuttle has been the United States' primary vehicle for carrying people and large equipment into space.

A space shuttle has three main parts. The part you are probably most familiar with is the **orbiter**. The orbiter has wings like an airplane. When a space shuttle launches, the orbiter is attached to a huge fuel tank that contains liquid fuel. On the sides of the fuel tank are two large "booster rockets." All of this is needed to get the orbiter out of Earth's atmosphere. Once in space, the orbiter can be used to release equipment (such as a satellite or supplies for the International Space Station). It can be used to repair existing equipment, such as the Hubble Space Telescope. Astronauts can even do experiments directly on board the orbiter.

When the mission is complete, the orbiter re-enters Earth's atmosphere. The craft flies back to Earth more like a glider than an airplane. The Space Shuttle program did 135 missions between 1981 and 2011, when the remaining shuttles were retired. Since the space shuttles have retired, the ISS is serviced by Russian Soyuz spacecraft.

You can visit the retired shuttles around the country:

- Enterprise at the Intrepid Sea-Air-Space Museum, New York City.
- Discovery at the National Air and Space Museum, Chantilly Virginia.
- Atlantis at the Kennedy Space Center, Florida.
- Endeavour at the California Science Center, Los Angeles.

SpaceX

On May 30, 2020 NASA and SpaceX sent Robert Behnken and Douglas Hurley to the International Space Station from the Kennedy Space Center in Florida. These astronauts were testing SpaceX's Falcon 9 rocket and Crew Dragon spacecraft on their ability to transport people to and from the International Space Station.



This illustration shows the Crew Dragon spacecraft in low Earth orbit.

This historic launch is the first commercially built spacecraft to take astronauts into Earth's orbit. It is also the first time in the United States launched its astronauts from US soil since NASA's Space Shuttle Program ended in 2011. Falcon 9 is also the first rocket that can send things into Earth's orbit and then be reused for another flight.

These amazing firsts all contribute to NASA's Commercial Crew Program which partners NASA with private companies to build space transport systems to make space travel and research cheaper and more effective.

Science Friday: How A LEGO Shuttle Got To Space

How would you get a LEGO shuttle to space? In this video by Science Friday, Raul Oaida, 18-years-old, attached a LEGO shuttle, a video camera and a GPS tracker, to a huge helium balloon and sent them into space. The shuttle reached an altitude of 115,000 feet before heading back to Earth.



Summary

- Rockets are propelled into space by particles flying out one end at high speed. This allows them to escape gravity.
- Thousands of artificial satellites orbit Earth. Satellites are used for imaging, communications, navigation, and human habitation.
- Space stations are continuously inhabited by humans. The humans reach the space station by space shuttle.

Review

1. How does a rocket work?
2. Why are there so many satellites orbiting Earth at this time?
3. How do artificial satellites stay in orbit? Is this how natural satellites, like the Moon, stay in orbit?

Explore More

Use the resources below to answer the questions that follow.



1. How do scientists study Earth from space?
2. What does the Aqua satellite do?
3. What does the Terra satellite do?



4. What is Landsat?
5. Why is it important?
6. What has been learned from Landsat images?

This page titled 2.15: Satellites, Shuttles, and Space Stations is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

2.16: Introduction to Earth Science- Challenge 3

1. Telescopes that use lenses to bend light are called ___ telescopes.

refracting

2. Sir Isaac Newton created the first ___ telescopes.

reflecting

3. In which year did Galileo build the first telescope?

1608

4. A wave's ___ measures the number of wavelengths that pass a given point every second.

frequency

5. The Whirlpool Galaxy is about 23 million light-years from Earth. The image we see through a telescope on Earth is the galaxy ___.

as it was 23 million years ago

6. Visible light waves are composed of ___.

electric and magnetic fields

7. The largest artificial satellite, which is designed for human habitation, is ___.

the International Space Station (ISS)

8. Which satellite is designed for humans to live in space while conducting scientific research?

the ISS

9. Which type of satellite is used for the Global Positioning System (GPS)?

Navigational

This page titled 2.16: Introduction to Earth Science- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

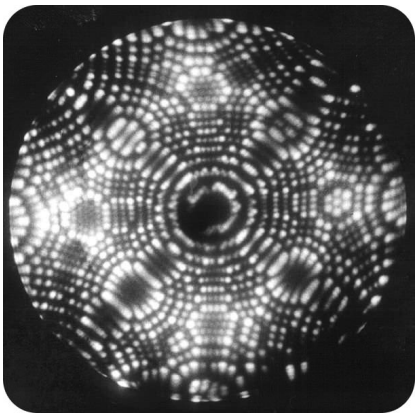
CHAPTER OVERVIEW

3: Planet Earth

3.1: Atoms and Molecules
3.2: Earth's Shape
3.3: Earth's Magnetic Field
3.4: Earth's Rotations
3.5: Earth's Revolutions
3.6: Coriolis Effect
3.7: Seasons
3.8: Planet Earth- Challenge 1
3.9: Eclipses
3.10: Solar Eclipses
3.11: Lunar Eclipses
3.12: Lunar Phases
3.13: Planet Earth- Challenge 2
3.14: Earth's Interior
3.15: Earth's Outer Layers
3.16: Earth's Inner Layers
3.17: Earth's Crust
3.18: Earth's Mantle
3.19: Earth's Core
3.20: Lithosphere and Asthenosphere
3.21: Planet Earth- Challenge 3

This page titled 3: Planet Earth is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.1: Atoms and Molecules



Can you see matter?

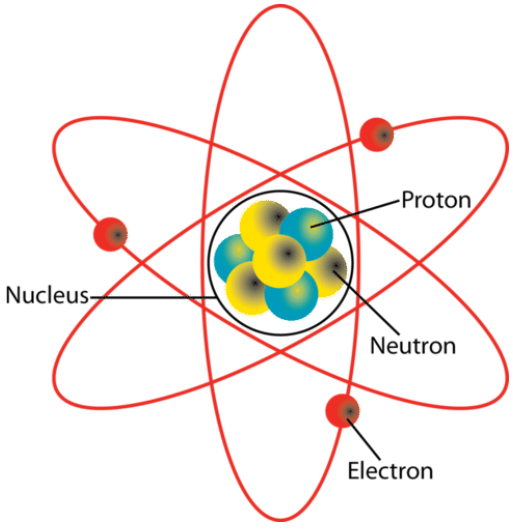
Matter is all around you. Everything you see is matter. All of this matter is made of small particles. The small particles are made of smaller particles.

What is Matter?

To understand minerals, we must first understand matter. **Matter** is the substance that physical objects are made of.

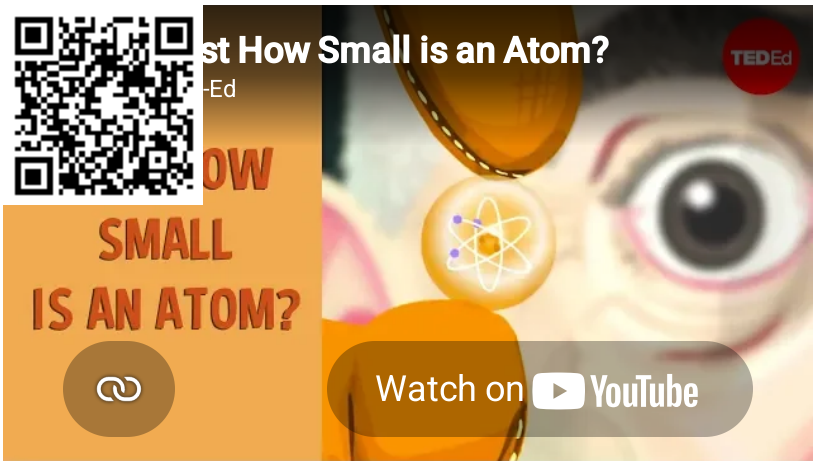
Atoms and Elements

The basic unit of matter is an **atom** (**Figure** below). At the center of an atom is its **nucleus**. **Protons** are positively charged particles in the nucleus. Also in the nucleus are **neutrons** with no electrical charge. Orbiting the nucleus are tiny electrons. **Electrons** are negatively charged. An atom with the same number of protons and electrons is electrically neutral. If the atom has more or less electrons to protons it is called an **ion**. An ion will have positive charge if it has more protons than electrons. It will have negative charge if it has more electrons than protons.



The nucleus of an atom is made up of protons (blue) and neutrons (yellow). Electrons (red) orbit around the nucleus.

An atom is the smallest unit of a chemical **element**. That is, an atom has all the properties of that element. All atoms of the same element have the same number of protons.



Molecules and Compounds

A **molecule** is the smallest unit of a **chemical compound**. A compound is a substance made of two or more elements. The elements in a chemical compound are always present in a certain ratio.

Water is probably one of the simplest compounds that you know. A water molecule is made of two hydrogen atoms and one oxygen atom (**Figure** below). All water molecules have the same ratio: two hydrogen ions to one oxygen ion.



A water molecule has two hydrogen ions (shown in gray) bonded to one oxygen ion (shown in red).

Summary

- An atom has negatively-charged electrons in orbit around its nucleus.
- The nucleus of an atom is composed of positively-charged protons, and neutrons, which have no charge.
- An atom that gains or loses electrons is an ion.

Review

1. Describe the parts of an atom. Where are these parts located?
2. What is an element?
3. What is a molecule made of?
4. How is an ion different from an atom?

This page titled 3.1: Atoms and Molecules is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.2: Earth's Shape

What is a flat-earther?

Flat-earther is a term used to describe someone who believes something despite the evidence or who does not believe something despite the evidence. There are actually people who believe that Earth is flat. They say that satellite photos are faked. They believe that the Apollo Moon landings were faked. But there are very few people alive today who actually believe that Earth is flat. There are, however, plenty of people who can be called flat-earthers. These people believe (or disbelieve) something despite the evidence.

Earth's Shape

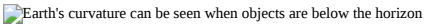
As you walk around, the ground looks flat. So why do you think that Earth is round? The best reason is that we have pictures of Earth taken from space. These photos show that Earth is round. Astronauts aboard the Apollo 17 shuttle took this one, called "The Blue Marble" (**Figure** below). Earth looks like a giant blue and white ball.



This is how the Earth looks from space—like a blue and white marble.

Did people only come to think that Earth is round when spacecrafts took photos? No! Even the ancient Greeks knew that Earth was round. They figured this out by observing the arc shape of the shadow on the Moon during a lunar eclipse. Since Galileo, people have looked through telescopes and seen that the planets orbit around the Sun. These bodies—the Sun and each of the planets—are round. If Earth is a planet, it is certainly round.

Another way to tell that Earth is round is to look at ships sailing off into the distance. What do you see when you watch a tall ship sail over the horizon of the Earth? The bottom part of the ship disappears faster than the top part (**Figure** below). What would that ship look like if Earth were flat? No part of it would disappear before the other. It would all just get smaller as it moved farther away.



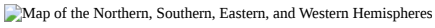
Earth's curvature is noticeable when objects at a distance are below the arc.

Hemispheres

Earth is a sphere (technically, an oblate spheroid, a bit squashed at the poles). As a sphere, it can be divided. Half of a sphere is a **hemisphere**. Earth is divided into hemispheres: north, south, east, west (**Figure** below).

Remember that the **Equator** is the line that falls at 0°. North of the Equator is the **Northern Hemisphere**. South of the Equator is the **Southern Hemisphere**. The North Pole is at 90°N. So there are 90 degree lines in the Northern Hemisphere. The South Pole is 90°S. So there are 90 degree lines in the Southern Hemisphere.

Earth also has an **Eastern Hemisphere** and a **Western Hemisphere**. These distinctions are made by humans simply so that locations can be more easily specified. The Prime Meridian is 0° longitude and passes through Greenwich, England. The International Date Line is the 180° meridian. The Eastern Hemisphere ranges east of the Prime Meridian to the International Date Line. It includes eastern Europe, Africa, Australia, and Asia. The Western Hemisphere extends west of the Prime Meridian to the International Date Line. It includes western Europe and the Americas.



The Northern, Southern, Eastern, and Western Hemispheres are highlighted.

Summary

- Ancient Greeks knew that Earth was round. They saw the shadow the planet cast on the Moon during a lunar eclipse.
- Through a simple telescope, the other planets appear to be round. So Earth must be round.
- A boat does not get smaller with distance but sinks below the horizon. This is more evidence that Earth is round.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Review

1. Before telescopes and spaceships, how did people know that Earth is round?
2. What would a ship sailing away from you look like if Earth were flat? If Earth were round?
3. Define where the hemispheres are located: northern, southern, western, and eastern.

Explore More

Use the resource below to answer the questions that follow.



1. What was the first photo of Earth? What did it prove?
2. Why are bodies in space spherical?
3. How did the planets form?
4. What is the only shape in nature that looks the same from all directions?
5. Why are there odd-shaped objects in space?

This page titled 3.2: Earth's Shape is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.3: Earth's Magnetic Field

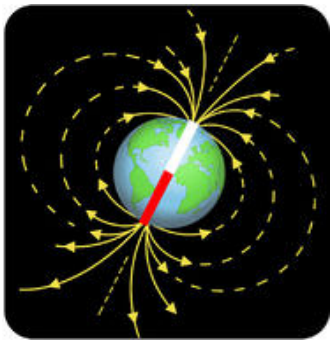


How can you find your way?

You can use Earth's magnetic field to tell you where you want to go. A compass needle aligns with Earth's magnetic field. People can navigate by finding magnetic north. If you know where north is, you can figure out how to get anywhere. A compass is great for finding your way when you're out in the field!

Earth's Magnetism

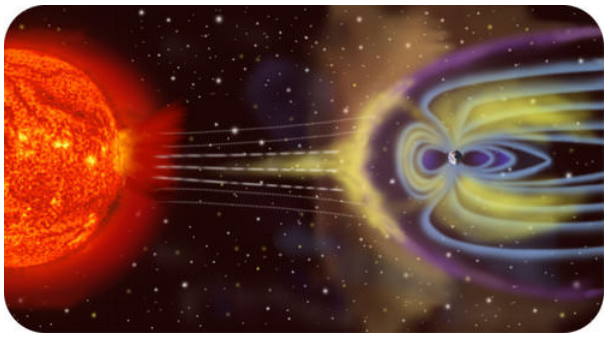
Earth has a **magnetic field** (**Figure** below). The magnetic field behaves like a giant bar magnet inside Earth. If you have a large bar magnet, you can hang it from a string. Then watch as it aligns itself in a north-south direction. It does this to line up with Earth's magnetic field.



Earth's magnetic field is like a bar magnet that resides in the center of the planet.

The magnetic field has north and south poles. The magnetic poles do not exactly match the geographic poles. So the North Magnetic Pole is not the same as the geographic North Pole. The same is true of the South Pole. The magnetic field is created by the movement of molten metal in the outer core.

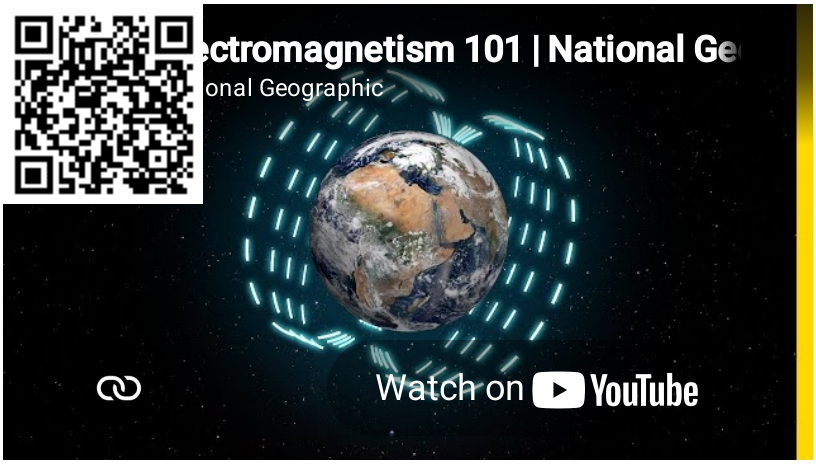
Earth's magnetic field extends several thousand kilometers into space. It shields us from harmful radiation from the Sun (**Figure** below).



Earth's magnetic field protects the planet from harmful radiation.

Magnetic Reversals

Something very strange has happened many times during Earth's history. The planet's magnetic field flipped! The North Magnetic Pole became the South Magnetic Pole. The South Magnetic Pole became the North Magnetic Pole. Scientists are not sure why this happens. The fact that it does happen is useful to scientists. In the chapter *Plate Tectonics*, you'll learn how.



Summary

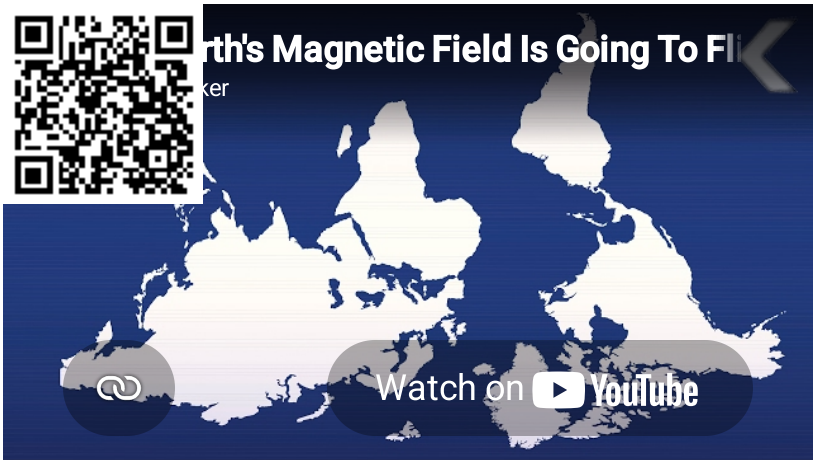
- Earth's magnetic field is like a bar magnet through the planet.
- The magnetic field is generated by convection in the liquid outer core.
- Occasionally the magnetic field flips. The North Magnetic Pole becomes the South Magnetic Pole and the South Magnetic Pole becomes the North Magnetic Pole.

Review

1. Why does Earth have a magnetic field?
2. Why is it important for Earth to have a magnetic field?
3. What is a magnetic field reversal?

Explore More

Use this resource to answer the questions that follow.

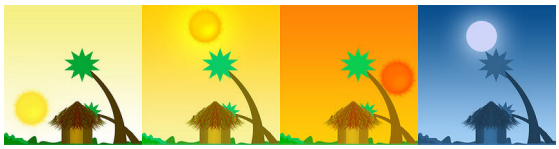


1. What generates Earth’s magnetic field? Why is the magnetic field important?
2. What is a magnetic field flip? Roughly how often does it happen?
3. Why do scientists interested in Earth’s magnetic field collect cores from rocks at the Mid-Atlantic Ridge?
4. When was the last major magnetic field flip?
5. How do ancient pottery give scientists clues about Earth’s magnetic field? Why is it more precise than rocks?

6. When was Earth's magnetic field strength high and when was it lower (note that BCE means before current era and years correlate with the BC and AD system)?
7. What has happened to magnetic north since it was first located in the early 19th century? How has the field changed in the past two centuries?

This page titled 3.3: Earth's Magnetic Field is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.4: Earth's Rotations

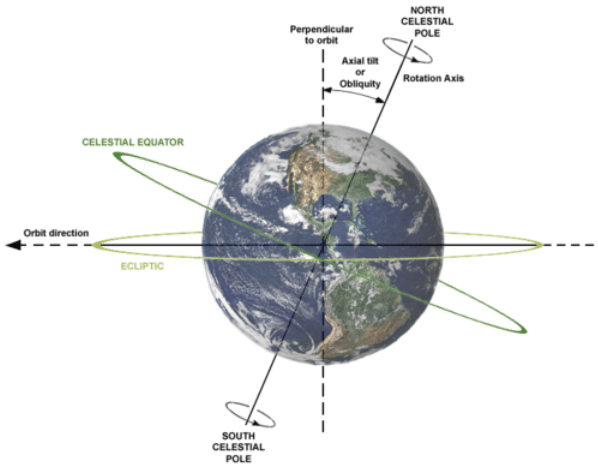


How do you know Earth rotates?

Something amazing happens every day (unless you live very far north or very far south)! The amazing thing is that the Sun rises in the east. It also sets in the west. We know that the Sun doesn't actually move around Earth. What causes the Sun to rise and set is that Earth rotates on its axis. This rotation creates day and night.

Earth's Axis of Rotation

Imagine a line passing through the center of Earth. The line exits the planet at the top and at the bottom. The point at the top is the North Pole. The point at the bottom is the South Pole. This imaginary line is called an **axis**. The points are the north and south geographic poles. The geographic poles are different from the magnetic poles, and they are in different places on the planet.



Earth rotates on an axis, an imaginary line that goes from the North (celestial) Pole to the South (celestial) Pole.

Note that Earth's axis of rotation is tilted. The axis is not perpendicular to the plane of the ecliptic. This plane is the one that solar system bodies are mostly lined up in.

Earth spins around its axis, just as a top spins around its spindle. This spinning movement is called **rotation**. The axis is Earth's **axis of rotation**. Earth rotates on its axis once every 24 hours.

Day-Night Cycle

To an observer looking down at the North Pole, Earth appears to rotate counterclockwise. From nearly all points on Earth, the Sun appears to move across the sky from east to west each day. Of course, the Sun is not moving from east to west at all; Earth is rotating. The Moon and stars also seem to rise in the east and set in the west.

Earth’s rotation means that there is a cycle of daylight and darkness approximately every 24 hours. This is the length of a day. Different places experience sunset and sunrise at different times, and the amount of daylight and darkness also differs by location.

Further Reading

Coriolis Effect

Summary

- Sun, Moon, and stars appear to travel from east to west each day.
- Earth rotates on its axis every 24 hours.
- Earth's rotation causes the day-night cycle.

Review

1. What is an axis of rotation? Where is Earth's axis of rotation?
2. Why do the Sun, Moon, and stars appear to rise in the east and set in the west?
3. What is the length of a day-night cycle? Is it the same everywhere on Earth?

Explore More

Use the resources below to answer the questions that follow.



1. Why does the Earth spin?
2. Why has the Earth's spin slowed?
3. What will eventually happen to the Moon?

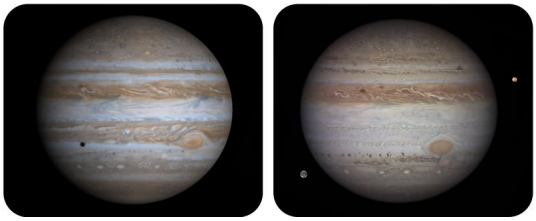


https://k12.libretexts.org/@go/page/5342

4. How long does it take for the Earth to complete a rotation?
5. In what direction is the Earth rotating?

This page titled 3.4: Earth's Rotations is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.5: Earth's Revolutions



What kind of revolution are we talking about?

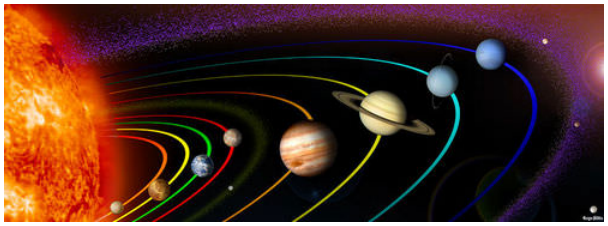
Copernicus caused a revolution. He said that Earth revolved around the Sun. With his telescope, Galileo found a lot of evidence for this. He could see moons orbiting Jupiter. If moons can orbit Jupiter, surely Earth can orbit the Sun. Yes? In the two images above, you can see Jupiter at two different times, showing moons in different places.

Earth's Revolution

Earth orbits a star. That star is our Sun. One **revolution** around the Sun takes 365.24 days. That is equal to one year. Earth stays in orbit around the Sun because of the Sun's gravity (**Figure** below).

Earth's orbit is not a circle. It is a bit elliptical. So as we travel around the Sun, sometimes we are a little farther away from the Sun. Sometimes we are closer to the Sun.

Students sometimes think the slightly oval shape of our orbit causes Earth's seasons. That's not true! The seasons are due to the tilt of Earth’s axis, as discussed in the previous concept.



Earth and the other planets in the solar system make elliptical orbits around the Sun. The ellipses in this image are highly exaggerated.

The distance between the Earth and the Sun is about 93 million miles, or 150 million kilometers. Earth revolves around the Sun at an average speed of about 27 kilometers (17 miles) per second. Mercury and Venus are closer to the Sun, so they take shorter times to make one orbit. Mercury takes only about 88 Earth days to make one trip around the Sun. All of the other planets take longer amounts of time. The exact amount depends on the planet's distance from the Sun. Saturn takes more than 29 Earth years to make one revolution around the Sun. How old would you be if you were on Jupiter?

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



Summary

- Earth's orbit around the Sun is somewhat elliptical.
- Earth's seasons are not caused by the shape of its orbit.
- Earth and the other planets of the solar system revolve around the Sun.

Review

1. How long does it take for Earth to make one revolution around the Sun?
2. Is Earth farther from the Sun in the winter and closer in the summer? Explain.
3. Describe Earth's orbit around the Sun. Describe the orbits of the other planets.

Explore More

Use this resource to answer the questions that follow.



1. What did Aristotle and Ptolemy say about the relationship of Earth to other celestial bodies?
2. In what ways did planets not fit their ideas?
3. Why was the geocentric model a hypothesis that needed to be thrown out?
4. What did Copernicus say about the solar system? What was the heliocentric model?
5. Why was Copernicus' model wrong?
6. What was Kepler's innovation?
7. What contributions did Galileo's telescope make to accepting the Copernicus/Kepler model of the solar system?

8. What did The Church do with the heliocentric model?
9. What is wrong with the heliocentric model?
10. Why do we know that the geocentric model is wrong today?

This page titled 3.5: Earth's Revolutions is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.6: Coriolis Effect



Is this an example of the Coriolis effect?

Does Coriolis determine which direction water in a toilet will swirl? Unfortunately, no. Friction and the power of the flush have too big an influence. But in the atmosphere and oceans, Coriolis affects flow direction.

Coriolis Effect

The **Coriolis effect** is not a force, even though that's what it is sometimes called. Coriolis does not force anything to happen! Coriolis is an effect. What does that mean?

The Coriolis effect describes how Earth's rotation steers winds and surface ocean currents. Unlike land, air and water move freely (in the absence of obstacles). The Coriolis effect causes the path of a freely moving object to appear to curve. This is because Earth is rotating beneath the object. So even though the object's path is straight, it appears to curve. The curve appears to be to the right in the Northern Hemisphere. It appears to be to the left in the Southern Hemisphere.

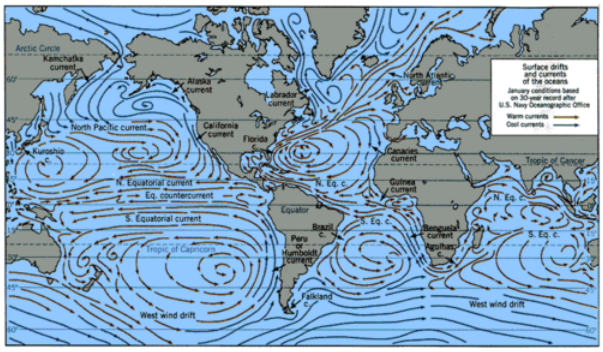
Here is an example in the Northern Hemisphere. A plane takes off from City A . The pilot wants to land in City B, which is 500 miles due north. But the plane will not arrive there without corrections. City B was due north of City A when the plane took off. But during the time it takes for the airplane to fly 500 miles, City B moves east. This happens because of Earth's rotation. So if the airplane flies due north, it will arrive at a different city, City C. City C is west of City B (in the Northern Hemisphere). To reach City B, the pilot should curve right while flying north. The opposite happens in the Southern Hemisphere. In the flights between cities pictured below (**Figure** below), the flight paths look curved. Since a flight path must curve to the right in the Northern Hemisphere, can you tell which city the plane took off from in each case?



The Coriolis effect is the reason that airplanes' flight paths look curved, even though they are the shortest possible path. Although these flight paths show curves, what's wrong with this picture? (The curves do not all follow the path due to Coriolis.)

Effect for Air or Water

As wind or an ocean current moves, the Earth spins underneath it. Wind or water that travels toward the poles from the Equator curves to the east. Wind or water that travels toward the Equator from the poles curves to the west. The Coriolis effect bends the direction of surface currents to the right in the Northern Hemisphere. The currents curve left in the Southern Hemisphere (**Figure** below).



The Coriolis effect causes winds and currents to form circular patterns. The direction that they spin depends on the hemisphere that they are in.

Summary

- Earth rotates beneath freely moving objects like water and air. Compared with a spot on the planet, the objects appear to be moving.
- Freely moving objects appear to move right in the Northern Hemisphere. They appear to move left in the Southern Hemisphere.
- Coriolis is an effect rather than a force. Coriolis does not force a motion. An object appears to have a change of motion due to the Coriolis effect.

Review

1. What is the Coriolis effect?
2. How does the Coriolis effect explain the curved flight paths in the image above (**Figure** above)?
3. How does Coriolis affect wind and water?

Explore More

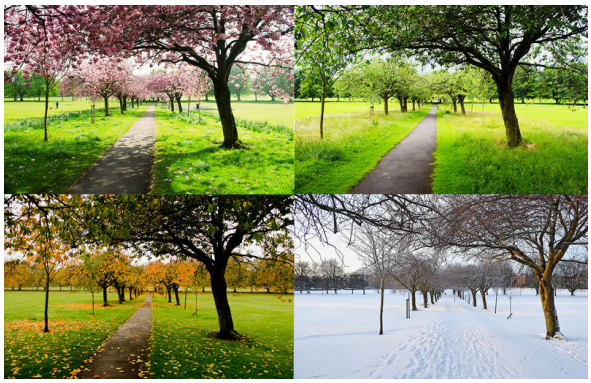
Use these resources to answer the questions that follow.



1. What is the Coriolis effect?
2. What is subject to the Coriolis effect?
3. What is the direction of deflection in the Northern Hemisphere?
4. What is the direction of deflection in the Southern Hemisphere?

This page titled 3.6: Coriolis Effect is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.7: Seasons



Do you like the seasons?

Do you live in a place with well-defined seasons? Do you appreciate the change of the seasons? In other words, are you happy that Earth's axis is tilted?

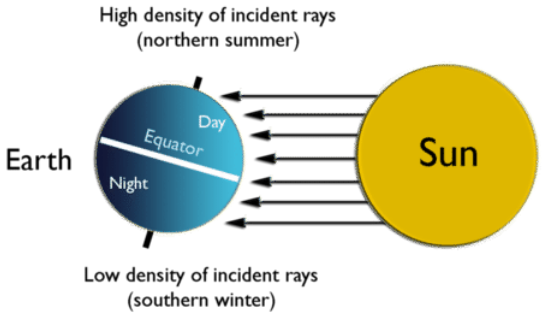
Earth's Seasons

Some people think that Earth is closer to the Sun in the summer and farther away from the Sun in the the winter. But that's not true! Why can't that be true? Because when it's summer in one hemisphere, it's winter in the other. So what does cause the seasons? The seasons are caused by the 23.5° tilt of Earth's axis. One hemisphere points more directly toward the Sun than the other hemisphere. As Earth orbits the Sun, the tilt of Earth's axis stays lined up with the North Star.

Solstice refers to the position of the Sun when it is closest to one of the poles. At equinox, the Sun is directly over the Equator.

Northern Hemisphere Summer/Southern Hemisphere Winter

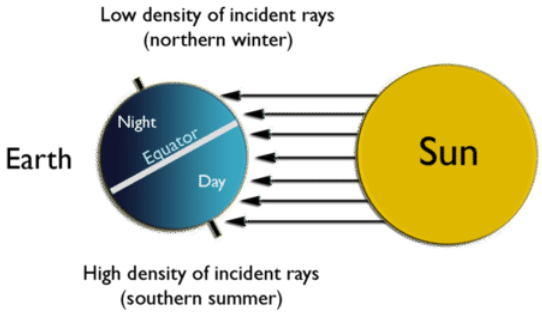
During summer in the Northern Hemisphere, the North Pole is tilted toward the Sun. The Sun's rays strike the Northern Hemisphere more directly (**Figure** below). The region gets a lot of sunlight. **Summer solstice** is June 21 or 22. At that time, the Sun's rays hit directly at the Tropic of Cancer (23.5°N). This is the farthest north that the Sun will be directly overhead. Summer solstice in the Northern Hemisphere is winter solstice in the Southern Hemisphere.



Summer solstice in the Northern Hemisphere.

Northern Hemisphere Winter/Southern Hemisphere Summer

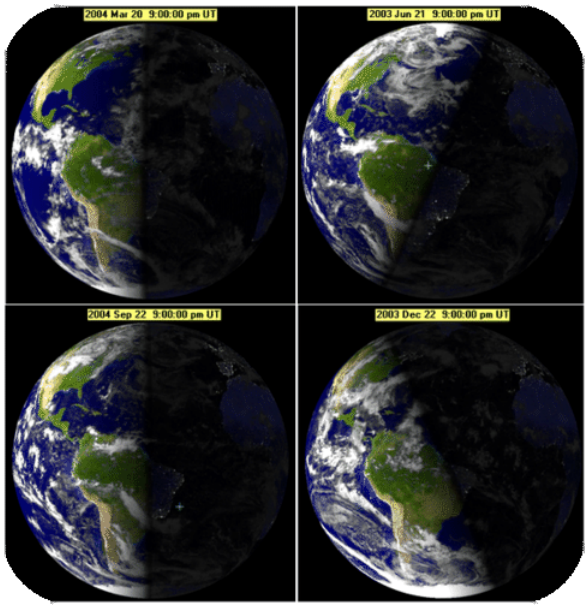
Winter solstice for the Northern Hemisphere happens on December 21 or 22. The North Pole of Earth's axis points away from the Sun (**Figure** below). Light from the Sun is spread out over a larger area. With fewer daylight hours in winter, there is also less time for the Sun to warm the area. When it is winter in the Northern Hemisphere, it is summer in the Southern Hemisphere.



During summer in the Southern Hemisphere, the Sun's rays directly strike the Tropic of Capricorn (23.5°S). Sunlight is spread across a large area near the South Pole. No sunlight reaches the North Pole.

Equinox

Equinox comes halfway between the two solstices. At equinoxes, the Sun's rays shine most directly at the Equator (**Figure** below). The daylight and nighttime hours are exactly equal on an equinox. The autumnal, or fall, equinox happens on September 22 or 23. The vernal, or spring, equinox happens March 21 or 22 in the Northern Hemisphere.



Where sunlight reaches on spring equinox, summer solstice, vernal equinox, and winter solstice. The time is 9:00 p.m. Universal Time, at Greenwich, England.

Summary

- Earth has seasons because of the (23.5°) tilt of its axis of rotation.
- In the Northern Hemisphere, at summer solstice the Sun is closest to the North Pole (around June 22). At winter solstice, the Sun is closest to the South Pole (around December 22). In the Southern Hemisphere, the names are changed.
- At equinox, the Sun is directly over the Equator. Autumnal equinox is around September 22. Spring equinox is around March 22.

Review

1. Imagine that it is summer solstice in the Northern Hemisphere. What is the date, and where is the Sun? What is happening in the Southern Hemisphere?
2. Describe why Earth has seasons.
3. What are equinoxes? When do they come?

This page titled 3.7: Seasons is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.8: Planet Earth- Challenge 1

1. A nucleus contains which particle(s)?

Protons and neutrons

2. If the number of protons of a neutral atom is 24, how many electrons does it have?

24

3. What part of the atom orbits the nucleus?

Electron

4. Earth's magnetic field ___.

has changed direction in the past

5. What generates Earth's magnetic field?

Convection in the liquid outer core

6. Which form of iron and nickel generates a magnetic field in the outer core of the earth?

Molten

7. Which French scientist used a pendulum to help confirm Earth's movement: Foucault, Einstein, Newton, or Galileo?

Foucault

8. Earth's rotational speed is about ___.

1,700 km/hour

9. Apparent shifts in the swing of a Foucault pendulum is the best evidence for the idea that ___.

Earth spins on its axis

10. According to the geocentric model, ___ is at the center of the universe.

Earth

11. In the geocentric model of the universe, everything in the heavens revolves around ___.

Earth

12. How long does it take Earth to make a complete rotation on its axis?

1 day

13. March 20th is associated with the ___.

Vernal equinox

14. Earth has seasons, because its axis of rotation is tilted at ___ degrees to the orbital plane.

23.5

15. The time when daylight and nighttime hours are exactly equal is called the ___.

equinox

This page titled 3.8: Planet Earth- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.9: Eclipses

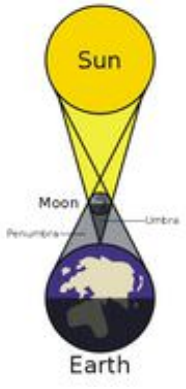


If science wasn't around to tell you what it is, would an eclipse scare you?

Ancient people could not predict eclipses and didn't know when one would end or even that it would end. Rituals to persuade the Sun or Moon to return to its normal state were developed. And they worked! The heavens always return to normal after an eclipse.

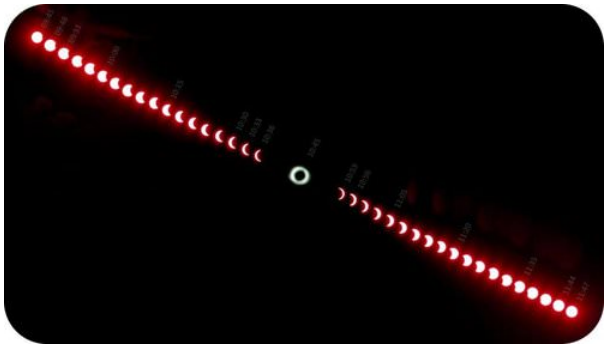
Solar Eclipses

A **solar eclipse** occurs when the new Moon passes directly between the Earth and the Sun (**Figure** below). This casts a shadow on the Earth and blocks Earth's view of the Sun.



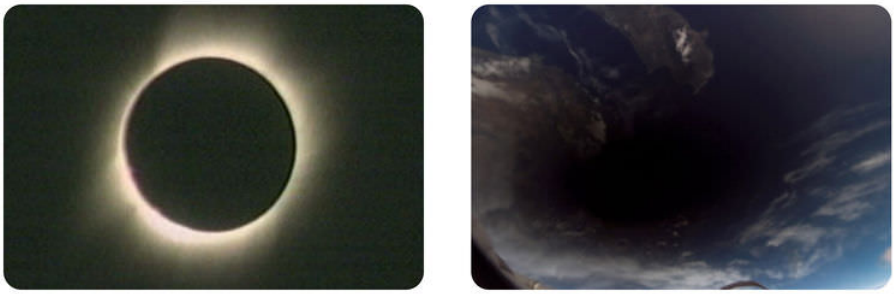
A solar eclipse, not to scale.

A total solar eclipse occurs when the Moon's shadow completely blocks the Sun (**Figure** below). When only a portion of the Sun is out of view, it is called a partial solar eclipse.



A solar eclipse shown as a series of photos.

Solar eclipses are rare and usually only last a few minutes, because the Moon casts only a small shadow (**Figure** below).



The Moon's shadow in a solar eclipse covers a very small area.

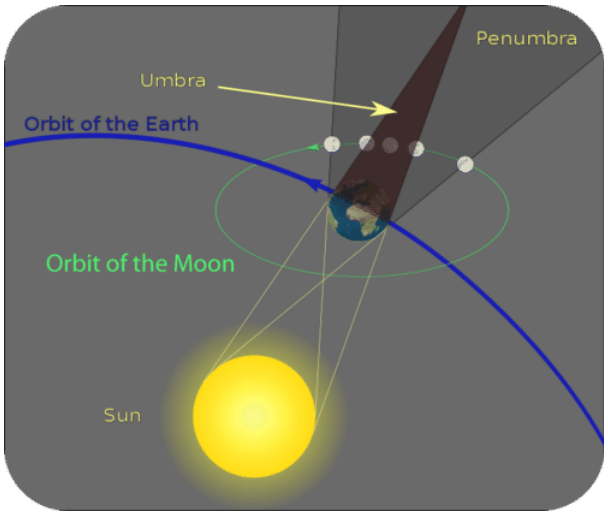
As the Sun is covered by the Moon's shadow, it will actually get cooler outside. Birds may begin to sing, and stars will become visible in the sky. During a solar eclipse, the corona and solar prominences can be seen.

A solar eclipse occurs when the Moon passes between Earth and the Sun in such a way that the Sun is either partially or totally hidden from view. Some people, including some scientists, chase eclipses all over the world to learn or just observe this amazing phenomenon.



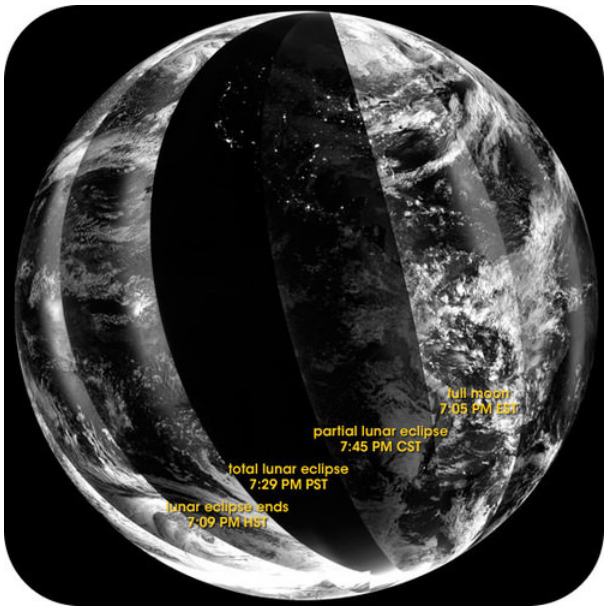
Lunar Eclipses

A **lunar eclipse** occurs when the full moon moves through Earth's shadow, which only happens when Earth is between the Moon and the Sun and all three are lined up in the same plane, called the ecliptic (**Figure** below). In an eclipse, Earth's shadow has two distinct parts: the **umbra** and the **penumbra**. The umbra is the inner, cone-shaped part of the shadow, in which all of the light has been blocked. The penumbra is the outer part of Earth's shadow where only part of the light is blocked. In the penumbra, the light is dimmed but not totally absent.



A lunar eclipse.

A total lunar eclipse occurs when the Moon travels completely in Earth's umbra. During a partial lunar eclipse, only a portion of the Moon enters Earth's umbra. Earth's shadow is large enough that a lunar eclipse lasts for hours and can be seen by any part of Earth with a view of the Moon at the time of the eclipse (**Figure** below). A lunar eclipse does not occur every month because Moon's orbit is inclined 5-degrees to Earth's orbit, so the two bodies are not in the same plane every month.



Partial lunar eclipses occur at least twice a year, but total lunar eclipses are less common.

Summary

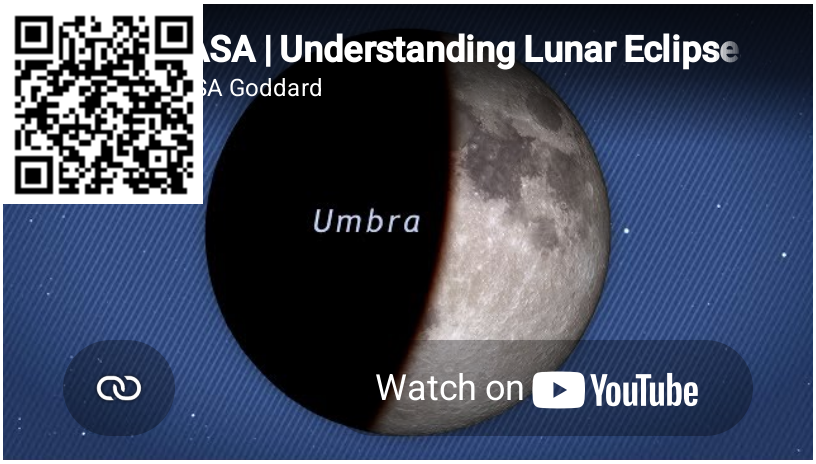
- During a solar eclipse, the new Moon passes between Earth and Sun.
- During a lunar eclipse, the full Moon moves through Earth's shadow.
- The umbra is the part of the shadow in which light is completely blocked and the penumbra is the part of the shadow that is partially lit.

Review

1. What happens during a solar eclipse?
2. What happens during a lunar eclipse?
3. Why do we not see lunar eclipses every month?

Explore More

Use this resource to answer the questions that follow.



1. About how often does a lunar eclipse take place?
2. When does a lunar eclipse occur? When does a solar eclipse occur?
3. Why don't eclipses happen at every new and full moon?
4. What circumstances must be in place for there to be a lunar eclipse?
5. What is the name of the central part of Earth's shadow? What happens to the Moon when it is there and why?

Resources





This page titled 3.9: Eclipses is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.10: Solar Eclipses



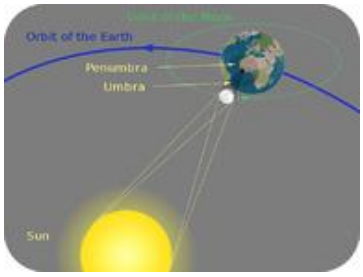
Can you see a solar eclipse?

Of course! This photo of a partial solar eclipse was taken on May 20, 2012 in Gilbert, Arizona. The maximum was 82% at that location. Further north people experienced totality. Much of the United States experienced a total solar eclipse on January 31, 2017. The next total solar eclipse in North America is April 8, 2024 and will be visible in the US from Texas to Maine. If you try to view an eclipse, be sure to use eye protection!

Solar Eclipses

When a new moon passes directly between the Earth and the Sun, it causes a **solar eclipse** (**Figure** below). The Moon casts a shadow on the Earth and blocks our view of the Sun. This only happens if all three are lined up and in the same plane. This plane is called the ecliptic. The ecliptic is the plane of Earth's orbit around the Sun.

The Moon's shadow has two distinct parts. The **umbra** is the inner, cone-shaped part of the shadow. It is the part in which all of the light has been blocked. The **penumbra** is the outer part of Moon's shadow. It is where the light is only partially blocked.



During a solar eclipse, the Moon casts a shadow on the Earth. The shadow is made up of two parts: the darker umbra and the lighter penumbra.

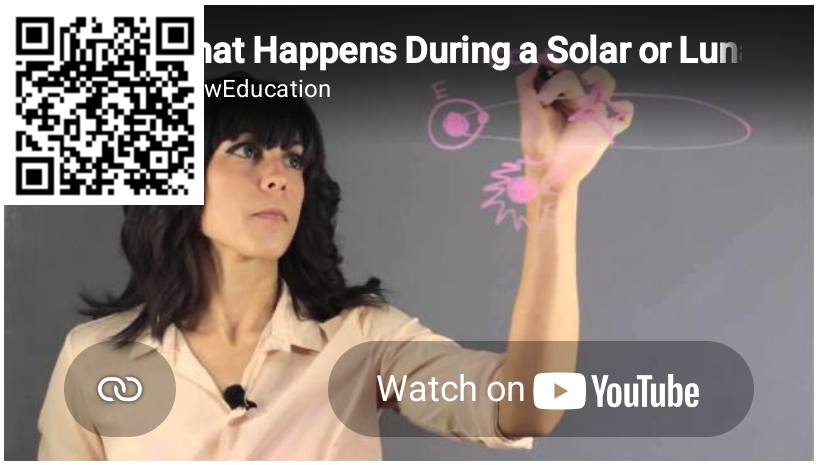
When the Moon's shadow completely blocks the Sun, it is a total solar eclipse (**Figure** below). If only part of the Sun is out of view, it is a partial solar eclipse. Solar eclipses are rare events. They usually only last a few minutes. That is because the Moon's shadow only covers a very small area on Earth, and Earth is turning very rapidly.

Solar eclipses are amazing to experience. The light disappears so that it's like night, only strange. Birds may sing as they do at dusk. Stars become visible in the sky. It gets colder outside. Unlike at night, though, the Sun is out. So during a solar eclipse, it's easy to see the Sun's corona and solar prominences.

LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



A photo of a total solar eclipse.



Summary

- During a solar eclipse, the new moon passes between Earth and Sun.
- The umbra is the part of the shadow in which light is completely blocked.
- The penumbra is the part of the shadow that is partially lit.

Review

1. What is a solar eclipse?
2. What causes a solar eclipse?
3. What is the relationship of the umbra and the penumbra?

Explore More

Use this resource to answer the questions that follow.



1. What happens during a solar eclipse? What happens during a total solar eclipse?

2. What can scientists learn during total solar eclipses that they can't otherwise learn?
3. How do we know that the corona is hotter than the Sun's surface?
4. How did a total eclipse prove Einstein's general theory of relativity?
5. What do you need to do to see a total eclipse? How long does it last?
6. What safety precautions do you need to follow before you view an eclipse?
7. When is the next total solar eclipse in North America?

This page titled 3.10: Solar Eclipses is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.11: Lunar Eclipses

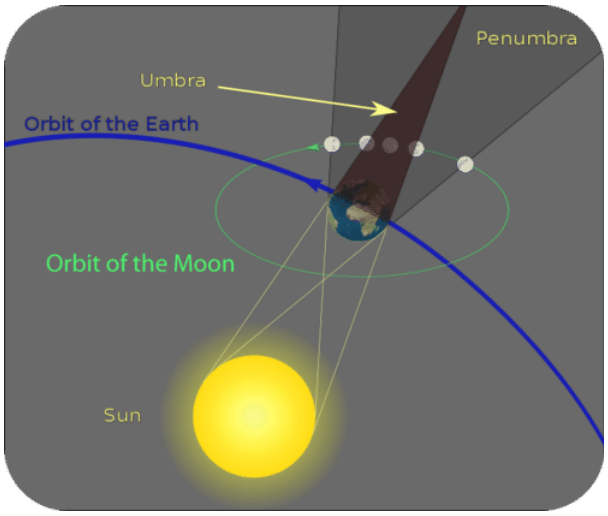


Can you see a lunar eclipse?

Again, of course! Anyone with a view of the Moon can see a lunar eclipse. The next four total lunar eclipses predicted for North America will be on January 20, 2019, May 26, 2021, May 15, 2022, and November 8, 2022.

Lunar Eclipses

Sometimes a full moon moves through Earth's shadow. This is a **lunar eclipse** (**Figure** below). During a total lunar eclipse, the Moon travels completely in Earth's umbra. During a partial lunar eclipse, only a portion of the Moon enters Earth's umbra. When the Moon passes through Earth's penumbra, it is a penumbral eclipse. Since Earth's shadow is large, a lunar eclipse lasts for hours.

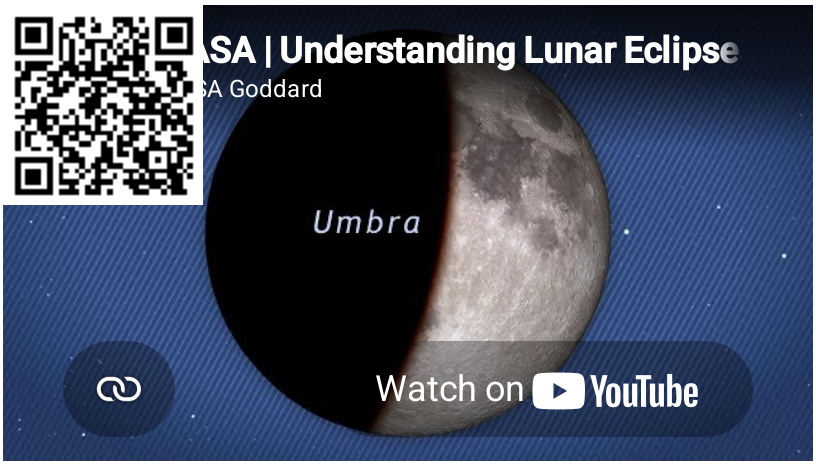


A lunar eclipse.

Partial lunar eclipses occur at least twice a year, but total lunar eclipses are less common. The Moon glows with a dull red coloring during a total lunar eclipse (**Figure** below).



A lunar eclipse is shown in a series of pictures.



Check out the video below for more information about the super blue moon which occurred on January 31, 2018 which had an added bonus of a lunar eclipse.



Summary

- During a lunar eclipse, the full moon moves through Earth's shadow.
- Earth's shadow is large so lunar eclipses last longer than solar eclipses. They cover more area too.
- The umbra is the part of the shadow in which light is completely blocked.
- The penumbra is the part of the shadow that is partially lit.

Review

1. What causes a lunar eclipse?
2. Why are you more likely to see a lunar eclipse than a solar eclipse?
3. When does a lunar eclipse occur?

This page titled 3.11: Lunar Eclipses is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.12: Lunar Phases



Can the Moon cast shadows?

Of course! A full moon is very bright. It is bright enough to cast shadows. If you are out away from city lights and the Moon is full, you might cast your own Moon shadow.

The Phases of the Moon

The Moon does not produce any light of its own. It only reflects light from the Sun. The Moon has phases because it orbits around Earth. One orbit takes about 28 days. As the moon moves around Earth, different parts of it appear to be lit up by the Sun. The Moon sometimes appears fully lit and sometimes completely dark. Sometimes it is partially lit. The different appearances of the Moon are referred to as phases of the Moon (**Figure** below).

A **full moon** occurs when the whole side facing Earth is lit. This happens when Earth is between the Moon and the Sun.



The moon's phases are a result of the moon's orbit around Earth.

About one week later, the Moon enters the quarter-moon phase. Only half of the Moon’s lit surface is visible from Earth, so it appears as a half circle.

Another week later, the Moon moves between Earth and the Sun. The side of the Moon facing Earth is completely dark. This is called a **new moon**. Sometimes you can just barely make out the outline of the new moon in the sky. This is because some sunlight reflects off the Earth and hits the Moon.

One week after that, the Moon is in another quarter-moon phase. Finally, in one more week, the Moon is back to full.

Before and after the quarter-moon phases are the gibbous and crescent phases. During the **crescent** moon phase, the Moon is less than half lit. It is seen as only a sliver or crescent shape. During the **gibbous** moon phase, the Moon is more than half lit. It is not full. The Moon undergoes a complete cycle of phases about every 29.5 days.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Summary

- The appearance of the Moon from Earth has distinct phases.
- A full moon is completely lit; a new moon is completely dark.
- A gibbous moon is more than half lit; a crescent moon is less than half lit.

Review

1. Describe how the Sun, Moon, and Earth are aligned during a full moon.
2. Describe how the Sun, Moon, and Earth are aligned during a new moon.
3. Draw and label pictures of the Moon in its phases.

Explore More

Use the resource below to answer the questions that follow.



1. Why does the moon have phases?
2. What are the four main phases of the moon? How long does it take to change from one to another?
3. What is the name for a moon that is less than half full? More than half full?
4. What is the name for a moon that is getting larger? Getting smaller?
5. What causes a lunar eclipse? Why doesn't a lunar eclipse occur during each full moon?

This page titled 3.12: Lunar Phases is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.13: Planet Earth- Challenge 2

1. During which phase of the Moon do solar eclipses occur?

New moon

2. A new moon passes between Earth and the Sun during a ___.

solar eclipse

3. The inner, cone-shaped part of the shadow, in which all of the light has been blocked, is called the ___.

umbra

4. If only a portion of the Sun is blocked by the Moon's shadow, it is a ___ solar eclipse.

partial

5. What is the outer part of the shadow of the Moon called?

Penumbra

6. Solar eclipses occur when the Moon is in what phase?

New moon

7. Lunar eclipses last for hours, because ___.

Earth's shadow is large

8. Which of the following is true of total lunar eclipses: they are less common than partial lunar eclipses, the whole moon enters Earth's umbra, they last for hours, or all of the above

All of the above

9. There are at least ___ partial lunar eclipses each year.

2

10. When only half of the Moon's lit surface is visible on Earth, we call it a ___.

quarter moon

11. During a full moon, the Moon is ___.

on the far side of Earth, opposite the Sun

12. What is the correct order of the phases of the Moon, from unlit to fully lit?

New moon, crescent, quarter moon, gibbous, full moon

This page titled 3.13: Planet Earth- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.14: Earth's Interior



How deep can we go into Earth's interior?

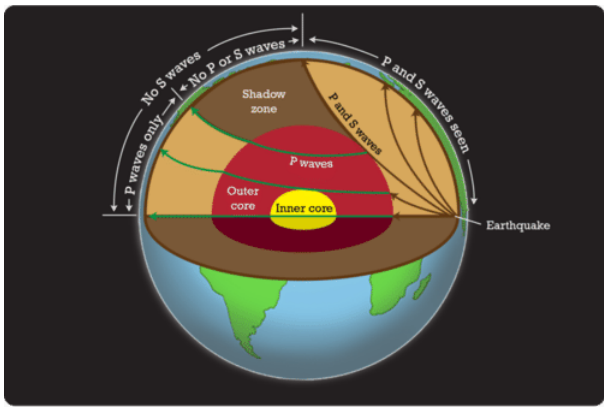
Not very deep, that's for sure! The deepest a drill hole has gotten was the Kola Superdeep Borehole. That hole got to 40,230 feet (12,262 m), about one-third of the way into the crust in that area. So learning about what's deeper requires less direct methods. A few of these methods will be described in this concept.

Learning About Earth's Interior

If someone told you to figure out what is inside Earth, what would you do? How could you figure out what is inside our planet? How do scientists figure it out?

Seismic Waves

Geologists study earthquake waves to "see" Earth's interior. Waves of energy radiate out from an earthquake's focus. These waves are called **seismic waves** (**Figure** below). Seismic waves go different speeds through different materials. They change speed when they go from one type of material to another. This causes them to bend. Some seismic waves do not travel through liquids or gases. They just stop. Scientists use information from seismic waves to understand what makes up the Earth's interior.



The properties of seismic waves allow scientists to understand the composition of Earth's interior.

Meteorites

Scientists study **meteorites** to learn about Earth's interior. Meteorites formed in the early solar system. These objects represent early solar system materials (**Figure** below). Some meteorites are made of iron and nickel. They are thought to be very similar to Earth's core. An iron meteorite is the closest thing to a sample of the core that scientists can hold in their hands!



This meteorite contains the mafic minerals olivine and pyroxene. It also contains metal flakes, similar to the material that separated into Earth's core (metal) and mantle (ultramafic rock).

Density

Earth's overall density is higher than the density of crustal rocks, so the core must be made of something dense, like metal.

Magnetic Field

Since Earth has a magnetic field, there must be metal within the planet. Iron and nickel are both magnetic.

Summary

- Different types of seismic waves behave differently in different materials. Their behavior can tell scientists about the material they travel through.
- Earth must contain metal. Its density, and the fact that it has a magnetic field, require it.
- Meteorites formed early in the solar system. They indicate something about Earth's interior.

Review

1. How do scientists know that Earth's interior contains metal?
2. What do meteorites tell us about Earth's interior?
3. How do scientists use seismic waves to learn about Earth's interior?

Explore More

Use the resource below to answer the questions that follow.

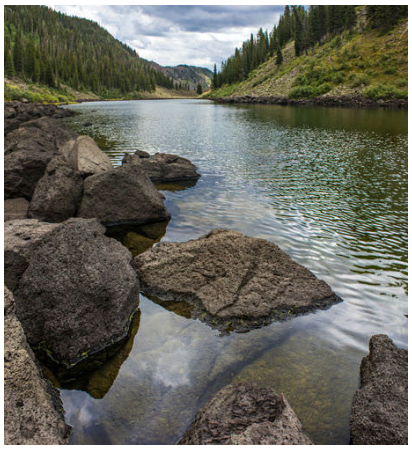


1. What types of waves do earthquakes produce?
2. What are the fastest body waves?

3. What is the shadow zone?
4. What do S-waves do?
5. List and explain the two types of surface waves.

This page titled 3.14: Earth's Interior is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.15: Earth's Outer Layers



Does this look familiar?

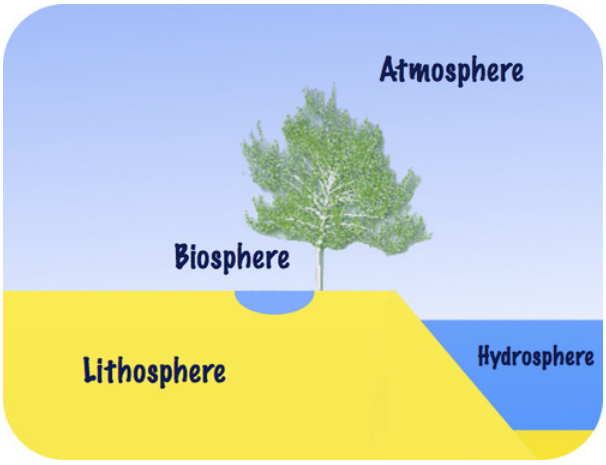
Gases, water, rock, and living organisms are all found at Earth's surface. These materials are also found above or below the surface. They interact with each other and in doing so alter each other. For example, the hydrosphere may cause some of the lithosphere to wash away.

Spheres

Earth is made of layers. Since Earth is round, the layers all have the ending "-sphere" (**Figure** below).

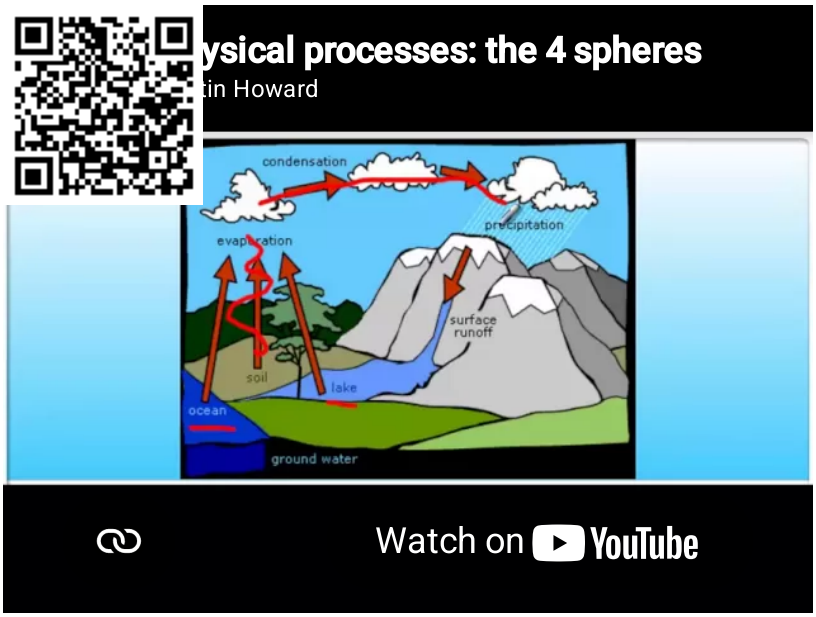
Some of the different parts of the Earth are the:

- **Atmosphere**: The thin layer of air, mostly nitrogen and oxygen, that surrounds the Earth.
- **Hydrosphere**: All the water on Earth.
- **Biosphere**: All the living organisms on Earth.
- **Lithosphere**: The solid rock part of Earth, including mountains, valleys, continents, and all of the rock beneath the oceans.



Earth has four layers: atmosphere, hydrosphere, biosphere, and lithosphere.

All of Earth’s layers interact. Therefore, Earth’s surface is constantly undergoing changes.



Summary

- Earth is made of layers. The names end in sphere because Earth is round.
- Some of the layers are: atmosphere, biosphere, hydrosphere, and lithosphere.
- The lithosphere is the brittle crust and uppermost mantle.

Review

1. What is the atmosphere?
2. What is the lithosphere?
3. Where is the hydrosphere?
4. How do Earth's layers interact? Give an example.

Explore More

Use the resource below to answer the questions that follow.

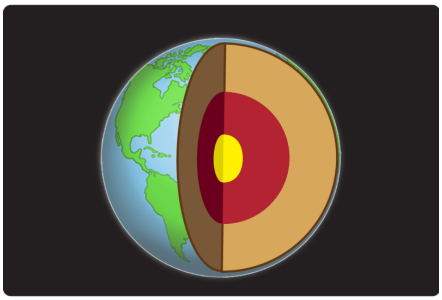


1. What are the four major systems of Earth?

2. What are the components of the geosphere?
3. What is the hydrosphere?
4. Where does Earth's energy come from?
5. What are ecosystems?
6. What is feedback?

This page titled 3.15: Earth's Outer Layers is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.16: Earth's Inner Layers

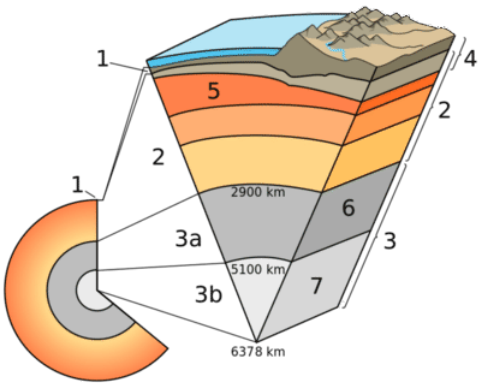


What's below our feet? What's way below?

If we could cut Earth open, we'd see the following layers from inside to outside: inner core, outer core, mantle, and crust. Alternatively, you can think of the brittle lithosphere riding on the plastic asthenosphere. Whew!

Layers by Composition

The layers scientists recognize are pictured below (**Figure** below).



A cross section of Earth showing the following layers: (1) crust (2) mantle (3a) outer core (3b) inner core (4) lithosphere (5) asthenosphere (6) outer core (7) inner core.

Core, mantle, and crust are divisions based on composition:

1. The **crust** is less than 1% of Earth by mass. The two types are oceanic crust and continental crust.
2. The **mantle** is hot, dense, dark (ultramafic) rock. It represents about 68% of Earth's mass.
3. The **core** is mostly iron metal. The core makes up about 31% of the Earth. Earth's metallic core has two layers: a solid inner layer and a liquid outer layer.

The terms core, mantle, and crust will be described in more detail in the next three concepts.



Layers by Mechanical Properties

Lithosphere and asthenosphere are divisions based on mechanical properties:

1. The **lithosphere** is composed of both the crust and the uppermost mantle. The lithosphere is a brittle, rigid solid. It is easily cracked or broken.
2. The **asthenosphere** is below the lithosphere. The asthenosphere is also in the upper mantle. This layer is solid, but it can flow and bend. A solid that can flow is like silly putty.

Summary

- By composition, Earth is divided into core, mantle, and crust.
- By mechanical properties, the crust and upper mantle are divided into lithosphere and asthenosphere.
- The core-mantle-crust divisions are based on composition.
- The lithosphere-asthensophere divisions are based on mechanical properties.

Review

1. What are the the layers of Earth, based on composition? Where are they located?
2. What is the composition of the different layers?
3. How do the lithosphere and asthenosphere differ from each other?

Explore More

Use the resource below to answer the questions that follow.



1. What is the core?
2. Explain the core's structure.
3. What is the mantle?
4. What is the crust?
5. Why does the Earth have layers?

This page titled 3.16: Earth's Inner Layers is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.17: Earth's Crust



What do these two photos have in common?

Both of these photos are of Earth's crust. The crust on the left is on the continent. It's what you see and walk on every day. The crust on the right is in the ocean. You may have seen pictures, but to see it in person you need special equipment.

Crust

Crust, mantle, and core differ from each other in chemical composition. It's understandable that scientists know the most about the crust and less about deeper layers. Earth's **crust** is a thin, brittle outer shell. The crust is made of rock. This layer is thinner under the oceans and much thicker in mountain ranges.

Oceanic Crust

There are two kinds of crust. **Oceanic crust** is made of basalt lavas that flow onto the seafloor (**Figure** below). It is relatively thin, between 5 to 12 kilometers thick (3 - 8 miles). The rocks of the oceanic crust are denser (3.0 g/cm^3) than the rocks that make up the continents. Thick layers of mud cover much of the ocean floor.



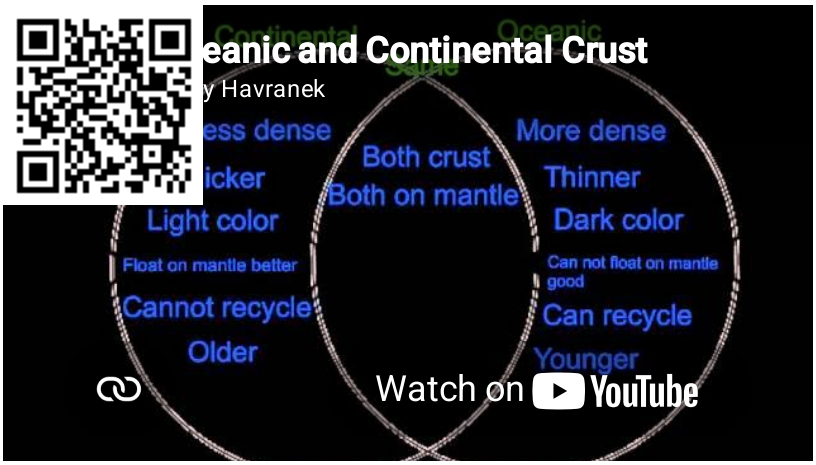
Gabbro is a dark dense rock that can be found in oceanic crust.

Continental Crust

Continental crust is much thicker than oceanic crust. It is 35 kilometers (22 miles) thick on average, but it varies a lot. Continental crust is made up of many different rocks (**Figure** below). All three major rock types—igneous, metamorphic, and sedimentary—are found in the crust. On average, continental crust is much less dense (2.7 g/cm^3) than oceanic crust. Since it is less dense, it rises higher above the mantle than oceanic crust.



The average composition of continental crust is granite.



Summary

- Oceanic crust is thinner and denser than continental crust.
- Oceanic crust is darker in color and denser (more mafic). Continental crust is lighter in color and density (more felsic).
- Earth's crust is very thin relative to Earth's radius.

Review

1. What are the properties of crust?
2. Describe the properties of oceanic crust.
3. Describe the properties of continental crust.

Explore More

Use this resource to answer the questions that follow.

https://www.sciencemag.org/news/2018/09/watch-hurricane-put-dent-earth-s-crust

1. Where did Hurricane Harvey make landfall? How much water did it dump?
2. Where did the water go after the storm?
3. What happened to Earth’s crust?
4. How can scientists determine the weight of the water from Harvey?
5. What is depression of crust called?
6. Where did the water go after Harvey?
7. How long did it take for the water stored on land to dissipate?
8. Why will storms strike with increased frequency and ferocity?
9. What does the narrator’s mom always say?

This page titled 3.17: Earth's Crust is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.18: Earth's Mantle

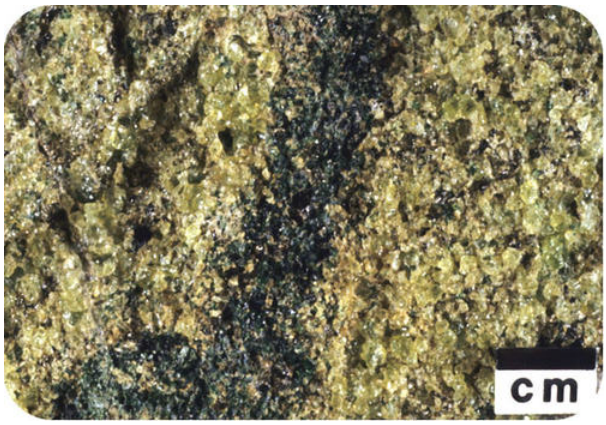


What does mantle rock look like?

You can't go to the mantle, but small pieces of the mantle can come to you. Kimberlite forms deep in the mantle and can emerge in the crust during violent eruptions. Kimberlite can contain diamonds. Most kimberlite reached the surface much earlier in Earth's history.

Mantle

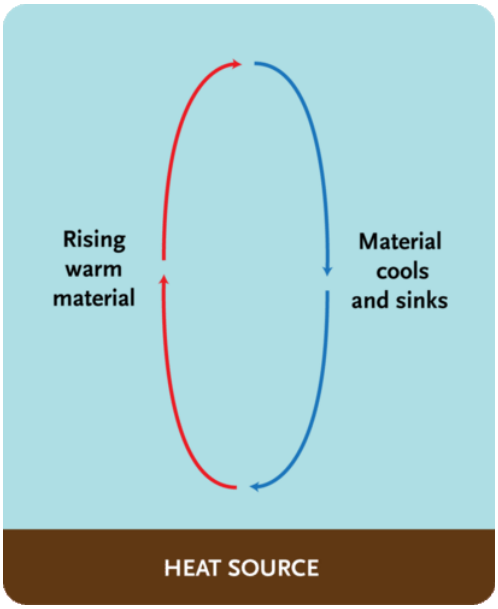
Beneath the crust is the **mantle**. The mantle is made of hot, solid rock. Scientists know this because of seismic waves, meteorites, and the heat that comes from inside the planet. Mantle rock is mostly **peridotite**, which is rich in iron and magnesium (**Figure** below). Peridotite is rare at Earth's surface.



The rock of the mantle is mostly peridotite. Peridotite is formed of crystals of olivine (green) and pyroxene (black).

Conduction and Convection

Through the process of conduction, thermal energy flows from warmer objects to cooler objects (**Figure** below). This transfer of energy is known as heat. The lower mantle is heated directly by conduction from the core. In **conduction**, energy is transferred as atoms collide.



In the process of conduction, thermal energy flows from warmer objects to cooler objects.

Hot lower mantle material rises upward (**Figure** above). As it rises, it cools. At the top of the mantle it moves horizontally. Over time it becomes cool and dense enough that it sinks. Back at the bottom of the mantle, it travels horizontally. Eventually the material gets to the location where warm mantle material is rising. The rising and sinking of warm and cooler material is called **convection**.



Summary

- The mantle is composed of solid peridotite.
- Conduction from the core heats the lower mantle.
- Mantle convection brings hot material up toward the surface. It brings cooler material down toward the core.

Review

1. How do scientists know what the mantle is made of?
2. What is conduction?
3. How does convection work in the mantle?

Explore More

Use this resource to answer the questions that follow.



1. In which ocean did researchers try to drill into the mantle in 1961? In 2016?
2. How much of Earth is made of mantle?
3. Where in the ocean would you have the best chance of drilling to the mantle?
4. Why did the researchers stop drilling in 1961?
5. What noteworthy sample did researchers bring to the surface in 2016?
6. What happens at the Moho discontinuity?
7. What are extremophiles? Where do they live?
8. How deep did the drilling go in 2016? How deep do they hope to get?
9. What do scientists hope to find? Why would that sort of thing be found inside Earth?

This page titled 3.18: Earth's Mantle is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.19: Earth's Core



Is this what the core looks like?

Yes! The outer core, anyway. The outer core is liquid metal, like in this photo. Of course, the metal is under an incredible amount of pressure.

Core

The dense, iron **core** forms the center of the Earth. Scientists know that the core is metal. The inner core is solid, and the outer core is molten. Here are some of the reasons they know this:

- Metallic meteorites are thought to be from the same type of material that is found at the core (**Figure** below).



An iron meteorite is the closest thing to the Earth's core that we can hold in our hands.

- Scientists calculate Earth's density from the planet's rotation. To match the total density, the inner layers must be denser than the outer layers. They must be as dense as metal.
- Seismic waves show that the outer core is liquid. The inner core is solid.
- For there to be a magnetic field, there must be liquid metal. The metal must be convecting. If the core did not have convecting metal, there would be no magnetic field.



Summary

- Density calculations show that Earth's core is metal.
- Seismic waves show that the inner core is solid and the outer core is liquid.
- Metallic meteorites and the magnetic field are also clues about the makeup of the core.

Review

1. What evidence is there that Earth's core is metal?
2. What evidence is there that the outer core is molten?
3. Why does Earth have a magnetic field?

Explore More

Use this resource to answer the questions that follow.



1. What layers does the core have within it according to the study described in this video?
2. How deep is the core? What is its temperature?
3. What clues to researchers use to “see” what is in Earth’s interior?
4. What was the inner core thought to be previously?
5. What do scientists now think is inside the core? How big is it?
6. What is the interior made of? How do scientists know this is different from the material outside of it?
7. How are crystals aligned in the inner inner and outer inner cores?

8. Why is this information important?

This page titled 3.19: Earth's Core is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.20: Lithosphere and Asthenosphere



Can you think of a solid that can flow?

You use one twice a day! Toothpaste is a solid that can flow. Is the asthenosphere made of toothpaste? Only if the toothpaste is ultramafic in composition, and then it would only be able to flow if it were really, really hot. Still the toothpaste analogy gives you a good image of how the asthenosphere might behave if you squeezed it!

Lithosphere

The **lithosphere** is composed of both the crust and the portion of the upper mantle that behaves as a brittle, rigid solid. The lithosphere is the outermost mechanical layer, which behaves as a brittle, rigid solid. The lithosphere is about 100 kilometers thick. How are crust and lithosphere different from each other?

The definition of the lithosphere is based on how Earth materials behave, so it includes the crust and the uppermost mantle, which are both brittle. Since it is rigid and brittle, when stresses act on the lithosphere, it breaks. This is what we experience as an earthquake.

Although we sometimes refer to Earth's plates as being plates of crust, the plates are actually made of lithosphere. Much more about Earth's plates follows in the chapter "Plate Tectonics."

Asthenosphere

The **asthenosphere** is solid upper mantle material that is so hot that it behaves plastically and can flow. The lithosphere rides on the asthenosphere.

Summary

- The lithosphere is the brittle crust and uppermost mantle.
- The asthenosphere is a solid but it can flow, like toothpaste.
- The lithosphere rests on the asthenosphere.

Review

1. Where is the lithosphere? What layers does it include?
2. What is the asthenosphere?
3. How do the lithosphere and asthenosphere differ?
4. If the lithosphere is resting on the asthenosphere and you put a lot of weight on the lithosphere, say ice in a glacier, how would the lithosphere respond?

Explore More

Use this resource to answer the questions that follow.



1. Where is the crust? What is it made of?
2. How think is the crust?
3. What layer is next and where is it?
4. What is the mantle made of?
5. Where does lava come from? What is magma?
6. Where is the outer core? What is it made of?
7. What is at the center of the Earth? Where is it?
8. What is the inner core made of? Is it solid, liquid or gas? Why?
9. How do scientists know what is below the crust?

This page titled 3.20: Lithosphere and Asthenosphere is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

3.21: Planet Earth- Challenge 3

1. The high point of a wave is called the ___.

crest

2. Earth's magnetic field is a clue that Earth's interior is made of ___.

metal

3. Scientists have learned a lot about Earth's interior through the study of ___.

seismic waves, Earth's magnetic field, and rocks

4. The lithosphere consists of the ___ and uppermost mantle.

crust

5. Which layer of Earth is made up of mostly iron metal?

Core

6. The ___ is made up of rock that is less dense than the mantle.

crust

7. ___ crust is thinner and denser than continental crust.

Oceanic

8. Which crust (Oceanic or Continental) is made up of basaltic rock?

Oceanic

9. Continental crust is ___.

felsic

10. Scientists know that the mantle is made up of rock based on evidence from ___.

seismic waves, heat flow, and meteorites

11. The ___ heats up the mantle.

core

12. Scientists can tell that the ___ is made of hot, solid rock from seismic waves, meteorites, and Earth's own internal heat.

mantle

This page titled 3.21: Planet Earth- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

4: Earth's Minerals and Rocks

4.1: Minerals
4.2: Mineral Groups
4.3: Mineral Identification
4.4: Mineral Formation
4.5: Earth's Minerals and Rocks- Challenge 1
4.6: Rocks
4.7: Rock Cycle Processes
4.8: Igneous Rocks
4.9: Intrusive and Extrusive Igneous Rocks
4.10: Igneous Rock Classification
4.11: Earth's Minerals and Rocks- Challenge 2
4.12: Sedimentary Rocks
4.13: Lithification of Sedimentary Rocks
4.14: Sedimentary Rock Classification
4.15: Metamorphic Rocks
4.16: Metamorphic Rock Classification
4.17: Earth's Minerals and Rocks- Challenge 3

This page titled 4: Earth's Minerals and Rocks is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.1: Minerals



Are you a mineral?

There used to be a TV commercial that said "you are what you eat." If that's true, then you are partly the mineral halite. That's just table salt, after all.

What is a Mineral?

A **mineral** is a solid material that forms by a natural process. A mineral can be made of an element or a compound. It has a specific chemical composition. Its chemical composition is different from other minerals. Each type of mineral has physical properties that differ from others. These properties include crystal structure, hardness, density, and color. For example, silver is a soft, shiny metal. Salt is a white, cube-shaped crystal. Diamond is an extremely hard, translucent crystal.

Forms by Natural Processes

Minerals form by natural processes. Minerals are created by processes that happen in or on the Earth. For example, when hot lava cools, mineral crystals form. Minerals also precipitate from water. Some minerals grow when rocks are exposed to high pressures and temperatures.

Could a mineral be made by a process that was not natural? People make gemstones in a laboratory. Synthetic diamond is a common one. But that stone is not a mineral. That's because a mineral must be created by natural processes. This is part of the definition of a mineral.

Inorganic Substance

A mineral is an inorganic substance. It was not made by living organisms. Organic substances contain carbon. Some types of organic substances are proteins, carbohydrates, and oils. Everything else is inorganic. In a few cases, living organisms make inorganic materials. The calcium carbonate shells made by marine animals are inorganic.

Definite Composition

All minerals have a definite chemical makeup. A few minerals are made of only one kind of element. Silver is a mineral made of only silver atoms. Diamond and graphite are both made of only the element carbon.

Minerals that are not just a single element are made of chemical compounds. For example, the mineral quartz is made of the compound silicon dioxide, or SiO_2. This compound has one atom of the element silicon for every two atoms of the element oxygen.

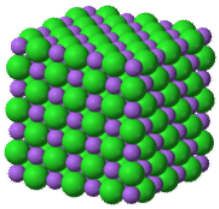
Each mineral has its own unique chemical formula. For example, the mineral hematite has two iron atoms for every three oxygen atoms. The mineral magnetite has three iron atoms for every four oxygen atoms. Many minerals have very complex chemical formulas that include several elements. However, even in more complicated compounds, the elements occur in definite ratios.

Solid Crystals

Minerals must be solid. For example, ice and water have the same chemical composition. Ice is a solid, so it is a mineral. Water is a liquid, so it is not a mineral.

Some solids are not crystals. Glass, or the rock obsidian, are solid. However, they are not crystals. In a **crystal**, the atoms are arranged in a pattern. This pattern is regular and it repeats. The image below shows how the atoms are arranged in halite (table salt) (**Figure** below). Halite contains atoms of sodium and chlorine in a pattern. Notice that the pattern goes in all three dimensions.

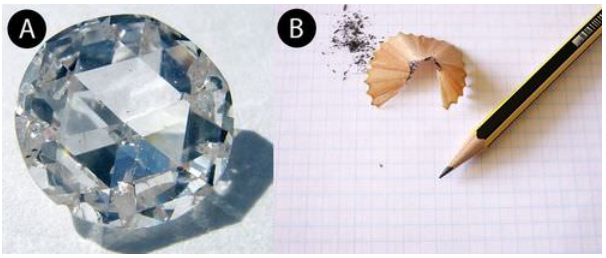
CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



Sodium ions (purple balls) bond with chloride ions (green balls) to form halite crystals.

The pattern of atoms in all halite is the same. Think about all of the grains of salt that are in a salt shaker. The atoms are arranged in the same way in every piece of salt.

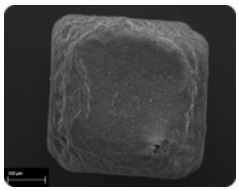
Sometimes two different minerals have the same chemical composition. But they are different minerals because they have different crystal structures. Diamonds are very valuable as gemstones, because they are very pretty and very hard. Graphite is the “lead” in pencils. It's not hard at all! Amazingly, both are made of just carbon. Compare the diamond with the pencil lead (**Figure** below). Why are they so different? The carbon atoms in graphite bond to form layers. The bonds between each layer are weak. The carbon sheets can just slip past each other. The carbon atoms in diamonds bond together in all three directions. This strong network makes diamonds very hard.



Diamonds (A) and graphite (B) are both made of only carbon, but they're not much alike.

Physical Properties

The patterns of atoms affect a mineral's physical properties. A mineral's crystal shape is determined by the way the atoms are arranged. For example, you can see how atoms are arranged in halite (**Figure** below). Below, you can see how salt crystals look under a microscope (**Figure** below). Salt crystals are all cubes whether they're small or large.



Under a microscope, salt crystals are cubes. In this crystal, the corners have worn away.

Physical properties help scientists identify different minerals; this is explored in the concept "Mineral Identification."

Summary

- A mineral is an inorganic, crystalline solid.
- A mineral forms through natural processes. It has a definite chemical composition.
- Minerals can be identified by their characteristic physical properties. They include crystalline structure, hardness, density, breakage, and color.

Review

1. What properties does a substance have to have to be a mineral?
2. How are diamond and graphite similar? How are they different?
3. How is a mineral's shape determined?

Explore More

Use this resource to answer the questions that follow.



1. What are the first two criteria for something to be a mineral?
2. What is the third thing? What does that mean?
3. What is the common name for halite? What is it made of chemically?
4. What is true about the elements that make up a mineral?
5. Why does halite break into little cubes?
6. What is the evidence for an ice cube being a mineral?
7. Why isn't glass a mineral?

This page titled 4.1: Minerals is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.2: Mineral Groups



What would you do with this mineral?

Imagine you are in charge of organizing more than 100 minerals for a museum exhibit. You know that people learn more if they see the minerals together in groups. So how would you group the minerals together in the exhibit? What are some of the possibilities? Size? Shape? Color?

Learn about the minerals behind modern life with this video.

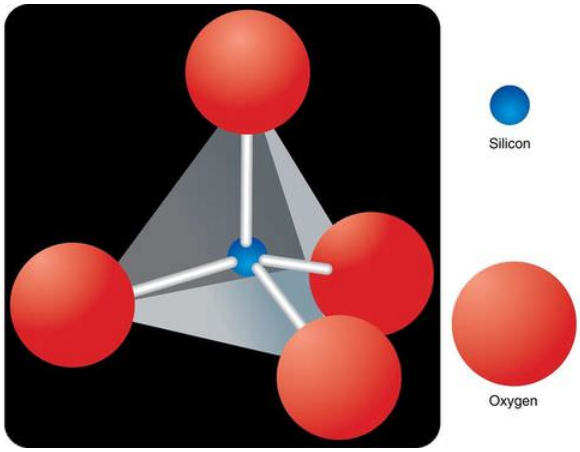
Mineral Groups

Mineralogists are scientists who study minerals. They divide minerals into groups based on chemical composition. Even though there are over 4,000 minerals, most minerals fit into one of eight mineral groups.

Silicate Minerals

Silicates are the largest mineral group. About 1,000 silicate minerals are known. Silicate minerals are also extremely common. They make up over 90% of Earth's crust!

Silicates contain silicon atoms and oxygen atoms. One silicon atom is bonded to four oxygen atoms. These atoms form a tetrahedron (**Figure** below). The silica tetrahedron is the building block of silicate minerals. Most silicates contain other elements. These elements include calcium, iron, and magnesium.

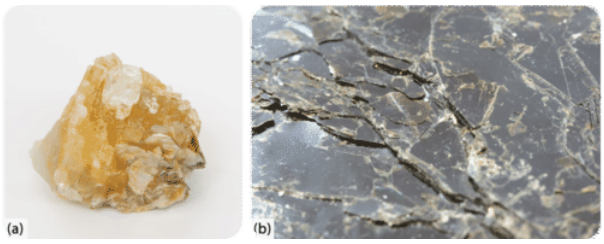


One silicon atom bonds to four oxygen atoms to form a pyramid

Silicate minerals are divided into six smaller groups. In each group, the silicate pyramids join together differently. The pyramids can stand alone. They can form into connected circles called rings. Some pyramids link into single and double chains. Others form large, flat sheets. Some join in three dimensions.

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

Feldspar and quartz are the two most common silicates. In beryl, the silicate pyramids join together as rings. Biotite is mica. The silicate pyramids come together to create thin, flexible sheets. Compare the beryl and the biotite pictured below (**Figure** below).



Beryl (a) and biotite (b) are both silicate minerals.

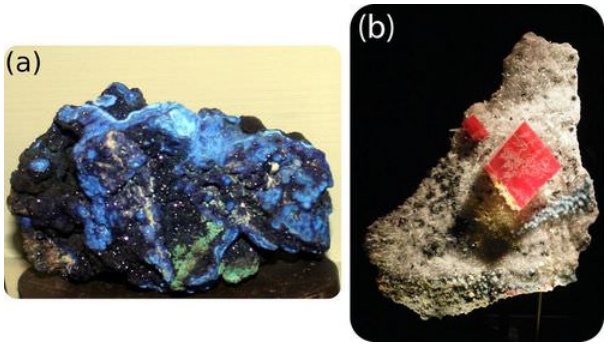
Native Elements

Native elements contain only atoms of one type of element. They are not combined with other elements. There are very few examples of these types of minerals. Some native elements are rare and valuable. Gold, silver, sulfur, and diamond are examples.

Carbonates

What do you guess **carbonate** minerals contain? If you guessed carbon, you would be right! All carbonates contain one carbon atom bonded to three oxygen atoms. Carbonates may include other elements. A few of these are calcium, iron, and copper.

Carbonate minerals are often found where seas once covered the land. Some carbonate minerals are very common. Calcite contains calcium, carbon, and oxygen. Have you ever been in a limestone cave or seen a marble tile? Calcite is in both limestone and marble. Azurite and malachite are also carbonate minerals. They contain copper instead of calcium. They are not as common as calcite. Malachite and azurite are used in jewelry; as you can see, they are very colorful (**Figure** below).



(a) The deep blue mineral is azurite and the green is malachite. (b) This red rhodochrosite is a carbonate mineral. Rhodochrosite is usually pink; the red crystals are rare.

Halides

Halide minerals are salts. They form when salt water evaporates. This mineral class includes more than just table salt. Halide minerals may contain the elements fluorine, chlorine, bromine, or iodine. Some halide minerals combine with metal elements. Common table salt is a halide mineral that contains the elements chlorine and sodium. Fluorite is a type of halide that contains fluorine and calcium. Fluorite can be found in many colors. If you shine an ultraviolet light on fluorite, it will glow!

Oxides

Earth's crust contains a lot of oxygen. The oxygen can combine with other elements to create oxide minerals. **Oxides** contain one or two metal elements combined with oxygen. Oxides are different from silicates, because they do not contain silicon. Many important metals are found as oxides. For example, hematite and magnetite are both oxides that contain iron. Hematite (Fe_2O_3) has a ratio of two iron atoms to three oxygen atoms. Magnetite (Fe_3O_4) has a ratio of three iron atoms to four oxygen atoms. Notice that the word "magnetite" contains the word "magnet." Magnetite (**Figure** below) is a magnetic mineral.



Magnetite is one of the most distinctive oxides since it is magnetic.

Phosphates

Phosphate minerals have a structure similar to silicates. In silicates, an atom of silicon is bonded to oxygen. In **phosphates**, an atom of phosphorus, arsenic, or vanadium is bonded to oxygen. There are many types of phosphate minerals, but phosphate minerals are rare. The composition of phosphates is complex. For example, turquoise contains copper, aluminum, and phosphorus (**Figure** below).



Turquoise is a phosphate mineral with a beautiful blue color. The stone is not as rare as some minerals and is commonly used for jewelry.

Sulfates

Sulfate minerals contain sulfur atoms bonded to oxygen atoms. Like halides, they can form in places where salt water evaporates. Many minerals belong in the sulfate group, but there are only a few common sulfate minerals. Gypsum is a common sulfate mineral that contains calcium, sulfate, and water. Gypsum is found in various forms. For example, it can be pink and look like it has flower petals. However, it can also grow into very large white crystals. Gypsum crystals that are 11-meters-long have been found. That is about as long as a school bus! Gypsum forms at the Mammoth Hot Springs in Yellowstone National Park (**Figure** below).



Gypsum is the white mineral that is common around hot springs. This is Mammoth Hot Springs in Yellowstone National Park.

Sulfides

Sulfides contain metal elements combined with sulfur. Sulfides are different from sulfates. They do not contain oxygen. Pyrite is a common sulfide mineral (**Figure** below). It contains iron combined with sulfur. Pyrite is also known as “fool’s gold.” Gold miners have mistaken pyrite for gold, because pyrite has a greenish gold color.



Pyrite has a similar color to gold. The appearance of the striations make pyrite different from gold.

Summary

- Silicates, made of building blocks of silica tetrahedrons, are the most abundant minerals on Earth.
- Silica tetrahedrons combine together in six different ways to create rings, single and double chains, large flat sheets, or 3-dimensional structures.
- Other mineral groups have other chemical components like carbonates, oxides, or phosphates.
- Minerals that are native elements are made of only one element.

Review

1. On what basis are minerals divided into groups?
2. What are the chemical characteristics of the most common mineral group?
3. How are the silicates categorized?

Explore More

Use the resource below to answer the questions that follow.



1. How are minerals classified?
2. What do silicate minerals contain?
3. Where are silicate minerals found?
4. List three examples of silicates.
5. What do non-silcate minerals contain?
6. What is a native element?
7. What are native elements used in?
8. List examples of carbonates.
9. What are halide minerals used for?

10. What are oxides used for?
11. What are sulfate minerals used for?
12. What are sulfide minerals used for?

https://www.pbs.org/video/nova-minerals-behind-modern-life/

This page titled 4.2: Mineral Groups is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.3: Mineral Identification



How do you identify a mineral?

You're in a competition getting ready to go onstage. You discover that you forgot your shirt! You call your mom and ask her (nicely) to bring it to you right away. But first you need to let her know which shirt it is. What would you tell her? You might describe the color, the way the fabric feels, and the length of the sleeves. These are all physical properties of your shirt. If you do a good job describing the shirt your mom will bring the right one. Minerals also have physical properties that are used to identify them.

How Are Minerals Identified?

Imagine you were given a mineral sample similar to the one pictured below (**Figure** below). You can use a mineral's properties to identify what type it is. How would you try to identify your mineral? You can observe some properties by looking at the mineral. For example, you can see that its color is green. The mineral has a needle-like, fibrous structure. But you can't see all mineral properties. You need to do simple tests to determine some properties. One common one is how hard the mineral is. The mineral's physical properties are determined by its chemical composition and crystal structure.



Green actinolite.

Color, Streak, and Luster

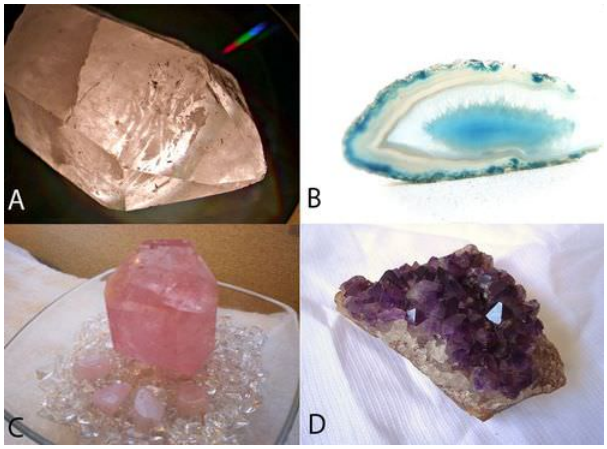
Diamonds have many valuable properties. Diamonds are translucent and extremely hard. The most valuable diamonds are large, well-shaped and sparkly. Some are not as pretty and are used for industrial purposes. Turquoise is another mineral that is used in jewelry because of its striking greenish-blue color. Many minerals have interesting appearances. Specific terms are used to describe the appearance of minerals.

Color

Color is probably the easiest property to observe. Unfortunately, you can rarely identify a mineral only by its color. Sometimes, different minerals are the same color. For example, you might find a mineral that is a golden color and think it is gold. But it might actually be pyrite, or "fool's gold," which is made of iron and sulfide. It contains no gold atoms.

A certain mineral may form in different colors. For example, pictured below are four samples of quartz (**Figure** below), including one that is colorless and one that is purple. The purple color comes from a tiny amount of iron. Iron is not normally found in quartz. When it is, it is a chemical impurity. Many minerals are colored by chemical impurities. Other factors can also affect a mineral's color. Weathering changes the surface of a mineral. Because color alone is unreliable, geologists rarely identify a mineral just on its color. To identify most minerals, they use several properties.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



Quartz comes in many different colors: (A) transparent quartz, (B) blue agate, (C) rose quartz, and (D) purple amethyst.

Streak

Streak is the color of the powder of a mineral. To do a streak test, you scrape the mineral across an unglazed porcelain plate. The plate is harder than many minerals, causing the minerals to leave a streak of powder on the plate. The color of the streak often differs from the color of the larger mineral sample (**Figure** below). Yellow-gold pyrite has a blackish streak. This blackish streak tells you that the mineral is not gold, because gold has a gold-colored streak.



Rub a mineral across an unglazed porcelain plate to see its streak. Hematite has a reddish-brown streak.

Streak is more reliable than color to identify minerals. Different minerals that are the same color may have a different color streak. For example, samples of hematite and galena are both dark gray. They can be told apart because hematite has a red streak and galena has a gray streak.

Luster

Luster describes the way light reflects off the surface of the mineral. You might describe diamonds as sparkly or pyrite as shiny. But mineralogists have special terms to describe luster. They first divide minerals into metallic and non-metallic luster. Minerals that are opaque and shiny, like pyrite, are said to have a “metallic” luster. Minerals with a “non-metallic” luster do not look like metals. There are many types of non-metallic luster. Six are described below (**Table** below).

Non-Metallic Luster	Appearance
Adamantine	Sparkly
Earthy	Dull, clay-like
Pearly	Pearl-like
Resinous	Like resins, such as tree sap
Silky	Soft-looking with long fibers
Vitreous	Glassy

Can you match the minerals (**Figure** below) with the correct luster, listed above (**Table** above), without looking at the caption?



(A) Diamonds have an adamantine luster. These minerals are transparent and highly reflective. (B) Kaolinite is a clay with a dull or earthy luster. (C) Opal's luster is greasy. (D) Chalcopyrite, like its cousin pyrite, has metallic luster. (E) Stilbite (orange) has a resinous luster. (F) The white ulexite has silky luster. (G) Sphalerite has a submetallic luster. (H) Chert is a mineral with a waxy luster.

Density

You are going to visit a friend. You fill one backpack with books so you can study later. You stuff your pillow into another backpack that is the same size. Which backpack will be easier to carry? Even though the backpacks are the same size, the bag that contains your books is going to be much heavier. It has a greater density than the backpack with your pillow.

Density describes how much matter is in a certain amount of space. Substances that have more matter packed into a given space have higher densities. The water in a drinking glass has the same density as the water in a bathtub or swimming pool. All substances have characteristic densities, which does not depend on how much of a substance you have.

Mass is a measure of the amount of matter in an object. The amount of space an object takes up is described by its volume. The density of an object depends on its mass and its volume. Density can be calculated using the following equation:

Density = Mass/Volume

Samples that are the same size but have different densities, will have different masses. Gold has a density of about 19 g/cm^3. Pyrite has a density of only about 5 g/cm^3. Quartz is even less dense than pyrite and has a density of 2.7 g/cm^3. If you picked up a piece of pyrite and a piece of quartz that were the same size, the pyrite would seem almost twice as heavy as the quartz.

Specific gravity is used to identify minerals. **Specific gravity** measures how heavy the mineral is relative to the same volume of water.

Hardness

Hardness is a mineral's ability to resist being scratched. Minerals that are not easily scratched are hard. You test the hardness of a mineral by scratching its surface with a mineral of a known hardness. Mineralogists use the Mohs Hardness Scale (**Table** below) as a reference for mineral hardness. The scale lists common minerals in order of their relative hardness. You can use the minerals in the scale to test the hardness of an unknown mineral.

Mohs Hardness Scale

As you can see, diamond is a 10 on the Mohs Hardness Scale. Diamond is the hardest mineral; no other mineral can scratch a diamond. Quartz is a 7. It can be scratched by topaz, corundum, and diamond. Quartz will scratch minerals that have a lower number on the scale. Fluorite is one. Suppose you had a piece of pure gold. You find that calcite scratches the gold. Gypsum does not. Gypsum has a hardness of 2 and calcite is a 3. That means the hardness of gold is between gypsum and calcite. So the hardness

of gold is about 2.5 on the scale. A hardness of 2.5 means that gold is a relatively soft mineral. It is only about as hard as your fingernail.

Hardness	Mineral
1	Talc
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Orthoclase feldspar
7	Quartz
8	Topaz
9	Corundum
10	Diamond

Cleavage and Fracture

Different types of minerals break apart in their own way. Remember that all minerals are crystals. This means that the atoms in a mineral are arranged in a repeating pattern. This pattern determines how a mineral will break. When you break a mineral, you break chemical bonds. Because of the way the atoms are arranged, some bonds are weaker than other bonds. A mineral is more likely to break where the bonds between the atoms are weaker.

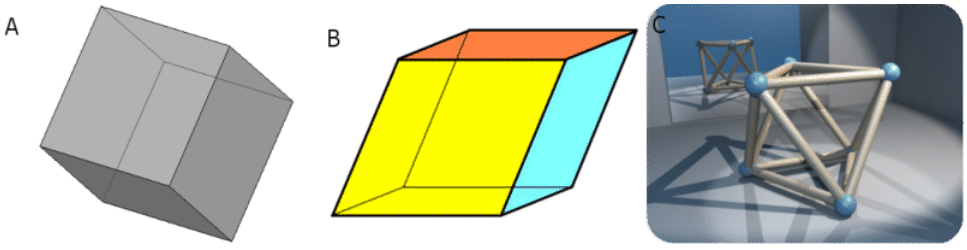
Cleavage

Cleavage is the tendency of a mineral to break along certain planes. When a mineral breaks along a plane, it makes a smooth surface. Minerals with different crystal structures will break or cleave in different ways (**Figure** below). Halite tends to form cubes with smooth surfaces. Mica tends to form sheets. Fluorite can form octahedrons.



Minerals with different crystal structures have a tendency to break along certain planes. (A) Halite breaks into cubes. (B) Muscovite breaks into sheets. (C) Fluorite breaks into octagons.

Minerals can form various shapes. Polygons are pictured below (**Figure** below). The shapes form as the minerals are broken along their cleavage planes. Cleavage planes determine how the crystals can be cut to make smooth surfaces. People who cut gemstones follow cleavage planes. Diamonds and emeralds can be cut to make beautiful gemstones.



(A) Cubes have six sides that are all the same size square. All of the angles in a cube are equal to 90°. (B) Rhombohedra also have six sides, but the sides are diamond-shaped. (C) Octahedra have eight sides that are all shaped like triangles.

Fracture

Fracture describes how a mineral breaks without any pattern. A fracture is uneven. The surface is not smooth and flat. You can learn about a mineral from the way it fractures. If a mineral splinters like wood, it may be fibrous. Some minerals, such as quartz, fracture to form smooth, curved surfaces. Pictured below is a mineral that broke forming a smooth, curved surface (**Figure** below).



This mineral formed a smooth, curved surface when it fractured.

Other Identifying Characteristics

Minerals have other properties that can be used for identification. For example, a mineral's shape may indicate its crystal structure. Sometimes crystals are too small to see. Then a mineralogist may use a special instrument to find the crystal structure.

Some minerals have unique properties. These can be used to the minerals. Listed below are some of these properties (**Table** below); an example of a mineral that has each property is also listed.

Property	Description	Example of Mineral
Fluorescence	Mineral glows under ultraviolet light	Fluorite
Magnetism	Mineral is attracted to a magnet	Magnetite
Radioactivity	Mineral gives off radiation that can be measured with Geiger counter	Uraninite
Reactivity	Bubbles form when mineral is exposed to a weak acid	Calcite
Smell	Some minerals have a distinctive smell	Sulfur (smells like rotten eggs)

Summary

- Some minerals have a unique property that makes them fairly easy to identify. But many do not.
- Different minerals can be identified by different properties.
- Cleavage can be a unique and beautiful indicator of mineral type.

Review

1. How does streak differ from color?
2. How does cleavage differ from fracture?
3. List a few minerals and the property that makes each of them unique; e.g. magnetite is magnetic.

Explore More

Use the resource below to answer the questions that follow.



1. What color streak would pyrite leave on sandpaper?
2. What color streak would real gold leave on sandpaper?
3. List some examples of the different types of quartz.
4. What characteristic do all types of quartz share?
5. What is unique about mica?
6. What is mica used for?
7. What was azurite used for in ancient times?
8. In what colors can calcite be found?
9. What color does green calcite streak? Is this true for all colors of calcite?
10. What is galena?
11. How can you tell that fluorite is not a calcite mineral?
12. How many sides does garnet have?

This page titled 4.3: Mineral Identification is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.4: Mineral Formation



Can you watch minerals forming?

Sure! Some kids get crystal growing kits. They mix up a solution and evaporate off the water. Mineral crystals are left behind. This is similar to the way halite and some other minerals form. These minerals evaporate from salt water.

Mineral Formation

Minerals form in a variety of ways. Some minerals form from very hot fluids. Some form from cool fluids. Some form when solid minerals rearrange.

Formation from Magma and Lava

You are on vacation at the beach. You take your flip-flops off so you can go swimming. The sand is so hot it hurts your feet. You have to run to the water. Now imagine if it were hot enough for the sand to melt.

Some places inside Earth are so hot that rock melts. Melted rock inside the Earth is called magma. **Magma** can be hotter than 1,000^{o}C. When magma erupts onto Earth's surface, it is known as **lava** (**Figure** below). Minerals form when magma and lava cool. Some minerals crystallize at hotter temperatures. These minerals form first. Other minerals form at cooler temperatures. These minerals form later.



Lava is melted rock that erupts onto Earth's surface.

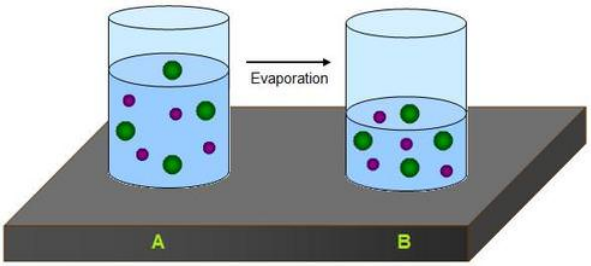
Formation from Solutions

Most water on Earth, like the water in the oceans, contains elements. The elements are mixed evenly through the water. Water plus other substances makes a solution. The particles are so small that they will not come out when you filter the water. But the elements in water can form solid mineral deposits.

Minerals from Salt Water

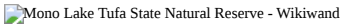
Fresh water contains a small amount of dissolved elements. Salt water contains many more dissolved elements. Water can only hold a certain amount of dissolved substances. When the water evaporates, it leaves behind a solid layer of minerals (**Figure** below). At this time, the particles come together to form minerals. These solids sink to the bottom. The amount of mineral formed

is the same as the amount dissolved in the water. Seawater is salty enough for minerals to precipitate as solids. Some lakes, such as Mono Lake in California, or Utah's Great Salt Lake, can also precipitate salts.



When the water in glass A evaporates, the dissolved mineral particles are left behind.

Salt easily precipitates out of water, as does calcite (**Figure** below). The limestone towers pictured below are made mostly of the mineral calcite. The calcite was deposited in the salty and alkaline water of Mono Lake, in California. Calcium-rich spring water enters the bottom of the lake. The water bubbles up into the alkaline lake. The calcite “tufa” towers form. When the lake level drops, the tufa towers are revealed.



Calcite tufa towers at Mono Lake, California.

Minerals from Hot Underground Water

Underground water can be heated by magma. The hot water moves through cracks below Earth’s surface. Hot water can hold more dissolved particles than cold water. The hot, salty solution has chemical reactions with the rocks around it. The water picks up more dissolved particles. As it flows through open spaces in rocks, the water deposits solid minerals. When a mineral fills cracks in rocks, the deposits are called **veins**. Pictured below is a white quartz vein (**Figure** below). When the minerals are deposited in open spaces, large crystals grow. These rocks are called geodes. Pictured below is a *geode* that was formed when amethyst crystals grew in an open space in a rock (**Figure** below).



A white quartz vein fills a crack in rock (left); Purple amethyst crystals grew inside a rock, forming a geode (right).



Summary

- Minerals form as magma or lava cools.
- Minerals form when they precipitate from hot fluids that have cooled down.
- Minerals form from dissolved substances when water evaporates.

Review

1. How do minerals form from magma or lava?
2. How do minerals form from cool water?
3. How do minerals form from hot water?

This page titled 4.4: Mineral Formation is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.5: Earth's Minerals and Rocks- Challenge 1

1. A mineral's shape is determined by the arrangement of its ___.

atoms

2. Minerals are ___, ___, and ___.

solid, naturally occurring, specific chemical compounds

3. What is an example of a rock that's not a mineral?

Coal is a rock but not a mineral, because it forms from organic matter.

4. Minerals are divided into groups by ___ composition.

chemical

5. ___ make up over 90% of Earth's crust.

Silicates

6. ___ are salts that form when salt water evaporates.

Halides

7. ___ is a measure of whether a mineral can scratch or be scratched by another mineral.

Hardness

8. ___ is the color of the powder a mineral leaves behind after it is rubbed against another surface.

Streak

9. Luster describes ___.

how shiny or dull a mineral appears

10. A ___ plots the stability of the various states (solid, liquid, gas) of a compound as a function of temperature and pressure.

phase diagram

11. Minerals, carried by hot water, fill cracks in rocks to form ___.

veins

12. Which lake in California contains many mineral precipitates?

Mono Lake

This page titled 4.5: Earth's Minerals and Rocks- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.6: Rocks

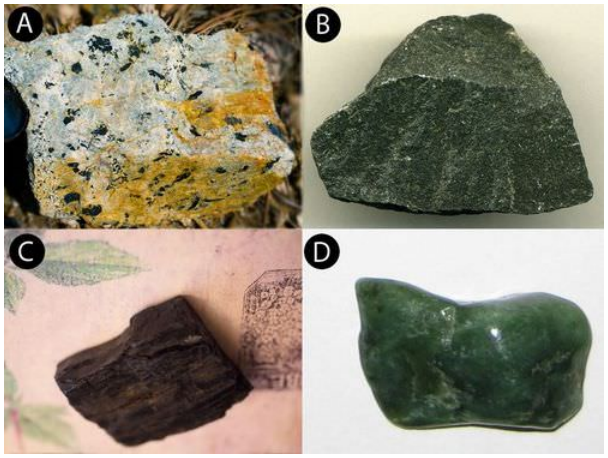


Will this rock be there forever?

Rocks may seem permanent, but they're not. Over time a rock will change into another type of rock. How this happens is known as the **rock cycle**. There are three main types of rocks. There are several processes that can change one type into another. First we need to learn what the rocks types and processes are.

What is a Rock?

A **rock** is a naturally formed, non-living Earth material. Rocks are made of minerals. The minerals may be so tiny that you can only see them with a microscope. The minerals may be really large. A rock may be made of only one type of mineral. More often rocks are made of a mixture of different minerals. A few types of rocks are made from materials that are not minerals. For example, coal is organic so it is not a mineral, nor is it made of minerals. Yet coal is a rock.



(A) Granite has large crystals because it cools slowly. (B) Basalt has very small crystals because it cools quickly. (C) Coal is made up of organic material. (D) Jade is made of the mineral jadeite.

Rocks are named for the combinations of minerals they are made of and the ways those minerals came together. Remember that different minerals form under different environmental conditions. So the minerals in a rock contain clues about the conditions in which the rock formed (**Figure** above).

Rock Types

Geologists group rocks based on how they form. There are three major rock types. Each will be described in more detail in the coming concepts.

- **Igneous rocks** form when magma cools below Earth's surface or lava cools at the surface.

- **Sedimentary rocks** form when sediments are compacted and cemented together. **Sediments** are pieces of rock. They may be gravel, sand, silt, or clay. Some sedimentary rocks form the solid minerals left behind after a liquid evaporates.
- **Metamorphic rocks** form when an existing rock is changed by heat or pressure. The minerals in the rock change but do not melt. The rock experiences these changes within the Earth.

Rocks can change from one type to another. The rock cycle describes how this happens.

Summary

- Nearly all rocks are made of minerals. A few are made of materials that do not fit the definition of minerals.
- Igneous rocks form from cooled magma or lava.
- Metamorphic rocks form as an existing rock is altered by high temperature or pressure.
- Sedimentary rocks form from sediments that are cemented and compacted.

Review

1. Name a rock type that is not made of minerals. How can a rock be made of material that is not minerals?
2. What is an igneous rock?
3. What is a metamorphic rock?
4. What is a sedimentary rock?

Explore More

Use the resource below to answer the questions that follow.



1. How do igneous rocks form?
2. Why do lessons about rocks always begin with igneous rocks?
3. What directly correlates with crystal size in an igneous rock?
4. How do sedimentary rocks form?
5. What two things related to sedimentary rocks do you see at the Grand Canyon?
6. What are metamorphic rocks?
7. How do metamorphic rocks form?
8. Can an igneous rock become an igneous rock? Can a sedimentary rock become a sedimentary rock? Can a metamorphic rock become a metamorphic rock?
9. Draw an diagram of the rock cycle. Include the processes that transform rocks from one type to another.

This page titled 4.6: Rocks is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.7: Rock Cycle Processes



Is this what geologists mean by the rock cycle?

Okay, maybe not. The rock cycle shows how any type of rock can become any other type of rock. The three rock types are joined together by the processes that change one to another.

The Rock Cycle

You learned about the three rock types: igneous, sedimentary, and metamorphic. You also learned that all of these rocks can change. In fact, any rock can change to become any other type of rock. These changes usually happen very slowly. Some changes happen below Earth's surface. Some changes happen above ground. These changes are all part of the rock cycle. The **rock cycle** describes each of the main types of rocks, how they form, and how they change.

The figure below shows how the three main rock types are related to each other (**Figure** below). The arrows within the circle show how one type of rock may change to rock of another type. These are the processes that change one rock type to another rock type.



The Rock Cycle.

Processes of the Rock Cycle

There are three main processes that can change rock:

- Cooling and crystallization. Deep within the Earth, temperatures can get hot enough to create magma. As magma cools, crystals grow, forming igneous rock. The crystals grow larger if the magma cools slowly, as it does if it remains deep within the Earth. If the magma cools quickly, the crystals will be very small. When crystals form from magma it is called **crystallization**.

- Weathering and erosion. Water, wind, ice, and even plants and animals all act to wear down rocks. Over time they can break larger rocks into sediments. Rocks break down by the process called **weathering**. Moving water, wind, and glaciers then carry these pieces from one place to another. This is called **erosion**. The sediments are eventually dropped, or **deposited**, somewhere. This process is called **sedimentation**. The sediments may then be compacted and cemented together. This forms a sedimentary rock. This whole process can take hundreds or thousands of years.
- Metamorphism. This long word means "to change form." A rock undergoes metamorphism if it is exposed to extreme heat and pressure within the crust. With **metamorphism**, the rock does not melt all the way. The rock changes due to heat and pressure. A metamorphic rock may have a new mineral composition and/or texture.

The rock cycle really has no beginning or end. It just continues. The processes involved in the rock cycle take place over hundreds, thousands, or even millions of years. Even though for us rocks are solid and unchanging, they slowly change all the time.



Summary

- The three main rock types are igneous, metamorphic, and sedimentary.
- The three processes that change one rock to another are crystallization, metamorphism, and erosion and sedimentation.
- Any rock can transform into any other rock by passing through one or more of these processes. This creates the rock cycle.

Review

1. What processes create igneous rocks?
2. What processes create metamorphic rocks?
3. What processes create sedimentary rocks?

Explore More

Use this video to answer the questions that follow.

1. What are the three rock types?
2. What happens to sedimentary rocks on Earth's surface?
3. What happens over time to make sediments into sedimentary rocks?
4. How can you tell a sedimentary rock from another type?
5. What happens to a sedimentary rock if you apply heat and pressure?
6. How might this happen?
7. How does an igneous rock form?
8. What causes the structures of igneous rocks to be different?
9. How can an igneous rock become a sedimentary rock? A metamorphic rock?

1. What are the three rock types?
2. What happens to sedimentary rocks on Earth's surface?
3. What happens over time to make sediments into sedimentary rocks?

4. How can you tell a sedimentary rock from another type?
5. What happens to a sedimentary rock if you apply heat and pressure?
6. How might this happen?
7. How does an igneous rock form?
8. What causes the structures of igneous rocks to be different?
9. How can an igneous rock become a sedimentary rock? A metamorphic rock?

This page titled 4.7: Rock Cycle Processes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.8: Igneous Rocks



Have you seen igneous rocks in the field?

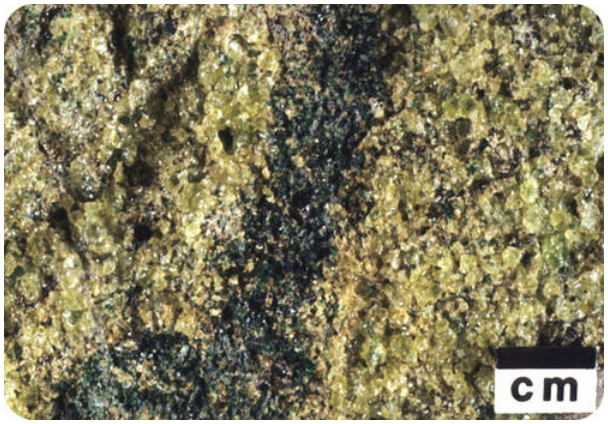
Igneous rocks are everywhere! One of the most common igneous rocks that make up the crust is granite. Many mountain ranges are made of granite. The spectacular features of Yosemite Valley, like Half Dome, are granitic. Volcanoes are made of igneous rocks, such as basalt. Igneous rocks are also found where you can't see them. Oceanic crust is mostly basalt and gabbro. The mantle is peridotite.

Igneous Rocks

Igneous rocks form when **magma** cools and forms crystals. Magma is melted rock. What an igneous rock looks like is determined by two things. One is the composition of the magma. The other is how fast the magma cools. The rate of cooling determines the texture of the rock.

Composition

Different igneous rocks contain minerals with different compositions. **Mafic** igneous rocks contain mafic minerals. Mafic minerals are dense and dark in color. They typically contain iron and magnesium; they are low in silica. Olivine and pyroxene are mafic minerals.



Olivine is the green mineral, pyroxene is the black mineral.

Felsic igneous rocks contain felsic minerals. They typically contain aluminum and sodium; they are high in silica. Quartz and potassium feldspar are felsic minerals. Minerals and rocks with a composition in between mafic and felsic are called intermediate.



Potassium feldspar is the pink mineral, plagioclase feldspar is the white mineral, and quartz is the gray mineral.



Summary

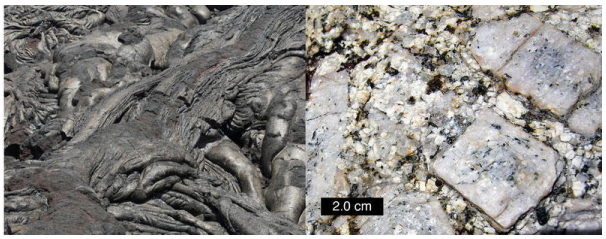
- Magma cools to form igneous rocks. Two factors determine what type of rock forms.
- The composition of the magma determines if the rock is mafic, felsic, or intermediate.
- The rate the magma cools determines the texture of the rock.

Review

1. How does an igneous rock form?
2. How do mafic and felsic minerals and rocks differ from each other?
3. What two factors determine what type of rock a magma will form?

This page titled 4.8: Igneous Rocks is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.9: Intrusive and Extrusive Igneous Rocks



Are these both igneous rocks?

These rocks don't even look like they're the same type! They are, at least in the same way that fish and mice are both vertebrates. They both cooled from magma, but the similarities end there. Can you tell what's different?

Cooling

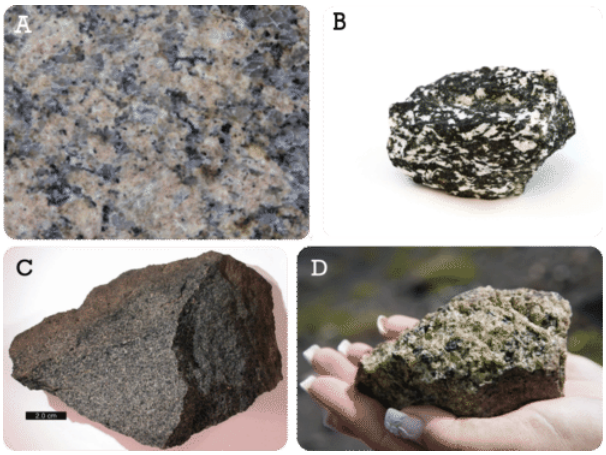
Igneous rocks cool from magma. The appearance of the rock is created by the composition of the magma. It is also determined by the rate that the magma cools. If the magma cools deep underground, it cools slowly. If the magma cools at or very near the surface, it cools quickly. This results in two different rock types. The rock types can be told apart by the size of their crystals. The size of the crystals creates the texture of the rock.



Intrusive Igneous Rocks

Intrusive igneous rocks cool underground. Deep in the crust, magma cools slowly. Slow cooling gives crystals a chance to grow. Intrusive igneous rocks have relatively large crystals that are easy to see. Intrusive igneous rocks are also called plutonic. A **pluton** is an igneous rock body that forms within the crust.

Granite is the most common intrusive igneous rock. Pictured below are four types of intrusive rocks (**Figure** below).



(A) This granite has more plagioclase feldspar than many granites. (B) Diorite has more dark-colored minerals than granite. (C) Gabbro. (D) Peridotite contains olivine and other mafic minerals.

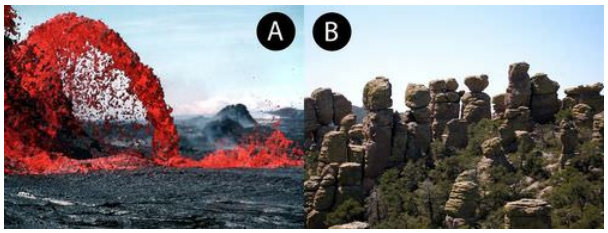
Geological processes have brought some igneous rocks to the surface. Pictured below is a landscape in California's Sierra Nevada Mountains made of granite that has been raised to create mountains (**Figure** below).



California's Sierra Nevada Mountains are intrusive igneous rock exposed at Earth's surface.

Extrusive Igneous Rocks

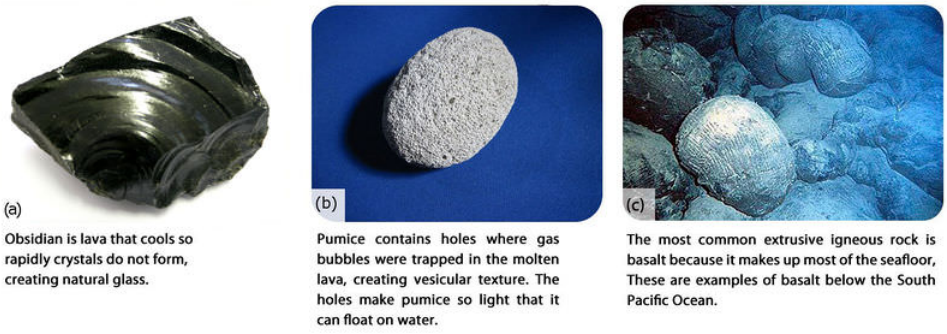
Extrusive igneous rocks form above the surface. The lava cools quickly as it pours out onto the surface (**Figure** below). Extrusive igneous rocks cool much more rapidly than intrusive rocks. The rapid cooling time does not allow time for large crystals to form. So extrusive igneous rocks have smaller crystals than igneous intrusive rocks. Extrusive igneous rocks are also called **volcanic rocks**.



(A) Lava cools to form extrusive igneous rock. The rocks here are basalts. (B) The strange rock formations of Chiricahua National Monument in Arizona are formed of the extrusive igneous rock rhyolite.

Some extrusive igneous rocks cool so rapidly that crystals do not develop at all. These form a glass, such as obsidian. Others, such as pumice, contain holes where gas bubbles were trapped in the lava. The holes make pumice so light that it actually floats in water.

The most common extrusive igneous rock is basalt. It is the rock that makes up the ocean floor. Shown below are three types of extrusive igneous rocks (**Figure** below).



Different cooling rate and gas content resulted in these different textures.

Summary

- Intrusive igneous rocks cool from magma slowly in the crust. They have large crystals.
- Extrusive igneous rocks cool from lava rapidly at the surface. They have small crystals.
- Texture reflects how an igneous rock formed.

Review

1. How do intrusive igneous rocks form? What is another name for these rocks?
2. How do extrusive igneous rocks form? What is another name for these rocks?
3. How can you use texture to determine whether an igneous rock is intrusive or extrusive?

Explore More

Use the resource below to answer the questions that follow.



1. How are intrusive rocks formed?
2. What size are the crystals in very coarse rocks? Why are they that size?
3. What are the most common coarse rocks?
4. How are extrusive rocks formed?
5. List the three textures for extrusive rocks.
6. Describe rhyolite.
7. Describe pumice.
8. Explain why obsidian appears black.

This page titled 4.9: Intrusive and Extrusive Igneous Rocks is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.10: Igneous Rock Classification



Is this igneous rock intrusive or extrusive?

You can't really tell from this view. A close up view would show small crystals in a dark colored rock. This indicates rapid cooling from a basalt lava. The most interesting feature you can see are the hexagonal "posts." For them to form, cooling must not have been too rapid. This amazing feature is Devil's Tower in Wyoming.

Igneous Rock Classification

Igneous rocks are classified by composition and texture. The composition can be felsic, intermediate, mafic, or ultramafic. The composition depends on the minerals the rock includes. A felsic rock will contain felsic minerals.

The mineral compositions are listed in **Table** below. The table includes examples of minerals.

Composition	Color	Density	Minerals
Felsic	Light	Low	Quartz, orthoclase feldspar
Intermediate	Intermediate	Intermediate	Plagioclase feldspar, biotite, amphibole
Mafic	Dark	High	Olivine, pyroxene
Ultramafic	Very dark	Very high	Olivine

Texture indicates how the magma cooled. Magma that cools rapidly has small or no visible crystals. Magma that cools slowly has large crystals; reference **Table** above for the type of rock, the amount of silica it has, and examples.



Rhyolite



Granite

Is this an intrusive or an extrusive igneous rock?



Basalt



Gabbro

Is this an intrusive or an extrusive igneous rock?

Pictured above are two pairs of igneous rocks (**Figures** above and above). The first pair is two rocks that formed from a felsic magma. The rhyolite cooled rapidly, and the granite cooled slowly. The second pair is two rocks that formed from mafic magma. The basalt cooled rapidly, and the gabbro cooled slowly. The color of the rocks and sizes of the crystals are your clues. There are other rock pairs that you could find listed below (**Table** below).

Type	Amount of Silica	Extrusive	Intrusive
Felsic	>69% SiO_2	Rhyolite	Granite
Intermediate	52-63%	Andesite	Diorite
Intermediate-Felsic	63-69%	Dacite	Granodiorite
Mafic	45-52%	Basalt	Gabbro
Ultramafic	<45%	Komatiite	Peridotite

Summary

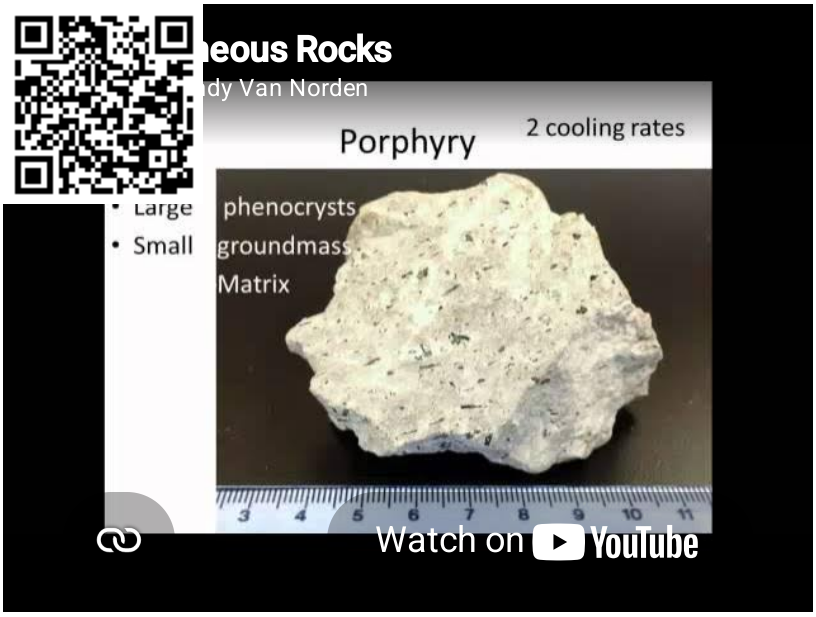
- Igneous rocks are classified first by composition. Categories go from from felsic to ultramafic. Color can indicate composition.
- Texture is second when classifying igneous rocks. Texture indicates how a rock cooled.
- Igneous rocks are categorized in pairs. The two rocks in a pair have the same composition but different textures: gabbro-basalt, diorite-andesite, and granite-rhyolite.

Review

1. Describe the formation of the igneous rock pair gabbro-basalt. Compare and contrast the two rock types.
2. How does the composition of a rock affect its color?
3. What are ultramafic rocks? What is their color?

Explore More

Use the resource below to answer the questions that follow.



1. How does the rate of magma cooling affect crystal size?
2. How does an igneous rock get a glassy texture?
3. What is the name of the texture if extremely small crystals form? Where do rocks like this form?
4. If there is lot of water in the cooling magma what is the texture? Where might this happen?

5. What is a good example of a glassy rock? What feature does this rock have that is just like glass?
6. What does felsic mean? What are the features of felsic minerals?
7. What does mafic mean? What are the features of mafic minerals?
8. What does ultramafic magma produce? Why is this rock important? What is its main crystal?
9. How does a porphyry form?

This page titled 4.10: Igneous Rock Classification is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.11: Earth's Minerals and Rocks- Challenge 2

1. A metamorphic rock forms from other rocks that are exposed to increased ___ and ___.

temperature; pressure.

2. When describing the texture of a rock or mineral, which features should be examined?

Size, shape, and the arrangement of mineral grains

3. Two different rocks must always differ in their ___.

composition and/or texture

4. Changes in ___ and ___ result in the formation of metamorphic rocks.

temperature; pressure

5. Sedimentary rocks are made up of ___.

pieces of other rocks that have cemented together

6. Which type of rock often contains fossils?

Sedimentary

7. Although both these types of igneous rock cool from magma, the composition of ___ rock is higher in iron and magnesium, while that of ___ rock is higher in aluminum, sodium, and silica.

mafic; felsic

8. ___ indicates the temperature at which minerals melt or crystallize.

Bowen's Reaction Series

9. Different ___ have different compositions and contain whichever elements and gases that were in the rocks that melted.

magmas

10. If a rock has many holes from gas bubbles, it is ___.

a vesicular rock

11. Large mountain ranges consisting of intrusive igneous rocks form when ___.

magma cools deep in the crust and then the resulting plutons are uplifted

12. Extrusive igneous rocks are also called ___ rocks.

volcanic

13. Which type of igneous rock is light in color?

Felsic

14. Which type of igneous rock is dark in color?

Mafic

15. ___ have very low silica content but high iron and magnesium content.

Ultramafic

This page titled 4.11: Earth's Minerals and Rocks- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.12: Sedimentary Rocks



Where can you go to see sediments?

Sediments are everywhere! One of the most fun places to see sediments is on a beach. Squishing sand between your toes is a great way to experience sediments first hand (or foot).

Sedimentary Rocks

Most sedimentary rocks form from sediments. The sediments must be packed together to form a rock. Sedimentary rocks also form as minerals precipitate from saline water. Sedimentary rock formation is described in the next concept.

Sediments

Sediments are small fragments of rocks and minerals. Pebbles, sand, silt, and clay are examples of sediments. Sedimentary rocks may include fossils. **Fossils** are materials left behind by once-living organisms. Fossils can be pieces of the organism, like bones. They can also be traces of the organism, like footprints.

Transport

Sediments are transported by water, wind, ice, or gravity. These agents move them from the place where they formed. The sediments are then deposited in a location.

Deposition

Sediments will eventually settle out of water (**Figure** below). For example, rivers carry lots of sediment. Where the water slows, it dumps these sediments along its banks, into lakes, and the ocean.



Cobbles, pebbles, and sands are the sediments that are seen on this beach.

When sediments settle out of water, they form horizontal layers. A layer of sediment is deposited. Then the next layer is deposited on top of that layer. So each layer in a sedimentary rock is younger than the layer under it (**Figure** below).



The rock layers at the Grand Canyon are horizontal. We know that layers at the bottom are older than layers at the top.

Sediments are deposited in many different types of environments. Beaches and deserts collect large deposits of sand. Sediments also end up at the bottom of the ocean and in lakes, ponds, rivers, marshes, and swamps. Avalanches produce large piles of sediment. The environment where the sediments are deposited determines the type of sedimentary rock that can form.



Summary

- Sediments are small fragments of minerals, rocks, or fossils.
- Sediments range in size from tiny bits of silt or clay to enormous boulders.
- Sediments are deposited in many different environments.

Review

1. What are sediments? What sizes are sediments?
2. What two things are needed to make a sedimentary rock?
3. What does the environment where sediments are deposited mean for the rock that eventually forms?

This page titled 4.12: Sedimentary Rocks is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.13: Lithification of Sedimentary Rocks



What steps led to this rock formation?

What do you see? The rock is a sandstone, so first there were rocks that weathered and eroded. The cross-bedding indicates that the sand was deposited in a dune. The sand was then buried deeply enough that it turned into rock. This concept will explore how something like sand could become a rock.

Sedimentary Rock Formation

There are two main types of sedimentary rocks: clastic and chemical. Clastic rocks are made of sediments, which are sometimes called clasts. Creating rocks from sediments is called **lithification**. Chemicals precipitate from liquid to form chemical sedimentary rocks.

Clastic Rocks

Over time, deposited sediments may harden into rock. First, the sediments are **compacted**. That is, they are squeezed together by the weight of sediments on top of them. Next, the sediments are **cemented** together. Minerals fill in the spaces between the loose sediment particles. These cementing minerals come from the water that moves through the sediments. Sedimentary rocks that form from sediments are called “clastic rocks.“ Clastic rocks are rock fragments that are compacted and cemented together (**Figure** below).



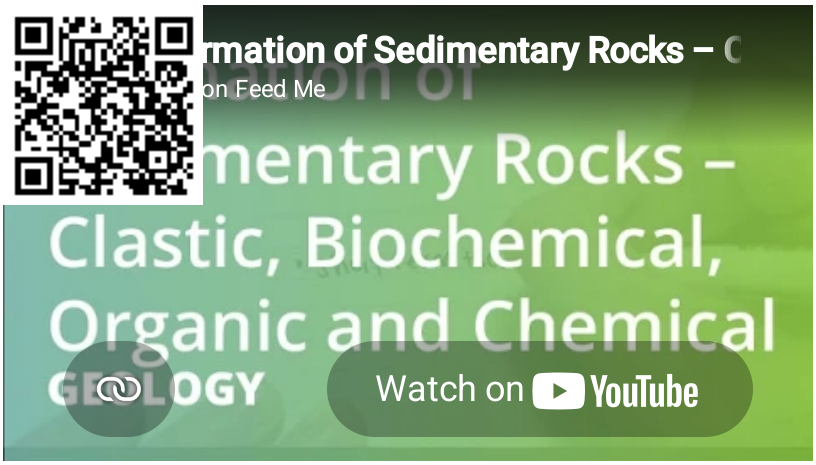
Conglomerates have larger clasts than sandstone, which have larger clasts than mudstone.

Chemical Sedimentary Rocks

Chemical sedimentary rocks form when crystals precipitate out from a liquid. The mineral halite, also called rock salt, forms this way. You can make halite! Leave a shallow dish of salt-water out in the Sun. As the water evaporates, salt crystals form in the dish. There are other chemical sedimentary rocks, like gypsum (**Figure** below).



Gypsum, with its rose-like structure, is a chemical sedimentary rock.



Summary

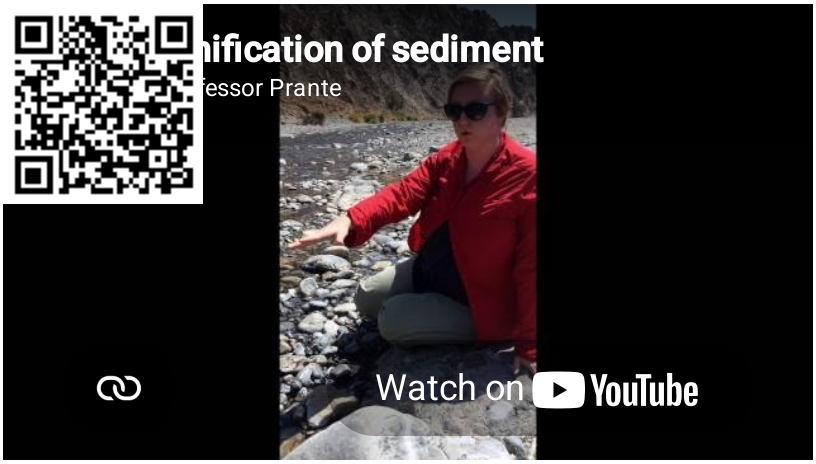
- Compaction and cementation lead to lithification of sedimentary rocks.
- Sediments are compacted by the weight of the rocks and sediments above them.
- Sediments are cemented by fluids that bind sediments together.
- Minerals precipitate to form sedimentary rocks.

Review

1. How does compaction lead to lithification?
2. How does cementation lead to lithification?
3. How do chemical sedimentary rocks form?

Explore More

Use this resource to answer the questions that follow.



1. What is the source of the water in this stream?
2. What do you think a poorly sorted sediment looks like?
3. What do you think a bimodal sediment looks like? Note that clasts is another name for a rock or rock fragment.
4. Why would a sediment become well rounded?
5. What is precipitating around the clasts?
6. How do the rocks stick together to undergo lithification?
7. How can rocks form at surface temperatures and pressures?

This page titled 4.13: Lithification of Sedimentary Rocks is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.14: Sedimentary Rock Classification





Can you tell which type of rock these are?

If you look up close, you would be able to see grains of sand. From this distance, you can see different layers from where the sand was laid down. This rock is sandstone. The sand grains are cemented together to make sandstone. Sandstone is a common type of sedimentary rock.

Types of Sedimentary Rocks

The main types of sedimentary rocks are clastic or chemical. Some sedimentary rocks are a third type: organic. Clastic sedimentary rocks are made of sediments. The sediments differ in size. Chemical sedimentary rocks are made of minerals that precipitate from saline water. Organic sedimentary rocks are made from the bodies of organisms.

Clastic Sedimentary Rocks

Clastic sedimentary rocks are grouped by the size of the sediment they contain. Conglomerate and breccia are made of individual stones that have been cemented together. In conglomerate, the stones are rounded. In breccia, the stones are angular. Sandstone is made of sand-sized particles. Siltstone is made of smaller particles. Silt is smaller than sand but larger than clay. Shale has the smallest grain size. Shale is made mostly of clay-sized particles and hardened mud.

Rock	Sediment Size	Other Features
Conglomerate	Large	Rounded
Breccia	Large	Angular
Sandstone	Sand-sized	
Siltstone	Silt-sized, smaller than sand	
Shale	Clay-sized, smallest	

When sediments settle out of calmer water, they form horizontal layers. One layer is deposited first, and another layer is deposited on top of it. So each layer is younger than the layer beneath it. When the sediments harden, the layers are preserved.

Chemical Sedimentary Rocks

Sedimentary rocks formed by the crystallization of chemical precipitates are called **chemical sedimentary rocks**. Dissolved ions in fluids precipitate out of the fluid and settle out, just like the halite pictured below (**Figure** below).



CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

The evaporite, halite, on a cobble from the Dead Sea, Israel.

Living creatures can help chemicals become sedimentary rocks. Limestone is an example.

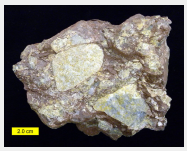
Organic Sedimentary Rocks

The bodies of organisms can make a sedimentary rock. Plant bodies are lithified to become coal. When shells are cemented together they make a type of limestone. So limestone can be considered chemical or organic.

Common Sedimentary Rocks

Listed below are some common types of sedimentary rocks (**Table** below).

https://k12.libretexts.org/@go/page/5374

Picture	Rock Name	Type of Sedimentary Rock
	Conglomerate	Clastic (fragments of non-organic sediments)
	Breccia	Clastic
	Sandstone	Clastic
	Siltstone	Clastic
	Shale	Clastic
	Rock salt	Chemical precipitate
	Rock gypsum	Chemical precipitate
	Dolostone	Chemical precipitate
	Limestone	Bioclastic (sediments from organic materials, or plant or animal remains)

Picture	Rock Name	Type of Sedimentary Rock
	Coal	Organic

Summary

- Sediments settle out of water in horizontal layers.
- Clastic sedimentary rocks are classified based on how they form and on the size of the sediments.
- Chemical sedimentary rocks precipitate from fluids.

Review

1. Describe the three main types of sedimentary rocks.
2. How can different types of limestone be bioclastic, chemical and organic?
3. List sedimentary rock types by grain size, from small to large.

Explore More

Use the resource below to answer the questions that follow.



1. List the three types of sedimentary rocks.
2. Where and how are clastic rocks found?
3. How do clastic rocks form?
4. Contrast conglomerates and breccia rocks.
5. What can be found in clastic rocks?
6. Explain the difference between layers and bands.
7. What can we learn from sedimentary rocks?
8. How do chemical rocks form?
9. What are bioclastic rocks?
10. List the two types of biocalstic rocks.

This page titled 4.14: Sedimentary Rock Classification is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.15: Metamorphic Rocks



What is the history of this rock?

The rock in this photo is a banded gneiss. The bands are made of different minerals. The light bands are more felsic, and the dark bands are more mafic. The minerals separated due to heat and pressure. The waviness of the bands also shows how the rock was hot enough to alter. It was not hot enough to melt all the way.

Metamorphism

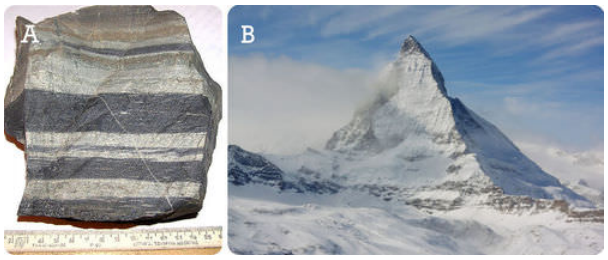
Metamorphic rocks start off as some kind of rock. The starting rock can be igneous, sedimentary, or even another metamorphic rock. Heat and/or pressure then change the rock into a metamorphic rock. The change can be physical, chemical, or both.

During metamorphism, a rock may change chemically. Ions move in or out of a mineral. This creates a different mineral. The new minerals that form during metamorphism are more stable in the new environment. Extreme pressure may lead to physical changes. If pressure is exerted on the rock from one direction, the rock forms layers. This is **foliation**. If pressure is exerted from all directions, the rock usually does not show foliation.

There are two main types of metamorphism: contact and regional.

Contact Metamorphism

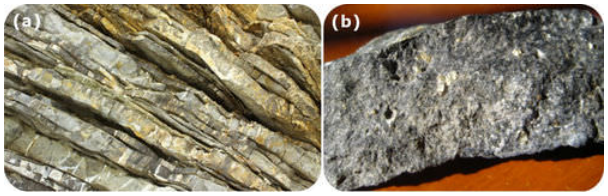
Contact metamorphism results when magma contacts a rock. The rock changes because of the magma's extreme heat (**Figure** below).



(A) Hornfels is a rock that is created by contact metamorphism. (B) Hornfels is so hard that it can create peaks like the Matterhorn in the Alps.

Regional Metamorphism

Regional metamorphism occurs over a wide area. Great masses of rock are exposed to pressure from rock and sediment layers on top of it. The rock may also be compressed by other geological processes. If the rock is buried deeply, it may experience high temperatures.



CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

(A) Regional metamorphic rocks often display layering called foliation. (B) Regional metamorphism with high pressures and low temperatures can result in blueschist.

Metamorphism does not cause a rock to melt completely. It only causes the minerals to change by heat or pressure. If the rock melts completely, it will cool to become an igneous rock.

Hornfels is a rock with alternating bands of dark and light crystals. Hornfels is a good example of how minerals rearrange themselves during metamorphism (**Figure** above). The minerals in hornfels separate by density. The result is that the rock becomes banded. Gneiss forms by regional metamorphism from extremely high temperature and pressure.



Summary

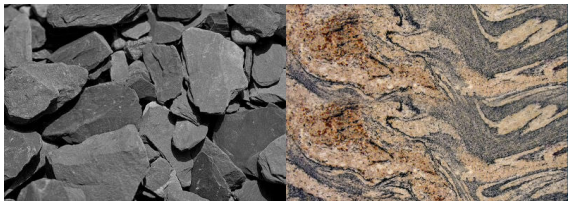
- Any type of rock—igneous, sedimentary, or metamorphic—can become a metamorphic rock.
- Contact metamorphism occurs when a rock is altered by heat from a nearby magma.
- Regional metamorphism occurs over a large area when a rock is buried or compressed.

Review

1. Compare and contrast the two types of metamorphism.
2. Under what conditions does a rock become foliated?
3. Describe how and why rocks are altered by regional metamorphism.

This page titled 4.15: Metamorphic Rocks is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.16: Metamorphic Rock Classification



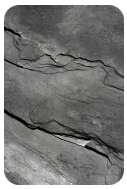
What's the difference in these two rocks?

The rock on the left was the sedimentary rock shale. Now it's the metamorphic rock slate. Slate looks very similar to shale, but it is harder and more platy. The rock on the right is gneiss. The light and dark minerals have separated into bands. Gneiss is produced by higher temperature metamorphism. The original rock was different in both cases.

Common Metamorphic Rocks

Some of the most common metamorphic rocks are listed below (**Table** below). Their parent rock and the type of metamorphism are also mentioned.

The table shows some common metamorphic rocks and their original parent rock.

Picture	Rock Name	Type of Metamorphic Rock	Comments
	Slate	Foliated	Metamorphism of shale
	Phyllite	Foliated	Metamorphism of slate, but under greater heat and pressure than slate
	Schist	Foliated	Often derived from metamorphism of claystone or shale; metamorphosed under more heat and pressure than phyllite
	Gneiss	Foliated	Metamorphism of various different rocks, under extreme conditions of heat and pressure
	Hornfels	Non-foliated	Contact metamorphism of various different rock types
	Quartzite	Non-foliated	Metamorphism of quartz sandstone
	Marble	Non-foliated	Metamorphism of limestone
	Metaconglomerate	Non-foliated	Metamorphism of conglomerate

Summary

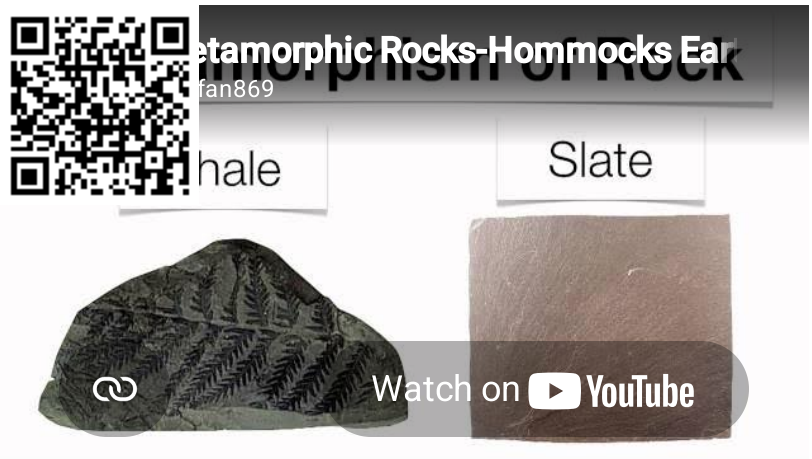
- Foliated metamorphic rocks are platy.
- Non-foliated metamorphic rocks are massive.
- The more extreme the amount of metamorphism, the more difficult it is to tell what the original rock was.
- Marble is metamorphosed limestone.

Review

1. What does a foliated metamorphic rock look like?
2. How do slate, phyllite, and schist differ from each other? How are they the same?
3. What is quartzite?

Explore More

Use the resource below to answer the questions that follow.



1. How are metamorphic rocks classified?
2. How do metamorphic rocks form?
3. What is recrystallization?
4. Why are these rocks the most dense?
5. Where do metamorphic rocks form?
6. Where does regional metamorphism occur?
7. What is a foliated rock?
8. What does shale become when heated and put under pressure?
9. What is schist?
10. Describe gneiss.
11. What is the evidence for regional metamorphosis?
12. What is contact metamorphism?
13. Where does contact metamorphism occur?
14. Describe non-foliated rocks.
15. Why is hornfels unique?

This page titled 4.16: Metamorphic Rock Classification is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

4.17: Earth's Minerals and Rocks- Challenge 3

1. Landslides drop large piles of sediment due to ___.

gravity

2. Weathering is a ___ phenomenon.

surface

3. Red rocks are formed when which element is present?

Oxygen

4. The process in which fluid deposits ions that bind loose sediment into rock is called ___.

cementation

5. Shale is made from ___.

clay

6. Order the following sedimentary rocks by grain size, from smallest to largest: sandstone, breccia/conglomerate, shale, and siltstone.

siltstone (1), shale (2), sandstone (3), and breccia/conglomerate (4)

7. Sediments are deposited ___.

horizontally

8. Which type of metamorphism occurs when nearby magma alters a rock?

Contact metamorphism

9. ___ metamorphism occurs over a large area.

Regional

10. Which of the following metamorphic rocks is foliated: quartzite, gneiss, or marble?

Gneiss

11. Metamorphism of limestone turns into ___.

marble

12. Slate is made from the metamorphism of ___.

shale

This page titled 4.17: Earth's Minerals and Rocks- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

5: Plate Tectonics

5.1: Continental Drift
5.2: Wegener and the Continental Drift Hypothesis
5.3: Magnetic Polarity Evidence for Continental Drift
5.4: Bathymetric Evidence for Seafloor Spreading
5.5: Magnetic Evidence for Seafloor Spreading
5.6: Seafloor Spreading Hypothesis
5.7: Plate Tectonics- Challenge 1
5.8: Earth's Tectonic Plates
5.9: Tectonic Plate Motions
5.10: Theory of Plate Tectonics
5.11: Divergent Plate Boundaries in the Ocean
5.12: Divergent Plate Boundaries
5.13: Transform Plate Boundaries
5.14: Plate Tectonics- Challenge 2
5.15: Ocean-Continent Convergent Plates
5.16: Ocean-Ocean Convergent Plate Boundaries
5.17: Continent-Continent Convergent Plate Boundaries
5.18: Continental Margins
5.19: Supercontinent Cycle and Pangaea
5.20: Intraplate Activity
5.21: Plate Tectonics- Challenge 3

This page titled 5: Plate Tectonics is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.1: Continental Drift



What does a scientist do with an interesting observation?

Alfred Wegener made an observation. From that observation, he made a hypothesis. He collected evidence that would support or refute his hypothesis. What did that process look like?

Wegener's Idea

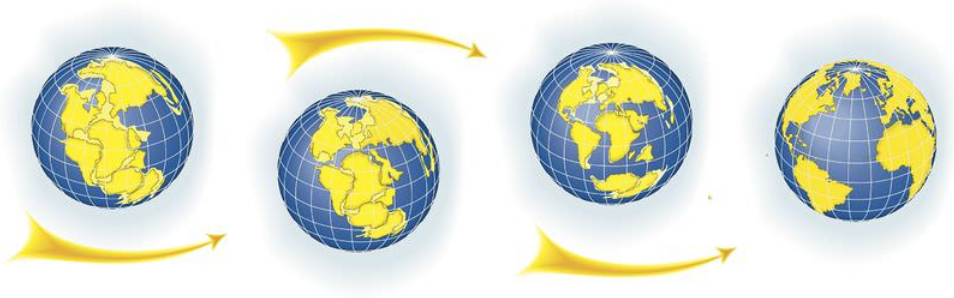
Alfred Wegener, born in 1880, was a meteorologist and explorer. In 1910, he noticed that South America and Africa appeared to fit together like puzzle pieces. He was certainly not the first person to notice this. But he was intrigued by the idea and thought a lot about it. He wondered if the two continents were once joined and then moved apart? He set out to find evidence to support or refute this idea.

Wegener's Evidence

Here is the main evidence that Wegener and his supporters collected for his continental drift hypothesis:

Fit of the Continents

The continents appear to fit together, and not just South America and Africa. If the continental margins are included, the fit is even better.



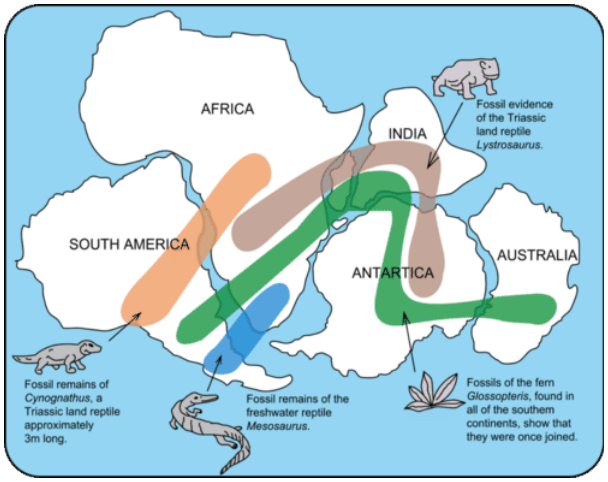
This figure shows the evolution of the continents, from the super-continent Pangaea to the way they look now.

Distribution of Fossils

Wegener found fossil evidence that the continents were once joined (**Figure** below). The same type of plant and animal fossils are found on continents that are now widely separated. These organisms would not have been able to travel across the oceans. So how did the fossils get so far apart?

Fossils of the seed fern Glossopteris are found across all of the southern continents. These seeds are too heavy to be carried across the ocean by wind. Mesosaurus fossils are found in South America and South Africa. Mesosaurus could swim, but only in fresh water. Cynognathus and Lystrosaurus were reptiles that lived on land. Both of these animals were unable to swim at all. Their fossils have been found across South America, Africa, India, and Antarctica.

Wegener thought that all of these organisms must have lived side by side. The lands later moved apart so that the fossils are separated.



Wegener used fossil evidence to support his continental drift hypothesis. The fossils of these organisms are found on lands that are now far apart. Wegener suggested that when the organisms were alive, the lands were joined and the organisms were living side-by-side.

Distribution of Rocks and Structures

Wegener found rocks of the same type and age on both sides of the Atlantic Ocean. He thought that it could not be a coincidence! He said that the rocks must have formed side by side. These rocks then drifted apart on separate continents.

Wegener also matched up mountain ranges across the Atlantic Ocean. The Appalachian Mountains were just like mountain ranges in eastern Greenland, Ireland, Great Britain, and Norway. Wegener concluded that they formed as a single mountain range. This mountain range broke apart as the continents split up. The mountain range separated as the continents drifted.

Climate Zones

Climate is found in zones around the planet. Warm tropical climates are mostly found near the Equator. Glaciers are mostly found nearer the poles. Wegener assumed that these things were true in the ancient past.

Glaciers

Wegener looked at evidence from ancient glaciers. Glaciers are found in very cold climates near the poles. The evidence left by some ancient glaciers is very close to the Equator. Did glaciers once exist near the equator? Wegener knew that this was extremely unlikely! However, if the continents had moved, the glaciers would have been centered close to the South Pole.

Tropics

Coral reefs are found only in warm water. Coal swamps are also found in tropical and subtropical environments. Wegener discovered ancient coal seams and coral reef fossils in areas that are much too cold today. Wegener thought that ancient coral and coal plants existed at about the same latitude where they are found today. He again stated that it was the continents that moved.

Summary

- Alfred Wegener made an observation. Africa and South America appeared to fit together like puzzle pieces.
- Wegener then asked an important question and set about to answer it. Were the continents once joined and then they drifted apart?

- Wegener collected a great deal of evidence to support his idea. Wegener's evidence included the fit of the continents, the distribution of ancient fossils, the placement of similar rocks and structures on the opposite sides of oceans, and indicators of ancient climate found in locations where those climates do not exist today.

Review

1. What was the scientific question that Wegener asked?
2. What did he need to do to explore the question and make it into a hypothesis?
3. What evidence did Wegener have to support his idea?
4. Describe how Wegener used each type of evidence to support his idea.

Explore More

Use the resources below to answer the questions that follow.



1. Who was Alfred Wegener?
2. What evidence did Wegener find for Pangaea?
3. What was the response to Wegener's hypothesis?



4. What is the continental drift hypothesis?
5. What do the continental plates consist of?
6. What were formed when Pangaea broke apart?
7. Is the word "theory" misused in these two videos? What is the better word?

This page titled 5.1: Continental Drift is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.2: Wegener and the Continental Drift Hypothesis



What is continental drift?

Wegener put together a tremendous amount of evidence that the continents had been joined. He advanced a great idea. But other scientists didn't accept it.

Wegener's Continental Drift Hypothesis

Wegener put his idea and his evidence together in his book, *The Origin of Continents and Oceans*. The book was first published in 1915. He included evidence that the continents had been joined. New editions of the book containing additional evidence were published later.

In his book he said that around 300 million years ago, the continents had all been joined. They created a single landmass he called Pangaea, meaning "all earth" in ancient Greek. The super-continent later broke apart. Since then the continents have been moving into their current positions. He called his hypothesis **continental drift**.



The Problem With The Hypothesis

Wegener had a lot of evidence to support his hypothesis. But he had a problem. The problem was that he could not explain how the continents could move through the oceans. He suggested that continental drift occurred like an icebreaker plows through sea ice (**Figure** below). He thought the continents could cut through the ocean floor.



An icebreaking ship.

Other scientists didn't buy his idea. They thought that the continents would be much more deformed than they are.

Wegener believed that Africa and South America had once been joined. He had the evidence. But very few scientists accepted his idea. He needed a mechanism that they would accept.

Alfred Wegener died in 1930 on an expedition on the Greenland icecap. The continental drift hypothesis was put to rest for a few decades. Only when technology could provide even more evidence for continental drift did scientists look into the idea again. Technology also helped scientists to develop a mechanism for how continents could drift.

Further Reading

Magnetic Polarity Evidence for Continental Drift

Bathymetric Evidence for Seafloor Spreading

Magnetic Evidence for Seafloor Spreading

Seafloor Spreading Hypothesis

Summary

- Alfred Wegener said that the continents had been joined as a single landmass, which he called Pangaea.
- Wegener thought that Pangaea was together about 300 million years ago.
- Wegener could not develop a mechanism for continents moving through oceanic crust that other scientists would accept.

Review

1. Describe the continental drift hypothesis.
2. Why did scientists reject Wegener’s idea? What was needed for them to accept it?
3. What was Wegener's mechanism for drifting continents?

Explore More

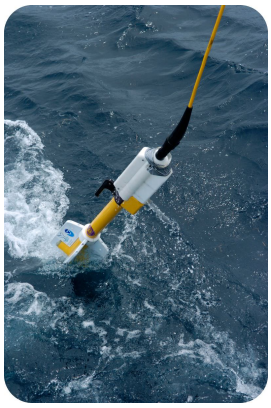
Use the resource below to answer the questions that follow.



1. What is uniformitarianism?
2. What did Wegener write about in his book?
3. What did Wegener think caused continental drift?
4. Give specific examples of the response to Wegener's continental drift hypothesis.
5. What did scientists learn after the war?

This page titled 5.2: Wegener and the Continental Drift Hypothesis is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.3: Magnetic Polarity Evidence for Continental Drift



How did technology play a role in developing Wegener's idea?

After Wegener's death, the continental drift idea was pretty much dead. It would have remained that way except for the development of technology. Using technology, scientists would find more evidence that continents had drifted. They would also be able to find the mechanism. This type of magnetometer was one of their important tools.

Magnetic Polarity

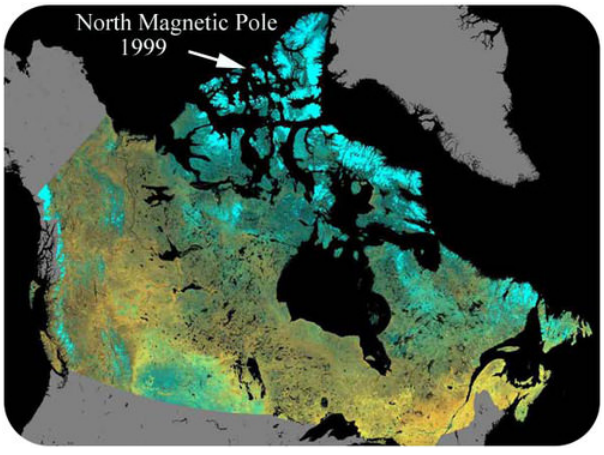
Some important evidence for continental drift came after Wegener's death. The following is the magnetic evidence: Earth's magnetic field surrounds the planet from pole to pole. If you have ever been hiking or camping, you may have used a compass to help you find your way. A compass points to the magnetic North Pole. The compass needle aligns with Earth's magnetic field.

Some rocks contain little compasses too! As lava cools, tiny iron-rich crystals line up with Earth's magnetic field. These crystals are **magnetite** crystals. Anywhere lavas have cooled, these magnetite crystals point to the magnetic poles. The little magnets point to where the North Pole was when the lava cooled. A **magnetometer** is a device capable of measuring the magnetic field. A magnetometer can be used on land. A magnetometer also can be dragged behind a ship.

Evidence for Continental Drift

Geologists used magnetometers to look at rocks on land. They wanted to know which direction magnetite crystals pointed. This would tell them where magnetic north was at the time the rocks cooled. This is what they learned:

- Magnetite crystals in fresh volcanic rocks point to the current magnetic north pole (**Figure** below).



Earth's current north magnetic pole is in northern Canada.

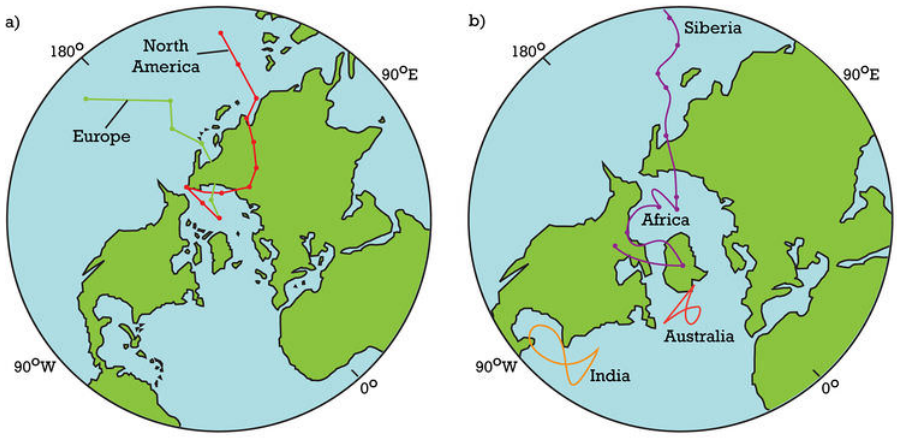
- Older rocks that are the same age and are on the same continent point to the same location. However, the location they point to is not the current north magnetic pole.

- Older rocks that are different ages and are on the same continent do not point to the same location. None of them point to the current magnetic north pole.
- Rocks on different continents that are the same age point to different locations. Only recent rocks point to the current north magnetic pole.

How did the geologists explain this? There is only one logical explanation. There was almost certainly only one north magnetic pole through Earth's history. The north magnetic pole is very likely in the same spot it has always been. If these two things are true, then the continents have moved.

Support for Wegener's Idea

Geologist tested the idea that the pole remained fixed but the continents moved. They fitted the continents together as Wegener had done. They moved them into the positions where they had been at the time the magnetite crystals cooled. The magnetite crystals pointed to the current north magnetic pole (**Figure** below). The magnetic pole seemed to have moved, but had not. They named the phenomenon **apparent polar wander**.



On the left: The apparent North Pole for Europe and North America if the continents were always in their current locations. The two paths merge into one if the continents are allowed to drift.

Geologists were now more interested in continental drift. More than ever, they needed a mechanism.



Summary

- Magnetite is a magnetic mineral found in lava. The magnetite points to the magnetic north pole when it cools.
- Scientists used magnetometers to show where the north magnetic pole had been when magnetite crystals cooled.

- Magnetite crystals of different ages and on different continents pointed to different spots. The simplest explanation is that the continents have moved.
- Apparent polar wander is another line of evidence for drifting continents.

Review

1. What is apparent polar wander?
2. Describe how magnetite indicates magnetic pole. Why does it sometimes point to a spot that is not where the pole is located?
3. How did scientists use magnetic evidence to conclude that the continents moved?

This page titled 5.3: Magnetic Polarity Evidence for Continental Drift is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.4: Bathymetric Evidence for Seafloor Spreading

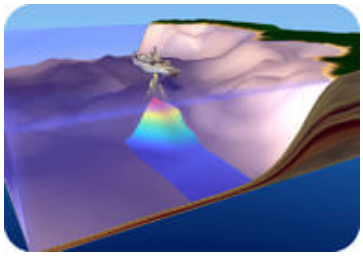


How can war further science?

Oddly, the thing that was needed to further Wegener's continental drift idea was World War II. U.S. Navy ships cruised the seas. They carried instruments that helped scientists to locate the mechanism for moving continents.

Echo Sounders

During World War II, battleships and submarines carried echo sounders. Their goal was to locate enemy submarines (**Figure** below). Echo sounders produce sound waves that travel outward in all directions. The sound waves bounce off the nearest object and then return to the ship. Scientists know the speed of sound in seawater. They then can calculate the distance to the object that the sound wave hit. Most of these sound waves did not hit submarines. They instead were used to map the ocean floor.



A ship sends out sound waves to create a picture of the seafloor below it. The echo sounder pictured has many beams, and, as a result, it creates a three dimensional map of the seafloor beneath the ship. Early echo sounders had only a single beam and created a line of depth measurements.

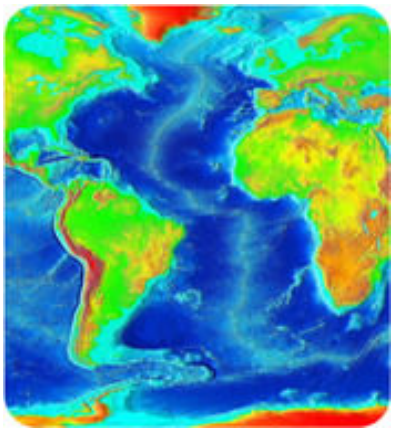
Seafloor Features

Scientists expected the seafloor to be flat and featureless. So they were shocked by what they saw: tremendous topographical features like mountain ranges, rifts, and trenches. Oceanographic research vessels continue to map the seafloor as they sail across the seas today. The map below is a modern map with data from several decades.

The major features of the ocean basins and their colors on the map include:

- **mid-ocean ridges**: A long chain of mountains that rises up high above the deep seafloor. An example is the light blue gash in middle of Atlantic Ocean. Light blue signifies higher elevation than dark blue.
- rift zones: In the middle of the mid-ocean ridges is a rift zone. The rift cuts the ridge into pieces. It is lower in elevation than the mountains of the mid-ocean ridge.
- deep sea **trenches**: Trenches are found in the sea. Some are near the edges of continents. Trenches are found near chains of active volcanoes. An example is the line of the very deepest blue, off of western South America.
- **abyssal plains**: Flat areas that may be dotted with volcanic mountains. An example is the consistent blue off of southeastern South America.
- **guyots**: Flat topped mountains that appear to have been eroded. Yet these mountains are thousands of feet below sea level.
- **continental margin**: The transition from the land to the deep sea. The continental margin is made of continental crust. More than one-quarter of the ocean basin is continental margin.

See if you can identify each of these features on the map (**Figure** below).



A modern map of the southeastern Pacific and Atlantic Oceans.

Of course the first scientists to observe these features wondered how they had formed. It turns out that they were crucial for fitting together ideas about seafloor spreading. And seafloor spreading would turn out to be the mechanism for continental drift.

Summary

- Echo sounders were used to search for enemy submarines during World War II. The depths they recorded allowed scientists to piece together bathymetric maps of the seafloor. Multi-beam sounders work on research vessels today.
- These maps revealed amazing features like mid-ocean ridges, deep-sea trenches, and abyssal plains.
- The features of the seafloor helped scientists to discover the mechanism for continental drift.

Review

1. How does an echo sounder create a bathymetric map?
2. What are the features of the seafloor that are elevated?
3. What are the features of the seafloor that are very deep?

Explore More

Use the resource below to answer the questions that follow.



1. What did Henry Hess use his sonar for?
2. What did Hess discover?

3. What was discovered in 1953?
4. What did Hess discover was occurring at the ridge?
5. What did Hess call his discovery?
6. What process recycles the crust?

This page titled 5.4: Bathymetric Evidence for Seafloor Spreading is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.5: Magnetic Evidence for Seafloor Spreading



What causes the strange stripes on the seafloor?

Magnetometers in the oceans discovered strange patterns. This pattern of stripes is like what they discovered on the seafloor. In this image, there is a dusky purple stripe in the center. Other colored stripes are symmetrical about the dusky purple stripe. In the oceans, magnetic stripes are symmetrical about a mid-ocean ridge axis. What does this have to do with continental drift?

Seafloor Magnetism

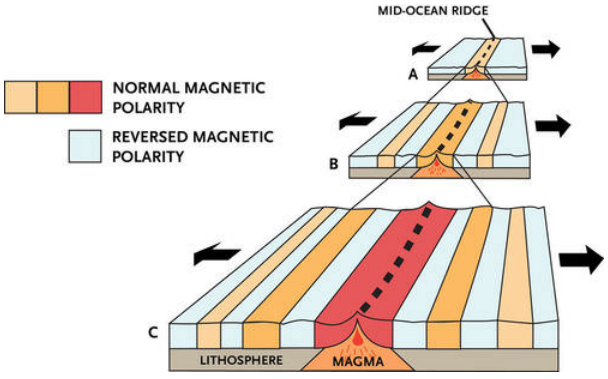
Warships also carried magnetometers. Like the echo sounders, the magnetometers were used to search for submarines. The magnetometers also revealed a lot about the magnetic properties of the seafloor.

Polar Reversals

Looking at the magnetism of the seafloor, scientists discovered something astonishing. Many times in Earth's history, the magnetic poles have switched positions. North becomes south, and south becomes north! When the north and south poles are aligned as they are now, geologists say it is **normal polarity**. When they are in the opposite position, they say that it is **reversed polarity**.

Magnetic Stripes

Scientists were even more surprised to discover a pattern of magnetism on the seafloor. There are stripes with different magnetism. Some stripes have normal polarity and some have reversed polarity. These stripes surround the mid-ocean ridges. There is one long stripe with normal magnetism at the top of the ridge. Next to that stripe are two long stripes with reversed magnetism. One is on either side of the normal stripe. Next come two normal stripes and then two reversed stripes, and so on across the ocean floor. The magnetic stripes end abruptly at the edges of continents. Sometimes the stripes end at a deep sea trench (**Figure** below).



Scientists found that magnetic polarity in the seafloor was normal at mid-ocean ridges but reversed in symmetrical patterns away from the ridge center. This normal and reversed pattern continues across the seafloor.

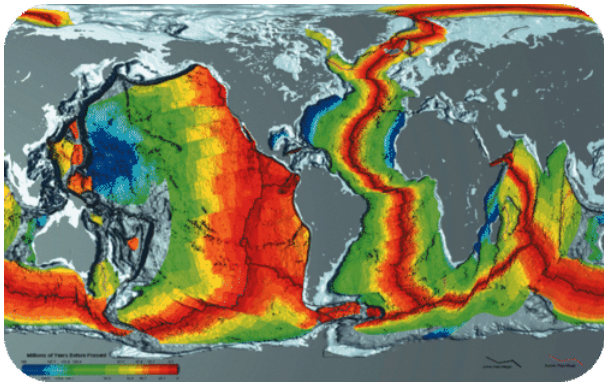
Magnetometers are still towed behind research ships. They continue to map the magnetism of the seafloor.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Seafloor Ages

Different seafloor magnetic stripes equal different ages. By using geologic dating techniques, scientists could figure out what these ages are. They found that the youngest rocks on the seafloor were at the mid-ocean ridges. The rocks get older with distance from the ridge crest. Scientists were surprised to find that the oldest seafloor is less than 180 million years old. This may seem old, but the oldest continental crust is around 4 billion years old.

Scientists discovered another way to tell the approximate age of seafloor rocks. The rocks at the mid-ocean ridge crest are nearly sediment free. The crust is also very thin there. With distance from the ridge crest, the sediments and crust get thicker. This also supports the idea that the youngest rocks are on the ridge axis, and that the rocks get older with distance away from the ridge (**Figure** below). This is because the crust is new at the ridge, and so it is thin and has no sediment. The crust gets older away from the ridge crest. It has cooled and has more sediment.



Seafloor is youngest near the mid-ocean ridges and gets progressively older with distance from the ridge. Orange areas show the youngest seafloor. The oldest seafloor is near the edges of continents or deep sea trenches.

This leads to an important idea: some process is creating seafloor at the ridge crest. Somehow the older seafloor is being destroyed. Finally, we get to the mechanism for continental drift.

Summary

- Data from magnetometers dragged behind ships looking for enemy submarines in WWII discovered amazing magnetic patterns on the seafloor.
- The magnetic pole reverses from time to time. The north pole becomes the south pole, and the south pole becomes the north pole.
- Rocks of normal and reversed polarity are found in stripes symmetrically about the mid-ocean ridge axis.
- The seafloor is youngest at the ridge crest and oldest far away from the ridge crest. The oldest seafloor rocks are about 180 million years, much younger than the oldest continental rocks.

Review

1. Describe how the magnetic stripe at the top of the mid-ocean ridge forms.
2. Describe the pattern the magnetic stripes make on the ocean floor.
3. How does magnetic polarity reveal the age of a piece of seafloor?
4. What is the pattern of seafloor age in the ocean basins?

This page titled 5.5: Magnetic Evidence for Seafloor Spreading is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.6: Seafloor Spreading Hypothesis



How do the continents move?

Harry Hess was a geology professor and a naval officer. He commanded an attack transport ship during WWII. Hess was intrigued by the seafloor maps produced with the ship's echo sounder. He thought about all of the evidence for continental drift. He thought about all of the unusual features of the seafloor. And he found the mechanism to explain them all.

The Evidence Comes Together

World War II allowed scientists to make some puzzling observations. The observations came from seafloor bathymetry and magnetism. These observations are:

- The seafloor of the Atlantic Ocean has a large mountain range running through it. Deep trenches are found far from the ridges. Guyots have eroded tops that are deep below sea level.
- The magnetic polarity of the seafloor changes. The center of the ridge is of normal polarity. Stripes of normal and reverse polarity are found symmetrical on both sides of the ridge.
- The youngest seafloor is at the ridge. The oldest is farthest from the ridge. The oldest seafloor is much younger than the oldest continent.

Scientists needed to explain these observations.

Mantle Convection

Not long after Wegener's death, scientists recognized that there is convection in the mantle. Deeper material is hotter and so it rises. Near the surface, it becomes cooler and denser so it sinks. This creates a **convection cell** in the mantle.

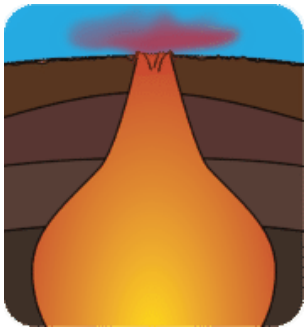
Seafloor Spreading

After the war, Harry Hess put together the ideas and evidence he needed. Hess resurrected Wegener's continental drift hypothesis. He reviewed the mantle convection idea. He thought about the bathymetric features and the patterns of magnetic polarity on the seafloor. In 1962, Hess published a new idea that he called **seafloor spreading**.

Hess wrote that hot magma rises up into the rift valley at the mid-ocean ridges. The lava cools to form new seafloor. Later more lava erupts at the ridge. The new lava pushes the seafloor horizontally away from the ridge axis (**Figure** below). The seafloor moves!

Magnetite crystals in the lava point in the direction of the magnetic north pole. The different stripes of magnetic polarity reveal the different ages of the seafloor.

In some places, the oceanic crust comes up to a continent. The moving crust pushes that continent away from the ridge axis as well. If the moving oceanic crust reaches a deep sea trench, the crust sinks into the mantle. The creation and destruction of oceanic crust is the reason that continents move.



Magma at the mid-ocean ridge creates new seafloor.

- As oceanic crust moves away from the ridge crest, it pushes a continent away from the ridge axis.
- If the oceanic crust reaches a deep sea trench, it sinks into the trench.
- The oldest crust is coldest and lies deepest in the ocean.

The flat topped guyots were once active volcanoes that were above sea level. They were eroded at their tops. As the seafloor moved away from the ridge, the crust sank deeper. The tops of the guyots went below sea level.

The Mechanism for Continental Drift

Seafloor spreading is the mechanism that Wegener was looking for! Convection currents within the mantle drive the continents. The continents are pushed by oceanic crust, like they are on a conveyor belt. Over millions of years the continents move around the planet's surface. The spreading plate takes along any continent that rides on it.



Summary

- Seafloor spreading is a mixture different ideas and data. Continental drift and mantle convection are supported by bathymetric and magnetic data from the seafloor.
- Harry Hess called his idea "an essay in geopoetry." This could be because so many ideas fit together so well. It could also be because, at the time, he didn't have all the seafloor data he needed for evidence.
- Seafloor spreading is the mechanism for the drifting continents.

Review

1. How does the pattern of magnetic stripes give evidence for seafloor spreading?
2. How does the topography of the seafloor give evidence for seafloor spreading?
3. How does seafloor spreading fit into the idea that continents move about on Earth's surface?

This page titled 5.6: Seafloor Spreading Hypothesis is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.7: Plate Tectonics- Challenge 1

1. Historically, ___ covered most of the earth, but today they form only on land and near the poles.

glaciers

2. ___ of prehistoric organisms have been found on widely separated continents, suggesting that these organisms once lived in the same regions or could travel between them easily.

Fossils

3. The Theory of Continental Drift states that ___.

the earth's crust consists of several different continental plates that are constantly moving.

4. Scientists rejected Wegener's theory, because ___.

no plausible mechanism to explain continental movement was known

5. Alfred Wegener died in ___ on an expedition to ___.

1930; the Greenland icecap

6. Magnetic crystals in older rocks of the same age on the same continent point to ___.

the same point, but not the current magnetic pole

7. What line of evidence made scientists realize that Wegener was right about continental drift?

Apparent polar wander

8. ___ crystallizes from fluid lava and points to the north magnetic pole as the lava cools.

Magnetite

9. Flat-topped mountains in the ocean are known as ___.

guyots

10. Who proposed the theory of seafloor spreading in the early 1960s?

Harry Hess

This page titled 5.7: Plate Tectonics- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.8: Earth's Tectonic Plates



What do you get when you combine continental drift and seafloor spreading?

Plate tectonics! In the next two concepts, we will analyze those words. What is a plate? What is tectonics? Then we put it together. Alfred Wegener, who died on the Greenland ice sheet at the age of 50, didn't live to see his work develop into plate tectonic theory.

What is a Plate?

Which portions of Earth make up the “plates” in plate tectonics? Again, the answer came about in part due to war. In this case, the Cold War. The scientists set up seismometer networks during the 1950s and early 1960s. The purpose was to see if other nations were testing atomic bombs. Since **seismometers** measure ground shaking, they also recorded earthquakes.

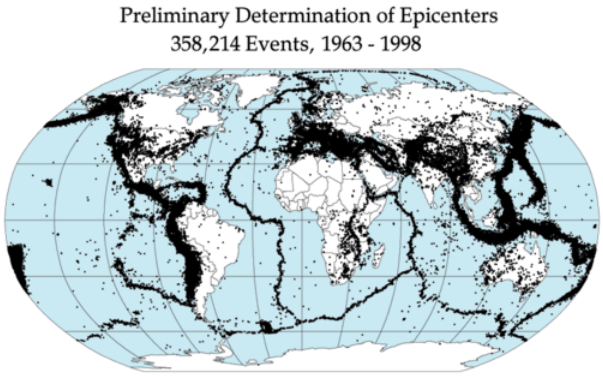
Using Earthquakes

The seismographs located earthquake epicenters. The **epicenter** is the point on Earth’s surface directly above the place where an earthquake occurs.

When earthquake epicenters are put on a map, they outline the **plates**. This is because earthquakes originate where plates come into contact with each other. Earthquakes are found primarily in lines around the edges of some continents. They are also found through the centers of some oceans. Some occur in patches in some land areas.

Lithospheric Plates

If you look at the map pictured below, you will see that the lithosphere is divided into plates (**Figure** below). There are a dozen major and several minor plates. Each plate is named for the continent or ocean basin it contains. Some plates are made entirely of oceanic lithosphere. A few are continental lithosphere only. But most plates are made of a combination of both. Notice the locations where the most earthquake epicenters are found.



A map of earthquake epicenters. The outlines of the lithospheric plates can be seen.

Plates of lithosphere sink into the asthenosphere. The asthenosphere, which is part of the upper mantle, is solid but can flow. If a weight is added to a plate, like a glacier, the plate will sink into the mantle. If the weight is taken away, like when the glacier melts, the plate will rise. This happens slowly over long periods of time.

Summary

- A plate is a large chunk of lithosphere. There are a dozen major plates and several minor plates.
- A plate can carry continental crust, oceanic crust, or some of each.
- Plates can be identified by the locations of earthquake epicenters.

Review

1. How did scientists draw boundaries around the plates?
2. What is a plate?
3. What is a plate made of?

This page titled 5.8: Earth's Tectonic Plates is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.9: Tectonic Plate Motions



What is tectonics?

Dividing the lithosphere into plates is one thing. Having the plates move around on the planet is another! A conveyor belt is a good analogy for how a plate moves. How the plates move and where they move is the "tectonics" part of plate tectonics.

Plate Motions

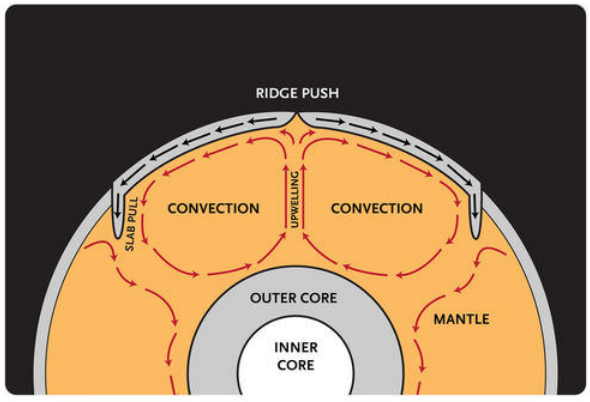
Scientists have determined the direction that each plate is moving (**Figure** below). Plates move around the Earth's surface at a rate of a few centimeters a year. This is about the same rate that fingernails grow.



Earth's plates are shown in different colors. Arrows show the direction the plate is moving.

How Plates Move

Convection within the Earth's mantle causes the plates to move. Mantle material is heated above the core. The hot mantle rises up toward the surface (**Figure** below). As the mantle rises, it cools. At the surface, the material moves horizontally away from a mid-ocean ridge crest. The material continues to cool. It sinks back down into the mantle at a deep sea trench. The material sinks back down to the core. It moves horizontally again, completing a **convection cell**.



https://k12.libretexts.org/@go/page/5387

Plates move for two reasons. Upwelling mantle at the mid-ocean ridge pushes plates outward. Cold lithosphere sinking into the mantle at a subduction zone pulls the rest of the plate down with it.

Seafloor spreading takes place as plates move apart from each other at a mid-ocean ridge. Mantle convection drives seafloor spreading.

Summary

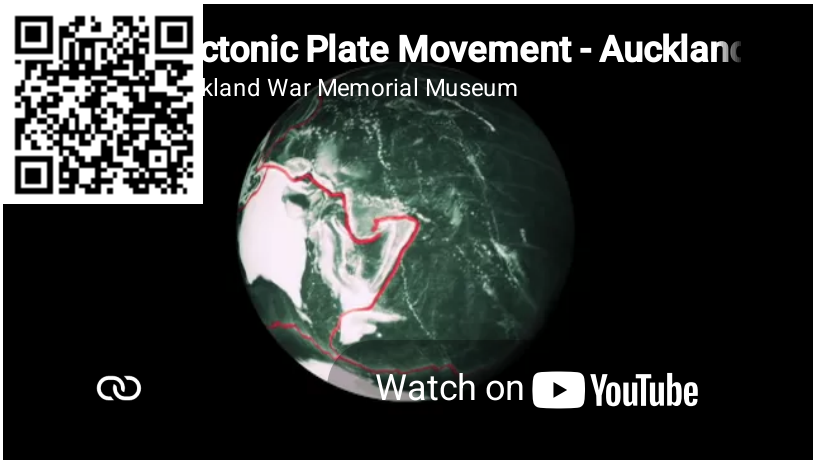
- Plates move by seafloor spreading
- Seafloor spreading is driven by mantle convection.
- Plates move as if on a conveyor belt.

Review

1. Describe how convection takes place in the mantle.
2. How does mantle convection cause seafloor spreading?
3. How does seafloor spreading move plates?

Explore More

Use the resource below to answer the questions that follow.



1. What would the Earth look like without the biosphere and atmosphere?
2. What are plates?
3. How fast are the plates moving?
4. What happens at the ridges?
5. What are subduction zones?
6. What heats Earth's interior?

This page titled 5.9: Tectonic Plate Motions is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.10: Theory of Plate Tectonics



What would Wegener think?

Like any great theory, plate tectonics makes a tremendous amount of sense. The whole story fits together so perfectly. Wegener had so much evidence that the continents had once been joined. Seafloor spreading is a perfect mechanism for moving those continents. It's really too bad that Alfred Wegener is not here to learn about the theory of plate tectonics. It seems certain that he would be ecstatic!

Plate Tectonics Theory

The theory of plate tectonics is what brings together continental drift and seafloor spreading. Plates are made of lithosphere topped with oceanic and/or continental crust. The plates are moved around on Earth's surface by seafloor spreading. Convection in the mantle drives seafloor spreading. Oceanic crust is created at mid-ocean ridges. The crust moves outward from the ridge over time. The crust may eventually sink into the mantle and be destroyed. If a continent sits on a plate with a mid-ocean ridge, the continent will be pushed along.

Plate Boundaries

Two plates meet at a **plate boundary**. There are three types of plate boundaries since there are three ways that plates can meet. Plates can move away from each other. They can move toward each other. Finally, they can slide past each other. The three types of plate boundaries are divergent, convergent, and transform. They are described in the following three concepts.

Most geological activity takes place at plate boundaries. This activity includes volcanoes, earthquakes, and mountain building. The activity occurs as plates interact. Giant slabs of lithosphere moving around can create a lot of activity! The features seen at a plate boundary are determined by the direction of plate motion and by the type of crust found at the boundary.

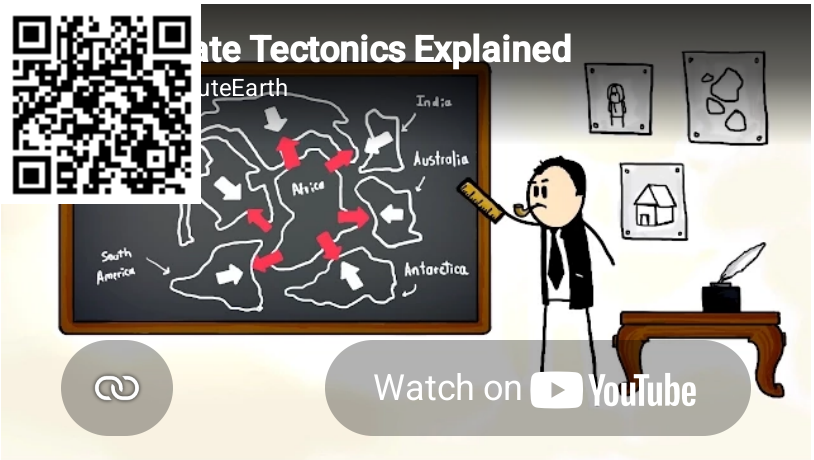
What The Theory Explains

The theory of plate tectonics explains most of the features of Earth’s surface. It explains why earthquakes, volcanoes and mountain ranges are where they are. It explains where to find some mineral resources. Plate tectonics is the key that unlocks many of the mysteries of our amazing planet. Plate tectonics theory explains why:

- Earth's geography has changed over time and continues to change today.
- some places are prone to earthquakes while others are not.
- certain regions may have deadly, mild, or no volcanic eruptions.
- mountain ranges are located where they are.
- many ore deposits are located where they are.
- living and fossil species of plants and animals are found where they are.
- some continental margins have a lot of geological activity, and some have none.

Plate tectonic motions affect Earth’s rock cycle, climate, and the evolution of life.

cK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



Summary

- The theory of plate tectonics brings together continental drift and seafloor spreading.
- At a plate boundary, two plates can be moving apart, together or past each other.
- Plate tectonics theory explains many things in geology, such as where volcanoes, earthquakes, mountain ranges, ore deposits, and other features are located.

Review

1. What is a plate boundary?
2. What three interactions can plates have? These are the three major types of plate boundaries.
3. In general, what does the theory of plate tectonics explain?

This page titled 5.10: Theory of Plate Tectonics is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.11: Divergent Plate Boundaries in the Ocean





Why a photo of a bridge with some bleak looking rock?

In Iceland, the Mid-Atlantic Ridge is above sea level. It's the only place we can see a mid-ocean ridge out of the water. The Midlina Bridge connects two plates. On the west side is the North American plate. On the east side is the Eurasian plate. A mid-ocean ridge is where new crust is created. Eventually this spot will be beneath the Atlantic Ocean.

Divergent Plate Boundaries

Plates move apart at **divergent plate boundaries**. In oceans, this happens at mid-ocean ridges -- on land, at continental rift zones.

Mid-ocean Ridges

In the oceans, plates move apart at mid-ocean ridges. Lava rises upward, erupts, and cools. Later, more lava erupts and pushes the original seafloor outward. This is seafloor spreading. Seafloor spreading forms new oceanic crust. The rising magma causes the ridge to be buoyant. This is why there are mountain ranges running through the oceans. The plates pulling apart cause earthquakes.

Most mid-ocean ridges are located deep below the sea. The island of Iceland sits right on the Mid-Atlantic ridge (**Figure** below).



The rift valley in Iceland that is part of the Mid-Atlantic Ridge.

Continental Rifting

A divergent plate boundary can also occur on a continent. This is called **continental rifting**. Magma rises beneath the continent. The crust thins, breaks, and then splits apart. This first produces a rift valley. The East African Rift is a rift valley. Eastern Africa is splitting away from the African continent. Eventually, as the continental crust breaks apart, oceanic crust will form. This is how the Atlantic Ocean formed when Pangaea broke up.

Summary

- Divergent plate boundaries in the ocean create mid-ocean ridges. This is where new seafloor is created by upwelling magma.
- Divergent plate boundaries rift a continent apart. Eventually a new ocean will form between the two continents.
- Iceland is a location where we can see a mid-ocean ridge above sea level.

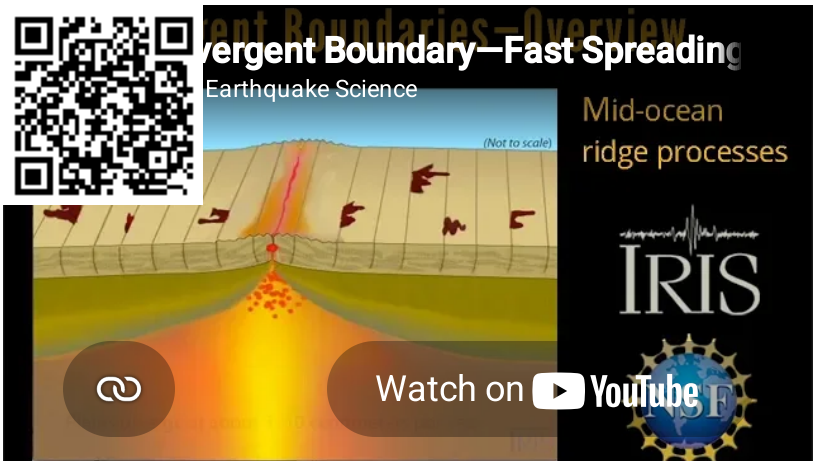
CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

Review

1. In what direction are the plates moving at a divergent plate boundary?
2. How does a convection cell in the mantle lead to volcanism at the mid-ocean ridge?
3. How does a continent break apart to form an ocean basin?

Explore More

Use the resource below to answer the questions that follow.



1. What causes divergence?
2. How is new crust created?
3. What erupts on the ocean floor?
4. How fast does divergence occur?
5. What is formed at a divergent boundary?

This page titled 5.11: Divergent Plate Boundaries in the Ocean is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.12: Divergent Plate Boundaries



What can we see in Western North America?

Many locations in western North America are being rifted apart. One such location is the Rio Grande Rift in Texas. At this location, hot mantle rises up beneath the crust to cause the divergence.

Tectonic Features of Western North America

Western North America has all three of the different types of plate boundaries and the features that are seen at them. A divergent plate boundary runs through the Gulf of California in Mexico. The divergence is pulling Baja California and mainland Mexico apart. Just north of there, around the US-Mexico border, in California, there is a transform boundary. Plates on both sides of the plate boundary are sliding past each other. Still further north, in the Pacific Northwest, a subduction zone just offshore is part of a convergent plate boundary.

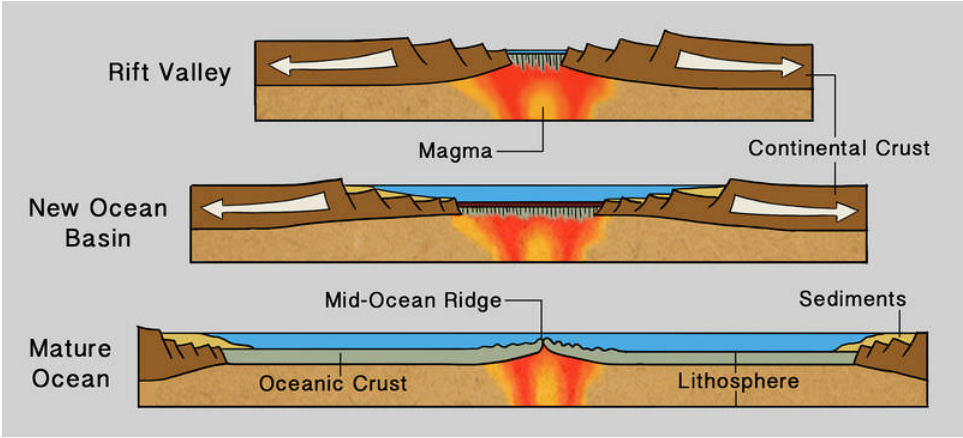


This map shows the three major plate boundaries in or near California.

In the **Figure** above a red bar where seafloor spreading is taking place. A long, black line is a transform fault and a black line with hatch marks is a trench where subduction is taking place. Notice how one type of plate boundary transitions into another.

Plate Divergence on Land

A divergent plate boundary on land rips continents apart (**Figure** below).



When plate divergence occurs on land, the continental crust rifts, or splits. This effectively creates a new ocean basin as the pieces of the continent move apart.

In **continental rifting**, magma rises beneath the continent, causing it to become thinner, break, and ultimately split apart. New ocean crust erupts in the void, ultimately creating an ocean between continents. On either side of the ocean are now two different lithospheric plates. This is how continents split apart.

These features are well displayed in the East African Rift, where rifting has begun, and in the Red Sea, where water is filling up the basin created by seafloor spreading. The Atlantic Ocean is the final stage, where rifting is now separating two plates of oceanic crust.

Baja California



Baja California is rifting apart from mainland Mexico, as seen in this satellite image.

Baja California is a state in Mexico just south of California. In the **Figure** above, Baja California is the long, skinny land mass on the left. You can see that the Pacific Ocean is growing in between Baja California and mainland Mexico. This body of water is called the Gulf of California or, more romantically, the Sea of Cortez. Baja is on the Pacific Plate and the rest of Mexico is on the North American Plate. Extension is causing the two plates to move apart and will eventually break Baja and the westernmost part of California off of North America. The Gulf of California will expand into a larger sea.



Volcanism in Baja California is evidence of rifting.

Rifting has caused volcanic activity on the Baja California peninsula as seen in the **Figure** above.

Can you relate what is happening at this plate boundary to what happened when Pangaea broke apart?

Summary

- Where continental rifting takes place, continents are split apart and an ocean may grow or be created between the two new plates.
- Baja California is rifting apart from mainland Mexico.
- Continental rifting can create major ocean basins, like the Atlantic.

Review

1. How is a divergent plate boundary on land different from one in the ocean?
2. What is happening to the Baja California peninsula?
3. How did continental rifting play into the breakup of Pangaea?

This page titled 5.12: Divergent Plate Boundaries is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.13: Transform Plate Boundaries



What does a transform plate boundary look like?

In the dry part of central California, it looks like this. On one side is the Pacific Plate. On the other side is the North American Plate. Before plate tectonics theory, people thought the San Andreas was just a fault. Now it's known to be a plate boundary!

Transform Plate Boundaries

Two plates may slide past each other in opposite directions. This is called a **transform plate boundary**. The plates meet at a **transform fault**. As you might imagine, plates do not slide past each other easily. These plate boundaries experience massive earthquakes. The world's best known transform fault is the San Andreas Fault in California (**Figure** below). At this fault, the Pacific and North American plates grind past each other. Transform plate boundaries are common as offsets along mid-ocean ridges. They are very small compared to transform faults on land.

Transform plate boundaries are different from the other two types of plate boundaries. At divergent plate boundaries, new oceanic crust is formed. At convergent boundaries, old oceanic crust is destroyed. But at transform plate boundaries, crust is neither created nor destroyed.



The red line is the San Andreas Fault. On the left is the Pacific Plate, which is moving northeast. On the right is the North American Plate, which is moving southwest. The movement of the plates is relative to each other.



Summary

- At transform plate boundaries, two plates move in opposite direction.
- Transform faults are the site of massive earthquakes.
- The San Andreas Fault is the boundary between the Pacific and North American plates. It is the site of massive earthquakes.

Review

1. What is the direction of plate motion at a transform plate boundary?
2. Why are transform faults prone to massive earthquakes?
3. Why are earthquakes at the San Andreas Fault so large?

This page titled 5.13: Transform Plate Boundaries is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.14: Plate Tectonics- Challenge 2

1. ___ is the artificial process by which salt water is converted to fresh water.

Desalination

2. Where are the oldest oceanic rocks found?

Far from mid-ocean ridges

3. Seafloor spreading occurs at ___ boundaries.

divergent

4. When material in the mantle is heated at Earth's core, it rises towards Earth's surface. As it rises, it cools, moves laterally, becomes denser, and sinks, creating a ___ cell.

convection

5. ___ within the earth's mantle causes the plates to move.

Convection

6. Seafloor spreading pushes older seafloor outward, and new seafloor is created at a ___.

mid-ocean ridge

7. Two tectonic plates come together at a plate ___.

boundary

8. In which layer of Earth are plate-moving convection currents located?

Mantle

9. What are the three types of major plate boundaries?

Divergent, transform, and convergent plate boundaries

10. ___ is an example of a transform boundary.

The San Andreas Fault

11. Transform plate boundaries divide ___ into segments.

mid-ocean ridges

This page titled 5.14: Plate Tectonics- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.15: Ocean-Continent Convergent Plates



What do you see when oceanic lithosphere subducts?

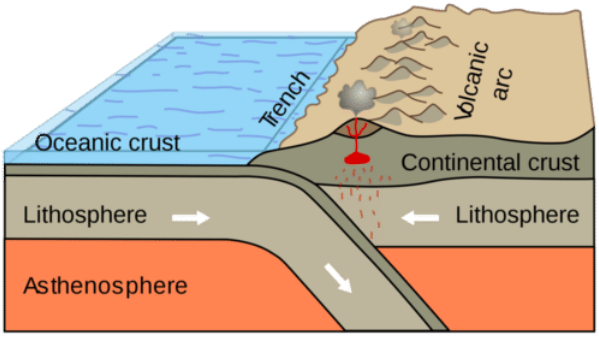
At a convergent plate boundary, when one plate is oceanic, there are large volcanoes. These volcanoes are found in lines that outline the subduction zone. Earthquakes also happen in these zones. The Aleutian Islands that border southern Alaska are an island arc. In this winter image from space, the volcanoes are covered with snow.

Convergent Plate Boundaries

A **convergent plate boundary** forms where two plates collide. That collision can happen between a continent and oceanic crust, between two oceanic plates, or between two continents. Oceanic crust is always destroyed in these collisions.

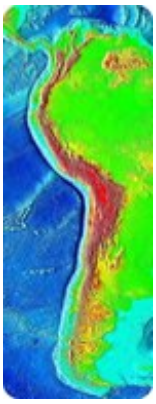
Ocean-Continent Convergence

Oceanic crust may collide with a continent. The oceanic plate is denser, so it undergoes **subduction**. This means that the oceanic plate sinks beneath the continent. This occurs at an ocean trench (**Figure** below). **Subduction zones** are where subduction takes place.



Subduction of an oceanic plate beneath a continental plate forms a line of volcanoes known as a continental arc and causes earthquakes.

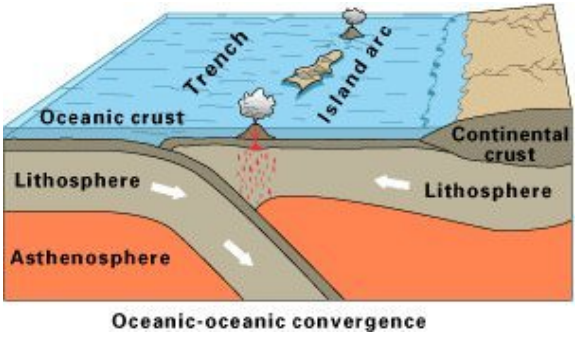
As you would expect, where plates collide there are lots of intense earthquakes and volcanic eruptions. The subducting oceanic plate melts as it reenters the mantle. The magma rises and erupts. This creates a volcanic mountain range near the coast of the continent. This range is called a **continental arc**. The Andes Mountains, along the western edge of South America, are a volcanic arc (**Figure** below).



A relief map of South America shows the trench west of the continent. The Andes Mountains line the western edge of South America.

Ocean-Ocean Convergence

Two oceanic plates may collide. In this case, the older plate is denser. This plate subducts beneath the younger plate. As the subducting plate is pushed deeper into the mantle, it melts. The magma this creates rises and erupts. This forms a line of volcanoes, known as an **island arc** (**Figure** below). Japan, Indonesia, the Philippine Islands, and the Aleutian Islands of Alaska are examples of island arcs (**Figure** below).



Oceanic-oceanic convergence

A convergent plate boundary subduction zone between two plates of oceanic lithosphere. Melting of the subducting plate causes volcanic activity and earthquakes.



https://k12.libretexts.org/@go/page/5393

The country of Japan is an island arc that lies at the intersection of the North American, Filipino, and Eurasian plates. Colors in this picture indicate elevation.



Summary

- When two plates come toward each other, they create a convergent plate boundary.
- If at least one plate is oceanic, there will be subduction.
- Subduction of a plate leads to melting and volcanism.
- An island arc is a line of volcanoes on an oceanic plate. A continental arc is a line of volcanoes on a continental plate.

Review

1. What is the direction of plate motion at a convergent plate boundary?
2. What creates an island arc?
3. How is a continental arc different from an island arc?

This page titled 5.15: Ocean-Continent Convergent Plates is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.16: Ocean-Ocean Convergent Plate Boundaries



What do you see in this satellite photo?

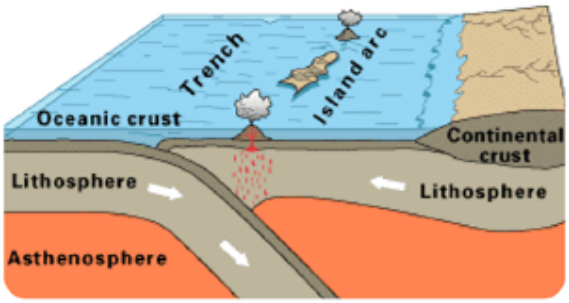
We continue our trip up western North America to find a convergent plate boundary where oceanic crust subducts beneath oceanic crust. North of the contiguous U.S. lies Canada, and north of Canada lies Alaska. A line of volcanoes, known as the Aleutian Islands, is the result of ocean-ocean convergence. In this satellite image is an erupting volcano, topped by snow or ice, and surrounded by seawater - a member of the Aleutian chain. Let's take a look at this boundary and the volcanic arc.

Convergent Plate Boundaries

When two plates converge, what happens depends on the types of lithosphere that meet. We explored what happens when oceanic crust meets continental crust. Another type of convergent plate boundary is found where two oceanic plates meet. In this case the older, denser slab of oceanic crust will plunge beneath the less dense one.

Ocean-Ocean

The features of a subduction zone where an oceanic plate subducts beneath another oceanic plate are the same as a continent-ocean subduction zone. An ocean trench marks the location where the plate is pushed down into the mantle. In this case, the line of volcanoes that grows on the upper oceanic plate is an **island arc**. Do you think earthquakes are common in these regions (**Figure** below)?



Oceanic-oceanic convergence

Subduction of an ocean plate beneath other oceanic crust results in a volcanic island arc, an ocean trench, and many earthquakes

In the north Pacific, the Pacific Plate is subducting beneath the North American Plate just as it was off of the coast of the Pacific Northwest. The difference is that here the North American plate is covered with oceanic crust. Remember that most plates are made of different types of crust. This subduction creates the Aleutian Islands, many of which are currently active (see **Figure** below). Airplanes sometimes must avoid flying over these volcanoes for fear of being caught in an eruption.



These North Pacific air routes carry more than 20,000 people and millions of dollars in cargo every day.

The island arc that is the Aleutian Islands is easily seen in this map of North Pacific air routes over the region.

Summary

- If the two plates that meet at a convergent plate boundary both are of oceanic crust, the older, denser plate will subduct beneath the less dense plate.
- The features of an ocean-ocean subduction zone are the same as those of an ocean-continent subduction zone, except that the volcanic arc will be a set of islands known as an island arc.
- The older plate subducts into a trench, resulting in earthquakes. Melting of mantle material creates volcanoes at the subduction zone.

Review

1. Compare and contrast the features of an ocean-ocean convergent plate boundary with the features of an ocean-continent convergent plate boundary.
2. How do the Aleutian volcanoes differ from the Cascades volcanoes?
3. How do island arcs get their name?

This page titled 5.16: Ocean-Ocean Convergent Plate Boundaries is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.17: Continent-Continent Convergent Plate Boundaries

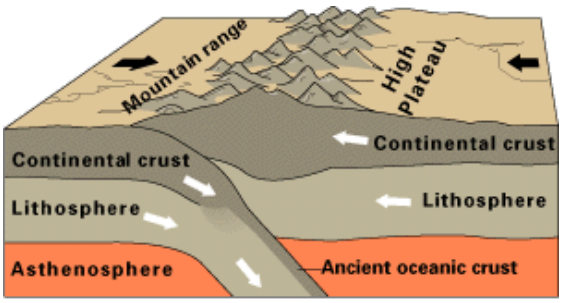


What do you see at a continent-continent convergent plate boundary?

Big mountains! The best place to see two continental plates converging is in the Himalayas. These mountains are the highest above sea level on Earth. They are very popular with mountain climbers.

Continent-Continent Convergence

Another type of **convergent plate boundary** is when two continental plates collide. Continental lithosphere is low in density and very thick. Continental lithosphere cannot subduct. So when two continental plates collide, they just smash together. This is just like what happens if you put your hands on two sides of a sheet of paper and bring your hands together. The material has nowhere to go but up (**Figure** below)! Earthquakes and metamorphic rocks result from the tremendous forces of the collision. But the crust is too thick for magma to get through. As a result, there are no volcanoes at continent-continent collision zones.



Continental-continental convergence

When two plates of continental crust collide, the material pushes upward. This forms a high mountain range. The remnants of subducted oceanic crust remain beneath the continental convergence zone.

Mountain Building

Continent-continent convergence creates some of the world's largest mountains ranges. The Himalayas (**Figure** below) are the world's tallest mountains. They form as two continents collide. The Appalachian Mountains are the remnants of a larger mountain range. This range formed from continent-continent collisions in the time of Pangaea.



The Karakoram Range is part of the Himalayas. K2, pictured here, is over 20,000 feet high. The number of mountains this tall in the Himalayas is impressive.

Further Reading

Continental Margins

Supercontinent Cycle and Pangaea

Summary

- Continental crust is too buoyant to subduct.
- When two continental plates converge, they smash together and create mountains.
- The amazing Himalaya Mountains are the result of this type of convergent plate boundary.
- The Appalachian Mountains resulted from ancient convergence when Pangaea came together.

Review

1. Compare and contrast these two types of convergent plate boundaries: (1) continent-continent, and (2) ocean-continent.
2. What causes mountain ranges to rise at convergent plate boundaries?
3. How did the Appalachian Mountains form?

Explore More

Use the resource below to answer the questions that follow.

1. What two types of plates come together at continent-continent convergent plate boundaries?
2. Which plate sinks into the mantle? What is the result of this?
3. What are two examples of this type of plate boundary?
4. At what type of plate boundary are the highest peaks on Earth located?

5. Where is the continental crust thickest on Earth?

This page titled 5.17: Continent-Continent Convergent Plate Boundaries is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.18: Continental Margins

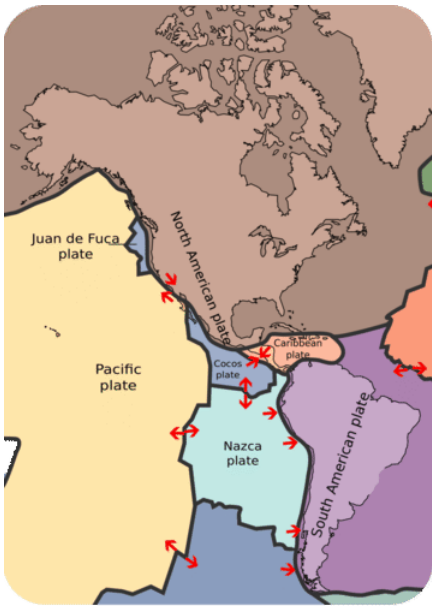


Can plate tectonics explain the differences in these beaches?

Plate tectonics explains why some beaches have lots of cliffs and some do not. A beach with lots of cliffs is near a plate boundary. A gentle beach is not. There are exceptions to this rule, but it works in some cases.

Continental Margins

Think of a continent, like North America. Surrounding the continent are **continental margins**. Continental crust grades into oceanic crust at continental margins. Continental margins are under water. Almost all of North America sits on the North American Plate (**Figure** below). Both sides of the continent have continental margins, but each is very different. One continental margin of North America is an active margin. The other is a passive margin. Can you guess which is which?



The North American plate and the plates that surround it.

Active Margins

If a continental margin is near a plate boundary, it is an **active margin**. The continental margin of western North America is near a set of plate boundaries. There are convergent boundaries, like where there is subduction off of the Pacific Northwest. There is a transform boundary, the San Andreas Fault. The small amount of the North American continent that is not on the North American Plate is across the San Andreas Fault. It is on the Pacific Plate. Western North America has a lot of volcanoes and earthquakes. Mountains line the region. California, with its volcanoes and earthquakes, is an important part of this active margin (**Figure** below).



Big Sur, in central California, has beautiful cliff-lined beaches.

Passive Margins

There are no volcanoes and very few earthquakes on the eastern edge of North America. The continental margin is a smooth transition from continental to oceanic lithosphere. The continental margin there becomes oceanic lithosphere, but both are on the North American Plate. There is no plate boundary. The far eastern edge of the North American Plate is the mid-Atlantic Ridge. The portion of a plate that does not meet another plate has no geological activity. It is called a **passive margin** (**Figure** below).



The eastern U.S. is a passive margin. Daytona Beach in Florida is flat and sandy, typical of a passive margin.



Summary

- Continental margins can be active or passive depending on whether they are near a plate boundary.
- Volcanoes and earthquakes are common at active margins. Active margins are near plate boundaries.
- Passive margins are passive. They have little or no geological activity.

Review

1. Describe the continental margin of Western North America.
2. Describe the continental margin of Eastern North America.
3. Why are there mountain ranges at passive margins?

This page titled 5.18: Continental Margins is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.19: Supercontinent Cycle and Pangaea



Is this Earth?

The existence of Wegener's supercontinent Pangaea is completely accepted by geologists today. The movements of continents explain so much about the geological activity we see. But did it all begin with Pangaea? Or were there other supercontinents that came before? What does the future of the continents hold?

Pangaea

Wegener had lots of evidence for his continental drift hypothesis. One line of evidence was the similarity of the mountains on the west and east sides of the Atlantic. Those mountains rose at convergent plate boundaries. The continents on both sides of the ocean (where the Atlantic is now) smashed together to create Pangaea. The proto-Atlantic ocean shrank as the Pacific Ocean grew.

The Appalachian mountains of eastern North America formed at this convergent plate boundary (**Figure** below). About 200 million years ago, they were probably as high as the Himalayas.



The Appalachian Mountains in New Hampshire.

Pangaea has been breaking apart since about 250 million years ago. Divergent plate boundaries formed within the continents to cause them to rift apart. The continents are still moving apart. The Pacific is shrinking as the Atlantic is growing. The Appalachians (**Figure** below) are now on a passive margin. The mighty mountains have weathered and eroded to what they are today.

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



The Appalachians along the eastern U.S. These mountains formed when North America and Eurasia collided as Pangaea came together.

The Supercontinent Cycle

Back before Pangaea, there were earlier supercontinents. Rodinia existed 750 million to 1.1 billion years ago. Columbia existed 1.5 to 1.8 billion years ago. If the continents continue in their current directions, they will come together to create a supercontinent on the other side of the planet in around 200 million years.

This is known as the **supercontinent cycle**. The continents smash together on opposite side of the planet around every 500 million years. The creation of supercontinents is responsible for most of the geologic features that we see. It is responsible for many features that are long gone.

Summary

- Pangaea came together as a set of continent-continent convergent plate boundaries.
- Pangaea is still breaking up as the continents move apart. The Atlantic Ocean is getting bigger, and the Pacific Ocean is getting smaller.
- The continents come together and break apart about every 500 million years. This is called the supercontinent cycle.

Review

1. Describe the plate tectonics processes that brought Pangaea together.
2. Describe the plate tectonics processes that split Pangaea up.
3. Why do scientists think that there will be another supercontinent in the future?

Explore More

Use the resource below to answer the questions that follow.



1. How did the continents form?
2. When did the continents get their current shape?
3. Describe how North America will look 100 million years from now.
4. What will happen to Africa in the future?

This page titled 5.19: Supercontinent Cycle and Pangaea is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.20: Intraplate Activity



Why does some geological activity take place away from plate boundaries?

The geological activity in these photos is not occurring at plate boundaries. Is plate tectonics wrong? Of course not! This activity can also be explained. It's the result of hotspots. Two hotspot locations are Hawaii and Yellowstone.

Intraplate Activity

Most geological activity takes place at plate boundaries. But some activity does not. Much of this **intraplate activity** is found at hot spots. **Hotspots** are plumes of hot material that rise through the mantle. Hotspot volcanoes erupt when the hot material melts to create magma.

Many hotspots appear to be fixed in the mantle. This means that they do not move relative to each other. Plates move above the hotspots, but the hotspots stay in the same spot. This feature is a very useful tool for scientists.

Hotspots in the Oceans

A chain of volcanoes form as an oceanic plate moves over a hotspot. This is how it happens. A volcano forms over the hotspot. Since the plate is moving, the volcano moves off of the hotspot. When the hotspot erupts again, a new volcano forms over it. This volcano is next to the first. Over time, there is a line of volcanoes. The youngest is directly above the hotspot. The oldest is the farthest away (**Figure** below).

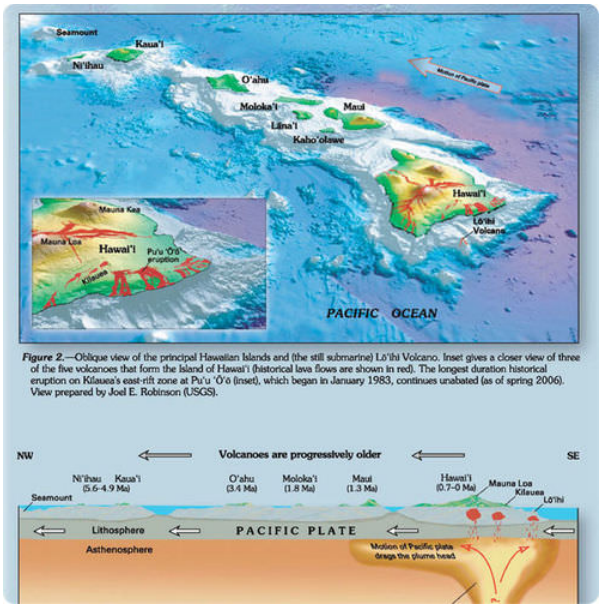


Figure 2.—Oblique view of the principal Hawaiian Islands and (the still submarine) Lō'ihi Volcano. Inset gives a closer view of three of the five volcanoes that form the Island of Hawai'i (historical lava flows are shown in red). The longest duration historical eruption on Kilauea's east-rift zone at Pu'u 'O'o (inset), which began in January 1983, continues unabated (as of spring 2006). View prepared by Joel E. Robinson (USGS).

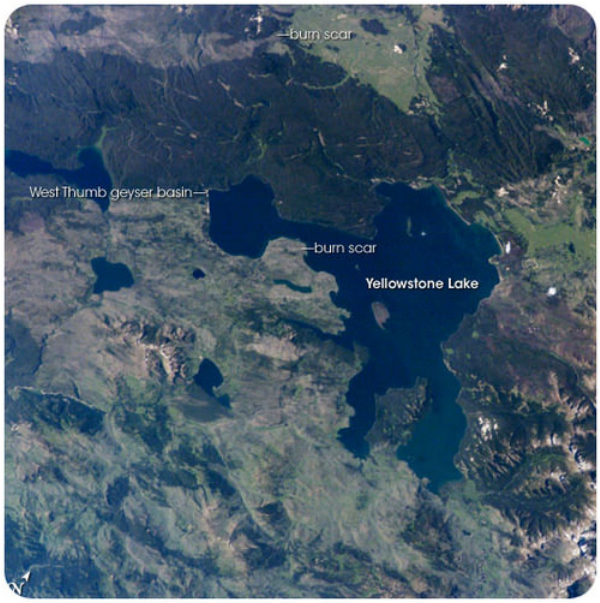
This view of the Hawaiian islands shows the youngest islands in the southeast and the oldest in the northwest. Kilauea volcano, which makes up the southeastern side of the Big Island of Hawaii, is located above the Hawaiian hotspot.

The Hawaii-Emperor chain of volcanoes formed over the Hawaiian Hotspot. The Hawaiian Islands formed most recently. Kilauea volcano is currently erupting. It is over the hotspot. The Emperor Seamounts are so old they no longer reach above sea level. The oldest existing of the Emperor Seamounts is about to subduct into the Aleutian trench off of Alaska. Older ones may already be in

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

the trench. Geologists can get age dates from the volcanic rocks that erupt at these hotspots. So they use hotspot chains to tell the direction and the speed a plate is moving.

Hotspots Beneath Continents



Yellowstone Lake lies at the center of a giant caldera. This hole in the ground was created by enormous eruptions at the Yellowstone hotspot. The hotspot lies beneath Yellowstone National Park.

Hotspots are also found under the continental crust. Since it is more difficult for magma to make it through the thick crust, they are much less common. One exception is the Yellowstone hotspot (**Figure** above). This hotspot is very active. In the past, the hotspot produced enormous volcanic eruptions. Now its activity is best seen in the region's famous geysers.



Summary

- Not all geological activity is found at plate boundaries. Activity within a plate is called intraplate activity. Most intraplate activity occurs at hotspots.
- Hotspot volcanoes erupt mostly on oceanic crust. A few hotspots erupt on continental crust. The difference is due to the thickness of the crust.

- Hotspots can be used to tell the speed and direction that a plate is moving.

Review

1. What is a hotspot?
2. How do scientists use hotspot volcanism to tell the direction and speed of a plate?
3. Compare and contrast hotspots in the oceans and on continents.

This page titled 5.20: Intraplate Activity is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

5.21: Plate Tectonics- Challenge 3

1. What happens when an oceanic plate and a continental plate converge?

The oceanic plate subducts beneath the continental plate.

2. Two lithospheric plates come together and one sinks beneath the other at a ___ zone.

subduction

3. Order the following events in the creation of an island arc: the subducting plate causes melting in the mantle above it (1); two oceanic plates converge (2); the magma finds a crack in the crust and fills a magma chamber beneath a volcano (3); the older, denser plate subducts into a trench (4)

2, 4, 1, 3

4. When two oceanic plates converge, an ___ is created.

island arc

5. The Himalayas and other mountain ranges are the result of the convergence of two ___ plates.

continental

6. When two continental plates converge, ___.

mountains grow upward

7. The tallest mountains on Earth are in the ___, which formed by two continental plates converging.

Himalayas

8. ___ is geologic activity that takes place away from plate boundaries.

Intraplate activity

9. What caused the bend in the Hawaii-Emperor volcanic chain?

The Pacific Plate changed its direction of motion.

10. Which volcano lies above the Hawaiian hotspot?

Kilauea

This page titled 5.21: Plate Tectonics- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

6: Geological Activity and Earthquakes

6.1: Geological Stresses
6.2: Principle of Horizontality
6.3: Folds
6.4: Faults
6.5: Mountain Building
6.6: Geological Activity and Earthquakes- Challenge 1
6.7: Earthquakes
6.8: Earthquake Zones
6.9: Earthquakes at Transform Plate Boundaries
6.10: Earthquakes at Convergent Plate Boundaries
6.11: Intraplate Earthquakes
6.12: Seismic Waves
6.13: Tsunami
6.14: 21st Century Tsunami
6.15: Geological Activity and Earthquakes- Challenge 2
6.16: Measuring Earthquake Magnitude
6.17: Locating Earthquake Epicenters
6.18: Earthquake Magnitude Scales
6.19: Predicting Earthquakes
6.20: Earthquake Damage
6.21: Earthquake Safe Structures
6.22: Staying Safe in an Earthquake
6.23: Geological Activity and Earthquakes- Challenge 3

This page titled 6: Geological Activity and Earthquakes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.1: Geological Stresses



When people have too much stress, they may break. What happens if a rock gets too much stress?

Lithospheric plates do a lot of moving on Earth's surface. Slabs of lithosphere smash into each other. They move sideways past each other along faults. Where conditions are right, magma rises through solid rock. It's no wonder that rocks experience stress! Rocks respond differently to different types of stress and under different conditions.

Types of Stress

Stress is the force applied to a rock. Plates experience stress when they collide, move apart, or slide past each other. Plates moving on a rounded surface experience stress. Stress happens to rocks on a smaller scale, too. Local movements can cause stress in rocks.

There are four types of stresses that affect rocks:

- **Confining stress** comes from the weight of all the overlying rock. This weight pushes down on a deeply buried rock. The rock is being pushed in from all sides, which compresses it. The rock will not deform because there is no place for it to move.
- **Compression** stress squeezes rocks together. Compression causes rocks to fold or fracture (**Figure** below). When two cars collide, compression causes them to crumple. Compression is the most common stress at convergent plate boundaries.



Stress caused these rocks to fold.

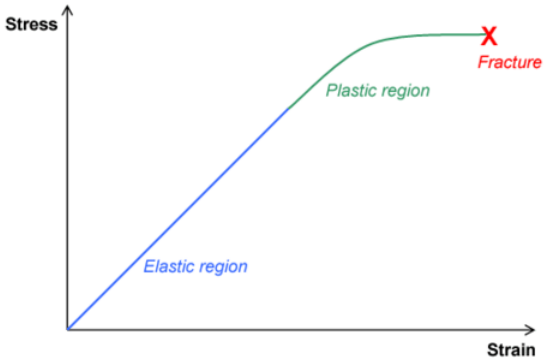
- **Tension** stress pulls rocks apart. Tension causes rocks to lengthen or break apart. Tension is the major type of stress found at divergent plate boundaries.
- **Shear** stress happens when forces slide past each other in opposite directions (**Figure** below). This is the most common stress found at transform plate boundaries.



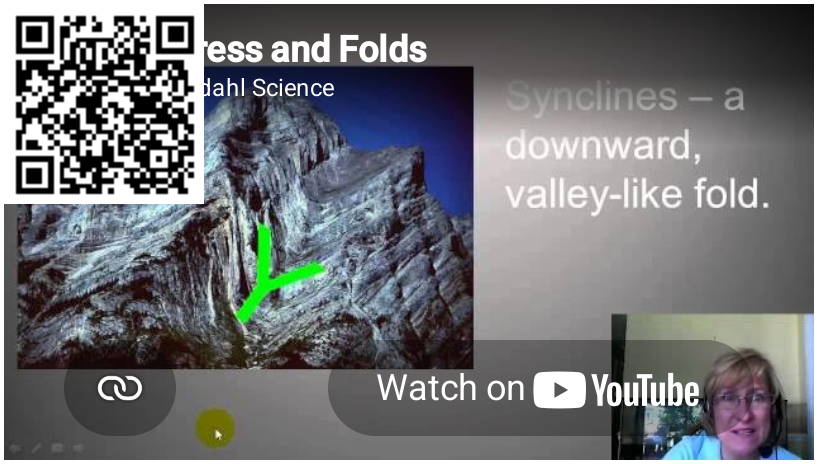
This rock has undergone shearing. The pencil is pointing to a line. Stresses forced rock on either side of that line to go in opposite directions.

Responses to Stress

The amount of stress on a rock may be greater than the rock's strength. In that case, the rock will undergo **strain** or **deformation** (**Figure** below). Deep within the Earth, the pressure is very great. A rock behaves like a stretched rubber band. When the stress stops, the rock goes back to its original shape. If more stress is applied to the rock, it bends and flows. It does not return to its original shape. Near the surface, if the stress continues, the rock will **fracture** (rupture) and break.



With increasing stress, the rock undergoes: (1) elastic deformation, (2) plastic deformation, and (3) fracture.



Summary

- Stress is the force applied to an object. Stresses can be confining, compression, tension, or shear.
- Rocks under stress may show strain or deformation. Deformation can be elastic or plastic, or the rock may fracture.
- Rocks respond to stress differently under different conditions.

Review

1. What type of stress would you find at a transform fault?
2. What type of stress would you find at a subduction zone?
3. Under what conditions will a rock fracture?

This page titled 6.1: Geological Stresses is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.2: Principle of Horizontality



What is the pattern of the Grand Canyon rock layers?

If you go to the Grand Canyon, you'll see layers of sedimentary rocks. These rocks are extremely well exposed for viewing. Some people call this "layer cake geology." It looks like a layer cake, but not as tasty. Just like a cake, the bottom layer is put down first. Subsequent layers are deposited next. Where the layers are not horizontal, there was deformation.

Sedimentary Rock Rules

Sedimentary rocks follow certain rules.

1. Sedimentary rocks form with the oldest layers on the bottom and the youngest on top.
2. Sediments are deposited horizontally so sedimentary rock layers are originally horizontal.
3. Sedimentary rock layers that are not horizontal are deformed.

Sedimentary rocks start out horizontal with the oldest on the bottom. Sedimentary rocks that are not horizontal must be deformed. This deformation produces geologic structures such as folds, joints, and faults that are caused by stresses. We can look at the deformation and structures out the deformation history of the rock.

Geologic Structures

Sedimentary rocks are formed in horizontal layers. This is magnificently displayed around the southwestern United States. The arid climate allows rock layers to be well exposed (**Figure** below). The lowest layers are the oldest, and the higher layers are younger. This concept is called **superposition** since it deals with the positions of rock layers.



Layers of different types of rocks are exposed in this photo from Grand Staircase-Escalante National Monument. White layers of limestone are hard and form cliffs. Red layers of shale are flakier and form slopes.

Folds, joints, and faults are caused by stresses. If a sedimentary rock is tilted or folded, we know that stresses have changed the rock.

Summary

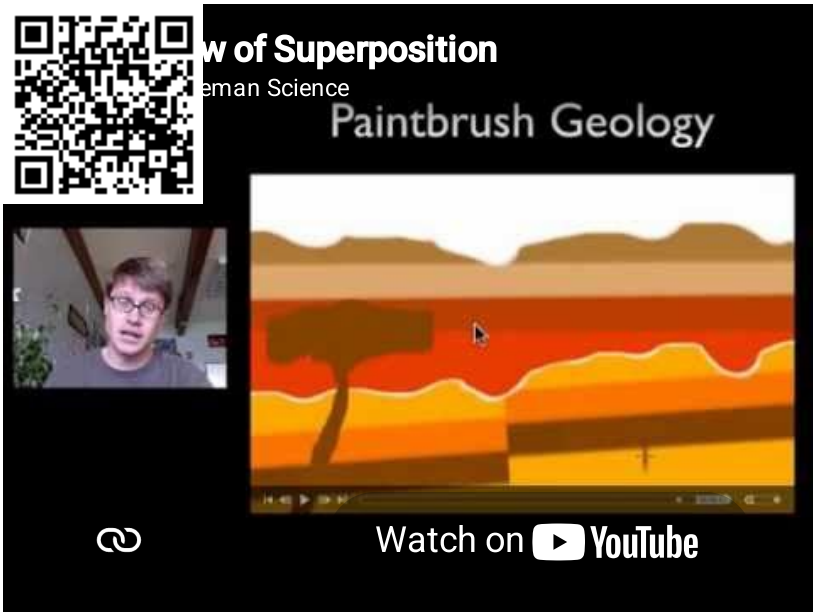
- Sedimentary rocks are laid down horizontally with the oldest at the bottom.
- Sedimentary rocks that are not horizontal have been deformed.
- Sedimentary rocks are very useful for determining the deformation history of an area.

Review

1. Why are sediments laid down horizontally?
2. Why are sediments laid down from oldest to youngest?
3. Why are sedimentary rocks so good for studying the geology of a region?

Explore More

Use the resource below to answer the questions that follow.



1. How is rock laid down?
2. What is the law of superposition?
3. Why is the law of superposition important?
4. Where is the oldest rock found?
5. Where is the youngest rock found?
6. Why do we know that the fault is younger than the three rock layers?
7. Is the intrusion the youngest rock in the section? How do you know?

This page titled 6.2: Principle of Horizontality is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.3: Folds

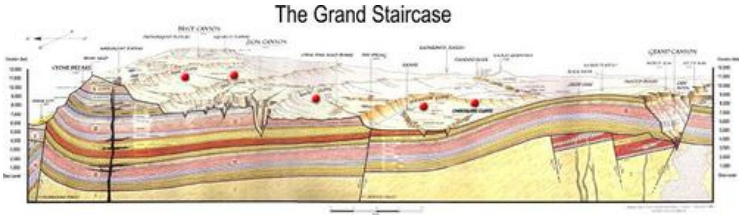


What folds can you see?

Moving around the desert Southwest, we see a lot of folds. This view is near the Valley of the Gods in Utah. Can you see all of the types of folds mentioned below? All of the folds mentioned in the text below are found in the arid Southwestern U.S.

Folds

Deep within the crust, as plates collide, rocks crumple into **folds**. You can model these folds by placing your hands on opposite edges of a piece of cloth and pushing your hands together. Your hands moving toward each other creates compressive stress. In sedimentary rocks, you can easily trace the folding of the layers (**Figure** below). In the image below, the rock layers are no longer horizontal. They tilt downhill from right to left in a monocline. Once rocks are folded, they do not return to their original shape.



This is a geologic cross section of the Grand Staircase in Utah. Where the rocks fold up, at the left of the diagram, is a small syncline.

There are three types of folds: monoclines, anticlines, and synclines.

Monocline

A **monocline** is a simple "one step" bend in the rock layers (**Figure** below). In a monocline, the oldest rocks are at the bottom, and the youngest are at the top.

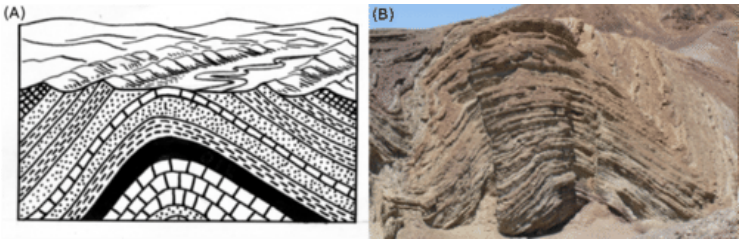


The rock layers in the center left are tilted in one direction, forming a monocline.

Anticline

An **anticline** is a fold that arches upward. The rocks dip away from the center of the fold (**Figure** below). The oldest rocks are found at the center of an anticline. The youngest rocks are draped over them at the top of the structure. When upward folding rocks

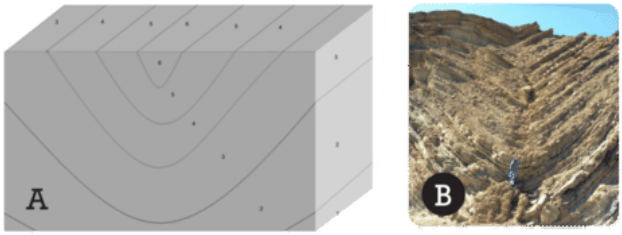
form a circular structure, that structure is called a **dome**. If the top of the dome is eroded off, the oldest rocks are exposed at the center.



(A) An anticline is a convex upward fold. (B) This anticline is at Calico Ghost Town, California.

Syncline

A **syncline** is a fold that bends downward (**Figure** below). In a syncline, the youngest rocks are at the center. The oldest rocks are at the outside edges. When rocks bend downward in a circular structure, it is called a **basin**. If the rocks are eroded, the youngest rocks are at the center. Basins can be enormous, like the Michigan Basin.



(A) A syncline is a concave downward fold. (B) This syncline is seen at Calico Ghost Town near Barstow, California.

Summary

- Rocks deform by compressive stress into folds.
- A monocline is a simple bend in one-direction.
- In an anticline, rocks arch upward. A three-dimensional anticline is a dome.
- In a syncline, rocks arch downward. A three-dimensional syncline is a basin.

Review

1. Draw a picture to show how compressive stresses lead to folds. Can these stresses create anticlines and synclines?
2. Do you think that anticlines and synclines are ordinarily found separately or next to each other?
3. Describe domes and basins. Where are the youngest rocks in each?

Explore More

Use the resource below to answer the questions that follow.



1. What is a geologic fold and what causes one to form?
2. What types of forces create a set of folds?
3. What is a monocline? Where are the older rocks found?
4. What is an anticline? Where are the older rocks found?
5. What is a syncline? Where are the older rocks found?

This page titled 6.3: Folds is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.4: Faults



Why is this lake so long and straight?

The photo is of Crystal Springs Reservoir near the San Francisco Bay Area. The water has collected in a low point in the land. The reason for the low point is a fault, the San Andreas Fault. On one side of the reservoir is the Pacific Plate. On the other side is the North American Plate. Would this be a good place to build a home?

Fractures

A rock under enough stress will fracture. There may or may not be movement along the fracture. If there is not movement, the fracture is a joint. If there is movement, the fracture is a fault.

Joints

If there is no movement on either side of a fracture, the fracture is called a **joint**. Basalt rocks in Asia show horizontal and vertical joints (**Figure** below). These joints formed as the lava cooled and contracted.



Columnar joints in basalt in Asia.

Faults

If the rocks on one or both sides of a fracture move, the fracture is called a **fault** (**Figure** below). Faults can occur alone or in clusters. A cluster of faults creates a **fault zone**. Earthquakes happen when rocks break and move suddenly. The energy released causes an earthquake.

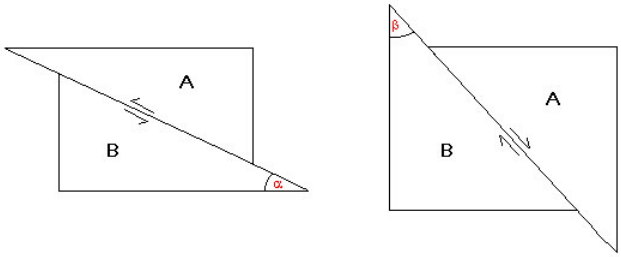


A series of faults offset this outcrop along Highway 191 in Moab, Utah.

Dip-Slip Fault

Slip is the distance rocks move along a fault, as one block of rock moves past the other. The angle of a fault is called the fault's **dip**. If the fault dips at an angle, the fault is a **dip-slip fault** (**Figure** below).

Imagine you are standing on a road looking at the fault. The hanging wall is the rock that overlies the fault. The footwall is beneath the fault. If you are walking along a fault, the hanging wall is above you. The footwall is where your feet would be. Miners often extract mineral resources along faults. They used to hang their lanterns above their heads. That is why these layers were called the hanging wall.



Block A is the hanging wall and block B is the footwall. The left diagram shows a reverse, or thrust, fault and the right diagram shows a normal fault.

Normal Faults

In **normal faults**, the hanging wall drops down relative to the footwall. Normal faults are caused by tension that pulls the crust apart. This causes the hanging wall to slide down. Normal faults can build huge mountain ranges in regions experiencing tension (**Figure** below).



The Sierra Nevada Mountains in eastern California rose up along a normal fault.

Thrust Faults

When compression squeezes the crust into a smaller space, the hanging wall pushes up relative to the footwall. This creates a **reverse fault**. A **thrust fault** is a type of reverse fault. With a thrust fault the angle of the fault is close to horizontal. Rocks can slip many miles along thrust faults (**Figure** below).



In this thrust fault, the rock on the right is thrust over the rock on the left. The rock on the right has also started to fold because of this movement.

Strike-Slip Faults

A **strike-slip fault** is a dip-slip fault where the dip of the fault plane is vertical. Strike-slip faults result from shear stresses. If you stand with one foot on each side of a strike-slip fault, one side will be moving toward you while the other side moves away from you. If your right foot moves toward you, the fault is known as a right-lateral strike-slip fault. If your left foot moves toward you, the fault is a left-lateral strike-slip fault (**Figure** below).

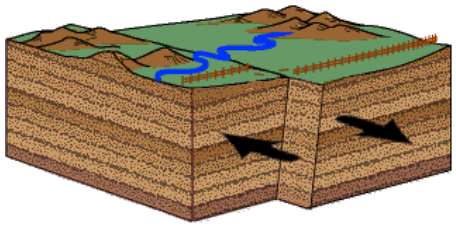


Diagram of a right lateral strike-slip fault.

San Andreas Fault

The San Andreas Fault in California is a right-lateral strike slip fault (**Figure** below). It is also a transform fault because the San Andreas is a plate boundary. Unlike what some people think, California will not fall into the ocean someday. The land west of the San Andreas Fault is moving northwestward, while the North American plate moves southeast. Someday, millions of years from now, Los Angeles will be a suburb of San Francisco!



The San Andreas Fault runs up through California. This transform fault separates the Pacific plate on the west and the North American plate on the east.

Summary

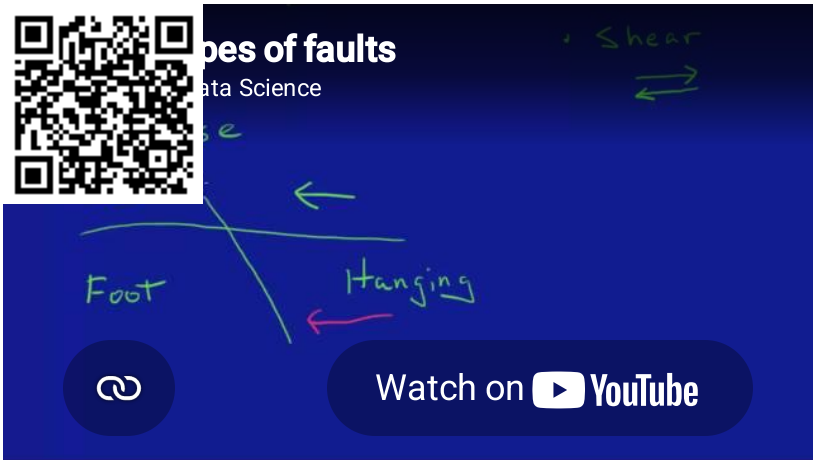
- A fracture with no movement on either side is a joint.
- Dip-slip faults show vertical movement. In a normal fault, the hanging wall drops down relative to the footwall. The reverse is true of a reverse fault.
- Strike-slip faults have horizontal motions due to shear stress.

Review

1. Compare and contrast normal and reverse faults.
2. Imagine you're looking at a cliff with layers of rock. What features would you see to indicate a fault?
3. What is a strike-slip fault?
4. What type of plate boundary can be a strike-slip fault or fault zone?

Explore More

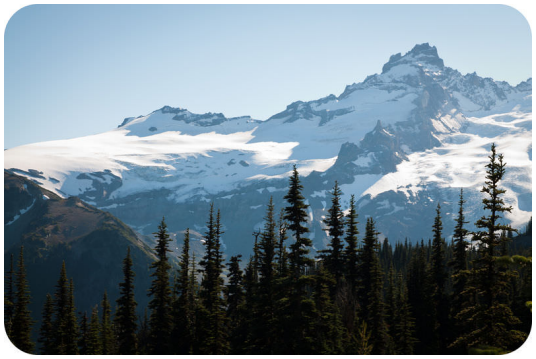
Use the resource below to answer the questions that follow.



1. In a normal fault, which is the hanging wall and which is the footwall?
2. What is the stress in a normal fault?
3. What is the stress in a reverse fault?
4. How does the hanging wall move relative to the footwall in a reverse fall?
5. Describe a strike-slip fault.

This page titled 6.4: Faults is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.5: Mountain Building



How do plate motions create mountains?

Plate tectonic processes create some of the world's most beautiful places. The North Cascades Mountains in Washington State are a continental volcanic arc. The mountains currently host some glaciers. There are many features left by the more abundant Ice Age glaciers. Changes in altitude make the range a habitable place for many living organisms.

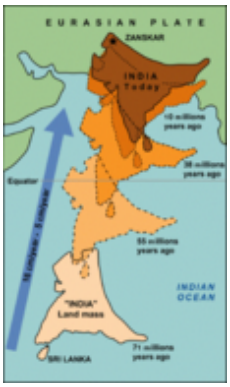
Stress and Mountain Building

Many processes create mountains. Most mountains form along plate boundaries. A few mountains may form in the middle of a plate. For example, hotspot volcanoes.

Continent-Continent Convergence

Most of the world’s largest mountains form as plates collide at convergent plate boundaries. Continental crust is too buoyant to get pushed down into the mantle. So when the plates smash together, the crust crumples upward. This creates mountains. Folding and faulting in these collision zones makes the crust thicker.

The world’s highest mountain range, the Himalayas, is growing as India collides with Eurasia. About 80 million years ago, India was separated from Eurasia by an ocean (**Figure** below). As the plates collided, pieces of the old seafloor were forced over the Asian continent. This old seafloor is now found high in the Himalayas (**Figure** below).



As India rams into Eurasia, the Himalaya Mountains rise.



The Himalayas.

Oceanic Plate Subduction

Volcanic mountain ranges form when oceanic crust subducts into the mantle at convergent plate boundaries. The Andes Mountains are a chain of coastal volcanic mountains. They are forming as the Nazca plate subducts beneath the South American plate (**Figure** below).

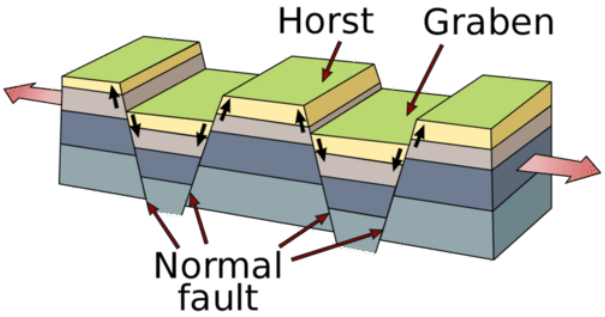


Cotopaxi is in the Andes Mountains of Ecuador. The 19,300 foot tall mountain is the highest active volcano in the world.

Rifting

Mid-ocean ridges form at divergent plate boundaries. As the ocean floor separates an enormous line of volcanoes is created.

Continents can also rift apart; a process called **continental rifting**. When continental crust is pulled apart, it breaks into blocks. These blocks of crust are separated by normal faults. This is known as **block faulting**. The blocks slide up or down. The result is alternating mountain ranges and valleys. This topography is known as basin-and-range (**Figure** below). The area near Death Valley, California is the center of a classic basin-and-range province (**Figure** below).



This diagram shows how a basin-and-range forms.



This photograph was taken from a basin with a range in the distance near Death Valley, California.

Summary

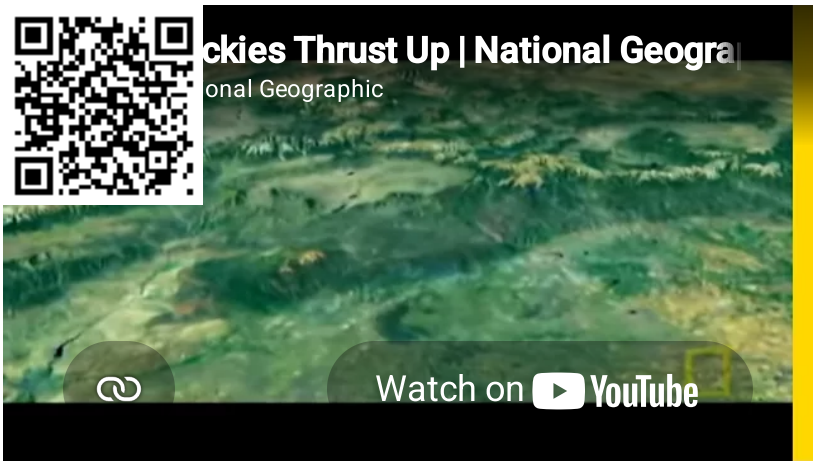
- Converging or diverging plates cause mountains to grow.
- Subduction of oceanic crust beneath a continental or oceanic plate creates a chain of volcanoes.
- Tensional forces bring about block faulting. This creates a basin-and-range valleys and mountains.

Review

1. Describe how plates create mountain ranges like the Himalayas.
2. Diagram how pulling apart continental crust could create mountains and basins. What are the mountains and basins called?
3. Why don't strike slip faults create mountains?

Explore More

Use the resource below to answer the questions that follow.



1. What created the landscape we see today on Earth?
2. What can cause mountains to form?
3. What are the Rocky Mountains made of?
4. How were the Rockies formed?
5. Why did the Rockies form so far inland from the plate margin?

This page titled 6.5: Mountain Building is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.6: Geological Activity and Earthquakes- Challenge 1

1. ___ is the type of stress that occurs at a transform boundary, which causes earthquakes.

Shearing

2. Why don't rocks deform under confining stress?

Space is too limited

3. Compressional stress ___.

decreases the space a rock takes up

4. Sedimentary rocks contain important information about ___.

the geological history of an area

5. As a rule, ___ rocks form in horizontal layers.

sedimentary

6. A ___ is a three-dimensional syncline.

basin

7. ___, which bend downward and have the youngest rocks in the center, and ___, which bend upward and have the oldest rocks in the center, are often found adjacent to each other.

Synclines; anticlines

8. The Michigan Basin is made by rock bent ___.

downward

9. A fracture with no movement on either side is a ___.

joint

10. The hanging wall drops down relative to the footwall in a ___.

normal fault

11. The Andes Mountains grow as the ___ subducts beneath the South American Plate.

Nazca Plate

12. ___ is a continental volcanic arc.

The Cascades

13. Mountain formation is associated with ___.

faulting, folding, and plate tectonics

This page titled 6.6: Geological Activity and Earthquakes- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.7: Earthquakes



What causes the greatest damage in an earthquake?

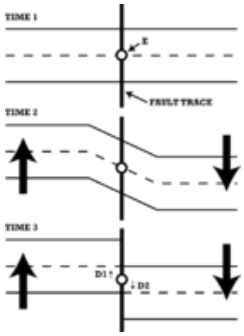
This photo shows the Mission District of San Francisco burning after the 1906 earthquake. The greatest damage in earthquakes is usually not from the ground shaking. The greatest damage is caused by the effects of that shaking. In this earthquake, the shaking broke the gas mains and the water pipes. When the gas caught fire, there was no way to put it out. Fire causes the greatest damage in many earthquakes.

Earthquake!

An **earthquake** is sudden ground movement. This movement is caused by the sudden release of the energy stored in rocks. An earthquake happens when so much stress builds up in the rocks that the rocks break. An earthquake's energy is transmitted by seismic waves.

Causes of Earthquakes

Almost all earthquakes occur at plate boundaries. All types of plate boundaries have earthquakes. Convection within the Earth causes the plates to move. As the plates move, stresses build. When the stresses build too much, the rocks break. The break releases the energy that was stored in the rocks. The sudden release of energy is an earthquake. During an earthquake the rocks usually move several centimeters. Rarely, they may move as much as a few meters. **Elastic rebound theory** describes how earthquakes occur (**Figure** below).



Elastic rebound theory. Stresses build on both sides of a fault. The rocks deform plastically as seen in Time 2. When the stresses become too great, the rocks return to their original shape. To do this, the rocks move, as seen in Time 3. This movement releases energy, creating an earthquake.

Focus and Epicenter

The two important words used to describe an earthquake's location are focus and epicenter.

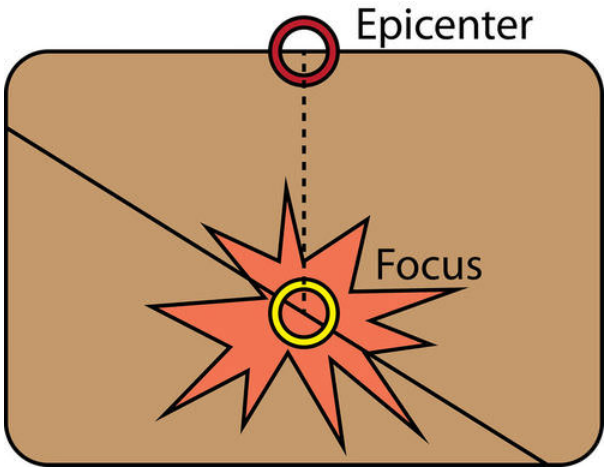
Focus

The point where the rock ruptures is the earthquake's **focus**. The focus is below the Earth's surface. A shallow earthquake has a focus less than 70 kilometers (45 miles). An intermediate-focus earthquake has a focus between 70 and 300 kilometers (45 to 200

miles). A deep-focus earthquake is greater than 300 kilometers (200 miles). About 75% of earthquakes have a focus in the top 10 to 15 kilometers (6 to 9 miles) of the crust. Shallow earthquakes cause the most damage. This is because the focus is near the Earth's surface, where people live.

Epicenter

The area directly above the focus, on the land surface, is the earthquake's **epicenter** (**Figure** below). The towns or cities near the epicenter will be strongly affected by the earthquake.



The focus of an earthquake is where the ground breaks. The epicenter is the point at the surface just above the focus.



Summary

- A sudden release of energy stored in rocks causes an earthquake.
- The focus is where the rocks rupture. The epicenter is the point on the ground directly above the focus.
- Most earthquakes are shallow. Shallow earthquakes do the most damage.

Review

1. Describe elastic rebound theory.
2. Where is an earthquake's focus? Where is its epicenter?
3. Why do shallow earthquakes cause the most damage?

Explore More



1. What is it called when you feel the ground move?
2. What does the Earth's interior resemble? What is the outside layer called?
3. What is Earth's outer layer made of? What are they called?
4. How fast does this outer layer move usually?
5. What is a fault? How big are they?
6. What happens when too much pressure builds up at a fault?

This page titled 6.7: Earthquakes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.8: Earthquake Zones



What caused the 2010 earthquake in Angol, Chile?

Angol, Chile, experienced a huge 8.8 magnitude earthquake in February 2010. The earthquake was due to subduction of the Nazca plate beneath South America. This subduction zone is part of the Pacific Ring of Fire.

Annual Earthquakes

In a single year, on average, more than 900,000 earthquakes are recorded. About 150,000 of them are strong enough to be felt. Each year about 18 earthquakes are major, with a Richter magnitude of 7.0 to 7.9, and on average one earthquake has a magnitude of 8 to 8.9.

Magnitude 9 earthquakes are rare. The United States Geological Survey lists five since 1900 (**Figure** below and **Table** below). All but the Great Indian Ocean Earthquake of 2004 occurred somewhere around the Pacific Ocean basin.



The 1964 Good Friday Earthquake centered in Prince William Sound, Alaska released the second most amount of energy of any earthquake in recorded history.

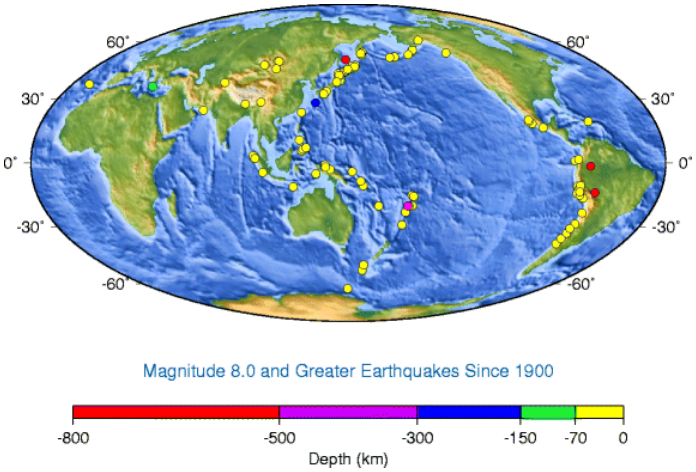
Location	Year	Magnitude
Valdivia, Chile	1960	9.5
Prince William Sound, Alaska	1964	9.2
Great Indian Ocean Earthquake	2004	9.1
Kamchatka, Alaska	1952	9.0
Tōhoku, Japan	2011	9.0

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

Earthquake Zones

Nearly 95% of all earthquakes take place along one of the three types of plate boundaries.

- About 80% of all earthquakes strike around the Pacific Ocean basin because it is lined with convergent and transform boundaries (**Figure** below). The region around the Pacific is called the Pacific **Ring of Fire** due to its earthquakes and volcanoes.
- About 15% take place in the Mediterranean-Asiatic Belt. Convergence is causing the Indian Plate to run into the Eurasian Plate.
- The remaining 5% are scattered around other plate boundaries. A few earthquakes take place away from plate boundaries. These are intraplate earthquakes.



Earthquake epicenters for magnitude 8.0 and greater events since 1900. The earthquake depth shows that most large quakes are shallow focus, but some subducted plates cause deep focus quakes.

Summary

- Small earthquakes are extremely common, but the largest earthquakes are extremely rare.
- The vast majority of earthquakes happen at plate boundaries.
- The Pacific Ocean basin has the most earthquakes due to convergent and transform plate boundaries. The Himalaya region has the second most due to the convergence of India and Asia.

Review

1. Why are most earthquakes at plate boundaries?
2. What two types of plate motions cause earthquakes around the Pacific Ring of Fire?
3. What type of plate motions cause the Mediterranean-Asiatic quakes?

Explore More

Use the resource below to answer the questions that follow.



1. What was the magnitude of the Chilean earthquake?
2. What two plates are converging near Chile that caused the earthquake?
3. What is the Ring of Fire? What occurs along this Fing of Fire?
4. What was the strongest earthquake ever recorded? When did it occur?
5. Why are scientists urging Memphis to adopt building codes similar to Chile's?

This page titled 6.8: Earthquake Zones is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.9: Earthquakes at Transform Plate Boundaries



What does the future of San Francisco hold?

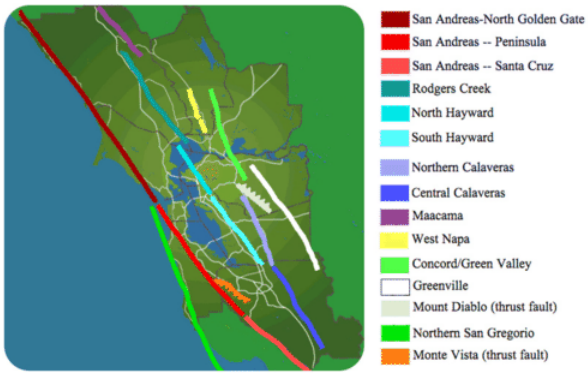
The last large earthquake along the San Andreas Fault in the San Francisco area struck in 1906. The city was devastated. Studies show that big quakes occur every 125 years or more. Small quakes seem to precede large ones, and there have been some small ones in recent years. What do you think the future holds for San Francisco?

Transform Plate Boundaries

Transform plate boundaries produce enormous and deadly earthquakes. These quakes at transform faults originate at shallow foci. This is because the plates slide past each other without moving up or down.

The San Andreas Fault that runs through much of California is an enormous transform plate boundary. It is the plate boundary between Pacific and North American plates. The largest earthquake in recorded history on the San Andreas Fault occurred in 1906. The quake's epicenter was just north of San Francisco. About 3,000 people died and 28,000 buildings were lost, mostly in the fire that followed the earthquake.

There are many other faults spreading off the San Andreas, to take up the plate motion. In total the San Andreas Fault system produces around 10,000 earthquakes a year (**Figure** below). While most of those earthquakes cannot even be felt by people nearby, occasionally one is very strong. In the San Francisco Bay Area, the Hayward Fault was the site of a magnitude 7.0 earthquake in 1868.



The San Andreas Fault runs through the San Francisco Bay Area. Other related faults cross the region. Lines indicate strike slip faults. Lines with hatches are thrust faults.

Other significant earthquakes in California include the 1989 Loma Prieta earthquake near Santa Cruz (**Figure** below) and the 1994 Northridge earthquake near Los Angeles.



Three people died in this mall in Santa Cruz during the 1989 Loma Prieta earthquake.

Although California is prone to many natural hazards, including volcanic eruptions at Mt. Shasta or Mt. Lassen, and landslides on coastal cliffs, the natural hazard the state is linked with is earthquakes. In this video, the boundaries between three different tectonic plates and the earthquakes that result from their interactions are explored.



New Zealand also has a transform fault with strike-slip motion, causing about 20,000 earthquakes a year! Only a small percentage of those are large enough to be felt. A 6.3 quake in Christchurch in February 2011 killed about 180 people.

Summary

- Transform fault earthquakes have shallow focus because the plates meet near the surface.
- The San Andreas Fault is actually a fault zone made up of a number of other active faults.
- New Zealand also has a transform plate boundary.

Review

1. Why are earthquakes at transform plate boundaries always shallow focus?
2. Why are there so many small faults in the San Francisco Bay Area?
3. Why do such large earthquakes take place along the San Andreas Fault?

Explore More

Use the resources below to answer the questions that follow.



1. How far does the San Andreas Fault extend?
2. If you have one foot on each side of the fault, which plate is each foot on? What regions share each plate?
3. What type of fault is it?
4. What causes an earthquake?
5. What is a creepmeter? How much movement does the creepmeter in the video sense?
6. How many earthquakes occur at the San Andreas fault each year?

This page titled 6.9: Earthquakes at Transform Plate Boundaries is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.10: Earthquakes at Convergent Plate Boundaries

What damage is done to people's lives by earthquakes?

In a large earthquake hundreds or thousands of people may die. Many more may lose their homes and livelihoods. After a large quake, the world's attention turns to help the victims. But soon there is another disaster in the news, and the world's attention turns. People may be left homeless due to an earthquake for many years.

Convergent Plate Boundaries

Earthquakes at convergent plate boundaries mark the location of the subducting lithosphere. The motion of the lithosphere as it plunges through the mantle causes the quakes (**Figure** below). At greater depths, the plate heats up enough to deform plastically.

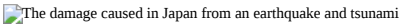
A cross section of earthquake epicenters. The depth outlines the subducting plate. There are shallow, intermediate, and deep earthquakes.

Convergent plate boundaries produce earthquakes most of the way around the Pacific Ocean basin.

Ocean-Ocean: Japan

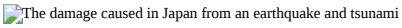
Earthquakes in Japan are caused by ocean-ocean convergence. In this part of the Pacific Ocean, oceanic crust subducts beneath oceanic crust. This creates as many as 1,500 earthquakes every year.

In March 2011, the 9.0 magnitude Tōhoku earthquake struck off of northeastern Japan. Damage from the quake was severe. Even more severe was the damage from the tsunami generated by the quake (**Figure** below and **Figure** below). A **tsunami** is an enormous ocean wave or set of waves generated by an underwater earthquake. In all, 25,000 people were known dead or missing.



The damage in Miyako, Iwate, Japan after a 9.0 magnitude earthquake and the massive tsunami it generated struck in March, 2011.

Here is an interactive feature article about the earthquake: http://www.nytimes.com/interactive/2011/03/11/world/asia/maps-of-earthquake-and-tsunami-damage-in-japan.html.



Destruction in Ofunato, Japan, from the 2011 Tōhoku Earthquake.

Ocean-Continent: Cascades

The Pacific Northwest of the United States is at risk from a potentially massive earthquake. The subduction of three small plates beneath North America produces active volcanoes, the Cascades. The region also experiences earthquakes. However, large earthquakes hit only every 300 to 600 years. The last was in 1700. That quake had an estimated magnitude of around 9. A quake of that magnitude today could produce an incredible amount of destruction and untold fatalities.

Continent-Continent: Asia

The collision of two continents also creates massive earthquakes. Many earthquakes happen in the region in and around the Himalayan Mountains. The 2005 Kashmir, India, earthquake is responsible for about 20,000 deaths, with many more people injured or made homeless (**Figure** below).

Damage from the 2005 Kashmir earthquake.



Summary

- Earthquakes occur all along the subducting plate as it plunges into the mantle.
- All three types of convergent plate boundaries produce massive earthquakes.
- Subduction zones around the Pacific Rim are responsible for many of the world's earthquakes.

Review

1. Why does a subducting plate produce so many earthquakes?
2. What depths of earthquakes does a subducting plate produce?
3. What caused the most destruction from the 2011 Japan earthquake?
4. In the chart above of depth vs. distance of the earthquakes, what is being outlined by the dots?

This page titled 6.10: Earthquakes at Convergent Plate Boundaries is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.11: Intraplate Earthquakes



When can you go up in the Washington Monument again?

An earthquake in August 2011 in Virginia cracked the top of the Washington Monument. After 32 months of repair, the monument reopened to the public. Other sites in Washington, D.C., like the National Cathedral, were also damaged.

Intraplate Earthquakes

About 5% of earthquakes take place within a plate, away from plate boundaries. These **intraplate earthquakes** are caused by stresses within a plate. Since plates move over a spherical surface, zones of weakness are created. Intraplate earthquakes happen along these zones of weakness. The earthquakes may take place along ancient faults or rift zones.

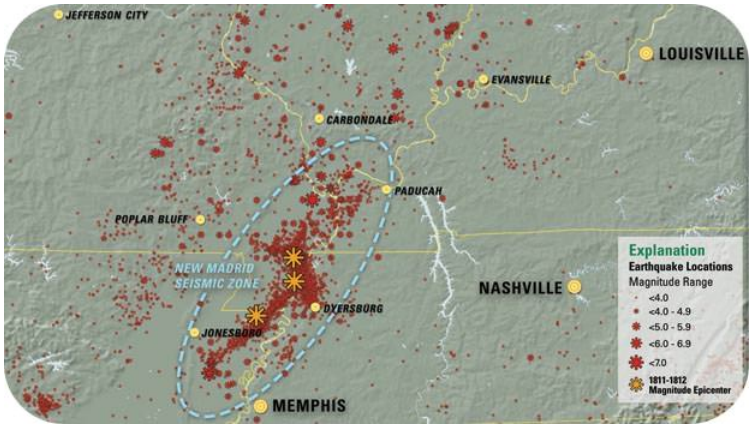
2011 Virginia Earthquake

In August 2011, the eastern seaboard of the U.S. was rocked by a magnitude 5.8 earthquake. While not huge, most of the residents had never experienced an earthquake. Many didn't know what had happened!

This region is no longer part of an active plate boundary. But a few hundred million years ago, at the end of the Paleozoic, things were different. Continent-continent convergence was bringing Pangaea together. This region was being uplifted into the ancestral Appalachian mountains. There are still ancient faults that sometimes reactivate.

New Madrid Earthquake

In 1812, a magnitude 7.5 earthquake struck near New Madrid, Missouri. The earthquake was strongly felt over approximately 50,000 square miles. The quake even altered the course of the Mississippi River. Because very few people lived in the area at the time, only 20 people died. Many more people live there today (**Figure** below). A similar earthquake today would undoubtedly kill many people and cause a great deal of property damage. The New Madrid Seismic Zone continues to be active.



The New Madrid seismic zone is located in the interior of the North American plate (near Missouri, Arkansas, Tennessee, Kentucky, and Illinois).

Summary

- Intraplate earthquakes occur because solid lithosphere travels on a round planet.
- Intraplate earthquakes hit reactivated ancient faults.
- Intraplate earthquakes are not usually as large as quakes along plate boundaries. Still, they can do a great deal of damage.

Review

1. What caused the New Madrid earthquakes?
2. What causes intraplate earthquakes?
3. Why did an earthquake strike Virginia in 2011? Why did it strike at that location?

Explore More

Use the resource below to answer the questions that follow.



1. How many active earthquake fault zones are there in the United States?
2. What is the second most active fault zone in the United States?
3. When did the New Madrid earthquake occur?
4. What was the magnitude of the New Madrid earthquake?
5. How many aftershocks occurred? What was the highest magnitude of an aftershock?
6. How long is the New Madrid fault?
7. How many people would be affected by another quake?
8. Where is the Ramapo fault?
9. Why is quiet along an active fault considered a problem?

This page titled 6.11: Intraplate Earthquakes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.12: Seismic Waves



Are seismic waves like ocean waves?

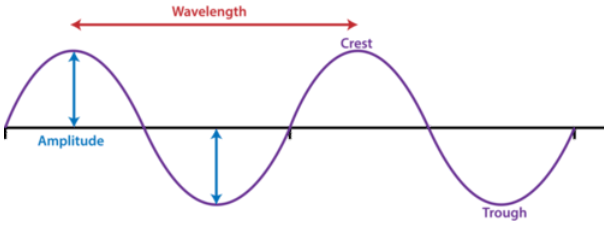
Yes, in some ways. Ocean waves travel at the interface between the sea surface and the atmosphere. They have all the features that all waves have. Some seismic waves also travel at an interface. Which ones?

Seismic Waves

Seismic waves are the energy from earthquakes. Seismic waves move outward in all directions away from their source. Each type of seismic wave travels at different speeds in different materials. All seismic waves travel through rock, but not all travel through liquid or gas. Geologists study seismic waves to learn about earthquakes and the Earth's interior.

Wave Structure

Seismic waves are just one type of wave. Sound and light also travel in waves. Every wave has a high point called a **crest** and a low point called a **trough**. The height of a wave from the center line to its crest is its **amplitude**. The horizontal distance between waves from crest to crest (or trough to trough) is its **wavelength** (**Figure** below).



The energy from earthquakes travels in waves, such as the one shown in this diagram.

Types of Seismic Waves

There are two major types of seismic waves. **Body waves** travel through the Earth's interior. **Surface waves** travel along the ground surface. In an earthquake, body waves are responsible for the sharp jolts. Surface waves are responsible for the rolling motions that do most of the damage in an earthquake.

Body Waves

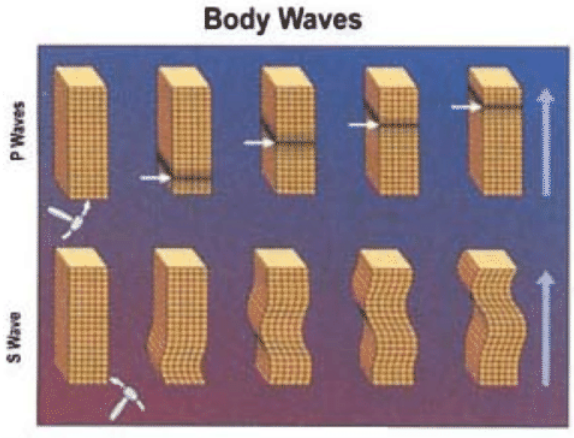
Primary waves (P-waves) and **secondary waves (S-waves)** are the two types of body waves (**Figure** below). Body waves move at different speeds through different materials.

P-waves are faster. They travel at about 6 to 7 kilometers (about 4 miles) per second. Primary waves are so named because they are the first waves to reach a seismometer. P-waves squeeze and release rocks as they travel. The material returns to its original size and shape after the P-wave goes by. For this reason, P-waves are not the most damaging earthquake waves. P-waves travel through solids, liquids, and gases.

S-waves are slower than P-waves. They are the second waves to reach a seismometer. S-waves move up and down. They change the rock's shape as they travel. S-waves are about half as fast as P-waves, at about 3.5 km (2 miles) per second. S-waves can move

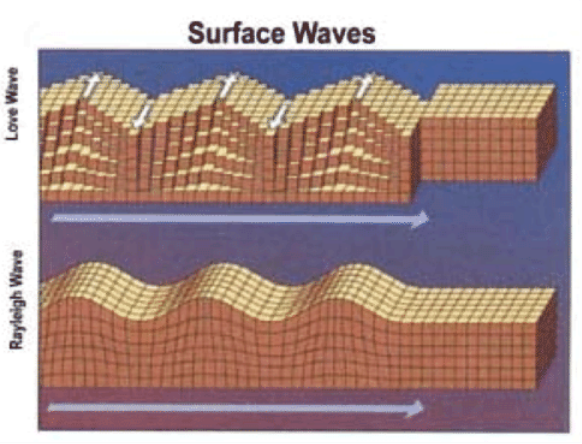
CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

only through solids. This is because liquids and gases don't resist changing shape.



P-waves and S-waves are the two types of body waves.

Surface Waves



Love waves and Rayleigh waves are the two types of surface waves.

Surface waves travel along the ground outward from an earthquake's epicenter. Surface waves are the slowest of all seismic waves. They travel at 2.5 km (1.5 miles) per second. There are two types of surface waves. **Love waves** move side-to-side, much like a snake. **Rayleigh waves** produce a rolling motion as they move up and backward (**Figure** above). Surface waves cause objects to fall and rise. They also cause objects to sway back and forth. These motions cause damage to rigid structures during an earthquake.

Summary

- Body waves travel through the body of a planet. Surface waves travel along the surface.
- There are two types of body waves: P-waves travel fastest and through solids, liquids, and gases; S-waves only travel through solids.
- Surface waves are the slowest, but they do the most damage in an earthquake.

Review

1. Draw a set of waves and label the parts: crest, trough, amplitude, wavelength.
2. Compare and contrast P-waves and S-waves.
3. Describe the motions of surface waves.

Explore More

Use the resource below to answer the questions that follow.



1. What are body waves?
2. Which waves move the fastest?
3. What are the S-waves? Describe them.
4. What happens to body waves as they move through the Earth?
5. What are the two types of surface waves?
6. Describe how surface waves travel.

This page titled 6.12: Seismic Waves is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.13: Tsunami



What is a tsunami?

"Tsunami" is a Japanese word meaning "harbor wave." Some people call them tidal waves. But these deadly waves are not related to tides and they are not restricted to harbors. Few words can express the horror these waves can bring.

Tsunami as Waves

Tsunami are deadly ocean waves from the sharp jolt of an undersea earthquake. Less frequently, these waves can be generated by other shocks to the sea, like a meteorite impact. Fortunately, few undersea earthquakes, and even fewer meteorite impacts, generate tsunami.

Wave Height

Tsunami waves have small wave heights relative to their long wavelengths, so they are usually unnoticed at sea. When traveling up a slope onto a shoreline, the wave is pushed upward. As with wind waves, the speed of the bottom of the wave is slowed by friction. This causes the wavelength to decrease and the wave to become unstable. These factors can create an enormous and deadly wave.

Landslides, meteorite impacts, or any other jolt to ocean water may form a tsunami. Tsunami can travel at speeds of 800 kilometers per hour (500 miles per hour).

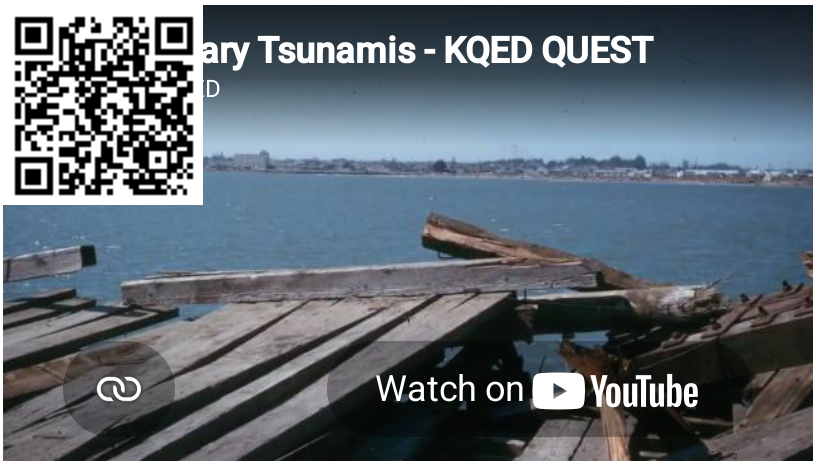
Wavelength

Since tsunami are long-wavelength waves, a long time can pass between crests or troughs. Any part of the wave can make landfall first.

In 1755 in Lisbon, Portugal, a tsunami trough hit land first. A large offshore earthquake did a great deal of damage on land. People rushed out to the open space of the shore. Once there, they discovered that the water was flowing seaward fast and some of them went out to observe. What do you think happened next? The people on the open beach drowned when the crest of the wave came up the beach.

Large tsunami in the Indian Ocean and more recently Japan have killed hundreds of thousands of people in recent years. The west coast is vulnerable to tsunami since it sits on the Pacific Ring of Fire. Scientists are trying to learn everything they can about predicting tsunamis before the next massive one strikes.

Although most places around the Indian Ocean did not have warning systems in 2005, there is a tsunami warning system in that region now. Tsunami warning systems have been placed in most locations where tsunami are possible.



Further Reading

21st Century Tsunami

Summary

- Tsunami have relatively low wave heights, so they are not noticeable until they move up a shore.
- Tsunami have long wavelengths. The time between two crests or two troughs can be many minutes.
- Tsunami warning systems have been placed in most locations where tsunami are possible.

Review

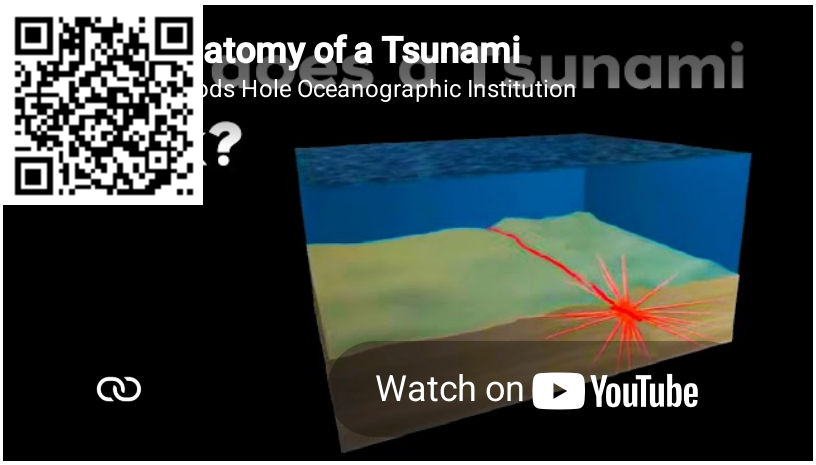
1. Why is a wave that is so powerful and tall on land unnoticeable at sea?
2. What should you do if you are at the beach and the water suddenly is sucked offshore?
3. Describe tsunami as waves in the way they travel up a shoreline and may strike as crests or troughs.

Explore More

Use this resource to answer the questions that follow.



1. What does the word tsunami mean in Japanese?
2. Why has Japan had so many tsunamis?
3. What causes a tsunami?
4. How fast do the waves travel?
5. What happens to the tsunami as it reaches the continental shelf?
6. How do tsunamis differ from regular waves?
7. What was the deadliest tsunami ever recorded? How many people died?
8. What does the Pacific Tsunami Warning Center do?



This page titled 6.13: Tsunami is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.14: 21st Century Tsunami

Why should you pay attention in school?

Eleven-year-old Tilly Smith and her family were walking along the beach in Phuket, Thailand, on December 26, 2004. Tilly noticed that the sea was bubbling. She thought this was like a video she'd seen in geography class two weeks earlier. The English schoolgirl insisted to her parents that a tsunami was coming. Her warning saved the approximately 100 tourists and civilians who were on that beach.

Tsunami

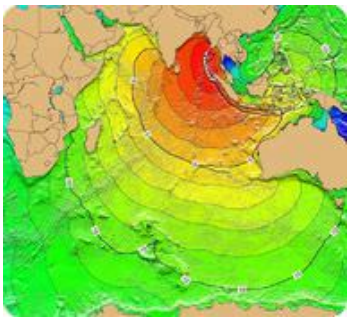
Earthquakes can cause **tsunamis**. These deadly ocean waves may result from any shock to ocean water. A shock could be a meteorite impact, landslide, or a nuclear explosion. But most come from large underwater earthquakes.

An underwater earthquake creates a tsunami this way: the movement of the crust displaces water. The displacement forms a set of waves. The waves travel at jet speed through the ocean. Since the waves have low amplitudes and long wavelengths, they are unnoticed in deep water. As the waves reach shore they compress. They are also pushed upward by the shore. For these reasons, tsunamis can grow to enormous wave heights. Tsunami waves can cause tremendous destruction and loss of life. Fortunately, few undersea earthquakes generate tsunamis.

The Boxing Day Tsunami, 2004

The Boxing Day Tsunami struck on December 26, 2004. The tsunami was caused by one of the largest earthquakes ever recorded. The Indian Ocean Earthquake registered magnitude 9.1. The quake struck near Sumatra, Indonesia, where the Indian plate is subducting beneath the Burma plate. It released about 550 million times the energy of the atomic bomb dropped on Hiroshima.

Several tsunami waves were created. The waves went around the Indian Ocean and struck eight countries (**Figure** below).



Travel time map for the Boxing Day Tsunami (in hours). Countries near red, orange, and yellow areas were affected the most.

About 230,000 people died. More than 1.2 million people lost their homes. Many more lost their way of making a living. Fishermen lost their boats, and businesspeople lost their restaurants and shops. Many marine animals washed onshore, including dolphins, turtles, and sharks.

Japan Tsunami, 2011

Japan received a one-two punch in March 2011. The 2011 Tōhoku earthquake offshore was a magnitude 9.0, and damage from the quake was extensive. The earthquake generated massive tsunami waves which hit the island nation. Waves in some regions topped 9 meters (27 feet).

The tsunami did much more damage than the massive earthquake. In the photo of Sendai (**Figure** below), the black smoke is coming from an oil refinery. The refinery was set on fire due to the earthquake. The tsunami prevented efforts to extinguish the fire for several days.



An aerial view shows the damage to Sendai, Japan caused by the earthquake and tsunami.

Worst of all was the damage done to nuclear power plants along the northeastern coast. Eleven reactors were automatically shut down. Power and backup power were lost at the Fukushima plant. This lead to equipment failures, meltdowns, and the release of radioactive materials. Cleanup of the disabled plants will go on for many years.

Tsunami Warning Systems

Most of the Indian Ocean tragedy could have been avoided if a warning system had been in place (**Figure** below). As of June 2006, the Indian Ocean now has a warning system. Communities around the Pacific have had a tsunami warning system since 1948.



This sign is part of the tsunami warning system used in communities around the Pacific Ocean since 1948.

As in Japan, warning systems aren't always helpful. People in communities very close to the earthquake do not have enough time to move out of the area. Farther away from the quake, evacuation of low-lying areas saves lives.

Summary

- Tsunamis have relatively low amplitude and long wavelengths. They are not noticeable until they move up a shore.
- Tsunami warning systems are now found in most locations where tsunamis are possible.
- The Boxing Day Tsunami of 2004 came from a massive earthquake. The waves traveled across the Indian Ocean, causing death and destruction in 12 nations.
- In Japan, the tsunami struck very quickly after the 9.0 earthquake in the subduction zone offshore. Many more people died from the tsunami than the quake.

Review

1. How can a wave that is so powerful and tall on land be unnoticeable at sea?
2. How does an earthquake generate a tsunami?
3. Why did the Boxing Day Tsunami cause so much damage all around the Indian Ocean basin?
4. Why do you think there was more damage from the tsunami in Japan than from the earthquake that caused it?

This page titled 6.14: 21st Century Tsunami is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.15: Geological Activity and Earthquakes- Challenge 2

1. An earthquake's ___ is found above its focus, on the land surface.

epicenter

2. Stress builds up on both sides of a fault. The rock deforms plastically, or bends, until the stress is too much. The rock on both sides of the fault snaps back into its original position and release energy. This is called ___ theory.

elastic rebound

3. ___ states that stress builds up along a fault until the fault breaks, causing an earthquake.

Elastic Rebound Theory

4. What percent of global earthquakes occurs within the Mediterranean-Asiatic belt?

15%

5. What percent of global earthquakes strikes around the Pacific Ocean?

80%

6. The Pacific Ocean basin has a lot of earthquakes, because it is surrounded by ___.

convergent and transform plate boundaries

7. Which of the following countries has a transform plate boundary: Canada, Argentina, New Zealand, or Australia?

New Zealand

8. What type of fault is found at a transform boundary?

Strike-slip fault

9. What was the magnitude of the Northridge earthquake, which occurred along a blind thrust fault near Los Angeles in 1994?

6.7

10. Intraplate seismic activity typically occurs ___.

along reactivated ancient faults

11. What was the magnitude of the 2011 Virginia earthquake?

5.8

12. The low point of a wave is called the ___.

trough

13. The high point of a wave is called the ___.

crest

14. The word "tsunami" means ___.

harbor wave

15. A ___ is caused by the displacement of water in the ocean.

tsunami

This page titled 6.15: Geological Activity and Earthquakes- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.16: Measuring Earthquake Magnitude



Have you ever felt an earthquake?

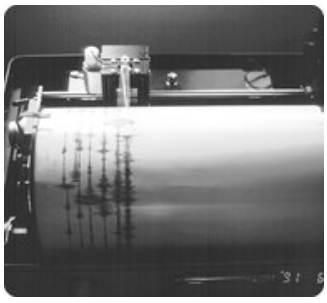
Small earthquakes are fairly common in some parts of the world. Depending on the quake, the land, and the setting, people experience them differently. You may wonder why your chair is moving, when you are sitting still. You may think someone is running across the roof. In a skyscraper, you may be swaying. Seismometers quantify this and record the energy released in the quake.

Measuring Seismic Waves

Seismic waves are measured on a seismograph. Seismographs contain a lot of information, and not just about earthquakes.

Seismometers

A **seismograph** is a machine that records seismic waves. In the past, seismographs produced a **seismogram**. A seismogram is a paper record of the seismic waves the seismograph received. Seismographs have a weighted pen suspended from a stationary frame. A drum of paper is attached to the ground. As the ground shakes in an earthquake, the pen remains stationary but the drum moves beneath it. This creates the squiggly lines that make up a seismogram (**Figure** below).

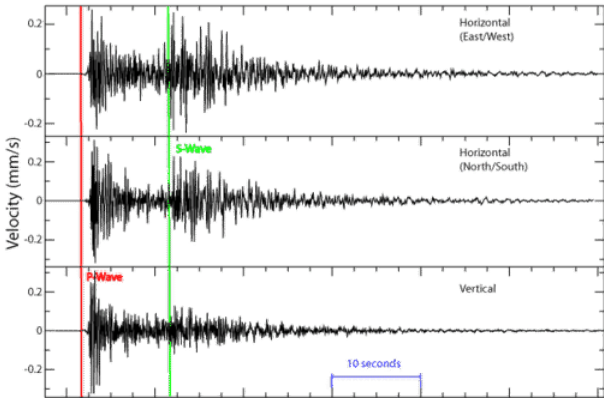


This seismograph records seismic waves.

Modern **seismometers** record ground motions using electronic motion detectors. The data are then kept digitally on a computer.

What We Learn from Seismograms

Seismograms contain a lot of information about an earthquake: its strength, length, and distance. Wave height is used to determine the magnitude of the earthquake. The seismogram shows the different arrival times of the seismic waves (**Figure** below). The first waves are P-waves since they are the fastest. S-waves come in next and are usually larger than P-waves. The surface waves arrive just after the S-waves. If the earthquake has a shallow focus, the surface waves are the largest ones recorded.



These seismograms show the arrival of P-waves and S-waves.

A seismogram may record P-waves and surface waves, but not S-waves. This means that it was located more than halfway around the Earth from the earthquake. What does that mean? Earth's outer core is liquid. S-waves cannot travel through liquid. So the liquid outer core creates an S-wave shadow zone on the opposite side of the Earth from the quake.

Like most things, seismographs are now digital. Information from seismic waves is fed into computers at seismic stations around the world.

Further Reading

Predicting Earthquakes

Earthquake Damage

Earthquake Safe Structures

Staying Safe in an Earthquake

Summary

- A seismograph records seismic waves on a seismogram. A seismometer is a digital seismic wave recorder.
- S-waves do not travel through liquids. So a seismogram with no S-waves is on the other side of the planet from the quake.
- Seismographs yield a tremendous amount of information about an earthquake.

Review

1. Define seismograph, seismogram, and seismometer.
2. What does a seismogram with P-waves but not S-waves mean and why?
3. How can you tell S-wave arrival from the end of the P-wave?

Explore More



1. Why was the Alaska Earthquake on March 27, 1964 so large? How large was it?
2. Name the types of plate boundaries that experience earthquakes.
3. When geologists discovered new oceanic crust forming at divergent plate boundaries, what two explanations did they come up with?
4. What happens at a subduction zone?
5. What is the common cause of all 6 megathrust earthquakes that have been recorded since 1900?
6. Why is it impossible (at least at this time) to predict when an earthquake will take place?

This page titled 6.16: Measuring Earthquake Magnitude is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.17: Locating Earthquake Epicenters



Can you find an earthquake epicenter?

The epicenter of the 2011 Japan earthquake was just offshore of Sendai. This is where the Pacific Plate plunges into a subduction zone. The earthquake had a relatively shallow depth of 20 miles (32 km). Remember that shallow quakes typically cause the most damage. How do scientists find an earthquake epicenter?

Finding the Epicenter

One seismogram indicates the distance to the epicenter. This is determined by the P-and S-wave arrival times. If a quake is near the seismograph, the S-waves arrive shortly after the P-waves. If a quake is far from the seismograph, the P-waves arrive long before the S-waves. The longer the time is between the P-and S-wave arrivals, the further away the earthquake was from the seismograph. First, seismologists calculate the arrival time difference. Then they know the distance to the epicenter from that seismograph. They can connect all the points that are that distance from the seismic station. This makes a circle around the station!

Next, the seismologists try to determine the location of the earthquake epicenter. To do this they need the distances to the epicenter from at least three seismographs. Let's say that they know that an earthquake's epicenter is 50 kilometers from Kansas City. They draw a circle with a 50 km radius around that seismic station. They do this twice more around two different seismic stations. The three circles intersect at a single point. This is the earthquake's epicenter (**Figure** below).



Seismographs in Portland, San Francisco, and Salt Lake City are used to find an earthquake epicenter.



Summary

- To find an earthquake epicenter you need at least three seismographs.
- Find the distance from each seismograph to the earthquake epicenter.
- The interception of the three circles is the epicenter.

Review

1. How do you determine the distance from the seismograph to the earthquake epicenter?
2. How do you find the epicenter from three seismographs?
3. What role does the S-P interval play in locating an earthquake epicenter?

This page titled 6.17: Locating Earthquake Epicenters is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.18: Earthquake Magnitude Scales



How do scientists measure earthquakes?

This 8.8 magnitude earthquake in Chile in 2010 caused over 500 deaths and thousands of injuries. Earthquakes and the damage they cause can be measured in a few different ways. One way is to describe the damage. The other way is to measure the energy of the quake.

Earthquake Intensity

The ways seismologists measure an earthquake have changed over the decades. Initially, they could measure only what people felt and saw: the intensity. For this, they used the Mercalli scale.

Mercalli Scale

Early in the 20th century, earthquakes were described in terms of what people felt and the damage that was done to buildings. The **Mercalli intensity scale** describes earthquake intensity.

There are many problems with the Mercalli scale. The damage from an earthquake is affected by many things. The type of ground a building sits on is very important to what happens to that building in a quake. Different people experience an earthquake differently. Using this scale, comparisons between earthquakes were difficult to make. A new scale was needed.

Earthquake Magnitude

For decades scientists have had equipment that can measure earthquake magnitude. The earthquake magnitude is the energy released during the quake.

The Richter Magnitude Scale

Charles Richter developed the **Richter magnitude scale** in 1935. The Richter scale measures the magnitude of an earthquake's largest jolt of energy. This is determined by using the height of the waves recorded on a seismograph.

The Richter scale is logarithmic. The magnitudes jump from one level to the next. The height of the largest wave increases 10 times with each level. So the height of the largest seismic wave of a magnitude 5 quake is 10 times that of a magnitude 4 quake. A magnitude 5 is 100 times that of a magnitude 3 quake. With each level, thirty times more energy is released. A difference of two levels on the Richter scale equals 900 times more released energy.

The Richter scale has limitations. A single sharp jolt measures higher on the Richter scale than a very long intense earthquake. Yet, this is misleading because the longer quake releases more energy. Earthquakes that release more energy are likely to do more damage. As a result, another scale was needed.

The Moment Magnitude Scale

The **moment magnitude scale** is the favored method of measuring earthquake magnitudes. It measures the total energy released by an earthquake. Moment magnitude is calculated by two things. One is the length of the fault break. The other is the distance the ground moves along the fault. Japan's Tōhoku earthquake in 2011 had a magnitude of 9.0 (**Figure** below).

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



Earthquake and tsunami damage in Japan, 2011. The Tōhoku earthquake had a magnitude of 9.0.

Summary

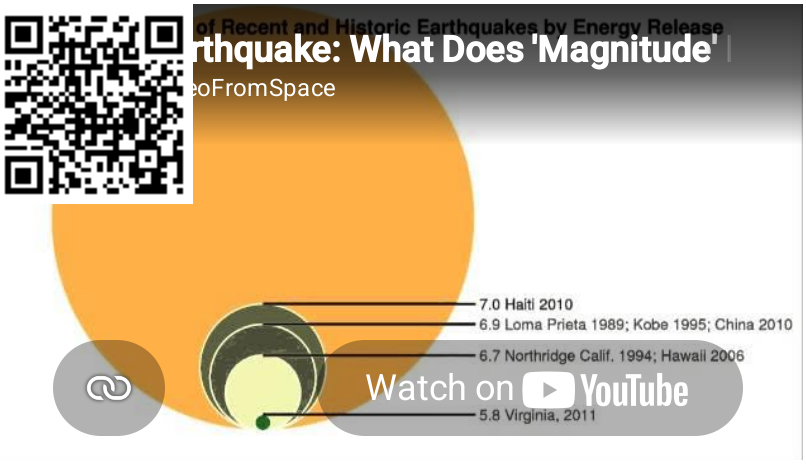
- Mercalli Intensity Scale depends on many factors other than the amount of energy released in the earthquake. These factors include the type of rock in the region. They also include the quality of the structures built in the area.
- The Richter scale is a logarithmic scale that measures the largest jolt of energy released by an earthquake.
- The moment magnitude scale is a logarithmic scale that measures the total amount of energy released by an earthquake.

Review

1. Under what circumstances might the Mercalli intensity scale be useful today? Why was it replaced by the Richter and then the moment magnitude scales?
2. Why do scientists prefer the moment magnitude scale to the Richter scale?
3. In 2011 there was a 5.8 magnitude quake that struck Virginia and a 9.0 quake that struck Japan. How might a 5.8 quake rate on the Mercalli scale in Virginia? How might a 5.8 magnitude quake rate on the Mercalli scale in Japan?

Explore More

Use the resource below to answer the questions that follow.



1. What was the magnitude of the 2010 Haiti earthquake?
2. What does magnitude mean?
3. How much larger is each earthquake magnitude?
4. What is the difference between two magnitudes?
5. What was the largest earthquake ever measured?

This page titled 6.18: Earthquake Magnitude Scales is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.19: Predicting Earthquakes



What if you could predict an earthquake?

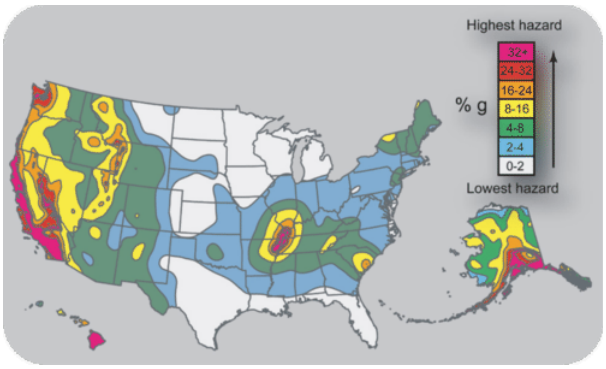
What would make a good prediction? Knowing where, when, and the magnitude of the quake would make it possible for people to evacuate. If you were right, you would be famous! But if you were wrong, many people would be angry with you.

Earthquake Prediction

Scientists are a long way from being able to predict earthquakes. A good prediction must be detailed and accurate. Where will the earthquake occur? When will it occur? What will be its approximate magnitude? With a good prediction, authorities could get people to evacuate. But if the prediction were wrong, a lot of money would be lost as people closed businesses and skipped work. Plus, people would be unlikely to believe the authorities the next time.

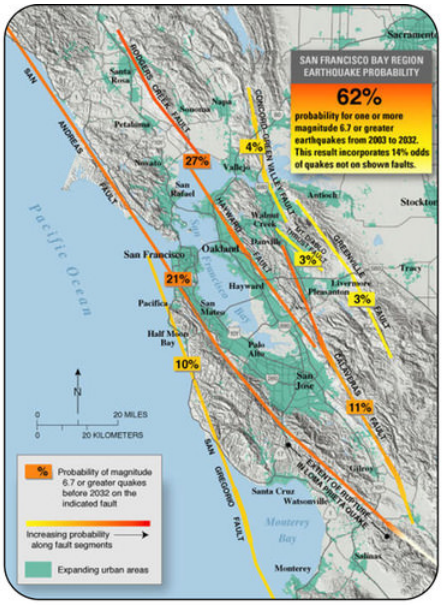
Predicting Where

Where an earthquake will occur is the easiest feature to predict. How would you predict this? Scientists know that earthquakes take place at plate boundaries. They tend to happen where they've happened before (**Figure** below).



This map shows earthquake probability regions in the United States.

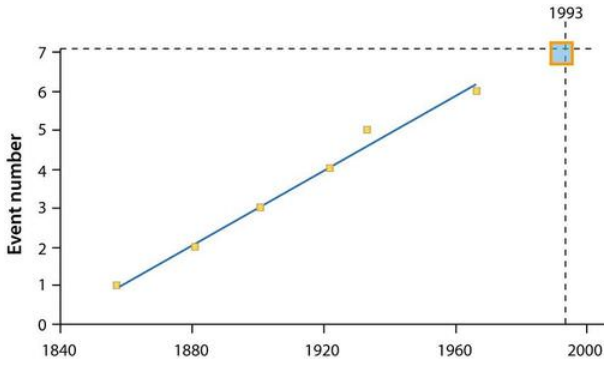
Fault segments behave consistently. A segment with frequent small earthquakes will likely continue to have frequent small earthquakes. A fault segment with infrequent huge earthquakes will likely have infrequent huge earthquakes. The image below shows the probabilities of earthquakes striking along various faults in the San Francisco area (**Figure** below). The time frame is between 2003 (when the figure was made) and 2032.



The probabilities of earthquakes striking along various faults in the San Francisco area between 2003 (when the work was done) and 2032.

Predicting When

When an earthquake will occur is much more difficult to predict. Stress on a fault builds up at the same rate over time. So earthquakes should occur at regular intervals. But, so far, scientists cannot predict when quakes will occur even to within a few years. Around Parkfield, California, an earthquake of magnitude 6.0 or higher occurs about every 22 years. So seismologists predicted that one would strike in 1993. But that quake came in 2004—11 years late (**Figure** below).



Trying to predict an earthquake in Parkfield, California.

Earthquake Signs

There are sometimes signs that a large earthquake is coming. There may be small quakes, called **foreshocks**. These can occur a few seconds to a few weeks before a major quake. Unfortunately, foreshocks are not very useful for predicting large earthquakes. Many quakes do not have foreshocks. Also, small earthquakes are not necessarily followed by a large earthquake.

There are other possible signs before an earthquake. The ground may tilt. Ground tilting is caused by the buildup of stress in the rocks. This may happen before a large earthquake, but it doesn't always. Water levels in wells may fluctuate. This is because water may move into or out of fractures before an earthquake. This is also an uncertain way to predict an earthquake. The difference in arrival times of P-waves and S-waves may decrease just before an earthquake occurs.

Folklore tells of animals behaving strangely just before an earthquake. Most people tell stories of these behaviors after the earthquake. Chinese scientists have actively studied the behavior of animals before earthquakes to see if there is a connection. So far nothing concrete has come of these studies.

https://k12.libretexts.org/@go/page/5419

Actions can reduce the damage once an earthquake has started. Seismometers can detect P-waves a few seconds before more damaging S-waves and surface waves arrive. In this time computers can shut down gas mains and electrical transmission lines. They can initiate protective measures in chemical plants, nuclear power plants, mass transit systems, airports, and roadways. Just a few seconds can be tremendously valuable.

Summary

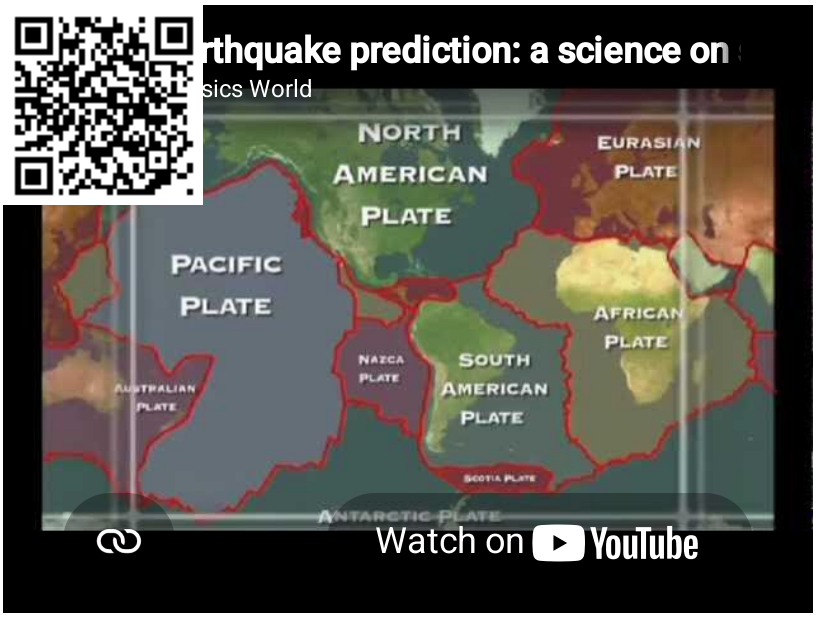
- A good prediction must indicate when and where an earthquake will take place.
- Fault segments behave the same way over time.
- Signs that an earthquakes may occur include foreshocks, ground tilting, water levels in wells, and the relative arrival times of P- and S-waves.

Review

1. Why is it easier to predict where a quake will occur than when?
2. List some of the signs that may predict earthquakes.
3. Along which fault in the San Francisco Bay area is a large earthquake most likely to strike?
4. The map of earthquake probability from the San Francisco Bay Area was made in 2003. How has the probability likely changed since there's been no major earthquake there in more than a decade?

Explore More

Use the resource below to answer the questions that follow.



1. What happened on April 18, 1906?
2. How fast is movement usually along San Andreas Fault? What is the rate of movement during a major quake?
3. Why is it difficult to predict earthquakes?
4. What information would a really great earthquake prediction give?
5. What can provide a warning for earthquakes about 10% of the time? Why is this warning system not all that reliable?
6. Why is monitoring the Earth from space useful? What does it tell scientists?

This page titled 6.19: Predicting Earthquakes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.20: Earthquake Damage




Is earthquake magnitude the most important factor in determining damage?

The type of construction has a tremendous effect on what happens during an earthquake. Damage and deaths are directly affected by the construction in an earthquake. For example, enormous damage was done in the 2011 Christchurch, New Zealand earthquake. However, far less was damaged in an earthquake of the same magnitude near the area in Iceland seen above.

Damage from Earthquakes

We know that earthquakes can kill lots of people. However, the ground shaking alone almost never kills people. Unlike in cartoons, the ground does not swallow people up! Deaths depend somewhat on an earthquake's size and the type of ground people inhabit. But a very important factor is the quality of the structures. People are killed when structures fall on them. More damage is done and more people are killed by the fires that follow an earthquake. Of course, the number of deaths is different from the property damage that a quake does.

What Makes Earthquakes Deadly?

What makes an earthquake deadly?

- Population density. The magnitude 9.2 Great Alaska Earthquake, near Anchorage, of 1964 resulted in only 131 deaths. At the time few people lived in the area (**Figure** below).



A landslide in a neighborhood in Anchorage, Alaska, after the 1964 Great Alaska earthquake.

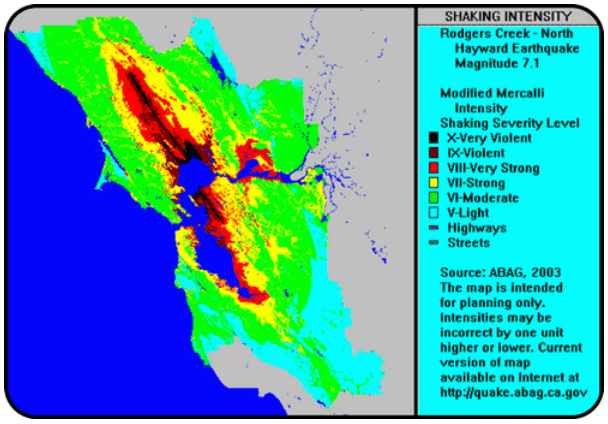
- Size, but not size. No one dies in a magnitude 1.0 earthquake. But large quakes do not always kill a lot of people. Only about 2,000 people died in the 1960 Great Chilean earthquake. This was the largest earthquake ever recorded. The Indian Ocean earthquake of 2004 was one of the largest ever. Still, most of the 230,000 fatalities were caused by the tsunami, not the earthquake.
- Ground type. Solid bedrock vibrates less than soft sediments, so there is less damage on bedrock. Sometimes sediments become saturated with water. They then undergo **liquefaction** and become like quicksand (**Figure** below). Soil on a hillside may become a landslide.



Liquefaction of sediments in Mexico City caused the collapse of many buildings in the 1985 earthquake.

City Planning

In earthquake-prone areas, city planners try to reduce hazards. They look at both the likelihood of a quake and the damage one would do. For example, in the San Francisco Bay Area, maps show how much shaking is expected for different ground types (**Figure** below). This allows planners to locate new hospitals and schools more safely.



The expected Modified Mercalli Intensity Scale for an earthquake of magnitude 7.1 on the northern portion of the Hayward Fault.



Summary

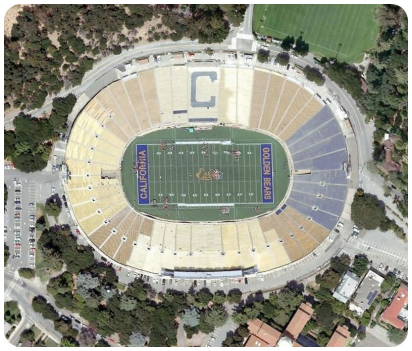
- Seismic waves rarely kill anyone. Structures falling on people and fires or tsunamis after the earthquake cause many more fatalities.
- City planning can lessen the damage done by earthquakes.
- Population density and ground type affect the number of fatalities.

Review

1. What causes liquefaction? Why is it damaging?
2. A 9.2 earthquake struck near Anchorage, Alaska in 1964, but few people died. If a similar quake struck today, how many fatalities would there be compared with the quake in 1964? Explain your reasoning.
3. Why do city planners look at Mercalli maps rather than predictions of earthquake magnitude?

This page titled 6.20: Earthquake Damage is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.21: Earthquake Safe Structures



Why is California Memorial Stadium called a "tectonic time bomb"?

The California Memorial Stadium is the home of football at the University of California, Berkeley. The site probably looked flat and easy to build on in 1922. But now scientists know that the Hayward Fault passes directly beneath both end zones. The stadium has been renovated in a $321 million project. The renovation involved 10 miles of steel cables, silicone fluid-filled shock absorbers, concrete piers, 3-feet of sand, plastic sheeting, and stone columns. Go Bears!

New Construction

New construction can be made safer in many ways:

- Skyscrapers and other large structures built on soft ground must be anchored to bedrock. Sometimes the bedrock lies hundreds of meters below the ground surface.
- The correct building materials must be used. Houses should bend and sway. Wood and steel are better than brick, stone, and adobe, which are brittle and will break.
- Larger buildings must sway, but not so much that they touch nearby buildings. Counterweights and diagonal steel beams are used to hold down sway.
- Large buildings can be placed on rollers so that they move with the ground.
- Buildings may be placed on layers of steel and rubber to absorb the shock of the waves.
- Connections, such as where the walls meet the foundation, must be made strong.
- In a multi-story building, the first story must be well supported.

The Transamerica Building in San Francisco, pictured below, rests on a 52-foot deep steel and concrete foundation. Steel rods reinforce the building internally and X-shaped trusses support it externally. In the 1989 Loma Prieta earthquake, the building shook for more than a minute and swayed more than 12 inches in each direction, but was not damaged.



The Transamerica Pyramid in San Francisco is more stable in an earthquake or in high winds than a rectangular skyscraper.

Retrofitting

Older buildings can be made more earthquake safe by **retrofitting**. Steel or wood can be used to reinforce a building's structure and its connections. Elevated freeways and bridges can also be retrofitted so that they do not collapse (**Figure** below).



This bridge in San Diego, California, was built in 1931. It was retrofitted and reopened in 2010 to meet earthquake standards.

Preventing Fire Damage

Fires often cause more damage than the earthquake. Fires start because seismic waves rupture gas and electrical lines. Breaks in water mains make it difficult to fight the fires (**Figure** below). The shapes of pipes can make a big difference. Straight pipes will break in a quake. Builders zigzag pipes so that they bend and flex when the ground shakes. In San Francisco, water and gas pipelines are separated by valves. Areas can be isolated if one segment breaks.



In the 1906 San Francisco earthquake, fire was much more destructive than the ground shaking.

Making Choices

Strong, sturdy structures are expensive to build. Communities must decide how safe to make their buildings. They must weigh how great the hazard is, what different building strategies will cost, and how much risk they are willing to take.



Summary

- New structures that are built to meet earthquake safety codes do much better in earthquakes.
- Old buildings can be retrofitted for better safety.
- Cost is an important factor in deciding how safe to make the structures in an area.

Review

1. What can be done to make a new building safer in an earthquake zone?
2. What can be done to retrofit an older building in an earthquake zone?
3. What can be done to reduce the damage from fire after an earthquake?
4. Should all buildings in all areas be built to the highest earthquake standards? What is a more cost-effective approach?

Explore More

Use the resource below to answer the questions that follow.



1. What is LA's most earthquake resistant building?
2. Why is this building chosen to be the safest?
3. Why is it called a floating building?
4. How many suspension points are in the building? How do they move?
5. What size earthquake should the building be able to withstand?
6. How far is it designed to move?

7. Why aren't all buildings in Los Angeles designed like this?

This page titled 6.21: Earthquake Safe Structures is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.22: Staying Safe in an Earthquake

How can you prepare for an earthquake?

If you live in earthquake country, the actions you take before, during, and after a quake could make the difference in your comfort for several days, or even your survival.

Protecting Yourself in an Earthquake

There are many things you can do to protect yourself before, during, and after an earthquake.

Before the Earthquake

- Have an engineer evaluate the house for structural integrity. Make sure the separate pieces—floor, walls, roof, and foundation—are all well-attached to each other.
- Bracket or brace brick chimneys to the roof.
- Be sure that heavy objects are not stored in high places.
- Secure water heaters all around and at the top and bottom.
- Bolt heavy furniture onto walls with bolts, screws, or strap hinges.
- Replace halogen and incandescent light bulbs with fluorescent bulbs to lessen fire risk.
- Check to see that gas lines are made of flexible material so that they do not rupture. Any equipment that uses gas should be well-secured.
- Everyone in the household should know how to shut off the gas line.
- Prepare an earthquake kit with three days supply of water and food, a radio, and batteries.
- Place flashlights all over the house and in the glove box of your car.
- Keep several fire extinguishers around the house to fight small fires.
- Be sure to have a first aid kit. Everyone should know basic first aid and CPR.
- Plan in advance how you will evacuate and where you will go. Do not plan on driving, as roadways will likely be damaged.

During the Earthquake

- If you are in a building, get beneath a sturdy table, cover your head, and hold on.
- Stay away from windows, mirrors, and large furniture.
- If the building is structurally unsound, get outside as fast as possible.
- If you are outside, run to an open area away from buildings and power lines that may fall.
- If you are in a car, stay in the car and stay away from structures that might collapse, such as overpasses, bridges, or buildings.

After the Earthquake

- Be aware that **aftershocks**, smaller quakes that come after the main trembler, are likely.
- Avoid dangerous areas like hillsides that may experience a landslide.
- Turn off water and power to your home.
- Call 911 only if there is a real emergency. Many people will be trying to get through to emergency services.
- Be prepared to wait for help or instructions. Assist others as necessary.

Summary

- Before an earthquake, be sure that your home is secure. Be sure that you have supplies to last a few days.
- During an earthquake, get to a safe place.
- After an earthquake, avoid dangerous situations, wait for instructions, and assist as necessary.

Review

1. What should you do to prepare for an earthquake?
2. What should you do during an earthquake?
3. What should you do after an earthquake?

Explore More

Use the resources below to answer the questions that follow.



1. When is California's 4th season?
2. What should you do to prepare your home?
3. What should your emergency plan include?
4. What should an emergency kit include?

This page titled 6.22: Staying Safe in an Earthquake is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

6.23: Geological Activity and Earthquakes- Challenge 3

1. How many seismic stations are needed to find the epicenter of an earthquake, and why?

Three, because this is the minimum number of circles that will intersect at one point.

2. To find the epicenter of an earthquake, ___ seismograms are needed.

three

3. The Richter Scale measures the magnitude of the ___ of an earthquake.

largest jolt of energy

4. An increase of one integer in the moment magnitude scale means ___.

thirty times more energy is released by an earthquake

5. In a ___ scale, each unit is an exponential increase over the previous unit.

logarithmic

6. Small earthquakes that come before large ones are known as ___.

foreshocks

7. Geologists cannot predict earthquakes, because ___.

they can't be sure when and where stress will be released along a fault.

8. Scientists can predict ___.

the region in which an earthquake will occur

9. ___ occurs when an earthquake causes sediments to saturate with water and become quicksand-like in consistency.

Liquefaction

This page titled 6.23: Geological Activity and Earthquakes- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

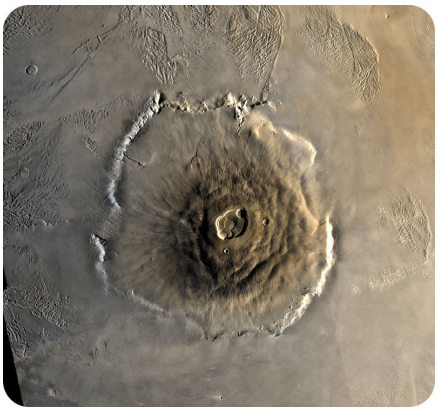
CHAPTER OVERVIEW

7: Geological Activity and Volcanoes

7.1: Volcanoes
7.2: Volcanoes at Plate Boundaries
7.3: Volcanic Hot Spots
7.4: Magma Composition
7.5: Explosive Eruptions
7.6: Effusive Eruptions
7.7: Predicting Volcanic Eruptions
7.8: Geological Activity and Volcanoes- Challenge 1
7.9: Types of Volcanoes
7.10: Supervolcanoes
7.11: Volcanic Landforms
7.12: Hot Springs and Geysers
7.13: Geological Activity and Volcanoes- Challenge 2

This page titled 7: Geological Activity and Volcanoes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

7.1: Volcanoes



Is Earth the only planet to have volcanoes?

On Earth, active volcanoes are found on all continents except Australia. Volcanoes even erupt under the ice on Antarctica! Volcanoes are also common elsewhere in the solar system. In fact, the biggest known volcano is on Mars. This image is of Olympus Mons, a shield volcano. Olympus Mons is three times the height of Mt. Everest, but its slopes are very gentle.

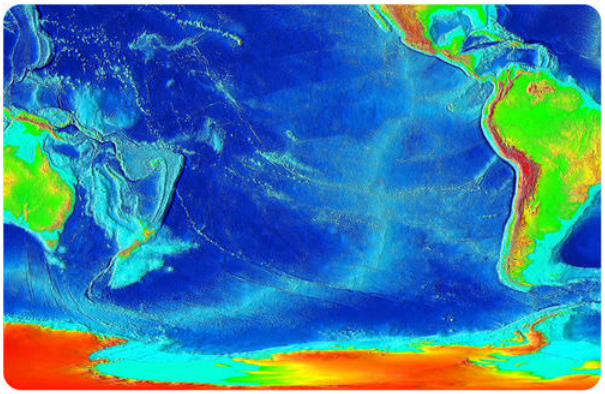
Volcanoes

A volcano is a vent through which the material from a magma chamber escapes. This may include lava, rock fragments, ash, and gases. Volcanic eruptions can come from many types of structures. Most people think of volcanoes as large, peaky cones. But volcanoes can be large and broad or tiny little cones. Volcanic eruptions can come from fractured domes, a vent in the ground, or from a giant hole in the ground.

Where They Are

Volcanoes are a vibrant manifestation of plate tectonics processes. Volcanoes are common along convergent and divergent plate boundaries. They are also found within lithospheric plates at hotspots. Wherever mantle is able to melt, volcanoes are likely to be the result.

The Pacific Ocean basin is a good place to look for different types of volcanoes. The light blue wavy line that goes up the right-center of the diagram is the East Pacific Rise. The rise is made of volcanoes at a divergent plate boundary. Trenches due to subduction are on the west and east sides of the basin. Subduction creates island arcs that are seen in the Western Pacific. Subduction also creates continental arcs seen along Central and South America. Hawaii is the line of volcanoes trending southeast-northwest near the center-top of the image (**Figure** below). The Hawaiian volcanoes are due to a hotspot.

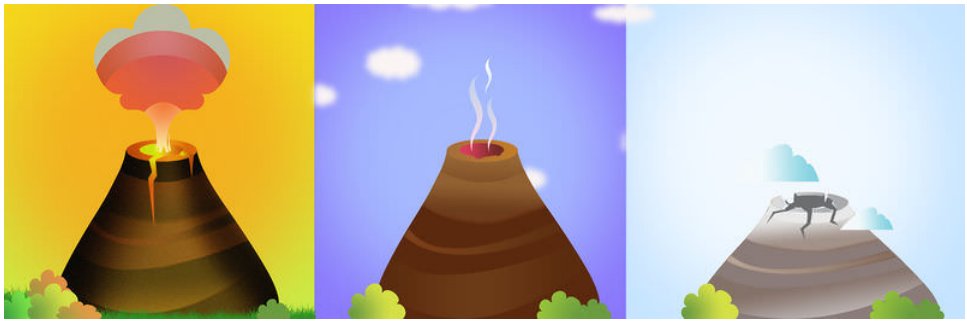


Volcanoes at divergent plate boundaries are in the East Pacific Rise. Convergent plate boundaries, where there are trenches, have volcanoes. Hotspot volcanoes are in chains in the middle of the ocean basin.

Creating Magma

Volcanoes erupt because mantle rock melts. This is the first stage in creating a volcano. How can rock melt? One way is if the temperature rises. Another way is if the pressure on the rock decreases; this will lower the rock's melting temperature. The melting temperature of a rock also goes down if water is added. Every time there is a volcanic eruption, one or more of these things happens. For each type of volcano mentioned in these concepts, think about how and why melting occurs.

Stages



Volcanoes can be active, dormant, or extinct.

Of all the volcanoes in the world, very few are erupting at any given time. Scientists question whether a volcano that is not erupting will ever erupt again and then describe it as active, dormant, or extinct.

- **Active**: Currently erupting or showing signs of erupting soon.
- **Dormant**: No current activity, but has erupted recently.
- **Extinct**: No activity for some time; will probably not erupt again.

Further Reading

Predicting Volcanic Eruptions

Summary

- Volcanoes are located along convergent and divergent plate boundaries. They can be found in the middle of plates at hot spots.
- Magma can be created when temperature rises, pressure lowers, or water is added.
- Volcanoes may be active, dormant, or extinct. This depends on whether there is the possibility of magma in their magma chambers.



Review

1. Where do most volcanoes occur? Why?
2. What is needed for magma to form?
3. If a volcano is dormant, can it become extinct?

This page titled 7.1: Volcanoes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

7.2: Volcanoes at Plate Boundaries

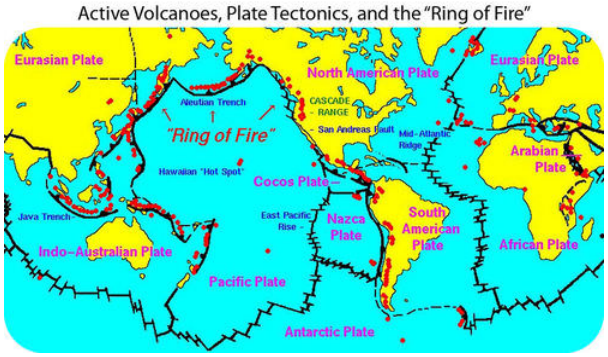


What good are plate boundaries?

Plate boundaries create natural resources, such as gold. But plate boundaries also create beautiful scenery like mountains. Volcanoes at convergent plate boundaries can be beautiful to look at. They can also be beautiful to visit or even climb!

Convergent Plate Boundaries

Converging plates can be oceanic, continental, or one of each. If at least one is oceanic, it will subduct. A subducting plate creates volcanoes. Many of the world's volcanoes are the result of subduction at a convergent plate boundary. A map of the world's active volcanoes is pictured below (**Figure** below).



World map of active volcanoes.

Melting

Mantle melting can come about three ways: (1) when the temperature rises, (2) if the pressure lowers (which lowers the melting point), and (3) if water is added, which lowers the melting point. Two of these (1 and 3) might explain why there are volcanoes at convergent plate boundaries: the temperature of the subducting plate increases as it sinks into the hot mantle (1). Sediments lying on top of the subducting plate contain water. As the sediments subduct, the water rises into the overlying mantle material. This lowers the melting temperature of the mantle (3). When the mantle above the subducting plate melts, volcanoes form above it. This leads to volcanoes in an island arc or continental arc.

Pacific Rim

Convergent plate boundaries are found around much of the Pacific Ocean basin. Trenches mark subduction zones. Volcanoes are found in an arc above those subduction zones.

The Cascades (**Figure** below) are a chain of volcanoes at a convergent boundary. In this region, an oceanic plate is subducting beneath a continental plate.



The Cascade Range is formed by volcanoes created from subduction of oceanic crust beneath the North American continent.

The Cascades have been active for 27 million years. The mountains we see today are no more than 2 million years old. The volcanoes receive a lot of winter snow, and many are covered by glaciers (**Figure** below).



Mt. Rainier, Washington.

Divergent Plate Boundaries

At divergent plate boundaries, hot mantle rock rises into the space where the plates are moving apart. As the hot mantle rock rises, it goes from higher to lower pressure. This is because there is no longer the weight of all the rock above it. Lower pressure lowers the melting temperature of the rock (2 in the previous section). This is why there is volcanism at divergent plate boundaries. Lava erupts through long cracks in the ground, or **fissures.**

Mid-Ocean Ridges

Volcanoes erupt at mid-ocean ridges, such as the Mid-Atlantic ridge. Seafloor spreading creates new seafloor in the rift valleys. This type of volcanism makes all of the ocean floor! Where a hotspot is located along the ridge, such as at Iceland, volcanoes grow high enough to create islands (**Figure** below).



A volcanic eruption on Iceland, where the Mid-Atlantic Ridge breaches the ocean surface.

Continental Rifting

Eruptions are found at divergent plate boundaries as continents break apart, known as **continental rifting**. The Mount Gahinga volcanoes (**Figure** below) are in the East African Rift between the African and Arabian plates. Baja California is breaking apart from mainland Mexico, also by continental rifting.



Mount Gahinga, a mountain in Uganda, located in the East African Rift valley.

Summary

- Subduction at convergent plate boundaries leads to melting and volcanoes.
- Convergent plate boundaries line the Pacific Ocean basin so that volcanic arcs line the region.
- Melting at divergent plate boundaries is due to release of pressure.
- At mid-ocean ridges seafloor is pulled apart and new seafloor is created. Rifting in a continent can create a new ocean eventually.

Review

1. What are the two sources of melting at convergent plate boundaries?
2. Why are there so many volcanoes around the Pacific Ocean basin?
3. What causes melting at divergent plate boundaries?

Explore More

Use the resource below to answer the questions that follow.



1. Where does the melted mantle rock rise?
2. What does spreading cause?
3. What happens where there is plate convergence?
4. How is carbon dioxide released from the rock?
5. How is carbon dioxide returned to the atmosphere?

This page titled 7.2: Volcanoes at Plate Boundaries is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

7.3: Volcanic Hot Spots

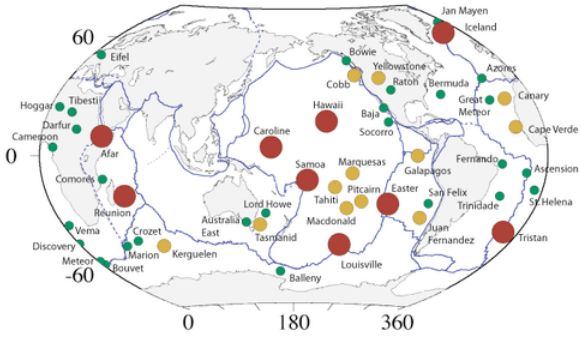


What does an intraplate eruption look like?

The Hawaiian Islands are formed from a hotspot beneath the Pacific Ocean. Volcanoes grow above the hotspot. Lava flows down the hillsides, and some of it reaches the ocean, causing the islands to grow. Too hot now, but a great place in the future for beach lovers!

Volcanic Hotspots

Some volcanoes form over active **hotspots**. Scientists count about 50 hotspots on the Earth. Hotspots lie directly above a column of hot rock called a **mantle plume**. Mantle plumes continuously bring hot rock up from the mantle toward the crust (**Figure** below). The rock melts due to the release of pressure.



Mantle plumes are found all over the world, especially in the ocean basins. The size of the eruptions is different at different plumes.

Hotspots may be in the middle of a tectonic plate. They create intraplate volcanoes.

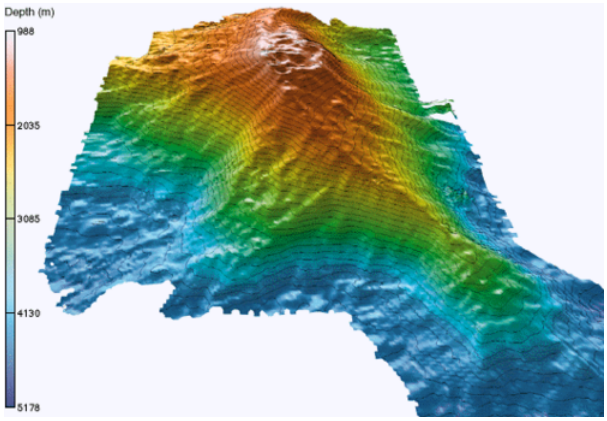
Hotspots Within Oceans

Hotspots are much more common beneath ocean crust. This is because ocean crust is thinner. The plume can more easily penetrate this crust. As the tectonic plates move above a hotspot, they form a chain of volcanoes. The islands of Hawaii formed over a hotspot in the middle of the Pacific plate. The volcanoes are massive shield volcanoes that together create the islands. The lavas are mafic and have low viscosity. These lavas produce beautiful ropy flows of pāhoehoe and clinkery flows of a'a. These lava types will be described in more detail in the concept Effusive Eruptions.

The Hawaii hotspot has been active for tens of millions of years. The volcanoes of the Hawaiian Islands formed at this hotspot. Older volcanoes that formed at the hotspot have eroded below sea level. These are called the Emperor Seamounts.

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

Loihi seamount is currently active beneath the water southeast of the Big Island of Hawaii. One day, the volcano will rise above sea level. Loihi will join the volcanoes of the island or create a new island (**Figure** below).



A bathymetric map of Loihi seamount. Loihi will be the next shield volcano in the Hawaiian-Emperor chain.

A hotspot beneath Hawaii, the origin of the voluminous lava produced by the shield volcano Kilauea can be viewed in this video.



Hotspots may also be active at plate boundaries. This is especially common at mid-ocean ridges. Iceland is formed by a hotspot along the Mid-Atlantic Ridge.

Hotspots Within Continents

Hotspots are found within continents, but not as commonly as within oceans. They are not common because it takes a massive mantle plume to penetrate the thick continental crust. Eruptions from these hotspots are rare but massive. The Yellowstone hotspot is a famous example of a continental hotspot.

Summary

- Volcanoes grow above hotspots. A hotspot is a zone of melting above a mantle plume.
- Hotspot volcanoes are better able to penetrate oceanic crust than continental crust. We see many more hotspot volcanoes in the oceans.
- Shield volcanoes commonly form above hotspots in the oceans.

Review

1. What causes melting at a hotspot?
2. Describe how the Hawaiian hotspot formed a chain of volcanoes.
3. Relative to the Hawaiian hotspot, where in the chain is the oldest volcano? Where is the youngest?
4. What do you think the future for Loihi seamount will be?

Explore More

Use the resource below to answer the questions that follow.



1. What is a hotspot?
2. What does a thermal plume allow for?
3. What happens during convection?
4. What carries the volcanoes away from a hotspot?
5. Why does the volcano subside when it moves off the hotspot?

This page titled 7.3: Volcanic Hot Spots is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

7.4: Magma Composition

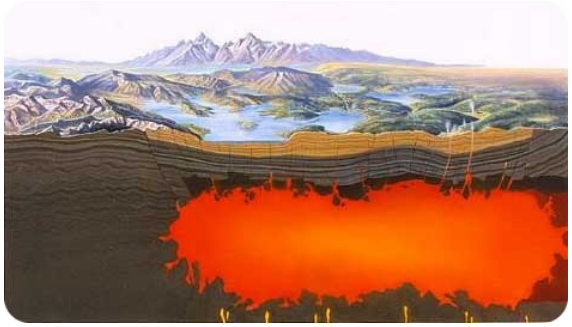


Are all volcanic eruptions alike?

The type of eruption a volcano has depends on the type of magma in its chamber. Some eruptions are explosive. Some eruptions are quiet. All eruptions are amazing!

Magma

Magma forms deep beneath the Earth's surface. Rock melts below the surface under tremendous pressure and high temperatures. Molten rock flows like taffy or hot wax. Most magmas are formed at temperatures between 600°C and 1300°C (**Figure** below).



Magma beneath a volcano erupts onto the volcano's surface. This image is of a magma chamber underlying Yellowstone.

Magma collects in **magma chambers** beneath Earth's surface. Magma chambers are located where the heat and pressure are great enough to melt rock. These locations are at divergent or convergent plate boundaries or at hotpots.

The chemistry of a magma determines the type of igneous rock it forms. The chemistry also determines how the magma moves. The higher the amount of silica in the magma, the higher the viscosity. **Viscosity** is a liquid's resistance to flow. Viscous magmas tend to stay below the surface or erupt explosively. These are felsic magmas, which are high in silica. When magma is fluid and runny, it is not viscous. This magma often reaches the surface by flowing out in rivers of lava. These are low-silica mafic magmas.

Lava

The way lava flows depends on what it is made of. Thick lava doesn't flow easily. It may block the vent of a volcano. If the lava traps a lot of gas, the pressure builds up. After the pressure becomes greater and greater, the volcano finally explodes. Ash and pyroclasts shoot up into the air. Pumice, with small holes in solid rock, shows where gas bubbles were when the rock was still molten.

Fluid lava flows down mountainsides. The rock that the flow becomes depends on which type of lava it is and where it cools. The three types of flows are a'a, pāhoehoe, and pillow lava.

- A'a lava is the thickest of the non-explosive lavas. A'a forms a thick and brittle crust, which is torn into rough, rubbly pieces. The solidified surface is angular, jagged, and sharp (**Figure** below). A'a can spread over large areas as the lava continues to flow underneath.



A'a flows can be found in Hawaii and are much sharper and more jagged than pāhoehoe.

- Pāhoehoe lava is thinner than a'a and flows more readily. Its surface looks more wrinkly and smooth. Pāhoehoe lava flows in a series of lobes that form strange, twisted shapes and natural rock sculptures (**Figure** below). Pāhoehoe lava can form lava tubes. The outer layer of the lava flow cools and solidifies. The inner part of the flow remains fluid. The fluid lava flows through and leaves behind a tube.



Ropy pahoehoe flows are common on Kilauea Volcano in Hawaii.

- Pillow lava is created from lava that enters the water. The volcanic vent may be underwater. The lava may flow over land and enter the water (**Figure** below). Once in the water, the lava cools very quickly. The lava forms round rocks that resemble pillows. Pillow lava is particularly common along mid-ocean ridges.



Lava erupting in the water can form bulbous, pillowy forms.



Summary

- Magmas differ in composition, which affects viscosity. Magma composition has a large effect on how a volcano erupts.
- Felsic lavas are more viscous and erupt explosively or do not erupt. Mafic lavas are less viscous and erupt effusively.
- Different lava types create different rock types, such as pahoehoe and a'a. Lavas that cool underwater become pillow lavas.

Review

1. What is the role of a magma chamber in a volcanic eruption?
2. How is magma composition related to viscosity?
3. Compare and contrast a'a, pahoehoe, and pillow lavas.

This page titled 7.4: Magma Composition is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

7.5: Explosive Eruptions



What would cause a giant explosion like this one?

The type of eruption a volcano has depends on the composition of the magma. Silica-rich, felsic magma is viscous and can trap a lot of gas. So these magmas produce explosive eruptions. Silica-poor, mafic magmas are not as viscous and trap little gas. These magmas produce quiet eruptions. Which type of eruption do you think is safest to be near?

Eruptions

All volcanoes share the same basic features. First, mantle rock melts. The molten rock collects in magma chambers that can be 160 kilometers (100 miles) beneath the surface. As the rock heats, it expands. The hot rock is less dense than the surrounding rock. The magma rises toward the surface through cracks in the crust. A volcanic **eruption** occurs when the magma reaches the surface. Lava can reach the surface gently or explosively.

Explosive Eruptions

An **explosive eruption** produces huge clouds of volcanic ash. Chunks of the volcano fly high into the atmosphere. Explosive eruptions can be tens of thousands of times as powerful as an atomic bomb (**Figure** below). Hot magma beneath the surface mixes with water. This forms gases. The gas pressure grows until it must be released. The volcano erupts in an enormous explosion.



Eyjafjallajökull volcano in Iceland spewed ash into the atmosphere in 2010. This was a fairly small eruption, but it disrupted air travel across Europe for six days.

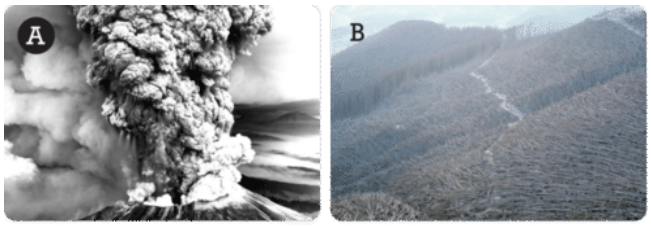
Ash and particles shoot many kilometers into the sky. The material may form a mushroom cloud, just like a nuclear explosion. Hot fragments of rock, called **pyroclasts**, fly up into the air at very high speeds. The pyroclasts cool in the atmosphere. Some ash may

stay in the atmosphere for years. The ash may block out sunlight. This changes weather patterns and affects the temperature of the Earth. For a year or two after a large eruption, sunsets may be especially beautiful worldwide.

Volcanic gases can form poisonous, invisible clouds. The poisonous gases may be toxic close to the eruption. The gases may cause environmental problems like acid rain and ozone destruction.

Mt. St. Helens

In 1980, Mount St. Helens, located between Portland, Oregon and Seattle, Washington, erupted explosively. The eruption killed 57 people, destroyed 250 homes, and swept away 47 bridges. The volcano blew off its top so that it lost over 400 meters (1,300 feet) of height. Mt. St. Helens is still active (**Figure** below). Within the crater, a new lava dome formed.

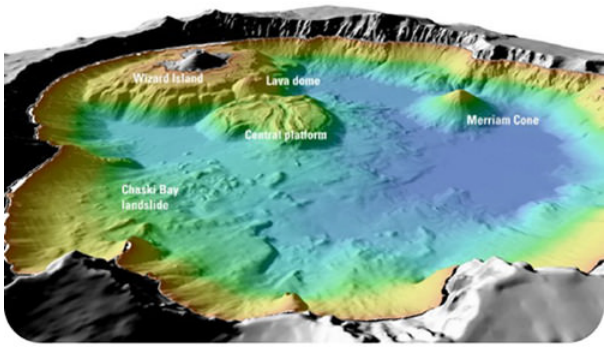


(A) Mount St. Helens eruption on May 18, 1980. Mt. Adams is in the background on the right. (B) The eruption of Mt. St. Helens blew down acres of trees like they were toothpicks.

Much of the damage in the eruption was due to pyroclastic flows. **Pyroclastic flows** of pyroclasts and ash knock down everything in their path. The temperature inside a pyroclastic flow may be as high as 1,000°C (1,800°F).

Lahars are mixtures of ash and water that travel down river valleys. On Mount St. Helens, the eruption melted glaciers. The water mixed with ash from the eruption and created tremendous lahars. The lahars raced down valleys and knocked out many bridges.

Mt St. Helens was not a very large eruption for the Cascades. Mt. Mazama blew itself apart in an eruption about 42 times more powerful than Mount St. Helens in 1980. Today all that remains of that huge stratovolcano is Crater Lake (**Figure** below and **Figure** below).



Crater Lake fills the caldera of the collapsed Mt. Mazama. The bathymetry of the lake shows volcanic features such as cinder cones.



https://k12.libretexts.org/@go/page/5429

Crater Lake, located in Crater Lake National Park in southern Oregon.



Summary

- Felsic magmas erupt explosively, creating pyroclastic eruptions.
- Pyroclastic eruption types include tephra, ash, and lahars.
- Mt. Mazama blew its top off and then collapsed, creating Crater Lake in Oregon.

Review

1. What is the role of water in an explosive eruption?
2. Why do felsic magmas erupt explosively?
3. How do volcanic gases affect the atmosphere?

This page titled 7.5: Explosive Eruptions is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

7.6: Effusive Eruptions



Isn't this an explosive eruption?

This is a strombolian eruption. This type of eruption was named for Mt. Stromboli in Italy. Strombolian eruptions spew lava into the air, but these eruptions do not have a massive explosion. They create lava flows.

Effusive Eruptions

Mafic magma creates gentler, **effusive eruptions**. There is little or no gas. The lava is thin and fluid so that it flows over the ground like a river. Mafic magma pushes toward the surface through fissures. Eventually, the magma reaches the surface and erupts through a vent (**Figure** below). Effusive eruptions are common in Hawaii, where lavas are mafic.



In effusive eruptions, lava flows readily, producing rivers of molten rock.



Effusive Eruptions Damage

Effusive eruptions rarely kill anyone because they move slowly. People can usually be evacuated before an effusive eruption. Still, effusive eruptions can be destructive. There is not much anyone can do to stop a lava flow from destroying a building or road (**Figure** below).



A road is overrun by an eruption at Kilauea volcano in Hawaii.

Summary

- Mafic magma creates effusive eruptions. The pressure builds but the lava flows fairly quietly.
- Effusive eruptions cause damage but rarely kill anyone.
- Mafic magma cools into different types of flows like a'a, pāhoehoe, and pillow lava.

Review

1. Why do mafic lavas flow rather than explode?
2. Compare and contrast lavas from explosive and effusive eruptions.
3. Why do effusive eruptions sometimes cause a lot of damage?

Explore More



1. Why is Kilauea considered one of the most active volcanoes in the world?
2. What does the height of Kilauea's lava lakes mean regarding upcoming eruptions?
3. Where does the lava go?
4. What do shield volcano eruptions look like?
5. Why is it difficult to predict a volcanic eruption from a volcano like Kilauea?
6. What would scientists need to know to better be able to predict eruptions from Kilauea?

This page titled 7.6: Effusive Eruptions is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

7.7: Predicting Volcanic Eruptions



What is one of the deadliest science jobs?

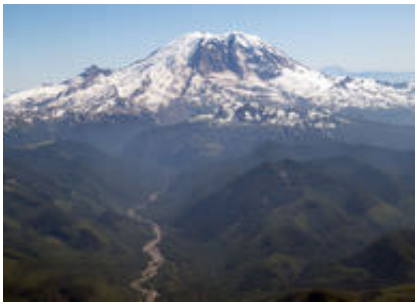
No one can predict exactly when a volcanic eruption will take place. There are clues, but no one knows exactly when. Sometimes a volcano will erupt when scientists are studying it. Volcanologists have a high fatality rate among scientists because forecasting eruptions is so difficult.

Predicting Volcanic Eruptions

Volcanic eruptions can be devastating, particularly to the people who live close to volcanoes. Volcanologists study volcanoes to be able to predict when a volcano will erupt. Many changes happen when a volcano is about to erupt. Even so, eruptions are very difficult to predict.

History of Volcanic Activities

Scientists study a volcano's history to try to predict when it will next erupt. They want to know how long it has been since it last erupted. They also want to know the time span between its previous eruptions. Scientists watch both active and dormant volcanoes closely for signs that show they might erupt.



Mount Rainier in Washington State is currently dormant. The volcano could, and probably will erupt again.

Earthquakes

Earthquakes may take place every day near a volcano. Before an eruption, the number and size of earthquakes increases. This is the result of magma pushing upward into the magma chamber. This motion causes stresses on neighboring rock to build up. Eventually the ground shakes. A continuous string of earthquakes may indicate that a volcano is about to erupt. Scientists use seismographs to record the length and strength of each earthquake.

Slope Tilt

All that magma and gas pushing upward can make the volcano's slope begin to swell. Ground swelling may change the shape of a volcano or cause rock falls and landslides. Most of the time, the ground tilting is not visible. Scientists detect it by using tiltmeters, which are instruments that measure the angle of the slope of a volcano.

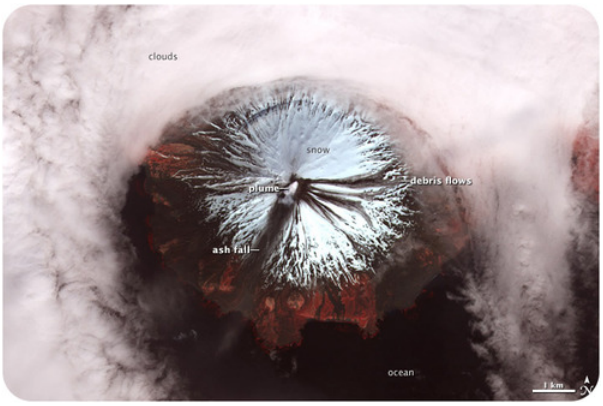
CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Gases

Scientists measure the gases that escape from a volcano to predict eruptions. Gases like sulfur dioxide (SO_2), carbon dioxide (CO_2), hydrochloric acid (HCl), and water vapor can be measured at the site. Gases may also be measured from satellites. The amounts of gases and the ratios of gases are calculated to help predict eruptions.

Remote Monitoring

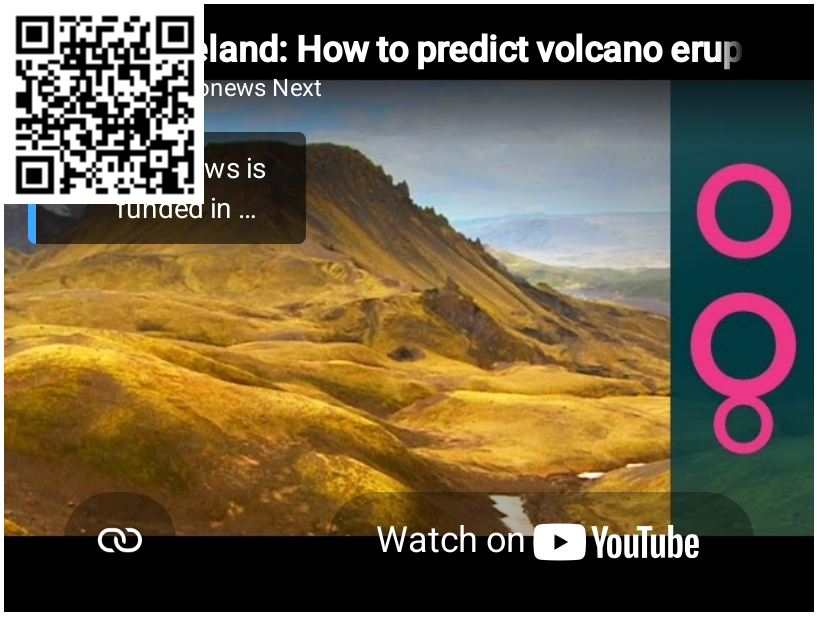
Satellites can be used to monitor more than just gases (**Figure** below). Satellites can look for high temperature spots or areas where the volcano surface is changing. This allows scientists to detect changes accurately and safely.



Mount Cleveland, in Alaska, is monitored by satellite.

Costs and Benefits of Predictions

No scientist or government agency wants to announce an eruption and then be wrong. There is a very real cost and disruption to society during a large-scale evacuation. If the scientists are wrong, people would be less likely to evacuate the next time scientists predicted an eruption. But if scientists predict an eruption that does take place, it could save many lives.



Summary

- Volcanologists use several lines of evidence to try to forecast volcanic eruptions.
- Magma moving beneath a volcano will cause earthquakes and slope deformation. Gases may be released from the magma out of the volcano vent.
- Deciding whether to call for an evacuation is very tricky.

Review

1. What do scientists look for to see if a volcano might erupt someday?
2. What are the signs that magma is moving beneath a volcano?
3. For what characteristics is a volcano monitored remotely?
4. Why is it helpful for scientists to be able to predict volcanic eruptions?

This page titled 7.7: Predicting Volcanic Eruptions is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

7.8: Geological Activity and Volcanoes- Challenge 1

1. A volcano on the Hawai'i hotspot is ___; a volcano that has just moved off the hotspot is ___; a volcano that is far from the hotspot is ___.

active; dormant; extinct

2. Volcanoes are located around ___ and ___ plate boundaries.

convergent; divergent

3. Mantle rock melts to form ___ if temperature rises, pressure decreases, or water mixes with the mantle.

magma

4. Lava erupts through long cracks in the ground called ___.

fissures

5. ___ are a chain of volcanoes in the Pacific Northwest of North America that formed on a convergent plate boundary.

The Cascades

6. Which of the following is/are example(s) of volcanic arcs: the Himalayas, Mount Gahinga, or the Cascades?

The Cascades

7. Hotspot volcanoes form when ___.

a plate moves over a mantle plume

8. A hotspot beneath the Big Island of Hawai'i is currently covered by the ___ volcano.

Kilauea

9. Eruptions of hotspots beneath continents are extremely explosive, because ___.

a mantle plume must be massive to penetrate continental crust

10. Magma viscosity is related to magma composition: the higher the silica content, the ___ the viscosity.

higher

11. ___ is a fluid's resistance to flow.

viscosity

12. ___ lava is low in silica, less viscous, and erupts effusively.

Mafic

13. A ___ is a volcanic mudflow made of ash and water, while a ___ is made of hot fragments of rock and ash.

lahar; pyroclastic flow

14. Before an explosive eruption, ___ pressure builds until it is released violently.

gas

15. Mt. Shasta, an active volcano, is located in ___.

California

This page titled 7.8: Geological Activity and Volcanoes- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

7.9: Types of Volcanoes



What does an active volcano look like?

Climbing up Mount St. Helens and looking into the crater at the steaming dome is an incredible experience. The slope is steep and the landscape is like something from another planet. Nothing's alive up there, except maybe a bird. When you're standing on the top, you can see other Cascades volcanoes: Mts. Adams, Rainier, Hood, Jefferson, and sometimes more.

Volcanoes

A volcano is a vent through which molten rock and gas escape from a magma chamber. Volcanoes differ in many features, such as height, shape, and slope steepness. Some volcanoes are tall cones, while others are just cracks in the ground (**Figure** below). As you might expect, the shape of a volcano is related to the composition of its magma. The three types of volcanoes are composite, shield, and cinder cones.

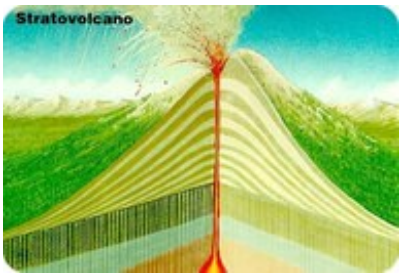
Composite Volcanoes



Mt. Fuji is a well-known composite volcano.

Figure above shows Mt. Fuji, a classic example of a composite volcano. **Composite volcanoes** have broad bases and steep sides. These volcanoes usually have a large crater at the top. The crater was created during the volcano's last eruption.

Composite volcanoes are also called stratovolcanoes. This is because they are formed by alternating layers (strata) of magma and ash (**Figure** below). The magma that creates composite volcanoes tends to be thick. The steep sides form because the lava cannot flow too far from the vent. The thick magma may also create explosive eruptions. Ash and pyroclasts erupt into the air. Much of this material falls back down near the vent. This creates the steep sides of stratovolcanoes. The composition of magma that erupts at composite volcanoes is usually felsic (rhyolite) or intermediate (andesite).



A cross section of a composite volcano reveals alternating layers of rock and ash. Frequently there is a large crater at the top from the last eruption.

Composite volcanoes are common along convergent plate boundaries. When a tectonic plate subducts, it melts. This creates the thick magma needed for these eruptions. The Pacific Ring of Fire is dotted by composite volcanoes.

Shield Volcanoes



Mauna Kea volcano in Hawaii.

Shield volcanoes look like a huge ancient warrior's shield laid down. Pictured above is Mauna Kea Volcano (**Figure** above) taken from Mauna Loa Volcano. Both volcanoes are part of the Big Island of Hawaii. A shield volcano has a very wide base. It is much flatter on the top than a composite volcano. The lava that creates shield volcanoes is relatively thin. The thin lava spreads out. This builds a large, flat volcano, layer by layer. The composition of lava at shield volcanoes is mafic. Shield volcanoes are very large. For example, the Mauna Loa Volcano has a diameter of more than 112 kilometers (70 miles). The volcano forms a significant part of the island of Hawaii. The top of nearby Mauna Kea Volcano is more than ten kilometers (6 miles) from its base on the seafloor.

Shield volcanoes often form along divergent plate boundaries. They also form at hotspots, like Hawaii. Shield volcano eruptions are non-explosive.



Cinder Cones

Cinder cones are the smallest and most common type of volcano. Cinder cones have steep sides like composite volcanoes. But they are much smaller, rarely reaching even 300 meters in height. Cinder cones usually have a crater at the summit. Cinder cones are composed of small fragments of rock, called cinders. The cinders are piled on top of one another. The cinders can be mafic, intermediate, or felsic in composition. These volcanoes usually do not produce streams of lava. Cinder cones often form near larger volcanoes. Most composite and shield volcanoes have nearby cinder cones.

Cinder cones usually build up very rapidly. They erupt only for a short time. Many produce only one eruption. For this reason, cinder cones do not reach the sizes of stratovolcanoes or shield volcanoes (**Figure** below).



A cinder cone volcano in Lassen National Park.

Further Reading

Supervolcanoes

Volcanic Landforms

Hot Springs and Geysers

Summary

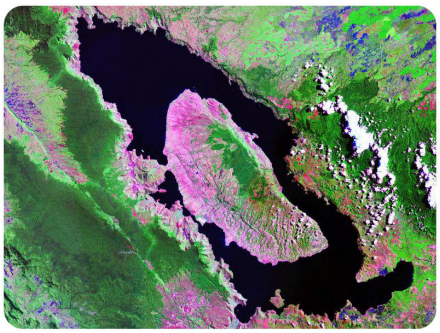
- Magma composition determines both eruption type and volcano type.
- Composite volcanoes are common at convergent boundaries. Shield volcanoes are produced at divergent plate boundaries and intraplate.
- Cinder cones are made of small fragments of a variety of compositions usually from a single eruption. They are found with composite and shield volcanoes.

Review

1. Why do mafic lavas produce shield-shaped volcanoes? Why do felsic lavas produce cone-shaped volcanoes?
2. How did composite and shield volcanoes earn their names?
3. What features would you use to identify each of the three volcano types?

This page titled 7.9: Types of Volcanoes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

7.10: Supervolcanoes



Is this a supervolcano?

Lake Toba in Indonesia is 100 km (62 mi) by 30 km (19 mi). The water fills a giant caldera created by a supervolcano. The eruption took place about 75,000 years ago, Earth's largest eruption in the past 25 million years. So much material was ejected into space that there was a 6- to 10-year volcanic winter. Some scientists think that only 10,000 humans survived worldwide. The numbers of other mammals also plummeted.

Calderas

During a massive eruption, all of the material in a magma chamber may be ejected. Without support, the mountain above the empty chamber may collapse. This produces a huge **caldera**. Calderas are generally round, bowl-shaped formations (**Figure** below).



Crater Lake, Oregon is the remnant of Mount Mazama. After an enormous eruption the mountain collapsed, forming a caldera. Crater Lake should actually be named Caldera Lake. Wizard Island, within the lake, is a cinder cone.

Supervolcanoes

Supervolcano eruptions are extremely rare in Earth's history. It's a good thing, because they are unimaginably large. To be considered a supervolcano, a volcano must erupt more than 1,000 cubic km (240 cubic miles) of material. Imagine how large that is compared with 1.2 km^3 for Mount St. Helens. Mount Pinatubo, which erupted in the Philippines in 1991, ejected only 25 km^3 of material. Not surprisingly, supervolcanoes are the most dangerous type of volcano.

Supervolcano Eruptions

The exact cause of supervolcano eruptions is still debated. However, scientists think that a very large magma chamber erupts entirely in one catastrophic explosion. This creates a caldera into which the surface collapses (**Figure** below). The composition of the eruption is felsic or highly felsic.



The caldera at Santorini in Greece is so large that it can be seen only by satellite.

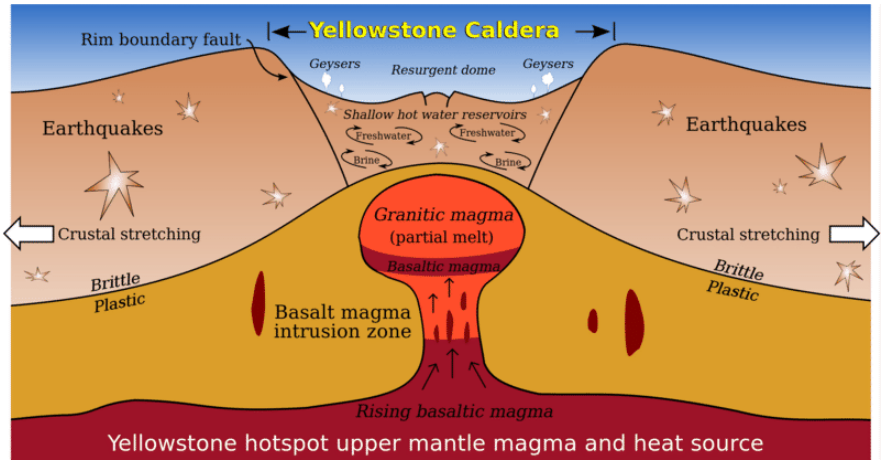
Yellowstone Caldera

The largest supervolcano in North America is beneath Yellowstone National Park in Wyoming. Much of the national park lies within the enormous Yellowstone Caldera. It is so large that you can stand on one rim and not see the other side.



What would cause such a giant caldera?

Yellowstone sits above a hotspot that has erupted catastrophically three times: 2.1 million, 1.3 million, and 640,000 years ago. Yellowstone has produced many smaller (but still enormous) eruptions more recently (**Figure** below). Fortunately, current activity at Yellowstone is limited to the region's famous geysers. No one knows when the supervolcano will erupt again.



https://k12.libretexts.org/@go/page/5434

The Yellowstone hotspot has produced enormous felsic eruptions. The Yellowstone caldera collapsed in the most recent super eruption.

Supervolcano Eruptions and Life on Earth

A supervolcano could change life on Earth as we know it. Ash could block sunlight so much that photosynthesis would be reduced and global temperatures would plummet. Volcanic eruptions could have contributed to some of the mass extinctions in our planet's history. No one knows when the next super eruption will be.

Summary

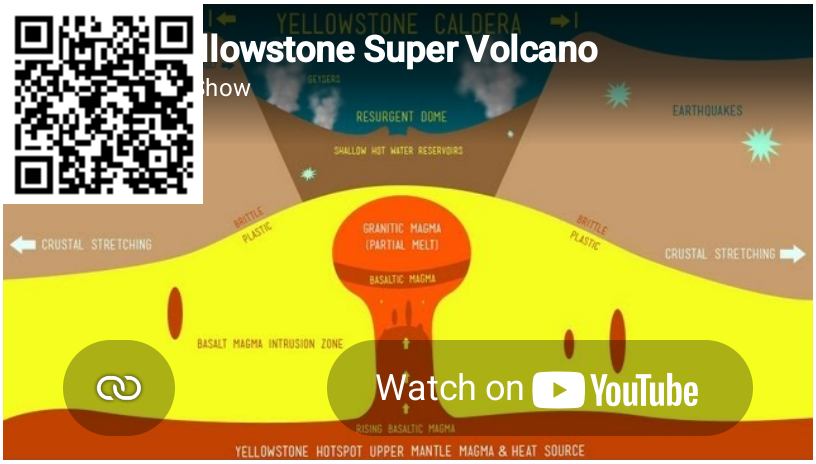
- A caldera forms after a massive eruption. The top of the volcano collapses, forming a basin.
- Supervolcano eruptions are rare but massive and deadly.
- Yellowstone Caldera is a supervolcano that has erupted catastrophically three times.
- Supervolcano eruptions can change the course of life on Earth.

Review

1. What is the composition of supervolcano eruptions? Why are these eruptions so massive?
2. What is the source of volcanism for the supervolcano at Yellowstone?
3. How could a supervolcano eruption change the course of life on Earth?

Explore More

Use the resource below to answer the questions that follow.



1. What is one of the Earth's largest volcanoes? Where is it found?
2. Why is Yellowstone considered a supervolcano?
3. How many times has Yellowstone erupted? When was the most recent?
4. When was the last supervolcano eruption?
5. What effect do scientists think the last supervolcano eruption had on climate?

This page titled 7.10: Supervolcanoes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

7.11: Volcanic Landforms



Why does this massive rock stick out like this?

Shiprock in New Mexico is visible for many miles around. Shiprock is the neck of an old volcano. The magma cooled into a rock that was harder than the surrounding volcano. So the volcano eroded away and left the neck. The peak is on the land of the Navajo Nation, for whom it has great religious significance.

Landforms from Lava

Extrusive igneous rocks cool at the surface. Volcanoes are one type of feature that forms from extrusive rocks. Several other interesting landforms are also extrusive features. Intrusive igneous rocks cool below the surface. These rocks do not always remain hidden. Rocks that formed in the crust are exposed when the rock and sediment that covers them erode away.

Volcanoes and Vents

The most obvious landforms created by lava are volcanoes. These are mostly cinder cones, composite volcanoes, and shield volcanoes. Eruptions also take place through other types of vents, commonly from fissures (**Figure** below). The eruptions that created the entire ocean floor are essentially fissure eruptions.



A fissure eruption on Mauna Loa in Hawaii travels toward Mauna Kea on the Big Island.

Lava Domes

When lava is thick, it flows slowly. If thick lava makes it to the surface, it cannot flow far from the vent. It often stays right in the middle of a crater at the top of a volcano. Here the lava creates a large, round **lava dome** (**Figure** below). Lava flows often make mounds right in the middle of craters at the top of volcanoes (**Figure** below).



Lava domes may form in the crater of composite volcanoes, as at Mount St. Helens.

Lava Plateaus

A **lava plateau** is made of a large amount of fluid lava. The lava flows over a large area and cools. This creates a large, flat surface of igneous rock. Lava plateaus may be huge. The Columbia Plateau covers over 161,000 square kilometers (63,000 square miles). It makes up parts of the states of Washington, Oregon, and Idaho (**Figure** below).



Layer upon layer of basalt have created the Columbia Plateau, which covers more than 161,000 square kilometers (63,000 square miles) in Washington, Oregon, and Idaho.

Land

New land is created in volcanic eruptions. The Hawaiian Islands are shield volcanoes. These volcanoes formed from fluid lava (**Figure** below). The island grows as lava is added on the coast. New land may also emerge from lava that erupts from beneath the water. This is one way that new land is created.



Lava erupts into the Pacific Ocean in Hawaii, creating new land.

Landforms from Magma

Magma that cools underground forms **intrusions** (**Figure** below). Usually this magma is very viscous, felsic magma. This magma does not rise easily and so cools slowly underground. Intrusions become land formations if they are exposed at the surface by uplift and erosion.



The granite intrusions that form the Sierra Nevada in California are well exposed.

Summary

- Landforms created by lava include volcanoes, domes, and plateaus.
- New land can be created by volcanic eruptions.
- Landforms created by magma include volcanic necks and domes.

Review

1. Why is it important that volcanic eruptions can form new land?
2. How do lava plateaus form?
3. Describe the granite exposed in the photo of the Sierra Nevada. What is its history?

Explore More

Use the resource below to answer the questions that follow.



https://k12.libretexts.org/@go/page/5435

1. What type of lava is produced by volcanoes? What does it look like when cooled?
2. How did the columns in the video form?
3. How was Fingal's cave formed?
4. Describe a basalt lava that doesn't contain much gas flows.
5. How does basalt behave when it has a lot of gas trapped within it?
6. How does the violence of the eruption of the flow with the gas compare to an eruption of a felsic volcano like Mt. St. Helens or Mt. Pinatubo?

This page titled 7.11: Volcanic Landforms is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

7.12: Hot Springs and Geysers



Hot spring, anyone?

Hot water from underground can pool at hot springs. Even some animals enjoy relaxing in nature's hot tubs. Care to join them?

Hot Springs and Geysers

Water sometimes comes into contact with hot rock. The water may emerge at the surface as either a hot spring or a geyser.

Hot Springs

When hot water gently rises to the surface, it creates a **hot spring**. A hot spring forms where a crack in the Earth allows water to reach the surface after being heated underground. Many hot springs are used by people and animals as natural hot tubs (**Figure** below). Some people believe that hot springs can cure illnesses. Hot springs are found all over the world, even in Antarctica!



Even in winter, the water in this hot spring in Yellowstone doesn't freeze. Bison move near hot springs to escape the extreme cold.

Geysers

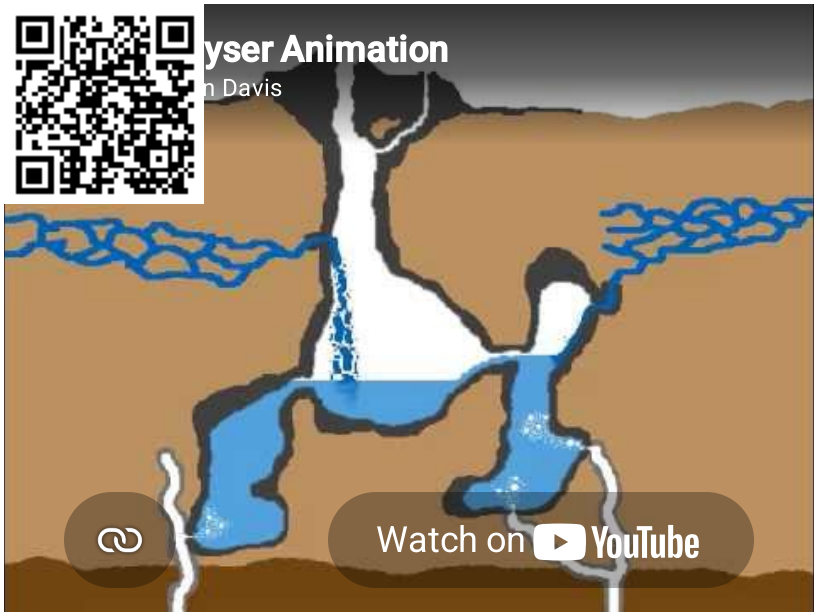
Geysers are also created by water that is heated beneath the Earth's surface. The water may become superheated by magma. It becomes trapped in a narrow passageway. The heat and pressure build as more water is added. When the pressure is too much, the superheated water bursts out onto the surface. This is a **geyser**.

There are only a few areas in the world where the conditions are right for the formation of geysers. Only about 1,000 geysers exist worldwide. About half of them are in the United States. The most famous geyser is Old Faithful at Yellowstone National Park. The geyser erupts every 60 to 70 minutes, shooting hot water nearly 60 meters in the air. It is rare for a geyser to erupt so regularly, which is why Old Faithful is famous. Castle Geyser (**Figure** below) is another geyser at Yellowstone Park; however, it does not erupt as frequently or predictably as Old Faithful.

cK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



Castle Geyser is one of the many geysers at Yellowstone National Park. Castle erupts regularly, but not as frequently or predictably as Old Faithful.



Summary

- When magma heats groundwater, it may come to the surface as a hot spring or a geyser.
- Geysers erupt because the water is trapped. The water becomes superheated until finally the pressure builds enough for it to break the seal.
- Yellowstone is famous for its geysers. Old Faithful erupts the most regularly.

Review

1. What creates a hot spring?
2. Why do geysers erupt rather than just bubble to the surface like a hot spring?
3. Are hot springs and geysers always found where there is active volcanism? What is the source of the heat?

This page titled 7.12: Hot Springs and Geysers is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

7.13: Geological Activity and Volcanoes- Challenge 2

1. Shield volcanoes are made from ___.

low viscosity lavas

2. Felsic lavas are ___ and don't travel as far from the volcanic vent as mafic lavas, resulting in steeper cones.

viscous

3. Cinder cones have a cone shape, because ___.

rock fragments shoot up in the air and fall back to the ground

4. A ___ is a circular-shaped hole into which a volcano (or supervolcano) may collapse during an explosive eruption.

caldera

5. The largest supervolcano in North America is ___.

Yellowstone

6. A ___ forms when a large amount of fluid lava spreads out and cools into a broad, flat surface.

lava plateau

7. Shiprock in New Mexico is an example of a ___.

volcanic neck

8. A ___ is a round mound of thick lava that cools near the mouth of a volcano.

lava dome

9. Half of the world's geysers are found ___.

in the U.S.

10. A ___ forms when superheated groundwater becomes trapped, building pressure until the water breaks through the seal of Earth's crust.

geyser

11. At least two of the hot spring areas in the continental U.S. are ___.

above supervolcanoes

This page titled 7.13: Geological Activity and Volcanoes- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

8: Earth's Fresh Water

8.1: Distribution of Water on Earth
8.2: States of Water
8.3: The Water Cycle
8.4: Uses of Water
8.5: Water Distribution
8.6: Safety of Water
8.7: Conserving Water
8.8: Earth's Fresh Water- Challenge 1
8.9: Streams and Rivers
8.10: Ponds and Lakes
8.11: Flooding
8.12: Glaciers
8.13: Earth's Fresh Water- Challenge 2
8.14: Groundwater
8.15: Groundwater Aquifers
8.16: Springs and Geysers
8.17: Earth's Fresh Water- Challenge 3
8.18: Groundwater Depletion
8.19: Groundwater Pollution
8.20: Water Pollution
8.21: Protecting Water From Pollution
8.22: Cleaning Up Groundwater
8.23: Earth's Fresh Water- Challenge 4

This page titled 8: Earth's Fresh Water is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.1: Distribution of Water on Earth

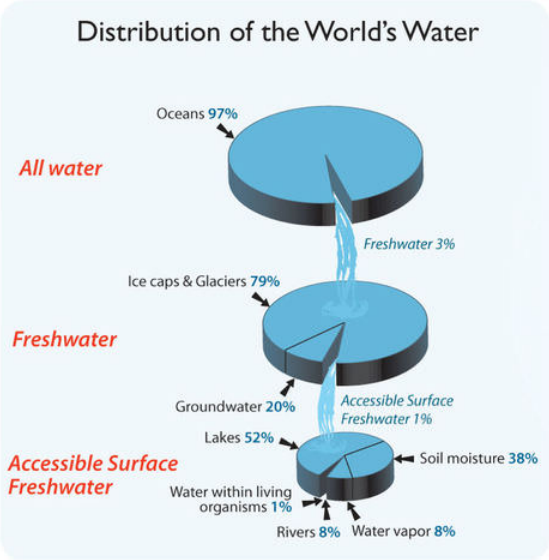


Where is Earth's Water?

Here's a photo of Earth from space again. It's pretty easy to see where most of Earth's water is. It's in the oceans. Nearly all of Earth's water is in the seas. Although it's extremely useful for ocean ecosystems, it's not very useful for people. So where is the water that we can use?

Where Is Earth's Freshwater?

Most of Earth's water is salt water in the oceans. As seen below, only 3 percent of Earth's water is fresh (**Figure** below). **Freshwater** is water that contains little or no dissolved salt. Most freshwater is frozen in ice caps and glaciers. Glaciers cover the peaks of some tall mountains. For example, the Cascades Mountains in North America and the Alps Mountains in Europe are capped with ice. Ice caps cover vast areas of Antarctica and Greenland. Chunks of ice frequently break off ice caps. They form icebergs that float in the oceans.



What percentage of Earth's surface freshwater is water vapor in the air?

Only a tiny fraction of Earth's freshwater is in the liquid state. Most liquid freshwater is under the ground in layers of rock. Of freshwater on the surface, the majority exists in lakes and soil. What percentage of freshwater on the surface is found in living things?

Water can remain in a particular location for a long time. This is known as a **reservoir**. Reservoirs for water include oceans, glaciers, ponds, or even the atmosphere. A water molecule may pass through a reservoir very quickly or may remain for much

longer. The amount of time a molecule stays in a reservoir is known as its **residence time**. The residence time of water in the ocean is 3,200 years. Of course, not every molecule stays that long. That number is an average for all molecules.

Summary

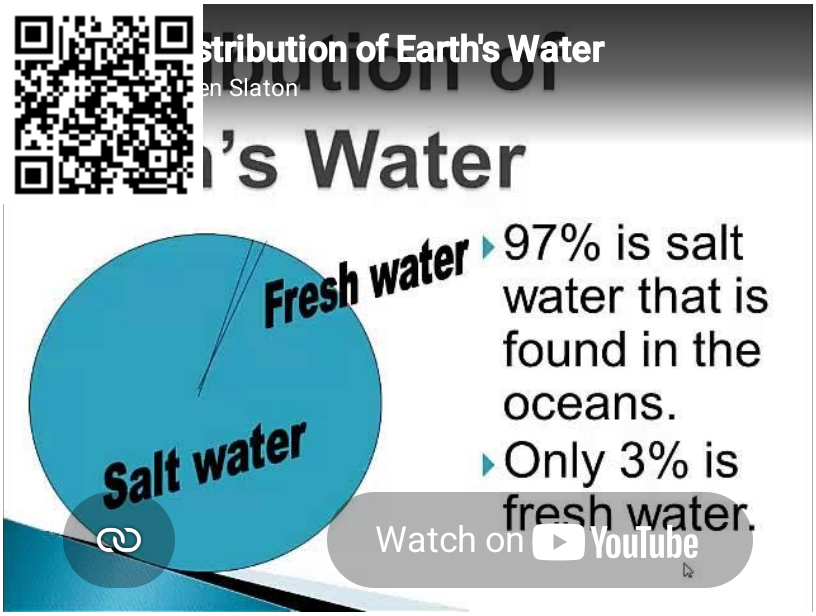
- Of Earth's water, 97% is in the oceans.
- Of the remaining 3%, much is trapped in ice and glaciers.
- A substance is stored in a reservoir. The amount of time it stays in that reservoir is its residence time.

Review

1. Earth has a tremendous amount of water. So why is water sometimes a scarce resource?
2. What are the reservoirs for water?
3. What is residence time? What does it mean to say the residence time of water in the atmosphere is nine days?

Explore More

Use this resource to answer the questions that follow.



1. How much of Earth's surface is covered with water? What is most of this water in?
2. What percent of Earth's water is salty? How much is fresh water?
3. Of all of the fresh water, what percentage is ice, what is shallow groundwater, what is deep groundwater, what is in lakes and rivers and what is in the atmosphere as water vapor?
4. How much of Earth's fresh water is available for human consumption?

This page titled 8.1: Distribution of Water on Earth is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.2: States of Water

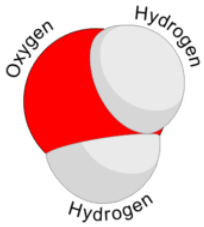


What are the three states of water in this photo?

Water is present as liquid, solid, and gas in this photo. We take water for granted here on Earth, because there is a lot of it!

The Water Molecule

A molecule of water (**Figure** below) is made of three atoms bonded together. Two of these atoms are hydrogen, and one atom is oxygen. The hydrogen atoms have a partial positive electrical charge. The oxygen atom has a partial negative electrical charge. The hydrogen atoms are located on one side and the oxygen atom on the other. This means that the side with the hydrogen ions has a slightly positive charge. The other side, the side without the hydrogen ions, has a slightly negative charge. The water molecule is a **polar molecule**.



A water molecule. The side with the hydrogen atoms has a slightly positive charge. The side with the oxygen atom has a slightly negative charge.

Water has remarkable properties. Water expands when it freezes, even though all other substances contract. This means that in the winter ice on a pond or lake will float. Water has high surface tension, because polar molecules tend to stick together. That's why drops stick together or some bugs can walk on the surface of a pond. Without water, life might not be able to exist on Earth. If it did exist, it would not be as diverse or as complex.

Three States of Matter

Water is the only substance on Earth that is present in all three states of matter. This means that water is present as a solid, liquid, and gas. Earth is the only planet with a significant amount of water present in all three states. All three phases may be present in a single location or in a region. The three phases are solid (ice or snow), liquid (water), and gas (**water vapor**). See ice, water, and clouds pictured below (**Figure** below).



CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

(A) Ice floating in the sea. Can you find all three phases of water in this image? (B) Liquid water. (C) Water vapor is invisible, but clouds that form when water vapor condenses are not.

Summary

- Water is a polar molecule. On one side there is a positive electrical charge. On the other side there is a negative charge.
- Water is the only substance on Earth that is stable in all three states.
- Earth is the only planet in the solar system that has water in all three states.

Review

1. What is a polar molecule?
2. What are the three states of matter?
3. What are some of the remarkable properties of water?

Explore More

Use the resource below to answer the questions that follow.



1. What is water made of?
2. Explain how water becomes a solid.
3. What happens when a solid melts?
4. How do molecules move in a liquid?
5. What are the major differences between a solid, a liquid, and a gas.

This page titled 8.2: States of Water is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.3: The Water Cycle

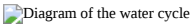


Where have these water molecules been?

Did you ever wonder where the water molecules you drink came from? Were some of the molecules trapped in a glacier? Flowing along the bottom of the ocean? Up high in a thundercloud? Maybe a water molecule that you drink today once quenched the thirst of a dinosaur. It's all entirely possible.

The Water Cycle

The **water cycle** (**Figure** below) is the movement of water through the oceans, atmosphere, land, and living things. The water cycle is powered by energy from the Sun.



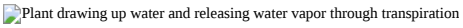
The water cycle has no beginning or end. Water just keeps moving along.

Water keeps cycling. The water cycle repeats over and over again. Each water molecule has probably been around for billions of years. That’s because Earth’s water is constantly recycled.

Processes in the Water Cycle

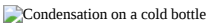
Water keeps changing state as it goes through the water cycle. This means that it can be a solid, liquid, or gas. How does water change state? How does it keep moving through the cycle? As seen above (**Figure** above), several processes are involved.

- **Evaporation** changes liquid water to water vapor. Energy from the Sun causes water to evaporate. Most evaporation is from the oceans, because they cover so much area. The water vapor rises into the atmosphere.
- **Transpiration** is like evaporation, because it changes liquid water to water vapor. In transpiration, plants release water vapor through their leaves (**Figure** below). This water vapor rises into the atmosphere.



Liquid water is taken up by plant roots. The plant releases water vapor into the atmosphere. This is transpiration.

- **Condensation** changes water vapor to liquid water. As air rises higher into the atmosphere, it cools. Cool air can hold less water vapor than warm air. So some of the water vapor condenses into water droplets. Water droplets may form clouds. Below is an example of condensation (**Figure** below).



A bottle that comes out of the refrigerator is cold. It cools the air near the bottle. Cooler air can hold less water so water vapor condenses onto the bottle.

- **Precipitation** is water that falls from clouds to Earth’s surface. Water droplets in clouds fall to Earth when they become too large to stay aloft. The water falls as rain if the air is warm. If the air is cold, the water may freeze and fall as snow, sleet, or hail. Most precipitation falls into the oceans. Some falls on land.
- **Runoff** is precipitation that flows over the surface of the land. This water may travel to a river, lake, or ocean. Runoff may pick up fertilizer and other pollutants and deliver them to a water body. In this way, runoff may pollute bodies of water.
- **Infiltration** is the process by which water soaks into the ground. Some of the water may seep deep underground. Some may stay in the soil, where plants can absorb it with their roots.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



Science Friday: Forecasting the Meltdown: The Aerial Snow Observatory

75% of Southern California's water supply comes from the snowpack in the Sierra Nevada Mountain Range. This video by Science Fridayexplains how NASA uses specialized instrumentation in the Airborne Snow Observatory to carefully measure the water content.



Further Reading

Uses of Water

Water Distribution

Safety of Water

Summary

- The water cycle recognizes all of the reservoirs of water. It also describes the processes that carry water between the reservoirs.
- Water changes state by evaporation, condensation, and sublimation.
- Plants release water through their leaves by transpiration.

Review

1. What is transpiration?
2. How are evaporation and condensation the same? How are they different?

3. What is the role of the major reservoirs in the water cycle?

This page titled 8.3: The Water Cycle is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.4: Uses of Water



Dynamic Earth and dynamic human development come together—where?

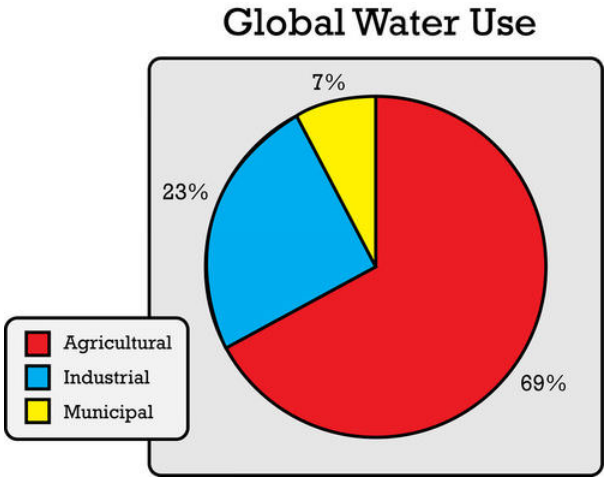
At a water park! There may be nothing as fun as a water park on a hot day. Fun is one of the uses of water. What are some others?

Water Consumption

Humans use six times as much water today as they did 100 years ago. People living in developed countries use a far greater proportion of the world's water than people in less developed countries. What do people use all of that water for?

How We Use Water

The image below shows how people use water worldwide (**Figure** below). The greatest use is for agriculture and then industry. Municipal use is last, but it is also important. Municipal use refers to water used by homes and businesses in communities.



In this global water use chart, see how much is used in agriculture. Why do you think so much water is used in agriculture?

Agriculture

Many crops are grown where there isn't enough rainfall for plants to thrive. For example, crops are grown in deserts of the American Southwest. How is this possible? The answer is irrigation. **Irrigation** is any way of providing extra water to plants. Most of the water used in agriculture is used for irrigation. Livestock also need water, but they use much less.

Irrigation can waste a lot of water. The type of irrigation pictured below (**Figure** below) is the most wasteful. The water is sprayed into the air and then falls to the ground. But much of the water never reaches the crops. Instead, it evaporates in the air or runs off the fields. Irrigation water may cause other problems. The water may dissolve agricultural chemicals, such as pesticides. When the water soaks into the ground, the dissolved chemicals do too. They may enter groundwater or run off into rivers or lakes. Salts in irrigation water can also collect in the soil. The soil may get too salty for plants to grow.



Overhead irrigation systems like this one are widely used to irrigate crops on big farms. What are some drawbacks of irrigation?

Industry

Almost a quarter of the water used worldwide is used in industry. Industries use water for many purposes. Chemical processes need a lot of water. Water is used to generate electricity. An important way that industries use water is to cool machines and power plants.

Household Uses

Think about all the ways people use water at home. Besides drinking it, they use it for cooking, bathing, washing dishes, doing laundry, and flushing toilets. The water used inside homes goes down the drain. From there it usually ends up in a sewer system. At the sewage treatment plant, water is treated and prepared for reuse.

Households may also use water outdoors. If your family has a lawn or garden, you may water them with a hose or sprinkler. You probably use water to wash the car (**Figure** below). Much of the water used outdoors evaporates or runs off into the gutter. The runoff water may end up in storm sewers that flow into a body of water, such as the ocean.



What will happen to the water that runs off the car? Where will it go?

Fun

Fun wasn't on the pie chart (**Figure** above), but it's important, too! There are many ways to use water for fun, from white water rafting to snorkeling. When you do these activities, you don’t actually use water. You are doing the activity on or in the water. What do you think is the single biggest use of water for fun? Believe it or not, it’s golf! Keeping golf courses green uses an incredible amount of water. Since many golf courses are in sunny areas, much of the water is irrigation water. Like any similar sprinkler system, much of this water is wasted. It evaporates or runs off the ground.



Sunshine brings golfers to the desert, but a lot of water is needed to make the desert green enough to play.

Environment

It's important to leave some water for the environment. In some places, water is used for wildlife habitat. Man-made lakes create places for fish and water birds. Leaving water in the ecosystems keeps the environment healthy for many species of plants and animals.



Summary

- People use water for agriculture, industry, and consumption.
- Water can also be used for fun and for the environment.
- Some water must remain in the environment to support ecosystems.

Review

1. Why do people use so much more water than they used to?
2. How is water used for agriculture? How can it be used better?
3. Why is it important to have water for fun and for the environment?

This page titled 8.4: Uses of Water is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.5: Water Distribution



What do you have to do to get water?

In the developed world, we just open a tap. Clean water is available all the time. In many developing regions, people often have to walk long distances to get clean water. Sometimes there isn't a source of clean water, and they just get what they can find. We take water for granted in the developed world.

Water Problems: Not Enough Water

Most Americans have plenty of fresh, clean water, but many people around the world do not. In fact, water scarcity is the world's most serious resource problem. How can that be? Water is almost everywhere, but much of it is unusable. What is usable is not always where it is needed.

Where Is All The Water?

One problem is that only a tiny fraction of Earth's water is fresh, liquid water that people can use. More than 97 percent of Earth's water is salt water in the oceans. Just 3% is freshwater. Most of the freshwater is frozen in ice sheets, icebergs, and glaciers (**Figure** below).



This glacier in Alaska stores a lot of frozen freshwater.

Rainfall and Water Supply

Rainfall varies around the globe. About 40% of the world's landmass gets very little rain. About the same percentage of the world's people don't have enough water. You can compare global rainfall with the worldwide freshwater supply at the two URLs below. Drier climates generally have less water for people to use. In some places, people may have less water available to them for an entire year than many Americans use in a single day! How much water is there where you live?

Wealth and the Water Supply

Richer nations can drill deep wells, build large dams, or supply people with water in other ways. In these countries, just about everyone has access to clean running water in their homes, and water is cheap and easy to get. It's no surprise that people in these countries use the most water. In poorer nations, there is little money to develop water supplies. Therefore, people get their water where they can.

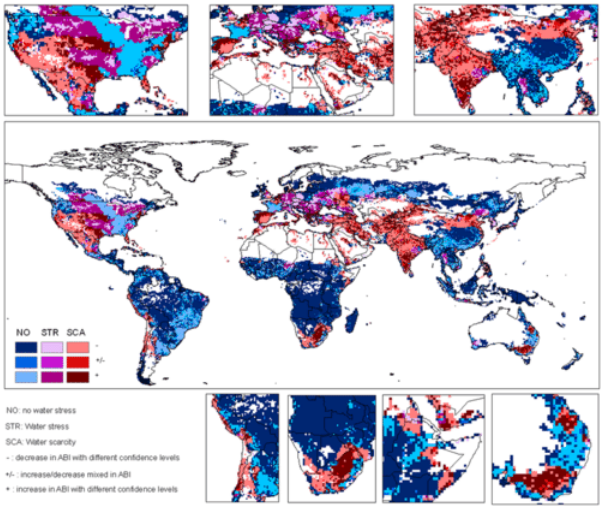
Water Shortages

Water shortages are common in much of the world. People are most likely to run short of water during droughts. A **drought** is a period of unusually low rainfall. Human actions have increased how often droughts occur. One way people exacerbate droughts is by cutting down trees. Trees add a lot of water vapor to the air. With fewer trees, the air is drier and droughts are more common.

We already use six times as much water today as we did a hundred years ago. As the number of people rises, our need for water will grow. By the year 2025, only half the world's people will have enough clean water. Water is such a vital resource that serious water shortages may cause other problems.

- Crops and livestock may die, so people will have less food available.
- Other uses of water, such as industry, may have to stop. This reduces the jobs people can get and the products they can buy.
- People and nations may fight over water resources.
- In extreme cases, people may die from lack of water.

Figure below shows the global water situation in the 2030s with water stress and water scarcity on the map.



Blues indicate no predicted water stress; pinks and lavenders predict water stress, and salmon to brown indicates water scarcity (variations of those colors indicate the amount of irrigation that will be done to produce crops).

Summary

- Fresh water is not evenly distributed across the planet.
- Many of the world's people live without access to enough clean water. That percentage is likely to increase as populations grow.
- During a drought, life may become very hard for many people.

Review

1. How is Earth's water distributed?
2. How do wealthier nations deal with water problems? How do poorer nations deal with water problems?
3. What is a drought? What can happen during a drought?

Explore More

Use the resource below to answer the questions that follow.



1. What is water scarcity?
2. Why do people take water for granted?
3. How much freshwater is there on Earth?
4. How many people do not have access to clean water?
5. What will occur by 2025?
6. What is physical water scarcity? Where does this occur?
7. What is economic water scarcity? Where does this occur?
8. What are two things you can do to reduce your water consumption?

This page titled 8.5: Water Distribution is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.6: Safety of Water



What do you see in this photo?

The Ganges River is sacred to the people of India. It is also a major source of water for drinking and bathing for millions of people. An estimated 400 million people are affected by pollution in the Ganges. What can be done to protect a water body that has so much pressure placed on it?

Water Safety

The water that most Americans get from their faucets is safe. This water has been treated and purified. At least 20% of the world's people do not have clean drinking water always available. That's more than 1 billion people. They must drink water from where they can get it, from rivers or ponds (**Figure** below). Human wastes may be in the water. If that's the case, the water will probably contain pathogens. **Pathogens** are organisms that cause diseases.



This girl is getting drinking water from a hole that has been dug. It may be the only source of water in this remote part of Tanzania where she lives.

Waterborne Disease

Unsafe drinking water causes 88% of diseases worldwide. In many nations, these diseases are the leading cause of death in children under the age of five. More than 14,000 people die every day from such diseases. Cholera is caused by bacteria. A person gets guinea worm from drinking the guinea worm larvae (**Figure** below). The cholera bacteria and guinea worms are examples of pathogens.

LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



Guinea worm.

Guinea worm is a serious problem in parts of Africa that is being eradicated. Learn what is being done to decrease the number of people suffering from this parasite at the video below:

Summary

- More than 1 billion people do not have access to water that is safe for drinking and washing.
- Waterborne diseases cause death and illness to people in many parts of the world.
- Government programs and international aid help to provide safe drinking water for some people.

Review

1. What are pathogens?
2. Why do people drink from water sources that are contaminated?
3. Why do nations fail to provide safe drinking water for their people?
4. Why do waterborne diseases rarely strike in the developed world?

This page titled 8.6: Safety of Water is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.7: Conserving Water



Can you figure out how to do these things better?

The photos above show water being wasted. Water being used for irrigation with much flying into the air. A large fountain in the desert. Excess water being used to wash a car. These sorts of waste occur all the time. How can these activities be done without so much waste? How can irrigation or car washing use less water? What can people enjoy in the desert that doesn't involve so much water?

Conserving Water

Conserving water means using less of it. Of course, this mostly applies to people in the wealthy nations that have the most water and also waste the most.

Saving Water in Irrigation

Irrigation is the single biggest use of water. Overhead irrigation wastes a lot of water. **Drip irrigation** (**Figure** below) wastes a lot less. Water pipes run over the surface of the ground. Tiny holes in the pipes are placed close to each plant. Water slowly drips out of the holes and soaks into the soil around the plants. Very little of the water evaporates or runs off the ground.



The above is a drip irrigation system. Look at the soil in the photo. It’s damp around each plant but dry everywhere else.

Rationing Water

Some communities save water with rationing. Much rationing takes place only during times of drought. During rationing, water may not be used for certain things. For example, communities may ban lawn watering and car washing. People may be fined if they use water in these ways. You can do your part. Follow any bans where you live.

Saving Water at Home

It’s easy to save water at home. If you save even a few gallons a day you can make a big difference in the long run. The best place to start saving water is in the bathroom. Toilet flushing is the single biggest use of water in the home. Showers and baths are the next biggest use. Follow the tips below to save water at home.

- Install water-saving toilets. They use only about half as much water per flush. A single household can save up to 20,000 gallons a year with this change alone!
- Remember what they say about bathroom flushing in California during rationing: If it's yellow, let it mellow; if it's brown, flush it down!

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

- Take shorter showers. You can get just as clean in five minutes as you can in 10. And you'll save up to 50 gallons of water each time you shower. That's thousands of gallons each year.
- Use low-flow shower heads. They use about half as much water as regular shower heads. They save thousands of gallons of water.
- Fix leaky shower heads and faucets. All those drips really add up. At one drip per second, more than 6,000 gallons go down the drain in a year—per faucet!
- Don't leave the water running while you brush your teeth. You could save as much as 10 gallons each time you brush. That could add up to 7,000 gallons in a year.
- Landscape your home with plants that need little water. This could result in a huge savings in water use. Look at the garden pictured below (**Figure** below); it shows that you don't have to sacrifice beauty to save water.



This beautiful garden contains only plants that need very little water.

Summary

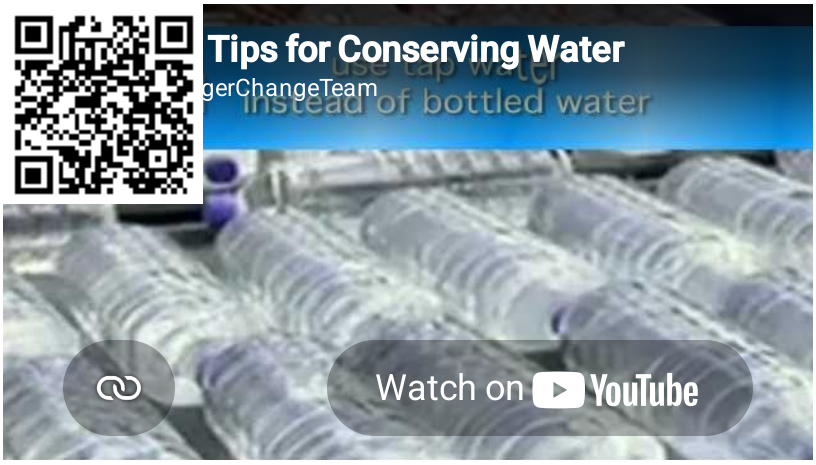
- Drip irrigation uses much less water than other methods.
- People can reduce water consumption by taking shorter showers, installing water-saving devices, and many other methods.
- Communities sometimes ration water during times of drought.

Review

1. How can you conserve water in your garden?
2. How can changing your personal habits conserve water?
3. How does drip irrigation work?

Explore More

Use the resource below to answer the questions that follow.



1. How much does bottled water cost compared to tap water?
2. Besides cost, what are the reasons that drinking bottled water is harmful?
3. What can make tap water taste better?

4. How much water does a front-loading washer save?
5. How long should you shower?
6. When should you water your garden? Why?

This page titled 8.7: Conserving Water is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.8: Earth's Fresh Water- Challenge 1

1. ___ time is the average amount of time a water molecule stays in a reservoir.

Residence

2. What percent of Earth's water is fresh water?

Approximately 3%

3. Water is a ___ molecule, or a molecule with a charge difference across the molecule.

polar

4. Water molecules contain two ___ atoms and one ___ atom.

hydrogen; oxygen

5. When water freezes and changes to its ___ state it expands, while most other substances contract.

solid

6. ___ is the state transition by which a substance changes from a solid to a gas without going through the liquid state.

Sublimation

7. Runoff is ___.

when water flows across Earth's surface

8. Precipitation is ___.

when water falls from clouds to Earth's surface

9. In which "flow-through pathway" does water travel through the finest soil pores?

Matrix flow

10. Precipitation is usually expressed in which units?

millimeters

11. Groundwater is pumped from a confined aquifer whose intergranular pressure ___.

increases, while the aquifer's pore water pressure decreases

This page titled 8.8: Earth's Fresh Water- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.9: Streams and Rivers



What makes this river so much fun to raft?

Whitewater rafting is a popular recreational activity. The river is fast because its in the mountains traveling downhill. There is a lot of water from snow melt higher up. Sometimes water is added from springs. Did you ever go whitewater rafting? It's fun!

What Are Streams and Rivers?

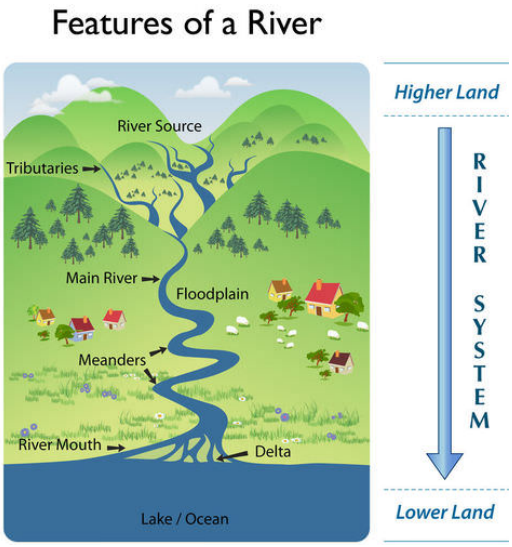
A **stream** is a body of freshwater that flows downhill in a channel. The channel of a stream has a bottom, or bed, and sides called banks. Any size body of flowing water can be called a stream. Usually, though, a large stream is called a **river**.

Features of Streams and Rivers

All streams and rivers have several features in common (**Figure** below). The place where a stream or river starts is its **source**. The source might be a spring, where water flows out of the ground. Or the source might be water from melting snow on a mountain top, like the stream pictured below (**Figure** below). A single stream may have multiple sources.



A stream flows fast and steep where it originates in the mountains. This stream, in Glacier National Park in Montana, is coming from snow melt.



Water in a stream flows along the ground from higher to lower elevation. What force causes the water to keep flowing?

A stream or river probably ends when it flows into a body of water, such as a lake or an ocean. A stream ends at its **mouth**. As the water flows into the body of water, it slows down and drops the sediment it was carrying. The sediment may build up to form a delta.

Several other features of streams and rivers are also shown above (**Figure** above).

- Small streams often flow into bigger streams or rivers. The smaller streams are called **tributaries**. A river and all its tributaries make up a river system.
- At certain times of year, a stream or river may overflow its banks. The area of land that is flooded is called the **floodplain**. The floodplain may be very wide where the river flows over a nearly flat surface.
- A river flowing over a floodplain may wear away broad curves. These curves are called **meanders**. Pictured below is an example of this (**Figure** below).

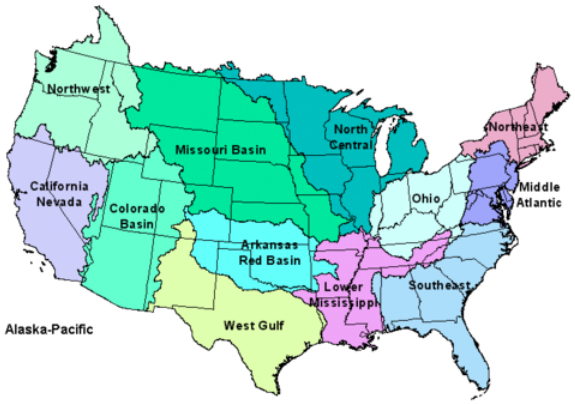


A river meanders across an estuary in South Carolina.

River Basins and Divides

All of the land drained by a river system is called its basin, or **watershed**. One river system's basin is separated from another river system's basin by a **divide**. The divide is created by the highest points between the two river basins. Precipitation that falls within a river basin always flows toward that river. Precipitation that falls on the other side of the divide flows toward a different river. A **continental divide** separates rivers that flow into different oceans.

Pictured below are the major river basins in the U.S. (**Figure** below).



River basins in the U.S.

Summary

- A moving body of water of any size is a stream. A river is a large stream.
- A tributary begins at its headwaters on one side of a divide. Two tributaries come together at a confluence.
- A river ends at an estuary. If the river drops sediment, it may create a delta.

Review

1. Describe the features of a river from where it begins to where it ends.
2. What happens to two drops of water that fall on opposite sides of a divide?
3. Why does a tributary not cross over a divide?

Explore More

Use the resources below (start at 0:49) to answer the questions that follow.



1. What is the tributary system? What does that mean in simple English?
2. What does a tributary flow into?
3. What do the tributaries in the Rocky Mountains near Woodland Park feed into? What does that flow into? And what does that flow into? And finally what does that flow into?
4. At what point does a tributary meet a river?
5. What is the biggest trunk river in the U.S.?

6. What is the end of the Mississippi River in the Gulf of Mexico?
7. What is a delta?
8. What is found in a delta?
9. How did a delta get its name?

This page titled 8.9: Streams and Rivers is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.10: Ponds and Lakes



Why are lakes important?

Lakes are important habitats for lots of plants and animals. The slow motions of the water are easier for organisms to live in than the water from rapidly moving streams. Some animals live on land but get at least part of their food from lakes or ponds. This eagle is fishing for its meal. What would happen if lakes dried up?

Ponds and Lakes

After a heavy rain, you may find puddles of water standing in low spots. The same principle explains why water collects in ponds and lakes. Water travels downhill, so a depression in the ground fills with standing water. A **pond** is a small body of standing water. A **lake** is a large body of standing water. Most lakes have freshwater, but a few are salty. The Great Salt Lake in Utah is an example of a saltwater lake.

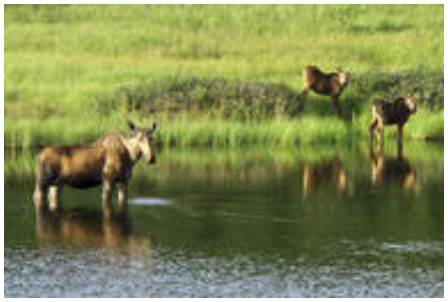
The water in a large lake may be so deep that sunlight cannot penetrate all the way to the bottom. Without sunlight, water plants and algae cannot live on the bottom of the lake. That's because plants need sunlight for photosynthesis.

Water in Ponds and Lakes

Ponds and lakes may get their water from several sources. Some falls directly into them as precipitation. Some enters as runoff and some from streams and rivers. Water leaves ponds and lakes through evaporation and also as outflow.

How Lakes Form

The depression that allows water to collect to form a lake may come about in a variety of ways. The Great Lakes, for example, are glacial lakes. A glacial lake forms when a glacier scrapes a large hole in the ground. When the glacier melts, the water fills the hole and forms a lake. A kettle lake forms in the sediment left by a glacier when a block of ice melts. Kettle lakes are found where continental glaciers once covered the land (**Figure** below). Over time lakes get water from rain, streams, and groundwater coming to the surface.

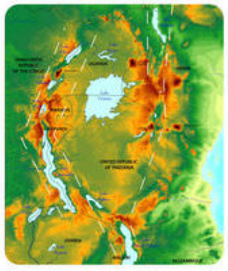


A moose in a kettle lake at Denali National Park in Alaska.

Other lakes are crater lakes or rift lakes (**Figure** below). Crater lakes form when volcanic eruptions create craters that fill with water. Rift lakes form when movements of tectonic plates create low places that fill with water.



This Russian lake formed in the crater created by a volcano.



The dotted white lines on this map mark the rift between tectonic plates in East Africa. Fault movements created depressions that filled with water. This formed many rift lakes, from Lake Malawi in the south to Lake Turkana in the north.

Craters and rifts become lakes when they fill with water. Where does the water come from?

The Great Lakes

Large lakes are similar to oceans. They have tides and currents. Large lakes can affect weather patterns. The Great Lakes (**Figure** below) contain 22% of the world's fresh surface water. The largest of them, Lake Superior, has a tide that rises and falls several centimeters each day. The Great Lakes cause "lake effect" snow. In the winter, a large amount of snow may fall downwind of the relatively warm lakes. The Great Lakes are home to countless species of fish and wildlife.



The Great Lakes of North America get their name from their great size.

Reservoirs

Many lakes are not natural but are human-made. People dam a stream in a suitable spot. Water backs up behind the dam, creating a lake. These lakes are "reservoirs" (**Figure** below).



Hoover Dam, near Las Vegas, Nevada, creates a reservoir on the Colorado River. The reservoir is called Lake Mead.

https://k12.libretexts.org/@go/page/5448

Summary

- Ponds are small water bodies often fed by springs.
- A lake or pond may form wherever water can collect. A lake basin could be a volcanic crater, where a glacier has carved out a depression, or a fault zone.
- A reservoir is a man-made lake.

Review

1. Describe how different types of lakes form.
2. How is a large lake like an ocean? How is it different?
3. What is the difference between ponds and lakes? How are they similar?

This page titled 8.10: Ponds and Lakes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.11: Flooding



Is the water cycle perfect?

The amount of water on Earth doesn't change. So if the water cycle was perfect, there would always be the right amount of water in each reservoir. In winter, there would be the right amount of snow. The snow would melt in the right amounts and at the right times in the spring. A good amount of rain would fall. Not so little that there would be a drought and not so much that there would be a flood. But the water cycle does not operate to human standards of perfect. Floods are all too common.

Floods

A **flood** occurs when so much water enters a stream or river that it overflows its banks. Flood waters from a river are pictured below (**Figure** below).



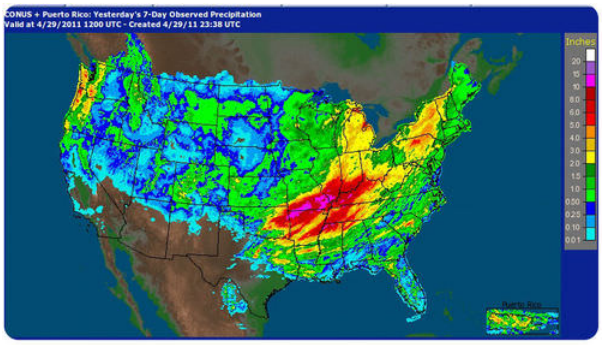
Flooding in Indiana.

Floods are a natural part of the water cycle, but they can cause a lot of damage. Farms and homes may be lost, and people may die. In 1939, millions of people died in a flood in China. Although freshwater is needed to grow crops and just to live, too much freshwater in the same place at once can be deadly.

Causes of Floods

Floods may occur when deep snow melts quickly in the spring. More often, floods are due to heavy rainfall. Floods happen when rain falls more quickly than water can be absorbed into the ground or carried away by rivers or streams.

Extremely heavy rains across the Midwestern U.S. in April 2011 led to flooding of the rivers in the Mississippi River basin in May 2011 (**Figure** below and **Figure** below).



This map shows the accumulated rainfall across the U.S. in the days from April 22 to April 29, 2011.



Record flow in the Ohio and Mississippi Rivers has to go somewhere. Normal spring river levels are shown in 2010. The flooded region in the image from May 3, 2011 is the New Madrid Floodway, where overflow water is meant to go. 2011 is the first time since 1927 that this floodway was used.

Buffers to Flooding

Heavily vegetated lands are less likely to experience flooding. Plants slow down water as it runs over the land, giving it time to enter the ground. If the ground is too wet to absorb more water, plants still slow the water's passage. Slower water keeps all the water from entering the stream at once. Wetlands play a key role in minimizing the impacts of floods. Wetlands act as a buffer between land and high water levels. Flooding is often more severe in areas that have been recently logged.

Flood Protection

People protect areas that might flood with dams. In dire situations, they use sandbags (**Figure** below). Dams are usually very effective, but high water levels sometimes cause a dam to break. In that case, flooding can be catastrophic. Flood waters can also overflow a dam. People may line a river bank with **levees** to protect against floods. These are high walls that keep the stream within its banks during floods. Flood protection in one location sometimes causes problems elsewhere. For example, a levee in one location may just force the high water upstream or downstream. This will lead to flooding in a different location. Sometimes water gets so high that the river must be allowed to flood.



Sandbags are put out to try to keep floodwaters from overtaking a town.

https://k12.libretexts.org/@go/page/5449

Effects of Floods



Within the floodplain of the Nile, soils are fertile enough for productive agriculture. Beyond this, infertile desert soils prevent viable farming.

Amazingly, floods can be good. Flood waters carry nutrients that are deposited on the floodplain. So floodplains are good places for farming. In the past, the Nile River (**Figure** above) in Egypt flooded each year. The flood waters brought much-needed nutrients in to farms. In the 1960s, Egypt built the Aswan Dam to protects crop and settlements from the floods. However, after the dam was built, farmers began to need fertilizers to feed their crops.

Summary

- Too much water in a drainage will result in a flood.
- Floods are made worse when vegetation is cleared, when the land is already soaked, or when hillsides have been logged.
- People build dams and levees to protect from flooding. In an emergency, sandbags can be put out.
- Floods are a source of nutrients on a floodplain.

Review

1. What is a flood?
2. What conditions make it more likely that a river will flood?
3. What was the role of flooding on the Nile River? What was the consequence of damming the river?
4. Why are there floods on rivers that have dams and other protections?

This page titled 8.11: Flooding is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.12: Glaciers



Can solid ice really move?

Yes! This is the Hubbard Glacier in Alaska. As the glacier meets the relatively warm seawater, it calves. Pieces of the glacier break off and fall into the water. These icebergs may be as large as a ten-story building.

Where Are The Glaciers?

Nearly all glacial ice is in the polar regions. The largest ice sheets are in Antarctica and Greenland. The remaining 1% of Earth's ice is found elsewhere, like in the mountains, for example. At higher altitudes, temperatures are colder. Snow is more likely to fall and not melt. Except Australia, every continent has glaciers in the high mountains.

Types of Glaciers

The types of glaciers are:

- **Continental glaciers** are large ice sheets that cover relatively flat ground. These glaciers flow outward from where the greatest amounts of snow and ice accumulate.
- **Alpine (valley) glaciers** flow downhill. Ice accumulates near the top of a mountain and then travels down existing valleys (**Figure** below).



An alpine glacier in the Swiss Alps. Where do you think the word "alpine" came from?

- **Ice caps** are large glaciers that cover a larger area than just a valley. An ice cap can bury an entire mountain range or region (**Figure** below). Glaciers come off of ice caps into valleys.



The continent of Antarctica is covered with an ice cap.

Glacial Growth

Glaciers are not static; they grow, they move, and they shrink. Currently, most glaciers are shrinking.

Formation

Glaciers grow when snowfall exceeds melting. Snow falls higher on the glacier. Over time, the snow converts to granular ice known as firn. As more snow and ice collect, the firn becomes denser. This is now glacial ice.

Glaciers form only on land because water is too warm. When a glacier flows into water, it usually breaks up into icebergs. Those icebergs eventually melt into the water.

Movement

How does an ice field become a glacier? In other words, why does the ice move? Whether an ice field moves depends on the amount of ice. It also depends on the steepness of the slope and the roughness of the ground surface. Ice moves where the pressure is so great that the ice needs to move away. Ice also slides at the bottom. Often the ground is lubricated by water that melted from the glacier above. Under some conditions, a glacier will move extremely fast. Under other conditions, the glacier may not move and will become an ice sheet.

Because the ice is moving, glaciers have cracks called **crevasses** (**Figure** below). There is a large crevasse at the top of an alpine glacier called a **bergshrund**. Below the bergshrund, the ice is moving downhill. Above the bergshrund, the ice is stuck to the mountain.

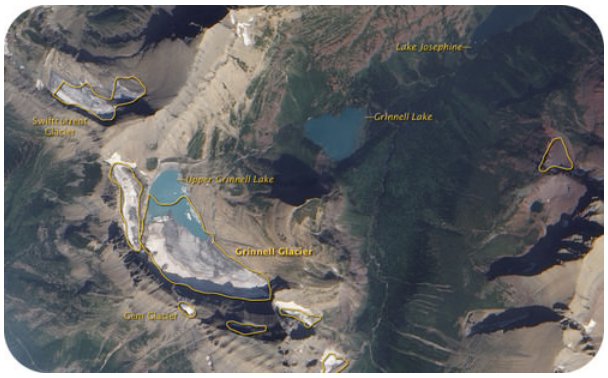


Crevasses in a glacier are the result of movement.

Shrinking

Glaciers are melting back in many locations around the world. When a glacier no longer moves, it is called an ice sheet. This usually happens when it is less than 0.1 square kilometers in area and 50 m thick.

In Glacier National Park (**Figure** below), many glaciers have become ice sheets. In 1850, the park had 150 glaciers. There are only about 25 today. The reason that there is so much melting is that summer temperatures have risen. Scientists estimate that the park will have no active glaciers as early as 2020.



This satellite image shows Grinnell Glacier, Swiftcurrent Glacier, and Gem Glacier in 2003. The outlines show the extent of the glaciers in 1950. Gem Glacier is only 0.020 km^2 (5 acres) in area. This makes it about one-fifth the size of the smallest active glaciers. Is Gem really a glacier?

Glaciers As A Resource

Melting glaciers in mountain regions provide an important source of water in the summer. Organisms and nearby human populations may depend on glacial melt water during long dry summers. People near the Andes in South America are just some of the groups that rely on glacial meltwater in the summer.

Summary

- Glaciers are ice that moves.
- Continental glaciers form in a central location with ice moving outward in all directions. Alpine glaciers form in high mountains and travel through valleys. Ice caps cover large areas.
- Because glaciers move, they have characteristic features like crevasses and bergshrunds.

Review

1. Compare and contrast alpine glaciers, continental glaciers, and ice caps.
2. Describe how an ice sheet could become a glacier.
3. How do glaciers serve as a water resource for people and organisms in the summertime?

Explore More

Use the resource below to answer the questions that follow.



1. What determines how fast a glacier moves?
2. How does a glacier move like a stream? Why?
3. Where are alpine glaciers and how can you tell that one was in an area?
4. What are the two continental glaciers that remain today? What did North America look like during the last Ice Age?

5. What happens in the zone of accumulation if more snow accumulates than ice melts? what happens if there is more melting than snowfall?

This page titled 8.12: Glaciers is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.13: Earth's Fresh Water- Challenge 2

1. A stream meets a large body of standing water at ___.

base level

2. Most rivers have a number of ___ that meet to form larger streams that make up the main river.

tributaries

3. ___ exist along rivers where overflow goes during flooding.

Floodplains

4. Large lakes are similar to the ocean, because they have ___ and currents.

tides

5. Large lakes alter ___ by increasing snow downwind.

weather

6. The water in Crater Lake in Oregon fills ___.

a caldera on Mt. Mazama

7. Humans build ___ to prevent rivers from bursting their banks during flooding.

levees

8. Plants reduce flooding by ___.

slowing rainwater down so it doesn't hit the ground all at once

9. A levee that protects a portion of land near a river from flooding ___.

may cause flooding upstream or downstream

10. ___ glaciers are large ice sheets that cover relatively flat ground.

Continental

11. ___ glaciers are found on tall mountains.

Alpine

12. Glaciers are a valuable resource, because ___.

they are a source of water in the summer

This page titled 8.13: Earth's Fresh Water- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.14: Groundwater



What are these faucets tapping into?

This certainly is an odd sight! We expect to see water at Earth's surface, but coming out of solid rock? Amazingly, much of Earth's fresh water is hidden from sight. It is present in rock and soil. In fact, 20 times more of Earth's liquid freshwater is found below the surface than on the surface.

Groundwater

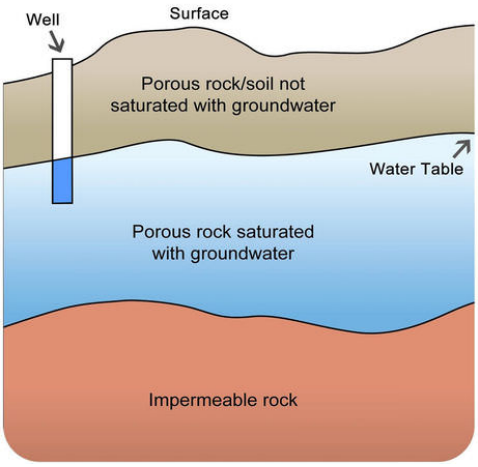
Freshwater below Earth's surface is called **groundwater**. The water infiltrates, or seeps down into, the ground from the surface. How does this happen? And where does the water go?

Porous and Impermeable Rock

Water infiltrates the ground because soil and rock may have air spaces between the grains. These pores, or tiny holes, result in the rock's **porosity**. If water can move through a rock, the rock is **permeable**. Eventually, the water reaches a layer of rock that is not porous. This rock is **impermeable**. Water stops moving downward when it reaches an impermeable layer.

The diagram below (**Figure** below) shows two layers of porous rock. The top layer is not saturated; it is not full of water. The next layer is saturated. The water in this layer has nowhere else to go. It cannot seep any deeper into the ground because the rock below it is impermeable.

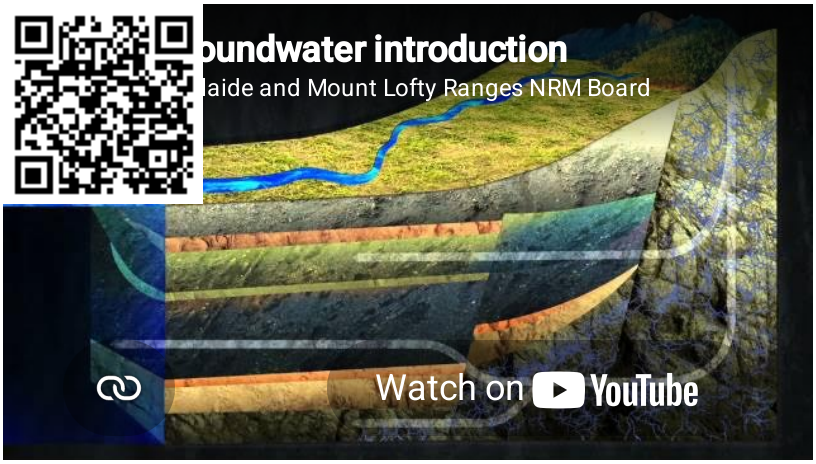
Groundwater and Water Table



Water seeps into the ground through permeable material. The water stops when it reaches an impermeable rock. Predict the purpose of the well in the diagram.

The Water Table

The top of the saturated rock layer above (**Figure** above) is called the **water table**. The water table isn't like a real table. It doesn't remain firmly in one place. Instead, it rises or falls, depending on how much water seeps down from the surface. The water table is higher when there is a lot of rain, and it is lower when the weather is dry.



Summary

- Water infiltrates into the ground.
- There is much more fresh water underground than on the surface.
- A rock layer must be porous and permeable to be a good aquifer. An impermeable layer makes up the bottom of an aquifer.
- The water table rises and falls with additions or subtractions to the groundwater system.

Review

1. Why does rock or soil need to be permeable for there to be groundwater?
2. How does water become groundwater?
3. What happens if there is an impermeable rock layer underground?
4. What can make the water table move up or down?

This page titled 8.14: Groundwater is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.15: Groundwater Aquifers

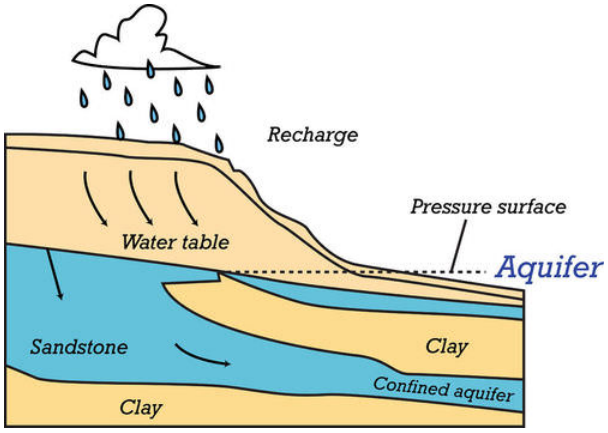


Do you take water for granted?

In some parts of the world, gathering water for the family is a process that takes several hours. What are you doing during the hours that kids your age might be helping their families gather water?

Aquifer

An underground layer of rock that is saturated with groundwater is called an **aquifer**. A diagram of an aquifer is pictured below (**Figure** below). Aquifers are generally found in porous rock, such as sandstone. Water infiltrates the aquifer from the surface. The water that enters the aquifer is called **recharge**.



An aquifer is a layer of saturated porous rock. It lies below the water table. An impermeable layer, such as clay, is below the aquifer.

Human Use of Aquifers

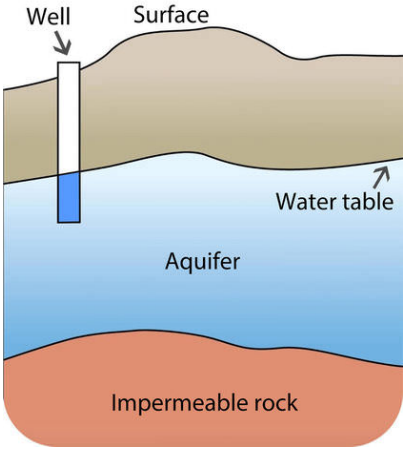
Most land areas have aquifers beneath them. Many aquifers are used by people for fresh water. The closer to the surface an aquifer is, the easier it is to get the water. However, an aquifer close to the surface is also more likely to become polluted. Pollutants can seep down through porous rock in recharge water.

An aquifer that is used by people may not be recharged as quickly as its water is removed. The water table may lower and the aquifer may even run dry. If this happens, the ground above the aquifer may sink. This is likely to damage any homes or other structures built above the aquifer.

Wells

Most groundwater does not flow out of an aquifer as a spring or geyser. So to use the water that's stored in an aquifer, people must go after it. How? They dig a well. A **well** (**Figure** below) is a hole that is dug or drilled through the ground down to an aquifer.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



A well runs from the surface to a point below the water table. Why must a well go lower than the water table?

People have depended on water from wells for thousands of years. To bring water to the surface takes energy, because the force of gravity must be overcome. Today, many wells use electricity to pump water to the surface. However, in some places, water is still brought to the surface the old-fashioned way—with human labor. The well pictured below (**Figure** below) is an example of this type of well. A hand-cranked pulley is used to lift the bucket of water to the surface.



This old water well uses human muscle power to bring water to the surface.

Summary

- An aquifer is a saturated layer of rock or soil.
- Most groundwater use is from wells.
- People use fresh water from aquifers from springs or wells.

Review

1. How does water enter an aquifer?
2. What happens to the water table in an extremely wet year? In an extremely dry one?
3. How do people get water from a well?

Explore More

Use the resource below to answer the questions that follow.



1. How has irrigation changed farming?
2. What is leading to people's demands for additional water?
3. What is the GRACE satellite doing?
4. How does GRACE find groundwater aquifers?
5. How people in India know the aquifers are being depleted?
6. What is the future of water?

This page titled 8.15: Groundwater Aquifers is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.16: Springs and Geysers



A sacred spring

At Tampak Siring in Bali, Indonesia, spring water emerges into a temple. The water is thought to have healing powers. Many Hindus come to the temple to submerge in the water and pray. They hope the water will cure their diseases.

Springs

The top of an aquifer may be high enough in some places to meet the surface of the ground. This often happens on a slope. The water flows out of the ground and creates a **spring**. A spring may be just a tiny trickle, or it may be a big gush of water.

Water flowing out of the ground at a spring may flow downhill and enter a stream. If the water from a spring can't flow downhill, it may spread out to form a pond or lake instead. In the desert, the only reliable water may be from springs (**Figure** below). A spring may allow wildlife to inhabit an uninhabitable area.



A desert oasis is created by a spring in Nevada.

Artesian Spring

Sometimes an aquifer is confined. A confined aquifer is trapped between two impermeable rock layers. Pressure from the rock layer on top forces the water out where the aquifer reaches the ground surface. Water that flows up to the surface naturally is an **artesian spring**. If people drill a well into a confined aquifer, the water may flow to the surface without assistance. This is an artesian well (**Figure** below).



This artesian well supplies the water for Schönbrunn Palace in Germany.

Mineral Springs and Hot Springs

Some springs have water that contains minerals. Groundwater dissolves minerals out of the rock as it seeps through the pores. The water in some springs is hot because it is heated by hot magma. Many hot springs are also mineral springs. That's because hot water can dissolve more minerals than cold water.

Springs in Yellowstone National Park are hot and contain dissolved minerals. Morning Glory Pool (**Figure** below) has a bright green color from dissolved minerals. Along the edge are thick orange mats of bacteria. The bacteria use the minerals in the hot water to make food.



Morning Glory Pool in Yellowstone National Park is a mineral spring.

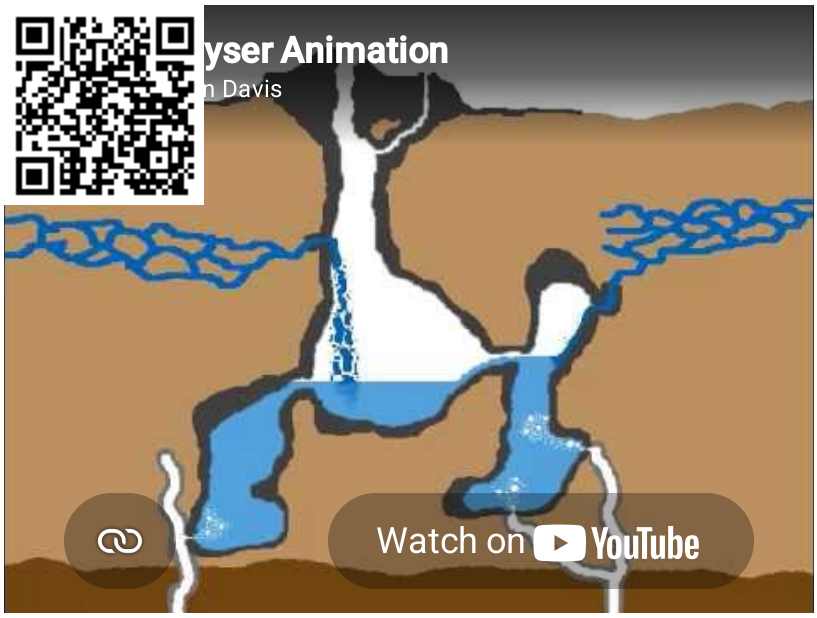
Geysers

Heated groundwater may become trapped in spaces within rocks. Pressure builds up as more water seeps into the spaces. When the pressure becomes great enough, the water bursts out of the ground at a crack or weak spot. This is called a **geyser**. When the water erupts from the ground, the pressure is released. Then more water collects and the pressure builds up again. This leads to another eruption.

Old Faithful (**Figure** below) is the best-known geyser in the world. The geyser erupts faithfully about every 70 minutes, day after day. During each eruption, it may release as much as 30,000 liters of water!



Old Faithful in Yellowstone National Park is a geyser named for its regular cycle of eruptions.



Summary

- Earth's internal heat can create a hot spring.
- If hot water becomes trapped, pressure may build up. When the water breaks free, it creates a geyser.

Review

1. What causes a spring?
2. Describe how a geyser erupts.
3. Where do the minerals in mineral springs come from?

This page titled 8.16: Springs and Geysers is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.17: Earth's Fresh Water- Challenge 3

1. The water table will rise if more water is added to the ___.

aquifer

2. When did most fossil water enter its aquifer?

Around the end of the ice ages

3. A(n) ___ is an underground layer of water-bearing, permeable rock.

aquifer

4. The bed of low permeability along an aquifer is known as an ___.

aquitard

5. A ___ flows naturally when the water table reaches the surface of the earth.

spring

6. The bottom of an aquifer is made of a rock layer that is ___ to water.

impermeable

7. Confined aquifers exist between ___.

two impermeable rock layers

This page titled 8.17: Earth's Fresh Water- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.18: Groundwater Depletion



What makes the desert bloom? Water!

You hear a lot about making the desert bloom. Many plants do well in the desert if they are given water. Since deserts do not have much water, groundwater is used. In many desert locations, groundwater is being consumed much faster than it is being recharged. What will happen in the future?

Human Use of Aquifers

Most land areas have aquifers beneath them. Many aquifers are used by people for freshwater. The closer to the surface an aquifer is, the easier it is to get the water. However, an aquifer close to the surface is also more likely to become polluted. Pollutants can seep down through porous rock in recharge water.

People may use the water in an aquifer faster than it is recharged. When this happens, the water table will lower. Wells may go dry. To get to the water, the well will need to be dug deeper.

As the water table lowers, the ground above the aquifer may sink. This is called **subsidence**. When the ground subsides, any homes or other structures built above the aquifer will be damaged. The San Joaquin Valley of California is one of the world's major agricultural areas. So much groundwater has been pumped that the land has subsided many tens of feet.

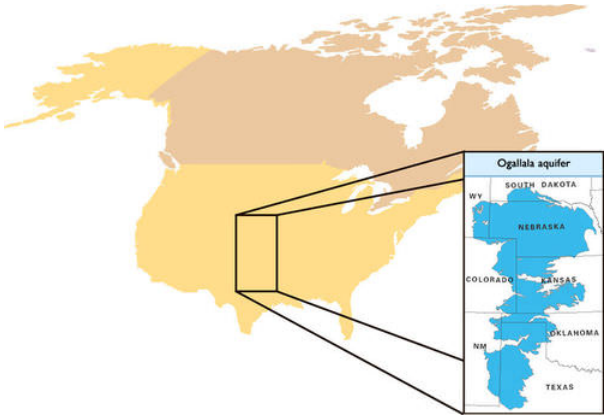


The signs on the pole show where ground level was at different years. The subsidence is due to groundwater depletion.

The Ogallala Aquifer

One of the biggest aquifers in the world is the Ogallala aquifer. As you can see below (**Figure** below), this aquifer lies beneath parts of eight U.S. states. In some places, it is less than a meter deep. In other places, it is hundreds of meters deep. The water in the aquifer is mostly from the last ice age.

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



In this map, the area over the Ogallala aquifer is shaded in blue.

The Ogallala aquifer is an important source of freshwater in the American Midwest. This is a major farming area, and much of the water is used to irrigate crops. The water in this aquifer is being used up ten times faster than it is recharged. If this continues, what might happen to the Ogallala aquifer?

Summary

- When water is pumped from an aquifer, the water table goes down. Wells must be drilled deeper to get water.
- The Ogallala Aquifer was filled in the ice age. It is heavily used to irrigate Midwestern farms. The use rate is several times faster than the recharge rate.
- Ground subsidence is a consequences of groundwater overuse.

Review

1. What are some of the problems that come from overuse of groundwater?
2. Why is the Ogallala aquifer important?
3. Why does groundwater removal cause the ground to subside?

Explore More

Use the resource below to answer the questions that follow.



1. Where is the Ogallala aquifer found?
2. What has put the Ogallala aquifer at risk?
3. What is the danger from the pipeline?
4. Why are people concerned about the pipeline?

This page titled 8.18: Groundwater Depletion is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

LibreTexts™

cK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

8.19: Groundwater Pollution



How could the water in this well be polluted?

Such an idyllic scene. The water from the well must taste as fresh as the springtime air. Of course, the water may be contaminated. Industrial waste from a factory down the road, or any number of other things, could have polluted the aquifer.

How Pollutants Enter Groundwater

Groundwater pollutants are the same as surface water pollutants: municipal, agricultural, and industrial. Groundwater is more susceptible to some sources of pollution. For example, irrigation water infiltrates into the ground, bringing with it the pesticides, fertilizers, and herbicides that were sprayed on the fields. Water that seeps through landfills also carries toxins into the ground. Toxic substances and things like gasoline are kept in underground storage tanks; more than 100,000 of the tanks are currently leaking and many more may develop leaks.



Tanks may break and leak whatever toxins they contain into the ground.

Filtered Water

Groundwater is a bit safer from pollution than surface water from some types of pollution, because some pollutants are filtered out by the rock and soil that water travels through as it travels through the ground or once it is in the aquifer. Rock and soil can't get out everything, however, depending on the type of rock and soil and on the types of pollutants. As it is, about 25% of the usable groundwater and 45% of the municipal groundwater supplies in the United States are polluted.

Pollutant Plume

When the pollutant enters the aquifer, contamination spreads in the water outward from the source and travels in the direction that the water is moving. This pollutant plume may travel very slowly, only a few inches a day, but over time can contaminate a large portion of the aquifer. Many wells that are currently in use are contaminated. In Florida, for example, more than 90% of wells have detectible contaminants and thousands have been closed.

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

Further Reading

Cleaning Up Groundwater

Summary

- Groundwater is susceptible to pollutants that infiltrate into the ground from underground storage tanks or agricultural fields.
- Rock and soil filters some pollutants as water travels down to and through an aquifer.
- A plume containing pollutants travels outward from the source and through the aquifer in the direction the water is moving.

Review

1. Is groundwater always cleaner than surface water?
2. Is water that is advertised as spring water necessarily free of contaminants? Why or why not?
3. How does groundwater move into and through an aquifer?

Explore More

Use this resource to answer the questions that follow.



1. What chemicals get into drinking water?
2. How does water get into the groundwater aquifer?
3. How does rock dissolve?
4. How does karst aquifers groundwater get contaminated?
5. What are the three types of contaminants?
6. What happens to these contaminates when it rains above a karst aquifer?
7. What do sediments increase pollution in an aquifer?

This page titled 8.19: Groundwater Pollution is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.20: Water Pollution



Do you live near water? Do you see pollution?

Water pollution is a worldwide problem. Almost anything released into the air or onto the land can end up in Earth's water.

Surface Water Pollution

Water pollution may come from one source. For example, chemicals from a factory may empty into a stream. Water pollution may come from more than one source, too. For example, chemicals may rain from the air into that same stream. It is much more difficult to control pollution from more than one source.

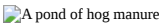
In developed nations, there are three main sources of water pollution:

1. Agriculture
2. Industry
3. Municipal, or community

Agriculture

Chemicals that are applied to farm fields include fertilizers and pesticides. Excess chemicals can be picked up by rainwater. The chemicals can end up in streams, ponds, lakes, or the ocean. Dissolved fertilizer causes tremendous numbers of water plants and algae to grow. This can lead to dead zones where nothing can live in lakes or the coastal oceans.

Waste from livestock can also pollute water. The waste contains **pathogens** that can cause diseases. Many farms in the U.S. have thousands of animals. These farms produce millions of gallons of waste. The waste is stored in huge lagoons, like the one pictured below (**Figure** below). Many leaks from these lagoons have occurred.

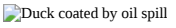


This is a pond of hog manure. Check out the vehicles at the bottom of the picture for scale.

Industry

Factories and power plants may pollute water with harmful substances.

- Many industries produce toxic chemicals.
- Nuclear power plants produce **radioactive** wastes.
- Oil tanks and pipelines can leak.



Oil spills are hard to clean up and kill a lot of wildlife.

Municipal

"Municipal" refers to the community. Households and businesses in a community can pollute the water supply. Municipal pollution comes from sewage, storm drains, septic tanks, boats, and runoff from yards. For example:

- People apply chemicals to their lawns. The excess can run off into surface waters.
- People may dispose of harmful substances incorrectly. For example, motor oil must not be drained into a storm sewer.
- Municipal sewage treatment plants dump treated wastewater into rivers or lakes. But the wastewater may not be treated for everything, or it may not be treated enough.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

403 ERROR

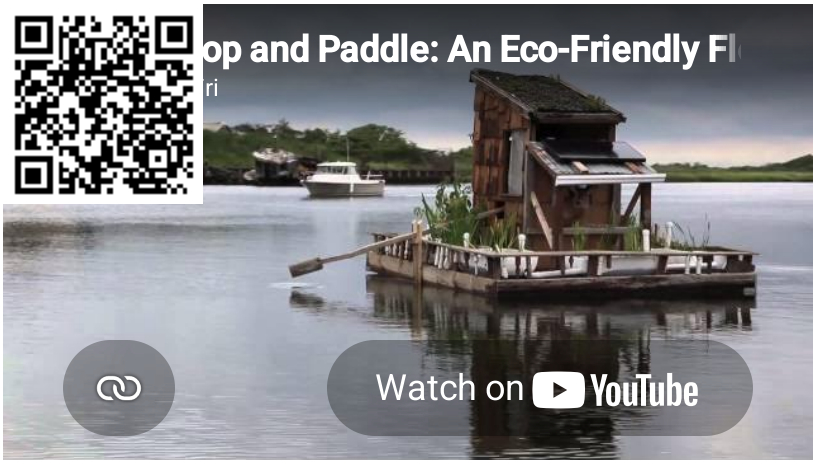
The request could not be satisfied.

Request blocked. We can't connect to the server for this app or website at this time. There might be too much traffic or a configuration error. Try again later, or contact the app or website owner.
If you provide content to customers through CloudFront, you can find steps to troubleshoot and help prevent this error by reviewing the CloudFront documentation.

```
Generated by cloudfront (CloudFront)
Request ID: Jb1hSYn2231_VdJh4Z9-adHefZxTZxP040I5pVvWXNWsk3p4zYfLgw==
```

Science Friday: Poop and Paddle: An Eco-Friendly Floating Toilet

How do wetlands filter water? In this video by Science Friday, inventor Adam Katzman describes how his toilet-boat converts human waste into cattails and clean water.



Summary

- Pollution enters water from municipal, industrial, agricultural sources.
- Fertilizer runoff can create dead zones in the ocean.
- People pollute water when they apply excess chemicals to their lawn. They may also dispose of pollutants incorrectly.

Review

1. Why do large animal farms cause a lot of pollution?
2. What are the three major sources of water pollution in the developed world?
3. How do you and your family pollute water?

This page titled 8.20: Water Pollution is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.21: Protecting Water From Pollution



How could a river burn?

In the mid 1900s, rivers sometimes caught fire. The Cuyahoga River did several times. The river was so full of oil and industrial waste that it was flammable. Nothing could live in it. A fire on the Cuyahoga River in 1969 gained national attention. Something had to be done to protect the water supply.

Protecting the Water Supply

The water supply can be harmed in two major ways. The water can be polluted, and it can be overused. Protecting the water supply must address both problems. We need to reduce how much pollution ends up in the water supply—keeping water from being polluted is easier and cheaper than cleaning it. We need to treat water that's already polluted. We need to conserve water by using less.

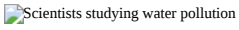
Controlling Water Pollution

Disasters, such as rivers burning, led to new U.S. laws to protect the water. For example, the Environmental Protection Agency (EPA) was established, and the Clean Water Act was passed. Now, water is routinely tested. Pollution is tracked to its source, and polluters are forced to fix the problem and clean up the pollution. They are also fined. These consequences have led industries, agriculture, and communities to pollute the water less than before, but the problem is no where near solved.

The Clean Water Act

Keeping water clean often requires laws. Laws ensure that people behave responsibly. The Clean Water Act regulates water pollution in the U.S. The law allows the EPA to set standards for water quality. The EPA regulates the pollutants that can enter waterways. The agency can provide money for wastewater treatment plants. The law was passed in 1972.

International groups are trying to improve global water quality. The United Nations and other groups provide the technology for treating water. They educate people in how to protect and improve their water (**Figure** below).



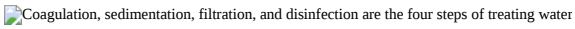
Scientists control water pollution by sampling the water and studying the pollutants that are in the water.

Water Treatment

Water treatment is a series of processes that remove unwanted substances from water. The goal of water treatment is to make the water safe to return to the natural environment or to the human water supply. Treating water for other purposes may not include all the same steps. That's because water used in agriculture or industry may not have to be as clean as drinking water.

Below, you can see how water for drinking is treated (**Figure** below). Treating drinking water requires at least four processes:

1. Chemicals are added to untreated water. They cause solids in the water to clump together. This is called **coagulation**.
2. The water is moved to tanks. The clumped solids sink to the bottom of the water. This is called **sedimentation**.
3. The water is passed through filters that remove smaller particles from the water. This is called **filtration**.
4. Chlorine is added to the water to kill bacteria and other microbes. This is called **disinfection**. Finally, the water is pure enough to drink.



Four processes are used to treat water to make it safe for drinking.

What Can You Do?

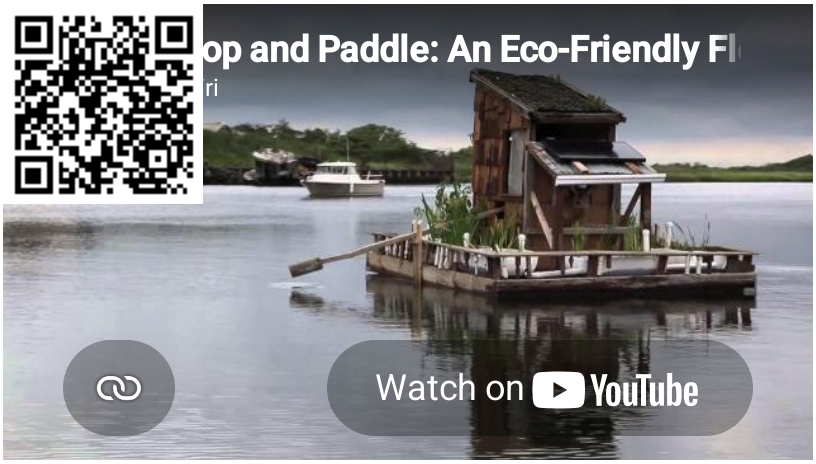
What can individuals do to protect water quality?

- Dispose of motor oil and household chemicals properly. Phone your community for instructions.
- Use lawn, garden, and farm chemicals sparingly. Use them wisely. Excess chemicals will run off into the water supply.

- Repair automobile or boat engine leaks immediately.
- Keep litter, pet waste, leaves, and grass clippings out of street gutters and storm drains.

Science Friday: Poop and Paddle: An Eco-Friendly Floating Toilet

How do wetlands filter water? In this video by Science Friday, inventor Adam Katzman describes how his toilet-boat converts human waste into cattails and clean water.



Summary

- There are multiple levels of water treatment. Some water is cleaned enough for use on lawns. Some must be made safe for drinking.
- Individuals can protect water by following some guidelines.
- The Clean Water Act regulates pollutants and provides money for wastewater treatment plants to be built.
- Keeping water from becoming polluted is easier, less expensive, and safer than cleaning it once it is polluted.

Review

1. How is water treatment better than water cleanup later?
2. How is wastewater treated?
3. What can you do to protect water quality?
4. What is the purpose of the Clean Water Act?

Explore More



1. How old is the Clean Water Act today?
2. What event was one of the springboards that led to the designing of the Clean Water Act?
3. What is a second event that was a springboard that led to the designing of the Clean Water Act?
4. How do laws, like the Clean Water Act, pass and then evolve?
5. Why might it be important to protect an entire watershed rather than just one location on one stream?
6. What principles might a nation have that would lead it to protect its water?
7. Why is it difficult to regulate water in a country like the United States?
8. Besides regulation, what do you need to get communities to protect their water?

This page titled 8.21: Protecting Water From Pollution is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.22: Cleaning Up Groundwater



Would you drink this water?

Cleaning water is not easy. Cleaning groundwater is especially difficult. If you want to drink clean water, groundwater must not become polluted, or it must be cleaned.

Groundwater Pollution

Pollutants in surface water can filter into the ground and enter a groundwater aquifer. Irrigation water can bring pesticides and other chemicals. Water can seep through landfills. Tanks of gasoline stored underground can leak.

Pollutants can be filtered out of water that travels through rock and soil. Filtering is very effective, but it doesn't get out all of the pollutants.

Pollutants that enter an aquifer spread outward from the source. They spread in the direction the water is moving.

Cleaning Groundwater

It is a lot easier and cheaper not to pollute surface water than it is to clean it. That is even truer for groundwater. To clean groundwater, the water must be cleaned. Also, the rock and soil it travels through must be cleaned. Then the toxic rock and soil must be put somewhere. Cleaning polluted groundwater is expensive and can take years. Sometimes it can't even be done.

Stages of Groundwater Cleaning

To clean groundwater, you must:

- Eliminate the pollution source: An underground tank must be pumped dry and then dug out from the ground. A factory must be required to stop releasing toxic chemicals. Farms must be more careful about the chemicals they put on their fields.
- Monitor the extent of the pollutant: Scientists test water in wells. Sometimes they drill wells to test water. They learn how the groundwater is flowing: how fast and in what direction. They study the contaminants in the groundwater. Then they determine where the contaminant plume is going.



CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Test wells are drilled to monitor groundwater pollution.

- Engage in remediation: A barrier is constructed in the aquifer. This isolates the contaminated groundwater from the rest of the aquifer. The contaminated groundwater must be treated. **Remediation** is correcting a problem.
  - The cheapest and easiest way is to treat the water in the aquifer.
    - **Bioremediation** is one way of treating the water in the aquifer. Microorganisms are bioengineered to eat the pollutant. The organisms are injected into the contaminated region. They consume the pollutant. Bioremediation is short for biological remediation.
    - **Chemical remediation** can also treat water in the aquifer. A chemical is pumped into the aquifer. The chemical destroys the contaminant.
  - It is much more difficult and expensive to remove the water from the aquifer and then treat it. The water is pumped to the surface. It is then cleansed using chemical or biological methods. It is re-injected into the aquifer. The contaminated rock and soil must be dug up and the pollutant destroyed. Then it is returned to the ground. This is done only in extreme cases.

Summary

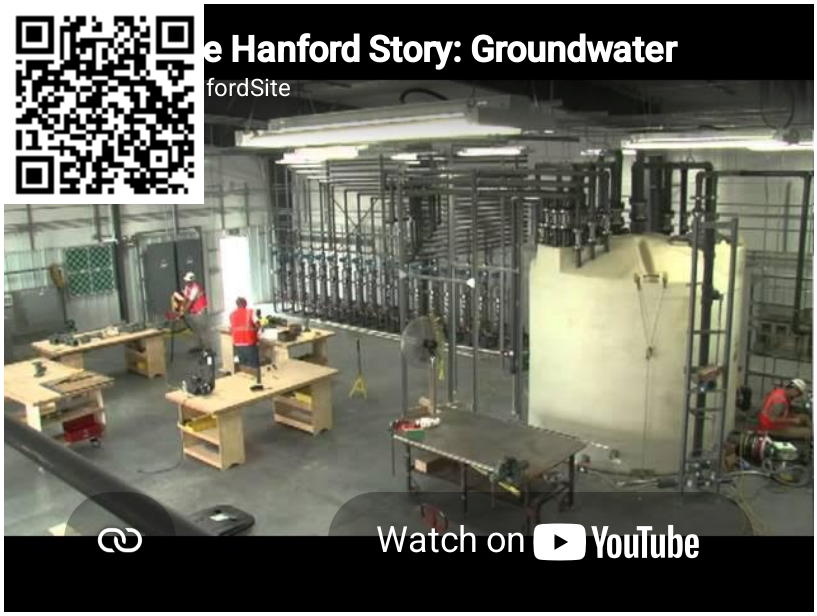
- To clean groundwater: remove the pollutant source, monitor the pollutant, and perform remediation.
- Scientists test the water in many wells to see where the contaminant is. They do this to tell where the contaminant is. Over time they can tell which direction the contaminant is moving.
- Cleaning groundwater in an aquifer requires bioremediation or chemical remediation. Bioremediation uses microorganisms to consume a pollutant. Chemical remediation destroys the contaminant.

Review

1. Why do contaminated soil or rock need to be cleaned in an aquifer?
2. What are the two types of remediation that can take place in an aquifer?
3. How do scientists monitor the contaminants in an aquifer?

Explore More

Use the resource below to answer the questions that follow.



1. What was the Hanford site used for?
2. What river needs to be protected? What is it used for?
3. By what routes did contamination get into the groundwater?
4. In the video, contamination decreased from 80 to 65 square miles. What was the main reason for that?

5. What is the goal at Hanford?
6. What is being done to clean the contaminated groundwater?
7. How are barriers used to clean groundwater?

This page titled 8.22: Cleaning Up Groundwater is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

8.23: Earth's Fresh Water- Challenge 4

1. Nutrients, such as ___ in fertilizer, promote algae growth in water.

nitrates

2. Radioactive substances, heavy metals, and oils are examples of ___.

industrial pollution

3. One indicator of aquatic health is BOD levels, which measure biological oxygen demand. Healthy systems have low BOD levels. A high BOD level indicates ___.

a highly polluted system due to a scarcity of oxygen and an excess of nutrients (especially nitrates)

4. While treating drinking water, chemicals are added to make solids in the water clump together in the process of ___.

coagulation

5. In water treatment, ___ is the process of removing smaller particles from the remaining liquid.

filtration

6. The first step of wastewater treatment is ___.

removing the large and small particles

7. In coastal areas, groundwater mining ___.

increases groundwater salinity

8. The ___ region of the U.S. has intense droughts and reduced groundwater levels.

South

9. In coastal areas, when aquifers get low, ___ may intrude.

salt water

10. Which of the following can pollute groundwater: landfills, hydraulic pumping operations, or mining operations?

All of these activities can pollute groundwater

11. While analyzing groundwater contamination, scientists focus on ___.

the site's geology, the nature of the contaminants, and the soil characteristics

12. Cleaning an aquifer does no good if you do not also ___.

eliminate the pollution source

13. ___ involves injecting microorganisms into contaminant plumes and allowing them to consume pollutants.

Bioremediation

14. Bringing toxic materials to the surface does not solve the problem of ___.

disposing them cleanly and safely

This page titled 8.23: Earth's Fresh Water- Challenge 4 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

9: Earth's Oceans

9.1: Importance of the Oceans
9.2: Seawater Chemistry
9.3: Ocean Zones
9.4: Earth's Oceans- Challenge 1
9.5: Wind Waves
9.6: Tides
9.7: Surface Currents
9.8: Ocean Currents and Climate
9.9: Deep Currents
9.10: Earth's Oceans- Challenge 2
9.11: Coastal Pollution
9.12: Ocean Garbage Patch
9.13: Oil Spills
9.14: Earth's Oceans- Challenge 3

This page titled 9: Earth's Oceans is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

9.1: Importance of the Oceans



What does this whale know about the oceans?

People divide up the seas into five oceans, but they are really all interconnected. Even so, they are all very different. This ocean is near a shore and is obviously in a cold region. It appears to be a good habitat for whales! No matter what, the oceans have a huge influence on the planet, locally and as a whole.

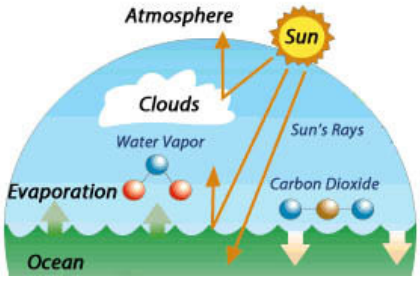
The Ocean Influence

Oceans cover more than 70% of Earth's surface. Oceans hold 97% of the planet's surface water. It’s no surprise that the oceans have a big influence on the planet. The oceans affect the atmosphere, climate, and living things.

Oceans and the Atmosphere

Oceans are the major source of water vapor in the atmosphere. Sunlight heats water near the sea surface (**Figure** below). As the water warms, some of it evaporates. The water vapor rises into the air, where it may form clouds and precipitation. Precipitation provides the freshwater needed by plants and other living things.

Gas Exchange Between Oceans and Atmosphere



The oceans and atmosphere exchange gases. Why does water vapor enter the atmosphere from the water?

Ocean water also absorbs gases from the atmosphere. The most important are oxygen and carbon dioxide. Oxygen is needed by living things in the oceans. Much of the carbon dioxide sinks to the bottom of the seas. Carbon dioxide is a major cause of global warming. By absorbing carbon dioxide, the oceans help control global warming, at least as long as the carbon dioxide stays in the seas.

Oceans and Climate

Coastal areas have a milder climate than inland areas. They are warmer in the winter and cooler in the summer. That’s because land near an ocean is influenced by the temperature of the oceans. The temperature of ocean water is moderate and stable. Why? There are two major reasons:

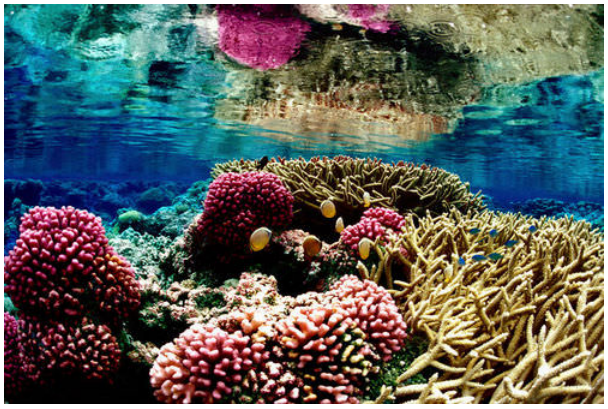
1. Water warms up and cools down much more slowly than land. As a result, oceans never get as hot or as cold as land.
2. Water flows through all the world’s oceans. Warm water from the Equator mixes with cold water from the poles. The mixing of warm and cold water makes the water temperature moderate.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Even inland temperatures are milder because of oceans. Without oceans, there would be much bigger temperature swings all over Earth. Temperatures might plunge hundreds of degrees below freezing in the winter. In the summer, lakes and seas might boil! Life as we know it could not exist on Earth without the oceans.

Oceans and Living Things

The oceans provide a home to many living things. In fact, a greater number of organisms lives in the oceans than on land. Coral reefs (**Figure** below) have more diversity of life forms than almost anywhere else on Earth. Biological diversity is shortened to **biodiversity**. Oceans contain the majority of **biomass** on Earth.



Coral reefs teem with life.



Further Reading

Ocean Zones

Surface Currents

Ocean Currents and Climate

Deep Currents

Summary

- Oceans are an important part of the water cycle. They absorb gases from the atmosphere. They evaporate and supply water vapor to the atmosphere.

- Oceans moderate Earth's temperature by not changing temperature rapidly. Oceans also distribute heat around the planet.
- Oceans have tremendous biodiversity. They also contain the majority of all biomass on Earth.

Review

1. How do the oceans moderate Earth's temperature?
2. What role do oceans play in the water cycle?
3. Why do oceans have so much biomass?

This page titled 9.1: Importance of the Oceans is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

9.2: Seawater Chemistry



What do you get when you vaporize seawater?

Salt! Human bodies need salt to live. Nowadays most of this salt comes from the oceans or saline lakes. Some salt comes from rocks that evaporated from seawater.

Makeup of Ocean Water

You know that ocean water is salty. How salty is it? What is the **salinity** of seawater? Average seawater is about 3.5% salt. The amount is different if there is a nearby source of freshwater. It is also different if there is a lot of evaporation in an area. How do you think these things affect seawater salinity? Seawater also contains other substances like sugars, acids, bases, and organic molecules.

Why Is Ocean Water Salty?

Ocean water is salty because water dissolves minerals out of rocks. The ions enter the water. This happens whenever water flows over or through rocks. Much of this water and its minerals end up in the oceans. Minerals dissolved in water form salts. When the water evaporates, it leaves the salts behind. As a result, ocean water is much saltier than other water on Earth.

How Salty Is Ocean Water?

Have you ever gone swimming in the ocean? If you have, then you probably tasted the salts in the water. By mass, salts make up about 3.5% of ocean water. The table below shows the most common minerals in ocean water (**Table** below). The main components are sodium and chloride. Together they form the salt known as sodium chloride. You may know the compound as table salt or the mineral halite.

Element	Percent
Oxygen	85.84
Hydrogen	10.82
Chloride	1.94
Sodium	1.08
Magnesium	0.1292
Sulfur	0.091
Calcium	0.04
Potassium	0.04
Bromine	0.0067
Carbon	0.0028

The amount of salts in ocean water varies from place to place. For example, near the mouth of a river, ocean water may be less salty. That's because river water contains less salt than ocean water. Where the ocean is warm, the water may be more salty. Can you explain why? (Hint: More water evaporates when the water is warm.)

Density

Seawater has lots of salts in it. This increases its **density** (mass per volume) over fresh water. Temperature and pressure also affect density.

Water density increases as:

- salinity increases.
- temperature decreases.
- pressure increases.

Differences in water density are responsible for deep ocean currents, as will be discussed in the concept "Deep Ocean Currents."

Summary

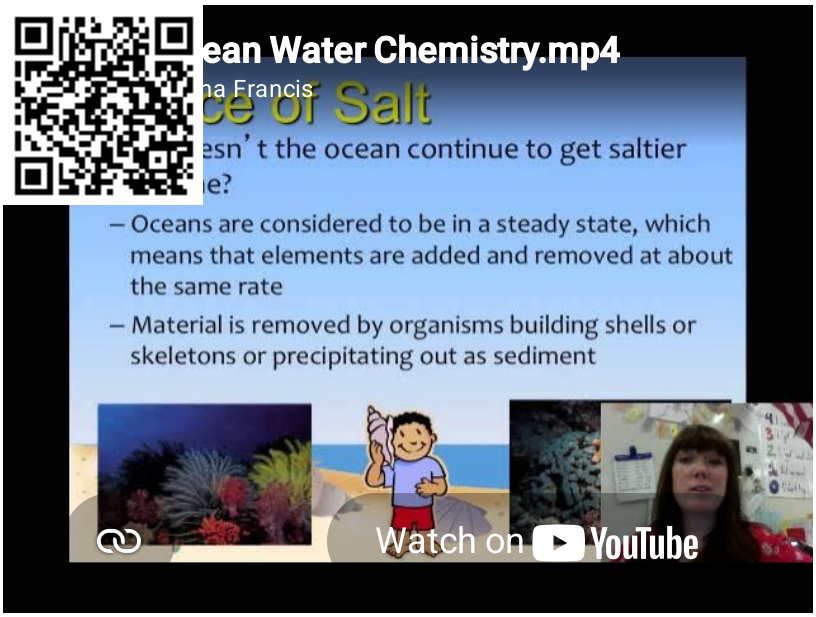
- Water moving through rock and soil picks up ions. Those ions end up as salts in large bodies of water.
- Ocean water contains salts and other substances.
- Water density increases as salinity and pressure increase, or as temperature decreases.

Review

1. Streams aren't salty, so why is the ocean salty?
2. Answer and explain the following: If evaporation is high, what happens to seawater density? If freshwater is added to a region, what happens to seawater density? If seawater gets very cold, what happens to its density?
3. What is salinity?

Explore More

Use the resource below to answer the questions that follow.



1. Why are oceans important?
2. Which dissolved gases are found in the oceans?
3. Which dissolved salts are contained in seawater?
4. What is salinity? What is the salinity of average seawater?
5. Where does the salt come from?
6. Why doesn't the ocean get saltier over time?
7. What changes the salinity in different places in the oceans?
8. What are the effects of salinity on water?
9. How does the surface temperature of ocean water vary?
10. Where is the coldest, densest ocean water?
11. What does carbon dioxide do in the oceans?
12. How does temperature change with depth? How does pressure change with depth?

This page titled 9.2: Seawater Chemistry is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

9.3: Ocean Zones

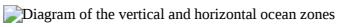


If you go down in the ocean, what do you see?

Imagine you're in a submersible going to the bottom of the ocean. The first thing you realize is that it's not light for very long. The next thing is that many of the creatures that live just below where it's light create their own light. This is called **bioluminescence**. What is the advantage of being able to light up if you live in the dark?

Ocean Zones

In addition to the amount of salts, other conditions in ocean water vary from place to place. One is the amount of nutrients in the water. Another is the amount of sunlight that reaches the water. These conditions depend mainly on two factors: distance from shore and depth of water. Oceans are divided into zones (**Figure** below) based on these two factors. The ocean floor makes up another zone.



Distance from shore and depth of water define ocean zones. Which zone is on the ocean floor?

Zones Based on Distance from Shore

There are three main ocean zones based on distance from shore. They are the **intertidal zone**, **neritic zone**, and **oceanic zone**. Distance from shore influences how many nutrients are in the water. Why? Most nutrients are washed into ocean water from land. Therefore, water closer to shore tends to have more nutrients. Living things need nutrients. So distance from shore also influences how many organisms live in the water.

Zones Based on Depth of Water

Scientists refer to the vertical extent of ocean water as the **water column**. Two main zones based on depth of water are the photic zone and aphotic zone. The **photic zone** is the top 200 meters of water. The **aphotic zone** is water deeper than 200 meters. The deeper you go, the darker the water gets. That’s because sunlight cannot penetrate very far under water. Sunlight is needed for photosynthesis. So the depth of water determines whether photosynthesis is possible. There is enough sunlight for photosynthesis only in the photic zone.

Water also gets colder as you go deeper. The weight of the water pressing down from above increases as well. At great depths, life becomes very difficult. The pressure is so great that only specially adapted creatures can live there.

Summary

- The small surface zone that has light is the photic zone. The entire rest of the ocean does not have light and is the aphotic zone.
- The ocean is divided into horizontal zones based on the depth of water beneath: the intertidal, neritic, and oceanic.
- Most of the life forms in the oceans live in, or at least visit, the surface.

LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

Review

1. Why is there so little life at the bottom of the ocean?
2. Compare and contrast the intertidal, neritic, and oceanic zones.
3. What would you expect to find in the photic zone? How would you expect that to be different from the aphotic zone?

Explore More

Use the resource below to answer the questions that follow.



1. Where can 90% of the of the ocean's life be found?
2. Where is the twilight zone? What lives there?
3. Where is the dark zone? What lives there?
4. Why is little life found in the dark zone?
5. What is the abyss? Where is it found?
6. Why are trenches so deep?

This page titled 9.3: Ocean Zones is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

9.4: Earth's Oceans- Challenge 1

1. Water changes temperature more ___ than land.

slowly

2. Oceans moderate Earth's temperature by ___.

absorbing thermal energy near the equator and moving it near the poles

3. Water density increases when temperature ___.

decreases

4. Seawater is rich in ___.

sodium chloride

5. The salts in seawater come from ___.

the weathering of rock and soil

6. The oceanic zone richest in life is the ___ zone.

photic

7. The aphotic zone makes up the ___ of the ocean.

majority

This page titled 9.4: Earth's Oceans- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

9.5: Wind Waves

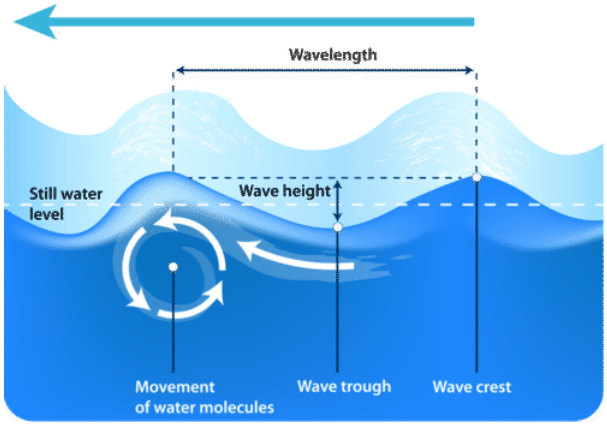


Surfin' U.S.A.

Jaws Beach in Maui, Hawaii, has legendary waves. The largest waves come when winds are very strong, usually in the winter. The rocks and reef offshore magnify the size of the incoming wave energy. Cowabunga!

Waves

Most ocean waves are caused by winds. A **wave** is the transfer of energy through matter. A wave that travels across miles of ocean is traveling energy, not water. Ocean waves transfer energy from wind to the water. The energy is transferred from one water molecule to the next. The energy of a wave may travel for thousands of miles. The water itself moves very little. The picture below shows how water molecules move when a wave goes by (**Figure** below). Once the wave starts, it doesn't need more wind to keep it going.



A wave travels through the water. How would you describe the movement of water molecules as a wave passes through?

The Size of Waves

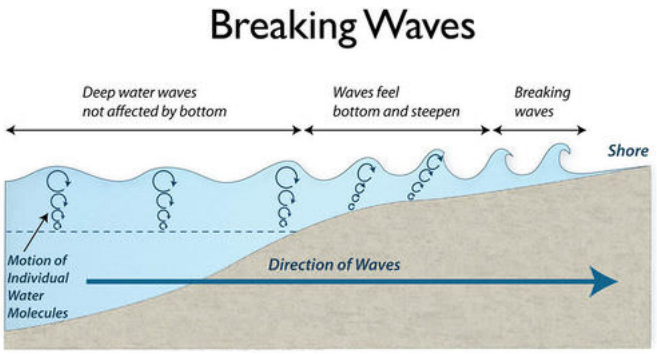
The figure above also shows how the size of waves is measured (**Figure** above). The highest point of a wave is the **crest**. The lowest point is the **trough**. The vertical distance between a crest and a trough is the **wave height**. Wave height is also called **amplitude**. The horizontal distance between two crests is the **wavelength**. Both amplitude and wavelength are measures of wave size.

The size of an ocean wave depends on how fast, over how great a distance, and how long the wind blows. The greater each of these factors is, the bigger a wave will be. Some of the biggest waves result from hurricanes. A hurricane is a storm that forms over the ocean. Its winds may blow more than 150 miles per hour! The winds also travel over long distances and may last for many days.

Breaking Waves

The figure below shows what happens to waves near shore (**Figure** below). As waves move into shallow water, they start to touch the bottom. The base of the waves drag and slow. Soon the waves slow down and pile up. They get steeper and unstable as the top

moves faster than the base. When they reach the shore, the waves topple over and break.

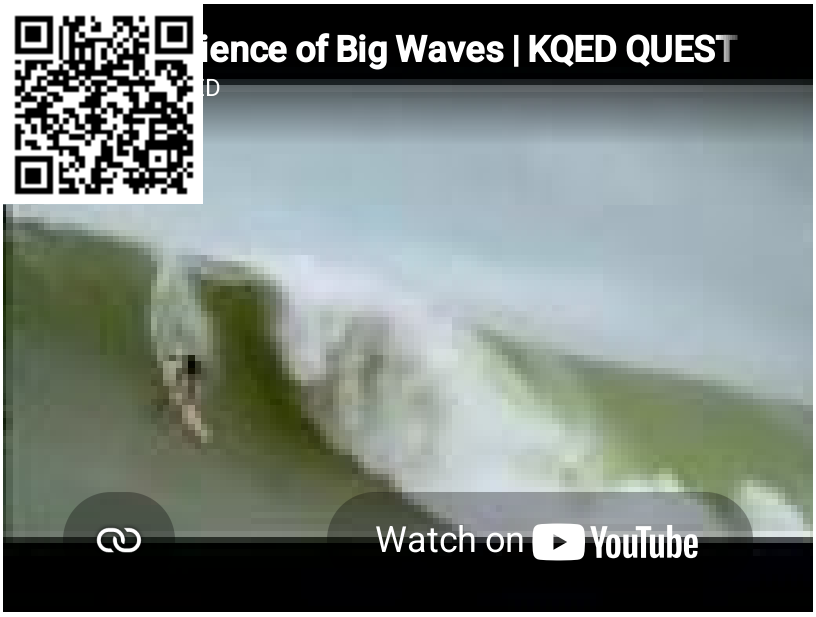


Waves break when they reach the shore.

Storm Surge

Some of the damage done by storms is from **storm surge**. Low pressure in a storm pulls water upward. Water piles up at a shoreline as storm winds push waves into the coast. Storm surge may raise sea level as much as 7.5 m (25 ft). This can be devastating in a shallow land area when winds, waves, and rain are intense.

Maverick waves are massive. Learning how they are generated can tell scientists a great deal about how the ocean creates waves and especially large waves.



Summary

- The largest wind waves are built when a strong wind blows for a long time over a large area.
- It is not the water that travels in a wave; it is the energy that is transferred from where the wave formed.
- A wave breaks when it is too tall to be supported by its base. This is common as a wave moves up the shore.

Review

1. How does a wave break onshore? How does a wave break in the ocean?
2. How does a wave move across the ocean?
3. How do hurricanes create large waves?

Explore More

Use the resources below to answer the questions that follow.



1. What can cause waves?
2. Where does the energy in a wave come from and how does it get into the wave?
3. What three factors affect the size and strength of waves?
4. How are large waves created?



5. What causes a wave to break at the shore?

This page titled 9.5: Wind Waves is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

9.6: Tides



Did you ever build a sandcastle?

A sandcastle lasts only until the next tide comes in. To build a sand castle the sand must be moist enough for the grains to stick together. So it has to be near the water. But that puts the castle in position to be buried by the next high tide. Oh well. You can build another one when the tide goes back out!

Tides

Tides are daily changes in the level of ocean water. They occur all around the globe. **High tides** occur when the water reaches its highest level in a day. **Low tides** occur when the water reaches its lowest level in a day. Tides keep cycling from high to low and back again. In most places the water level rises and falls twice a day. So there are two high tides and two low tides approximately every 24 hours.

Below, you can see the difference between high and low tides (**Figure** below). This is called the **tidal range**.



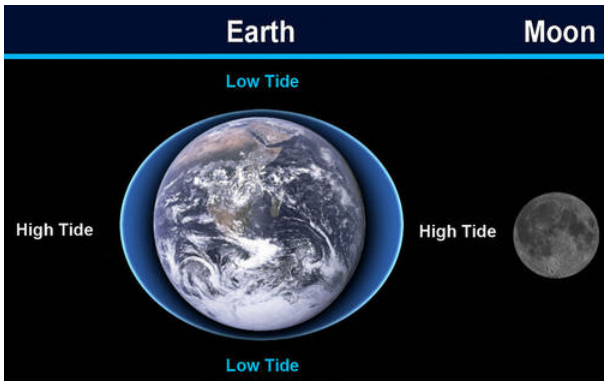
Where is the intertidal zone in this picture?

Why Tides Occur

The figure below shows why tides occur (**Figure** below). The main cause of tides is the pull of the Moon's gravity on Earth. The pull is greatest on whatever is closest to the Moon. Although the gravity pulls the land, only the water can move. As a result:

- Water on the side of Earth facing the Moon is pulled hardest by the Moon's gravity. This causes a bulge of water on that side of Earth. That bulge is a high tide.
- Earth itself is pulled harder by the Moon's gravity than is the ocean on the side of Earth opposite the Moon. As a result, there is bulge of water on the opposite side of Earth. This creates another high tide.
- With water bulging on two sides of Earth, there's less water left in between. This creates low tides on the other two sides of the planet.

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



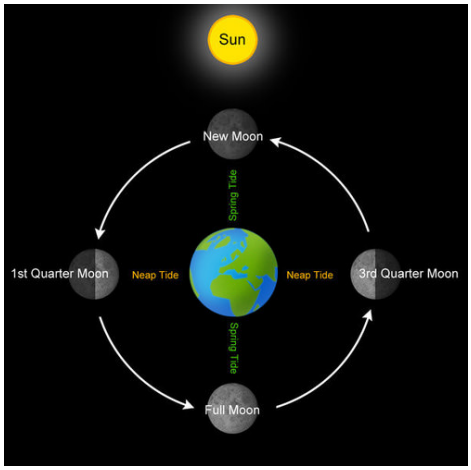
High and low tides are due mainly to the pull of the Moon's gravity.

Spring Tides and Neap Tides

The Sun's gravity also pulls on Earth and its oceans. The Sun is much larger than the Moon, so is its gravitational pull on Earth greater than the Moon's? The pull of the Sun's gravity is much less because the Sun is much farther away. In fact, the Sun's gravitational pull on Earth is a little less than half of the Moon's pull.

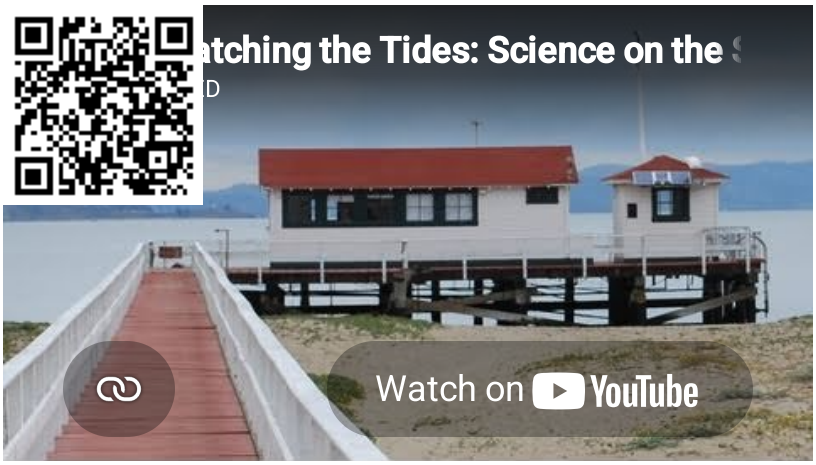
The figure below shows where the Moon is relative to the Sun at different times during the month (**Figure** below). The positions of the Moon and Sun relative to each other affects the tides. This creates spring tides or neap tides.

- **Spring tides** occur during the new moon and full moon. The Sun and Moon must either be in a straight line on the same side of Earth, or they must be on opposite sides of Earth. Their gravitational pull combines to cause very high and very low tides. Spring tides have the greatest tidal range.
- **Neap tides** occur during the first and third quarters of the Moon. The Moon and Sun are at right angles to each other. Their gravity pulls on the oceans in different directions so the highs and lows are not as great. Neap tides have the smallest tidal range.



The Sun and Moon both affect Earth's tides.

Studying ocean tides' rhythmic movements helps scientists understand the ocean and the Sun/Moon/Earth system. This QUEST video explains how tides work, and visits the oldest continually operating tidal gauge in the Western Hemisphere.



Summary

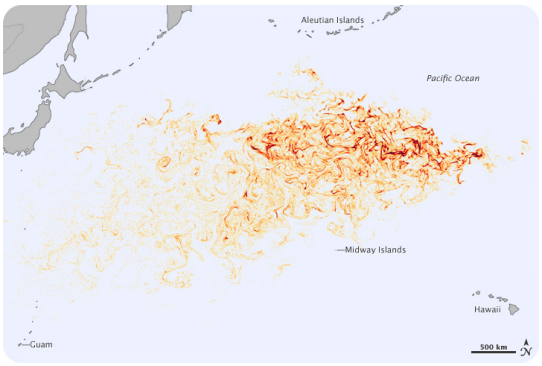
- The primary cause of tides is the gravitational attraction of the Moon. This causes two high and two low tides a day.
- When the Sun's and Moon's tides match, there are spring tides. When the two tides are opposed, there are neap tides.
- The difference between the daily high and the daily low is the tidal range.

Review

1. How does the Moon make two high and two low tides a day?
2. How does the Sun make two high and two low tides a day?
3. What causes spring tides? What causes neap tides?

This page titled 9.6: Tides is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

9.7: Surface Currents



What can debris tell us about surface currents?

The surface of the ocean is on the move. One way to see this is when something is dumped in the ocean. Where will it end up? The tsunami that struck Japan in March 2011 pulled a lot of material into the ocean. The image above is a model created in April 2012. The orange and red are where floating debris might be. Scientists are creating models of where the debris will go. But no one knows for sure where it will go or when it will get there.

Surface Currents

Like air in the atmosphere, ocean water moves in currents. A current is a stream of moving water that flows through the ocean. **Surface currents** are caused mainly by winds but not daily winds. Surface currents are caused by the major wind belts. These winds blow in the same direction all the time. So they can keep water moving in the same direction.

Surface currents are created by three things:

- global wind patterns
- the rotation of the Earth
- the shape of the ocean basins

Surface currents are extremely important because they distribute heat around the planet. Surface currents also have a tremendous influence on climate around the globe.

Global Wind Patterns

Winds on Earth are either global or local. Global winds blow in the same directions all the time. They are created when more solar energy strikes the Equator than the polar regions. More about global wind patterns is described in detail in the concept Global Wind Belts.

The major wind belts push the water in the surface currents. The water moves in the direction of :

- trade winds: east to west between the Equator and 30°N and 30°S.
- westerlies: west to east in the middle latitudes.
- polar easterlies: east to west between 50° and 60° north and south of the Equator and the North and South Poles.

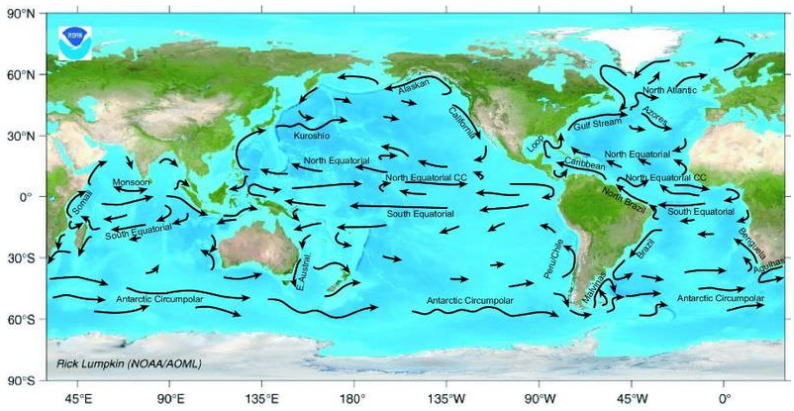
Earth's Rotation

The rotation of the Earth—that is, the **Coriolis effect**—causes the ocean currents to turn. More information about the phenomenon can be found in the concept Coriolis Effect.

Shape of the Ocean Basins

A surface current moves across the ocean. Eventually, the current runs into land (**Figure** below). When it does, it turns right in the Northern Hemisphere and left in the Southern Hemisphere. The direction is due to Coriolis effect.

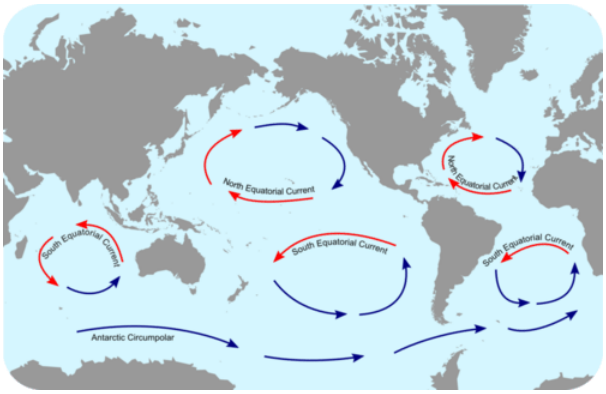
CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



The major surface ocean currents.

Gyres

The major surface currents are pictured below (**Figure** below). They flow in a clockwise direction in the Northern Hemisphere. In the Southern Hemisphere, they flow in the opposite direction. These loops are called **gyres**. Only the Antarctic Circumpolar Current flows nonstop around the globe.

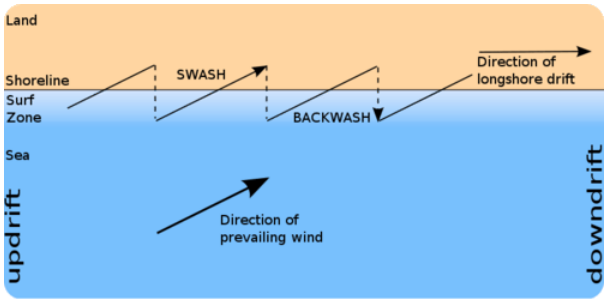


Earth's surface currents flow in the patterns shown here.



Local Surface Currents

Currents are also found along shorelines (**Figure** below). They are not related to the global wind belts. Two are **longshore currents** and **rip currents**.



Longshore currents move water and sediment parallel to the shore. They move in the direction of the prevailing local winds.

Rip currents are very dangerous currents! Rip currents move large amounts of water offshore quickly. Each summer in the United States, at least a few people die when they are caught in rip currents.

Summary

- Major surface ocean currents are the result of global wind patterns, Earth's rotation, and the shape of the ocean basins.
- Major surface currents circle the oceans in five gyres.
- Local surface currents, like longshore and rip currents, move near shorelines.

Review

1. Why does the North Pacific gyre move the way it does?
2. What should you do if you get stuck in a rip current? Why?
3. Why is the Antarctic Circumpolar Current different from other surface currents? What would surface currents look like if there were no continents?

Explore More

Use the resource below to answer the questions that follow.



1. What is a surface current?
2. What is a thermocline?

3. Where is the thermocline?
4. How do surface currents form?
5. What factors determine the movement of surface currents?
6. Why are currents different temperatures?
7. How do surface currents affect climate?
8. How are the currents monitored by NASA?

This page titled 9.7: Surface Currents is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

9.8: Ocean Currents and Climate



How do ocean currents create giant redwoods?

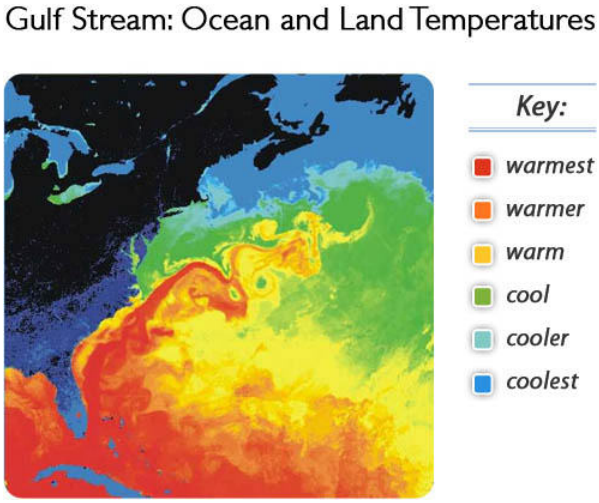
The California Current brings cool water south along the western United States. Cool water contacting warmer water creates fog. This creates a favorable habitat for the giant redwoods of the northern California coast.

Surface Currents and Climate

Large ocean currents can have a big impact on climate, especially of nearby coasts. The Equator and the poles have very different climates today. But these regions would be much more different without ocean surface currents. These currents move heat around the globe. The best known of these is the **Gulf Stream**, which warms parts of Europe. But other currents also alter near-shore climates. Like the Gulf Stream, the Kushiro Current warms Japan. Cooler currents that move from the polar regions to the Equator also alter climate.

The Gulf Stream

The Gulf Stream carries warm water from near the Equator up the eastern coast of North America. Look at the map below (**Figure** below); it shows how the Gulf Stream warms both the water and land along the coast.



In this satellite photo, different colors indicate the temperatures of water and land. The warm Gulf Stream can be seen snaking up eastern North America.

The warm water then flows across the Atlantic Ocean to Europe. The Gulf Stream's warm waters raise temperatures in the North Sea. The warmer ocean temperatures raise the air temperatures over land. The difference is between 3 to 6°C (5 to 11°F). London, U.K., for example, is about six degrees farther south than Quebec, Canada. However, London's average January temperature is nearly 16°C (28°F) warmer. London also gets a lot of rain (**Figure** below). Air traveling over the warm Gulf Stream water picks up moisture. Quebec is much drier but much snowier (**Figure** below).

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



London, England, in winter.



Quebec City, Quebec, in winter.

Summary

- Water in the Gulf Stream warms as it travels along the Equator. The Gulf Stream brings warm water north along the United States. It then travels across the northern Atlantic to the British Isles.
- The Gulf Stream creates a relatively warm wet climate for the British Isles. This compares with the frigid Quebec at about the same latitude.
- Ocean currents transfer heat from the Equator toward the poles. This moderates Earth's temperature.

Review

1. Why is England relatively mild and rainy in winter for its latitude? Why is central Canada, at the same latitude and during the same season, relatively dry and frigid?
2. Where else do you think ocean currents might moderate global climate?
3. What would Earth be like if ocean water did not move?

Explore More

Use the resource below to answer the questions that follow.



1. What occurred in the Atacama desert in July 2011? Why was this noteworthy?
2. What was the weather like in Australia in August and September 2011?
3. What happened in the summer of 2011 in the United States?
4. How many temperature records were broken in 2011 in the U.S.?
5. Why are scientists monitoring the Arctic ice?
6. What are the effects of the ice melt?
7. How is the Gulf Stream affected by the melting of the Arctic ice?

This page titled 9.8: Ocean Currents and Climate is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

9.9: Deep Currents



Why do small fish live in upwelling zones?

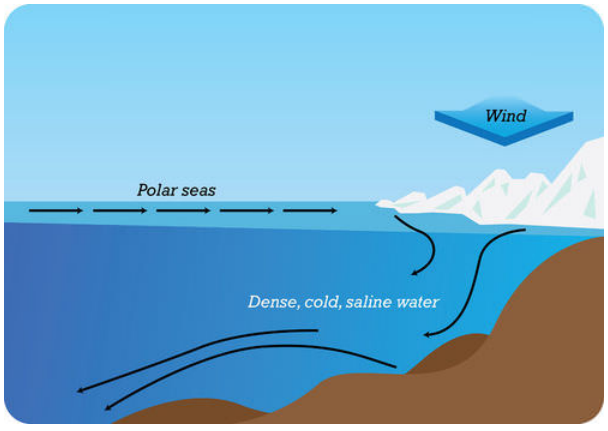
Seawater is always on the move. Water that comes up to the surface from deep is rich with nutrients. Plankton gather where nutrients are plentiful. Small fish come to eat the plankton. Of course, larger fish and birds come to eat the smaller fish. So upwelling is responsible for an abundance of life.

Deep Currents

Currents also flow deep below the surface of the ocean. **Deep currents** are caused by differences in density at the top and bottom. More dense water takes up less space than less dense water. It has the same mass but less volume. Water that is more dense sinks. Less dense water rises. What can make water more dense?

Downwelling

Water becomes more dense when it is colder and when it has more salt. In the North Atlantic Ocean, cold winds chill the water at the surface. Sea ice grows in this cold water, but ice is created from fresh water. The salt is left behind in the seawater. This cold, salty water is very dense, so it sinks to the bottom of the North Atlantic. **Downwelling** can take place in other places where surface water becomes very dense (**Figure** below).

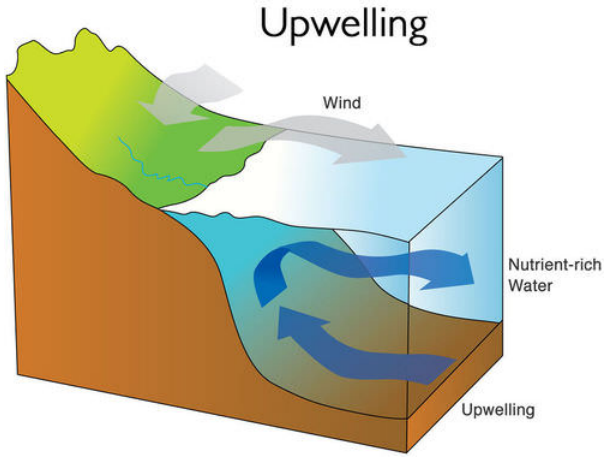


Deep currents flow because of differences in density of ocean water.

When water sinks it pushes deep water along at the bottom of the ocean. This water circulates through all of the ocean basins in deep currents.

Upwelling

Sometimes deep ocean water rises to the surface. This is called **upwelling**. The figure below shows why it happens (**Figure** below). Strong winds blow surface water away from shore. This allows deeper water to flow to the surface and take its place.



An upwelling occurs when deep ocean water rises to the surface.

When water comes up from the deep, it brings a lot of nutrients with it. Why is deep water so full of nutrients? Over time, dead organisms and other organic matter settle to the bottom water and collect. The nutrient-rich water that comes to the surface by upwelling supports many living things.

Upwelling also takes place along the Equator. Winds blow the surface water north and south. This leaves a void that deep water can upwell into. The nutrients rise to the surface and support a great deal of life in the equatorial oceans.

Summary

- Cooling or evaporation of fresh water from the sea surface makes surface water dense. This causes the surface water to undergo downwelling.
- Downwelling of cold, dense water pushes deep water along. This drives thermohaline circulation.
- Upwelling takes place at some coastlines or along the Equator. Upwelling brings cool, nutrient-rich water to the surface.

Review

1. Why is upwelling important?
2. What does downwelling do globally?
3. How are deep currents created?

Explore More

Use the resource below to answer the questions that follow.



1. How does temperature affect the density of water?
2. How does evaporation affect salinity and therefore density?
3. What does the density difference create?
4. What and where is the NADW?
5. What and where is the AABW?
6. Why are NADW and AABW important for global ocean circulation?
7. How long does it take a water molecule to complete the circuit of the global conveyor belt?
8. What is an upwelling? What does it do?

This page titled 9.9: Deep Currents is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

9.10: Earth's Oceans- Challenge 2

1. A wave moves across the ocean as ___ is transferred to the water in the direction the wave is traveling.

energy

2. When a wave breaks onshore, it is not the water but the ___ that has traveled from where the wave formed.

energy

3. A water molecule in a wind wave moves in a(n) ___ motion.

elliptical

4. ___ tides have the smallest tidal range.

Neap

5. Tides are caused primarily by the ___, whose gravity pulls on the ocean.

Moon

6. If you wanted to see the most tide pools on a shore, you should go ___.

during a spring tide, when the tide is low

7. In which direction do the westerlies blow in the middle latitudes?

West to East

8. The ___ Circumpolar Current is the only major current that does not meet a continent.

Antarctic

9. ___ are major surface currents that flow clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere.

Gyres

10. Ocean currents transfer thermal energy from the ___.

equatorial region to the polar regions

11. The Gulf Stream's warm water raises temperatures in the ___.

North Atlantic Ocean

12. If ocean water did not move, Earth would be blazing in the ___ region and frigid in the ___ regions.

equatorial; polar

13. ___ brings nutrients from the deep ocean to the surface, which sustains life.

Upwelling

14. Differences in temperature and salinity change the ___ of seawater.

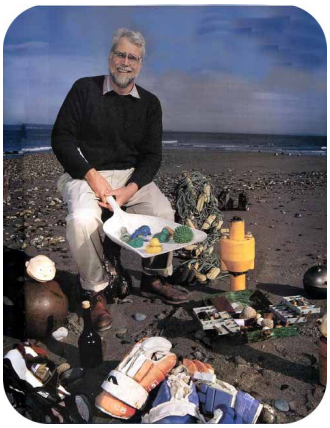
Density

15. ___ circulation is vertical movement of water that drives deep ocean circulation.

Thermohaline

This page titled 9.10: Earth's Oceans- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

9.11: Coastal Pollution



When is trash in the oceans good?

Well, not good exactly, but useful. In 1992, a ship lost 28,000 plastic bath toys in the North Pacific. Oceanographers sent out word and people alerted them when they found the toys on beaches. The oceanographers used these findings to map ocean currents.

Ocean Water Pollution

The oceans are vast. You might think they are too big to be harmed by pollution, but that’s not the case. Ocean water is becoming seriously polluted. This pollution affects the coasts. It even affects the seas far from shore.

Coastal Pollution

The oceans are most polluted along coasts. Why do you think that's the case? Of course, it's because most pollution enters the oceans from the land. Runoff and rivers carry the majority of pollution into the ocean. Many cities dump their **wastewater**, water mixed with waste, directly into coastal waters. In some parts of the world, raw sewage and trash may be thrown into the water (**Figure** below). Coastal water may become so polluted that people get sick if they swim in it or eat seafood from it. The polluted water may also kill fish and other ocean life.



This coastal ocean water is full of trash and sewage.

Much of the trash in the oceans is plastic. Many types of plastic do not degrade. Some break down into plastic molecules, but these can also be pollutants. Plastic shopping bags are extremely abundant in the oceans. Since water runs from land into the sea, chemicals can end up in the sea. Pesticides, herbicides, and fertilizers are among the chemicals.

Open Water Pollution

Most of the trash that is in the oceans comes from the land. About 20% comes from ships. Trash is thrown overboard by many vessels. Fishing boats throw over lines and nets.

There is a very large patch of garbage known as the Great Pacific Garbage Patch. Trash from the lands all around the North Pacific gets caught up in currents. The currents bring the trash into the center of the North Pacific Gyre. The concentration of trash increases toward the center of the gyre.

While recognizable pieces of garbage are visible, much of the trash is tiny plastic molecules. The molecules are invisible to the naken eye but can be seen in water samples. Plastic confetti-like pieces are also found in the gyre.

The size of the garbage patch is unknown, since it can't be seen from above. Some people estimate that it's twice the size of continental U.S, with a mass of 100 million tons.

Effect on Organisms

Animals can be harmed or killed by trash in the oceans. Seabirds and mammals may sometimes accidentally eat plastic bags. This may kill the animals. Fishing nets can entangle fish and other animals so that they cannot escape. Plastic molecules are ingested by organisms. Some that filter water for nutrients may take in a lot of plastic molecules. They may eventually die. Larger fish or humans eat them and may take in the plastics too. Some of the plastics may absorb harmful chemicals.



Plastic bags in the ocean can be mistaken for food by an unsuspecting marine predator.

Reducing Ocean Pollution

Everyone can help to keep trash from entering the ocean. Reduce your use of plastics, especially plastic bags. Dispose of trash and chemicals properly. Be sure that coastal communities dispose of trash safely. If you're on a ship, do not dump trash overboard. Be sure that ships obey laws that protect the seas.

Summary

- Most ocean pollution comes from land and most is found near the coasts. Most of this trash is plastic.
- Plastic trash does not usually biodegrade in the ocean. It breaks down into tiny plastic molecules.
- Ocean pollutants are harmful to marine organisms.

Review

1. What are the consequences of coastal pollution?
2. Since plastic doesn't biodegrade in the oceans, what happens to it?
3. What can you do to help keep the oceans clean?

Explore More

Use the resource below to answer the questions that follow.



1. What created the garbage patch?
2. How much stuff does it contain?
3. What makes up 80% of the patch?
4. What is the problem with plastic?
5. Where does the garbage come from?
6. What are a few of the consequences on marine life of all this plastic?
7. What is the best solution to stop adding to the patch?

This page titled 9.11: Coastal Pollution is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

9.12: Ocean Garbage Patch



How could these balloons kill a sea turtle?

Balloons flying off into the sky symbolize freedom and happiness. Eventually those balloons pop and the plastic falls to the surface. Much of this plastic will end up in the sea where it may be accidentally ingested by a marine organism — with dire results.

Marine Trash

Trash from land may end up as trash in the ocean, sometimes extremely far from land. Some of it will eventually wash ashore, possibly far from where it originated (**Figure** below).



Trash has washed up on this beach.

Sources of Trash

Although people had once thought that the trash found everywhere at sea was from ships, it turns out that 80% is from land. Some of that is from runoff, some is blown from nearshore landfills, and some is dumped directly into the sea.

The 20% that comes from ships at sea includes trash thrown overboard by large cruise ships and many other vessels. It also includes lines and nets from fishing vessels. Ghost nets, nets abandoned by fishers intentionally or not, float the seas and entangle animals so that they cannot escape. Containers sometimes go overboard in storms. Some noteworthy events, like a container of rubber ducks that entered the sea in 1992, are used to better understand ocean currents. The ducks went everywhere!

Makeup of Trash

About 80% of the trash that ends up in the oceans is plastic. This is because a large amount of the trash produced since World War II is plastic. Also many types of plastic do not biodegrade, so they simply accumulate. While many types of plastic photodegrade — that is, they break up in sunlight — this process works only when the plastics are dry. Plastic trash in the water does break down into smaller pieces, eventually becoming molecule-sized polymers. Other trash in the oceans includes chemical sludge and materials that do biodegrade, like wood.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Toxic chemicals

Some plastics contain toxic chemicals, such as bisphenol A. Plastics can also absorb organic pollutants that may be floating in the water, such as the pesticide DDT (which is banned in the U.S. but not in other nations) and some endocrine disruptors.

Effect on Organisms

Marine birds, such as albatross, and other animals, like sea turtles, live most of their lives at sea and come ashore just to mate. These organisms can't break down the plastic, and they may eventually die (**Figure** below). Boats may be affected. Plastic waste is estimated to kill 100,000 sea turtles and marine mammals annually, but exact numbers are unknown.



This albatross likely died from the plastic it had ingested.

Plastic shopping bags are extremely abundant in the oceans. If an organism accidentally ingests one, it may clog digestion and cause starvation by stopping food from moving through or making the animal not feel hungry.

The Great Pacific Garbage Patch

Trash from the lands all around the North Pacific is caught up in currents. The currents bring the trash into the center of the North Pacific Gyre. Scientists estimate that it takes about six years for trash to move from west coast of North America to the center of the gyre. The concentration of trash increases toward the center of the gyre.

While recognizable pieces of garbage are visible, much of the trash is tiny plastic polymers that are invisible but can be detected in water samples. The particles are at or just below the surface within the gyre. Plastic confetti-like pieces are visible beneath the surface at the gyre's center.



Plastic bags in the ocean can be mistaken for food by an unsuspecting marine predator.

The size of the garbage patch is unknown, since it can't be seen from above. Some people estimate that it's twice the size of continental U.S, with a mass of 100 million tons.

Effect on Organisms

In some areas, plastics have seven times the concentration of zooplankton. This means that filter feeders are ingesting a lot of plastics. This may kill the organisms, or the plastics may remain in their bodies. They are then eaten by larger organisms that store the plastics and may eventually die. Fish may eat organisms that have eaten plastic and then be eaten by people. This also exposes humans to toxic chemicals that the fish may have ingested with the plastic.

There are similar patches of trash in the gyres of the North Atlantic and Indian oceans. The Southern Hemisphere has less trash buildup because less of the region is continent.

Summary

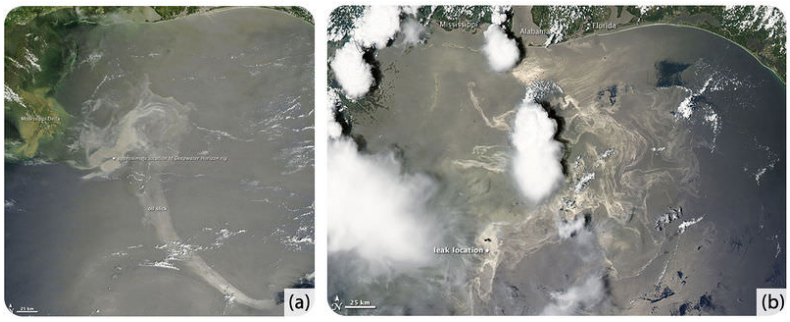
- Trash from land (80%) or human activities at sea (20%) ends up in the oceans; about 80% of this trash is plastic.
- Plastic trash does not usually biodegrade in the ocean but just forms tiny polymers that resemble plankton.
- Plastic pieces of trash and plastic molecules can kill marine organisms by becoming lodged in their digestive systems or by trapping them so they can't swim.

Review

1. How can plastic kill marine organisms?
2. Since plastic doesn't biodegrade in the oceans, what does the future hold? What can be done to make the future better?
3. Some people say that the Great Pacific Garbage Patch is a hoax. What can scientists do to show people that it is real?

This page titled 9.12: Ocean Garbage Patch is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

9.13: Oil Spills



Can you see the oil in a big oil spill?

Of course. The photo on the left shows the Gulf of Mexico oil spill after oil has leaked for nearly one month. About a month later, about twice as much oil had spilled into the Gulf, as seen on the right. The water moves and so the oil moves with it.

Oil Spills

Oil spills are another source of ocean pollution. To get at oil buried beneath the seafloor, oil rigs are built in the oceans. These rigs pump oil from beneath the ocean floor. Huge ocean tankers carry oil around the world. If something goes wrong with a rig on a tanker, millions of barrels of oil may end up in the water. The oil may coat and kill ocean animals. Some of the oil will wash ashore. This oil may destroy coastal wetlands and ruin beaches.

The Gulf of Mexico Oil Spill

The figure below shows workers trying to clean up oil on a Louisiana beach (**Figure** below). The oil washed ashore after a deadly oil rig explosion in the Gulf of Mexico in 2010.



After an oil rig explosion, hundreds of miles of beaches looked like this one. Cleaning them up was a huge task.

New drilling techniques allow oil companies to drill in deeper waters than ever before. In April 2010 a rig in the Gulf of Mexico exploded. Eleven workers were killed and 17 injured. When the drill rig sank, a pipe was disconnected and oil gushed into the Gulf. Three months later the well was capped. But 4.9 million barrels had entered the Gulf, about 16 times more oil than the largest oil spill to date.

Cleanup

Once the oil is in the water, there are three ways to try to clean it:

1. Removal: Corral and then burn the oil.
2. Containment: Use containment booms to trap the oil.
3. Dispersal: Use chemicals to get the oil to disperse, called **chemical dispersants**. Some scientists think that the harm to the environment from the dispersants is as great as the harm from the oil.

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

The total effect of the oil spill on the environment of the Gulf is not yet known. Oil is found in the sediments on the seafloor. Many people who fish or are involved in Gulf tourism were also impacted. Studies of the effects of the oil spill on people and animals will continue for many years.

What You Can Do

Small amounts of oil leak into the oceans from wells or ships. By reducing the amount of oil and gas you use, you decrease the need for these commodities. Also, be sure to dispose of motor oil correctly. Motor oil poured down a sewage grate can end up in the sea. It's important to be sure that companies follow environmental regulations. They must also be cautious when they drill or transport oil in the oceans. People can demand that companies protect the ocean environment.

403 ERROR

The request could not be satisfied.

Request blocked. We can't connect to the server for this app or website at this time. There might be too much traffic or a configuration error. Try again later, or contact the app or website owner.
If you provide content to customers through CloudFront, you can find steps to troubleshoot and help prevent this error by reviewing the CloudFront documentation.

```
Generated by cloudfront (CloudFront)
Request ID: _ZLXpFlJsbHoxIxzLBz55vq5dUVJDRvXJFvfGJMUTzrA55yDVOle2A==
```

Summary

- Most ocean pollution comes from land and most is found near the coasts. Most of this trash is plastic.
- Plastic trash does not usually biodegrade in the ocean but just forms tiny plastic molecules.
- Massive amounts of oil that have been spilled into a water body can be removed, contained, or dispersed. This is not easy or complete.

Review

1. What happened caused the Gulf of Mexico oil spill?
2. How can an oil spill be cleaned up? Does cleanup return the region to it's normal state?
3. What can you do to reduce the chance of oil entering the oceans?

This page titled 9.13: Oil Spills is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

9.14: Earth's Oceans- Challenge 3

1. A ___ is where algae have used up all the oxygen in the water, so nothing can live.

dead zone

2. Excess nutrients added to a body of water ultimately lead to an oxygen poor environment that results in a ___.

dead zone

3. ___ get washed into the oceans from farms and yards, causing algae to grow.

Fertilizers

4. Plastic trash may contain toxic chemicals like ___ that enter the ocean.

bisphenol A (BPA)

5. Plastics in the ocean break down ___.

into molecule-sized polymers

6. Many types of plastics do not biodegrade, but they may ___, which means they break up in sunlight.

photodegrade

7. The Gulf of Mexico spill in 2010 was caused by ___.

an explosion on a deepwater oil rig

8. Oil companies will continue to go for hard-to-get-at deposits as long as ___.

people will pay for the oil

9. Which oil company was responsible for the oil spill of the Valdez in Alaska?

Exxon

This page titled 9.14: Earth's Oceans- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

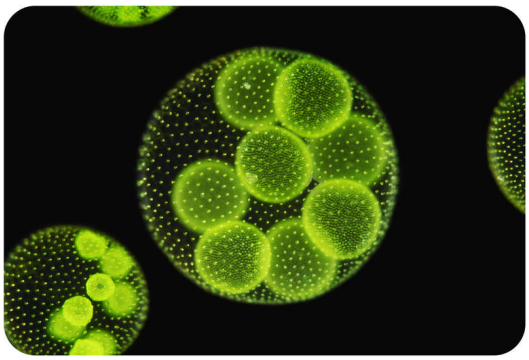
CHAPTER OVERVIEW

10: Atmospheric Processes

10.1: Importance of the Atmosphere
10.2: Composition of the Atmosphere
10.3: Pressure and Density of the Atmosphere
10.4: Temperature of the Atmosphere
10.5: Atmospheric Processes- Challenge 1
10.6: Troposphere
10.7: Stratosphere
10.8: Mesophere
10.9: Thermosphere and Beyond
10.10: Atmospheric Processes- Challenge 2
10.11: Electromagnetic Energy in the Atmosphere
10.12: Solar Energy on Earth
10.13: Thermal Energy Transfer in the Atmosphere
10.14: Heat Budget of Planet Earth
10.15: Solar Energy and Latitude
10.16: Greenhouse Effect
10.17: Atmospheric Processes- Challenge 3
10.18: Circulation in the Atmosphere
10.19: Local Winds
10.20: Global Wind Belts
10.21: Atmospheric Processes- Challenge 4
10.22: Air Quality
10.23: Types of Air Pollution
10.24: Effects of Air Pollution on the Environment
10.25: Causes of Air Pollution
10.26: Acid Rain
10.27: Ozone Depletion
10.28: Reducing Air Pollution
10.29: Atmospheric Processes- Challenge 5

This page titled 10: Atmospheric Processes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.1: Importance of the Atmosphere



Why is the atmosphere important?

Why is Earth the only planet in the solar system known to have life? The main reason is Earth's atmosphere. Organisms need the gases in the atmosphere to live. Water is also essential for life. Water vapor is one of the gases in the atmosphere. Green algae, like in this photo, are primitive life.

The Atmosphere

The **atmosphere** is a mixture of gases that surrounds the planet. We also call it air. The gases in the atmosphere include nitrogen, oxygen, and carbon dioxide. Along with water vapor, the atmosphere allows life to survive. Without it, Earth would be a harsh, barren world.

The Atmosphere's Importance

We are lucky to have an atmosphere on Earth. The atmosphere supports life and is also needed for the water cycle and weather. The gases of the atmosphere even allow us to hear.

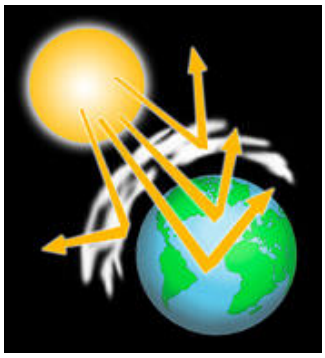
The Atmosphere and Living Things

Most of the atmosphere is nitrogen, but it doesn't do much. Carbon dioxide and oxygen are the gases in the atmosphere that are needed for life.

- Plants need carbon dioxide for **photosynthesis**. They use sunlight to change carbon dioxide and water into food. The process releases oxygen. Without photosynthesis, there would be very little oxygen in the air.
- Other living things depend on plants for food. These organisms need the oxygen plants release to get energy out of the food. Even plants need oxygen for this purpose.

The Atmosphere and the Sun's Rays

The atmosphere protects living things from the Sun's most harmful rays. Gases reflect or absorb the strongest rays of sunlight (**Figure** below).



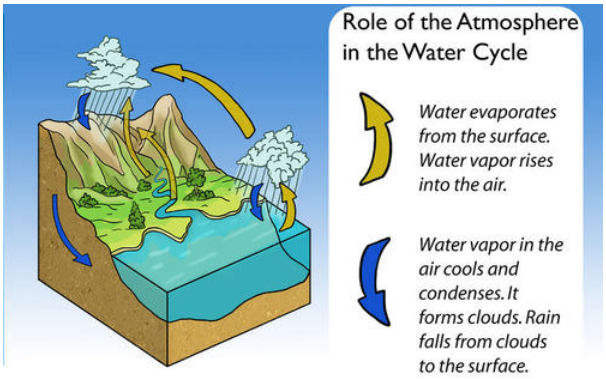
The atmosphere shields Earth from the most harmful solar rays.

The Atmosphere and Earth's Temperature

Gases in the atmosphere surround Earth like a blanket. They keep the temperature in a range that can support life. The gases keep out some of the Sun's scorching heat during the day. At night, they hold the heat close to the surface, so it doesn't radiate out into space.

The Atmosphere and Earth's Water

The image below shows the role of the atmosphere in the water cycle (**Figure** below). Water vapor rises from Earth's surface into the atmosphere. As it rises, it cools. The water vapor may then condense into water droplets and form clouds. If enough water droplets collect in clouds, they may come together to form droplets. The droplets will fall as rain. This how freshwater gets from the atmosphere back to Earth's surface.



The atmosphere is a big part of the water cycle. What do you think would happen to Earth's water without it?

The Atmosphere and Weather

Without the atmosphere, there would be no clouds or rain. In fact, there would be no weather at all. Most weather occurs because the atmosphere heats up more in some places than others.

The Atmosphere and Weathering

Weather makes life interesting. Weather also causes weathering. Weathering is the slow wearing down of rocks on Earth's surface. Wind-blown sand scours rocks like sandpaper. Glaciers of ice scrape across rock surfaces like a file. Even gentle rain may seep into rocks and slowly dissolve them. If the water freezes, it expands. This eventually causes the rocks to crack. Without the atmosphere, none of this weathering would happen. Rocks at the surface would be pristine and unaltered.

The Atmosphere and Sound

Sound is a form of energy that travels in waves. Sound waves cannot travel through empty space, but they can travel through gases. Gases in the air allow us to hear most of the sounds in our world. Because of air, you can hear birds singing, horns tooting, and friends laughing. Without the atmosphere, the world would be a silent, eerie place.

Summary

- The atmosphere is made of gases that are essential for photosynthesis and other life activities.
- The atmosphere is a crucial part of the water cycle. It is an important reservoir for water, and the source of precipitation.
- The atmosphere moderates Earth's temperature. Weather takes place in the atmosphere.
- Without air, Earth would be silent.

Review

1. What gases are used and expelled by photosynthesis and respiration?
2. How does the atmosphere keep Earth's temperature moderate?
3. How does the atmosphere play an important role in the water cycle?

Explore More

Use the resource below to answer the questions that follow.



1. What is the atmosphere?
2. Where does weather occur?
3. What does the atmosphere protect us from? Which layer?
4. What would happen if we didn't have the protective layer in the previous question?
5. What happens in the mesosphere?
6. What is made in the thermosphere?

This page titled 10.1: Importance of the Atmosphere is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.2: Composition of the Atmosphere

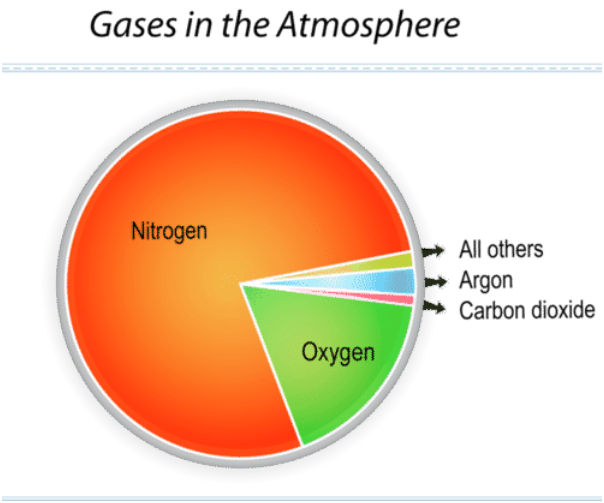


Just what is air?

Air is easy to forget about. We usually can't see it, taste it, or smell it. We can only feel it when it moves. But air is actually made of molecules of many different gases. It also contains tiny particles of solid matter.

Gases in Air

The figure below shows the main gases in air (**Figure** below). Nitrogen and oxygen make up 99% of air. Argon and carbon dioxide make up much of the rest. These percentages are the same just about everywhere in the atmosphere.



This graph identifies the most common gases in air.

Air also includes water vapor. The amount of water vapor varies from place to place. That's why water vapor isn't included in the figure above. It can make up as much as 4% of the air.

Water Vapor

Humidity is the amount of water vapor in the air. Humidity varies from place to place. It also varies in the same place from season to season. On a summer day in Atlanta, Georgia, humidity is high. The air feels very heavy and sticky. On a winter day in Flagstaff, Arizona, humidity is low. The air sucks moisture out of your nose and lips. Humidity can change rapidly if a storm comes in. Humidity can vary over a short distance, like near a lake. Even when humidity is at its highest, water vapor makes up about 4% of the atmosphere at most.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Greenhouse Gases

Greenhouse gases trap heat in the atmosphere. This is essential so that Earth has a more moderate temperature. Without greenhouse gases, nighttime temperatures would be frigid. Natural greenhouse gases include carbon dioxide, methane, water vapor, and ozone. CFCs and some other man-made compounds are also greenhouse gases. Human activities may increase the amount of greenhouse gases, like carbon dioxide, in the atmosphere.

Particles in the Air

Air includes many tiny particles. The **particulates** may consist of dust, soil, salt, smoke, or ash. Some particulates pollute the air and may make it unhealthy to breathe. But having particles in the air is very important. Tiny particles are needed for water vapor to condense on. Without particles, water vapor could not condense. Then clouds could not form, and Earth would have no rain.

Summary

- The major atmospheric gases are nitrogen and oxygen. The atmosphere also contains minor amounts of other gases, including carbon dioxide.
- Greenhouse gases trap heat in the atmosphere. These gases include carbon dioxide, methane, water vapor, and ozone.
- Not everything in the atmosphere is gas. Particulates are particles that are important as the nucleus of raindrops and snowflakes.

Review

1. What are the two major atmospheric gases? What are the important minor gases?
2. What are particulates? Why are they important?
3. What is humidity? How much humidity is in the air on a tremendously hot and humid day?

Explore More

Use the resource below to answer the questions that follow.



1. What does the atmosphere contain?
2. How much nitrogen does the atmosphere contain?
3. How much oxygen does the atmosphere contain?
4. What does the atmosphere do?
5. How many layers does the atmosphere have?
6. List the layers of the atmosphere and two characteristics of each layer.

This page titled 10.2: Composition of the Atmosphere is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.3: Pressure and Density of the Atmosphere



Have your ears ever popped?

If your ears have ever "popped," you have experienced a change in air pressure. Ears "pop" because the air pressure is different on the inside and the outside of your ears.

Properties of Air

We usually can't sense the air around us unless it is moving. But air has the same basic properties as other matter. For example, air has mass, volume, and, of course, density.

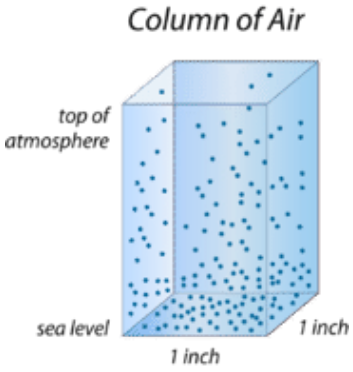
Density of Air

Density is mass per unit volume. Density is a measure of how closely molecules are packed together. The closer together they are, the greater the density. Since air is a gas, the molecules can pack tightly or spread out.

The density of air varies from place to place. Air density depends on several factors. One is temperature. Like other materials, warm air is less dense than cool air. Since warmer molecules have more energy, they are more active. The molecules bounce off each other and spread apart. Another factor that affects the density of air is altitude.

Altitude and Density

Altitude is height above sea level. The density of air decreases with height. There are two reasons: at higher altitudes, there is less air pushing down from above, and gravity is weaker farther from Earth's center. So at higher altitudes, air molecules can spread out more, and air density decreases (**Figure** below).



This drawing represents a column of air. The column rises from sea level to the top of the atmosphere. Where does air have the greatest density?

Air Pressure

Because air is a gas, its molecules have a lot of energy. Air molecules move a lot and bump into things. For this reason, they exert pressure. **Air pressure** is defined as the weight of the air pressing against a given area.

At sea level, the atmosphere presses down with a force of about 1 kilogram per square centimeter (14.76 pounds per square inch). If you are standing at sea level, you have more than a ton of air pressing against you. Why doesn't the pressure crush you? Air presses in all directions at once. Other molecules of air are pushing back.

Altitude and Air Pressure

Like density, the pressure of the air decreases with altitude. There is less air pressing down from above the higher up you go. Look at the bottle pictured below (**Figure** below). It was drained by a hiker at the top of a mountain. Then the hiker screwed the cap on the bottle and carried it down to sea level. At the lower altitude, air pressure crushed it. Can you explain why?



At high altitude the air pressure is the same inside and outside the bottle. At sea level, the pressure is greater outside than inside the bottle. The greater outside pressure crushes the bottle.

Summary

- Air density and pressure decrease with increasing altitude.
- Ears pop as air pressures inside and outside of the ear equalize.
- Gravity pulls more air molecules toward the center of the planet.

Review

1. Why does air density decrease with increasing altitude?
2. Why does temperature decrease with increasing altitude in the troposphere?
3. Why are we not crushed by the weight of the atmosphere on our shoulders?

Explore More

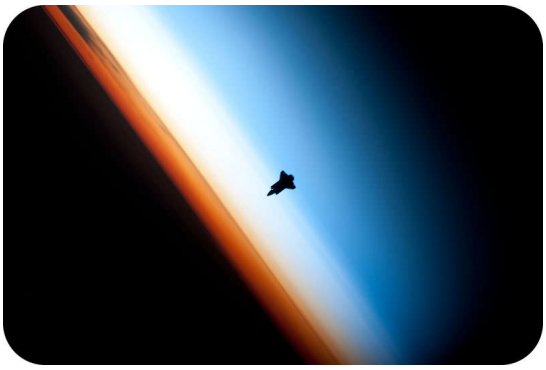
Use the resource below to answer the questions that follow.



1. What is pressure?
2. What causes air molecules to have pressure?
3. Where does the atmosphere end? What is out past the atmosphere?
4. What is air pressure?
5. What is the elevation and air pressure in Key West, Florida?
6. What is the elevation on Mt. Everest? Why do climbers often use extra oxygen up there?
7. Why does air pressure change with altitude?

This page titled 10.3: Pressure and Density of the Atmosphere is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.4: Temperature of the Atmosphere



Did you know that you can see the layers of the atmosphere?

The layers of the atmosphere appear as different colors in this image from the International Space Station. Imagine looking out the window at a view like that!

Air Temperature

The atmosphere has layers. The layers correspond with how temperature changes with altitude. By understanding the way temperature changes with altitude, we can learn a lot about how the atmosphere works.

Warm Air Rises

This is really important: Warm air rises. Why does warm air rise (**Figure** below)? Gas molecules are able to move freely. Gas molecules move more at higher temperatures. They can take up as much space as is available.

- When gas molecules are cool, they are sluggish. They take up less space. With the same number of molecules in less space, both air density and air pressure are higher.
- When gas molecules are warm, they move vigorously. They take up more space. Air density and air pressure are lower.

Warmer, lighter air is more buoyant than the cooler air above it. So the warm air rises. The cooler air is denser than the air beneath it. So it sinks down. This is convection: warm air rises, and cool air sinks. Warm fluids can undergo convection as well. This is described in the chapter *Plate Tectonics*.



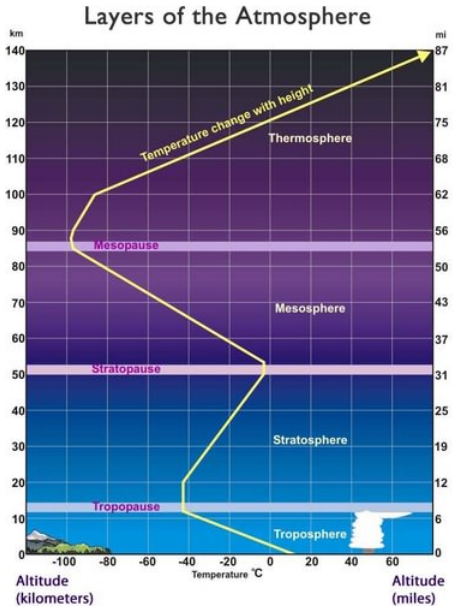
Papers held up by rising air currents above a radiator demonstrate the important principle that warm air rises.

Temperature Gradient

Air temperature changes with altitude. This does not occur in the same way as pressure and density, which decrease with altitude. Changes in air temperature are not regular. A change in temperature with distance is called a **temperature gradient**.

Temperature of the Atmosphere

Air temperature changes as altitude increases. In some layers of the atmosphere, the temperature decreases. In other layers, it increases (**Figure** below). Refer to this figure as you read about the layers in the coming concepts.



How does air temperature change in the layer closest to Earth?

Summary

- Warm air rises, cool air sinks. Warm air has lower density.
- Different layers of the atmosphere have different temperature gradients.
- Temperature gradient is the change in temperature with distance.

Review

1. What causes convection in the atmosphere?
2. How are the layers of the atmosphere divided?
3. What is temperature gradient? If you know that, then what is pressure gradient?

This page titled 10.4: Temperature of the Atmosphere is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.5: Atmospheric Processes- Challenge 1

1. The atmosphere is composed of 78% ___ and 21% ___.

nitrogen; oxygen

2. Plants need light energy, water, and carbon dioxide for the process of ___.

photosynthesis

3. The atmosphere traps warmth like a blanket, keeping Earth's temperature ___, allowing life to exist.

moderate

4. What gas is the most abundant in Earth's atmosphere?

nitrogen

5. Humidity is a measure of the amount of water ___ in the air.

vapor

6. Mountain climbers prepare for their journeys by setting up camp at gradually higher and higher elevations, acclimating to the ___.

less dense atmosphere

7. ___, or mass per unit volume, is a measure of how closely molecules are packed together.

Density

8. Elevation, or height above sea level, is also called ___.

altitude

9. Atmospheric ___ occurs when the planet's surface warms the bottom of the troposphere, decreasing its density and causing it to rise. At the same time, the air above is relatively cool and sinks.

convection

10. What is the order of layers of the atmosphere, from lowest to highest altitude?

troposphere, stratosphere, mesosphere, and thermosphere

This page titled 10.5: Atmospheric Processes- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.6: Troposphere



What if we took a field trip to the troposphere?

A field trip to the troposphere could start below sea level in Badwater Basin in Death Valley. It could end at the top of Mt. Everest at 29,029 feet (8,848m). In other words, every human activity that's in air is in the troposphere. You might say that your life is a field trip to the troposphere!

Troposphere

The **troposphere** is the lowest layer of the atmosphere. All of the air you breathe is in the troposphere. All of Earth's weather—wind, rain, snow, heat—is in the troposphere. The troposphere is the lowest and most important layer of the atmosphere!

Properties of the Troposphere

The troposphere is the shortest layer of the atmosphere. It rises to only about 12 kilometers (7 miles) above the surface. Even so, this layer holds 75% of all the gas molecules in the atmosphere. That’s because the air is densest in this layer.

In the troposphere, temperature decreases with altitude. The troposphere gets some of its heat directly from the Sun. Most, however, comes from Earth's surface. The surface is heated by the Sun. Some of that heat radiates back into the air. This makes the temperature higher near the surface than at higher altitudes.

Mixing of Air

Air in the troposphere is warmer closer to Earth’s surface. Warm air is less dense than cool air, so it rises higher in the troposphere. This starts a convection cell. Convection mixes the air in the troposphere. Rising air is also a main cause of weather. All of Earth’s weather takes place in the troposphere.

Temperature Inversion

Sometimes air doesn’t mix in the troposphere. This happens when air is cooler close to the ground than it is above. The cool air is dense, so it stays near the ground. This is called a temperature **inversion** (**Figure** below). An inversion can trap air pollution near the surface. Temperature inversions are more common in the winter. Can you explain why?

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



Temperature Inversion and Air Pollution. How does a temperature inversion affect air quality?

Tropopause

At the top of the troposphere is a thin layer of air called the tropopause. This layer acts as a barrier. It prevents cool air in the troposphere from mixing with warm air in the stratosphere.

Sorry

This video does not exist.

Summary

- In the troposphere, warm air ordinarily sits below cooler air.
- With a temperature inversion, cold air sits below warm air. This traps the cold air because it cannot rise into the warm air.
- An inversion starts over land at night or in the winter, or near the coast.

Review

1. Why is the troposphere the most important layer of the atmosphere?
2. What is the source of heat in the troposphere?
3. Describe the temperature gradient found in the troposphere.

This page titled 10.6: Troposphere is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.7: Stratosphere



Can we take a field trip to the stratosphere?

Sure we can! If you've ever flown on a jet airplane, you've been in the stratosphere. Airplanes fly in the stratosphere, because there is less friction. They get better gas mileage, and so costs are lower. There is also less turbulence, so passengers are happier. Can you identify the bottom of the stratosphere in the photo? It's where the clouds begin. Remember that all weather is in the troposphere.

Stratosphere

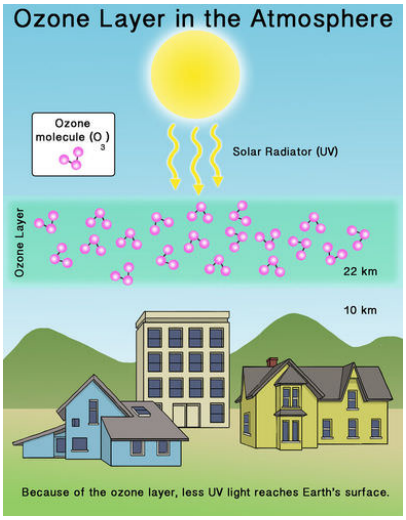
The **stratosphere** is the layer above the troposphere. The layer rises to about 50 kilometers (31 miles) above the surface.

Temperature in the Stratosphere

Air temperature in the stratosphere increases with altitude. Why? The stratosphere gets most of its heat from the Sun. Therefore, it's warmer closer to the Sun. The air at the bottom of the stratosphere is cold. The cold air is dense, so it doesn't rise. As a result, there is little mixing of air in this layer.

The Ozone Layer

The previous section said that the troposphere is the most important layer of the atmosphere. But it's not the only important layer. The stratosphere contains a layer of ozone gas. **Ozone** consists of three oxygen atoms (O_3). The **ozone layer** is in the stratosphere. Ozone in the layer absorbs high-energy ultraviolet (UV) radiation. UV radiation splits the ozone molecule (**Figure** below). The split creates an oxygen molecule (O_2) and an oxygen atom (O). This split releases heat that warms the stratosphere. By absorbing UV radiation, ozone also protects Earth's surface. UV radiation would harm living things without the ozone layer.



How does the ozone layer protect Earth's surface from UV light?

Stratopause

At the top of the stratosphere is a thin layer called the stratopause. It acts as a boundary between the stratosphere and the mesosphere.

Summary

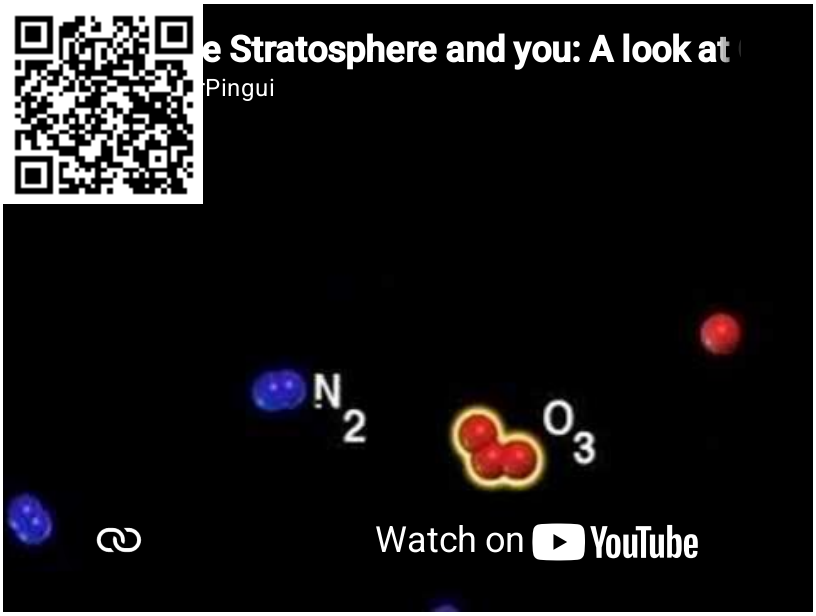
- There is little mixing between the troposphere and the stratosphere.
- Ozone gas protects life on Earth from harmful UV light.
- The ozone layer is in the stratosphere. It has a higher concentration of ozone than the rest of the atmosphere.

Review

1. Why doesn't air mix much in the stratosphere?
2. What is the ozone layer? Why is it important?
3. Why does air temperature increase with height in the stratosphere?

Explore More

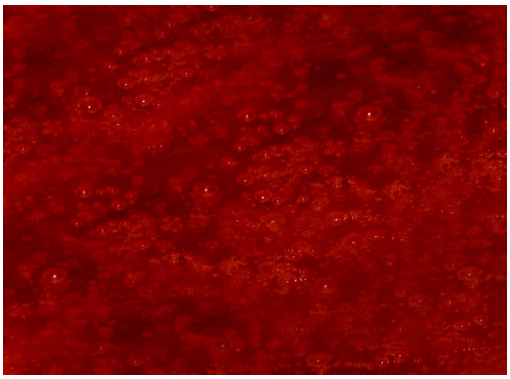
Use the resource below to answer the questions that follow.



1. Where is the stratosphere located?
2. How is ozone, the O3 molecule, created?
3. By what process does this ozone molecule become stable?
4. Why is ozone important?

This page titled 10.7: Stratosphere is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.8: Mesophere



Next up: a field trip to the mesosphere!

Not so fast. The mesosphere is the least known layer of the atmosphere. The mesosphere lies above the highest altitude an airplane can go. It lies below the lowest altitude a spacecraft can orbit. Maybe that's just as well. If you were in the mesosphere without a space suit, your blood would boil! This is because the pressure is so low that liquids would boil at normal body temperature.

Mesosphere

The **mesosphere** is the layer above the stratosphere. It rises to about 85 kilometers (53 miles) above the surface. Temperature decreases with altitude in this layer.

Temperature in the Mesosphere

There are very few gas molecules in the mesosphere. This means that there is little matter to absorb the Sun’s rays and heat the air. Most of the heat that enters the mesosphere comes from the stratosphere below. That’s why the mesosphere is warmest at the bottom.

Meteors in the Mesosphere

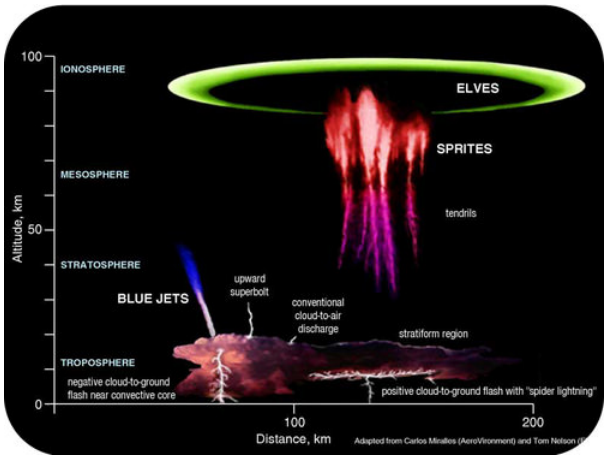
Have you ever seen a meteor shower (**Figure** below)? Meteors burn as they fall through the mesosphere. The space rocks experience friction with the gas molecules. The friction makes the meteors get very hot. Many meteors burn up completely in the mesosphere.



The Perseid meteor shower with the Milky Way.

Red Sprites and Blue Jets

Red sprites and blue jets are electrical discharges (**Figure** below). They are not the same thing as lightning. They more closely resemble the discharges seen in fluorescent tubes. These events occur much higher up in the atmosphere than lightning.



Red sprites occur higher in the atmosphere than blue jets, while both occur higher than lightning.

Polar Mesospheric Clouds

Clouds in the mesosphere are very rare. The ones that exist occur near the poles. The clouds are called **polar mesospheric clouds**. At the edge of these clouds are noctilucent clouds (**Figure** below). They are forming more often now, perhaps as a result of climate change.



Noctilucent clouds are the highest clouds in the atmosphere.

Mesopause

At the top of the mesosphere is the mesopause. Temperatures here are colder than anywhere else in the atmosphere. They are as low as -100° C (-212° F)! Nowhere on Earth's surface is it that cold.

Summary

- The mesosphere has a very low density of gas molecules.
- Temperature decreases in the mesosphere with altitude. This is because the heat source is the stratosphere.
- The mesosphere has red sprites, blue jets, and two types of clouds.
- The mesosphere is no place for human life!

Review

1. How does temperature change with altitude in the mesosphere? Why?
2. What types of clouds are found in the mesosphere?
3. How can meteors burn in the mesosphere when the air density is so low?

Explore More

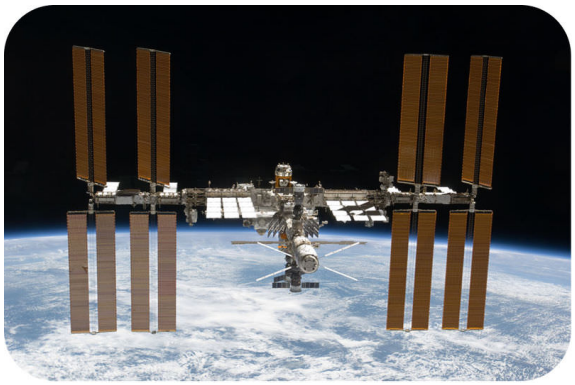
Use the resource below to answer the questions that follow.



1. Where is the mesophere found?
2. What does it protect us from? What is a shooting star?
3. What are noctilucent clouds?
4. When can noctilucent clouds be seen? Why?

This page titled 10.8: Mesophere is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.9: Thermosphere and Beyond



Can you take a field trip to the thermosphere? Maybe some day!

The inhabitants of the International Space Station and other space stations live in the thermosphere. They are not directly in the thermosphere, of course. They must be inside the station or inside a space suit at all times. Maybe some day you will join them!

Thermosphere

The **thermosphere** is the layer above the mesosphere. It rises to 600 kilometers (372 miles) above the surface. The International Space Station and other space stations orbit Earth in this layer.

Temperature in the Thermosphere

Temperature increases with altitude in the thermosphere. Surprisingly, it may be higher than 1000° C (1800° F) near the top of this layer! The Sun's energy there is very strong. The molecules absorb the Sun's energy and are heated up. But there are so few gas molecules that the air still feels very cold. Molecules in the thermosphere gain or lose electrons. They then become charged particles called ions.

Magnetosphere

Earth's **magnetosphere** is controlled by the magnetic field. The magnetosphere protects the planet from the **solar wind**. Solar wind consists of ions that fly from the Sun to Earth very fast. The magnetosphere protects Earth's ozone layer. So life on Earth needs the protection of the magnetosphere.

Northern and Southern Lights

Have you ever seen a brilliant light show in the night sky? Sometimes the ions in the thermosphere glow at night. Storms on the Sun energize the ions and make them light up. In the Northern Hemisphere, the lights are called the northern lights, or aurora borealis. In the Southern Hemisphere, they are called southern lights, or aurora australis. They are referred to together as the **aurora** (**Figure** below and **Figure** below).



The aurora as seen from the Northern Hemisphere, known as the Aurora Borealis.



The aurora borealis as seen from the International Space Station.

Exosphere

The **exosphere** is the layer above the thermosphere. This is the top of the atmosphere. The exosphere has no real upper limit; it just gradually merges with outer space. Gas molecules are very far apart in this layer, but they are really hot. Earth's gravity is so weak in the exosphere that gas molecules sometimes just float off into space.

Summary

- The solar wind is made of high speed particles from the Sun. The magnetosphere protects Earth from the solar wind.
- Particles from the Sun energize ions in the thermosphere. This creates the northern and southern lights.
- Gas molecules are exceedingly rare in the exosphere.

Review

1. What are the properties of the thermosphere?
2. Why are gas molecules so rare in the exosphere?
3. What causes the aurora? Where in the atmosphere does it take place?

Explore More

Use the resource below to answer the questions that follow.



1. What is the ultimate cause of the aurora borealis?
2. What occurs in the Sun to release energy?
3. What is plasma? What does it do?
4. What is a solar storm?
5. How long does it take a solar storm to reach Earth?
6. What protects us from solar storms?
7. Why do the aurora typically take place only in the polar regions?

This page titled 10.9: Thermosphere and Beyond is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.10: Atmospheric Processes- Challenge 2

1. The layer of the atmosphere in which all living things exist and that which allows you to breathe is the ___.

troposphere

2. If a mountaintop is 10,000 ft. higher than the valley below, we can expect the temperature to be ___.

36 degrees Fahrenheit lower

3. All of the wind, rain, and snow on Earth, as well as all of the air you breathe, is in the ___.

troposphere

4. The ozone layer is part of the ___, where the concentration of ozone is high.

stratosphere

5. The ozone layer is found between ___ and ___ in altitude.

15 km; 30 km

6. Why is air in the stratosphere stable?

Warmer air lies above cooler air

7. The temperature in the mesosphere ___ with altitude.

decreases

8. Temperatures in the ___ and the ___ decrease with altitude

thermosphere; mesosphere

9. What type of clouds form in the mesosphere?

noctilucent

10. Medium and high frequency radio waves are reflected back to Earth by the ___.

ionosphere

11. The Van Allen radiation belts are ___.

regions of ionized particles

This page titled 10.10: Atmospheric Processes- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.11: Electromagnetic Energy in the Atmosphere



Where can you find energy?

Picture yourself sitting by the campfire. You and your family are using the fire to stay warm on a chilly evening. As the Sun goes down, the air gets colder. You move closer to the fire. Heat from the fire warms you. Light from the fire allows you to see your relatives. Maybe you put marshmallows on a stick and roast them. Yum.

What Is Energy?

What explains all of these events? The answer can be summed up in one word: energy. **Energy** is defined as the ability to do work. Doing anything takes energy. A campfire obviously has energy. You can feel its heat and see its light. You can use its energy to cook food.

Forms of Energy

Heat and light from the campfire are forms of energy. There are many other forms of energy. Here are a few that are important in Earth science:

- chemical energy: Energy that is let off after a chemical reaction.
- luminous energy: Also called light.
- nuclear energy: Energy that is let off when the atom of a nucleus is split.
- radiant energy: Energy of electromagnetic radiation. This is the topic of the concept "Solar Energy on Earth."
- sound energy: Energy from sound waves.
- thermal energy: Also called heat.

Conservation of Energy

Energy cannot be created or destroyed. It can change form. For example, a piece of wood has chemical energy stored in its molecules. When the wood burns, the chemical energy changes to thermal energy and light energy.

Lightning converts electric potential energy into three kinds of energy. They are light energy, sound energy, and thermal energy.

You convert chemical energy in food to movement (**Figure** below). That's another way energy is transferred from one form to another!

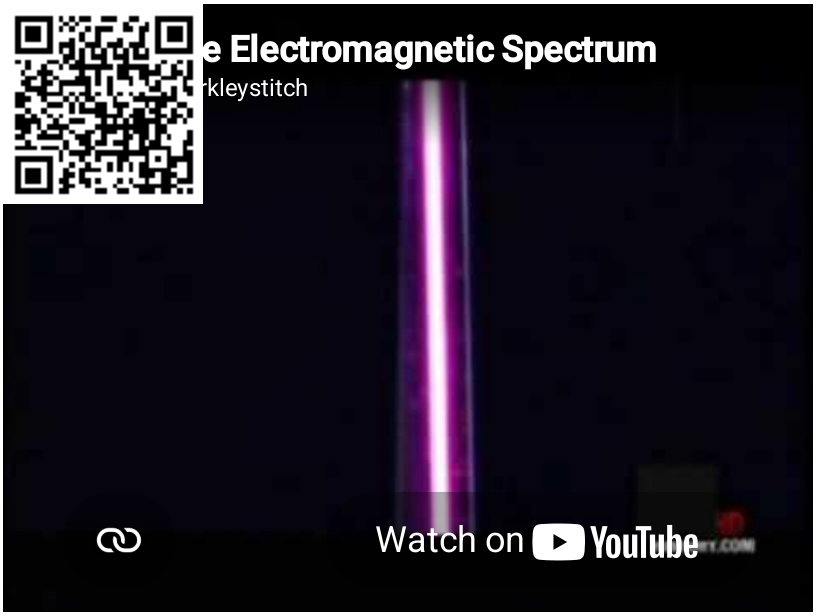
CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



If the girl eats this apple it will provide the energy needed for her to run.

Movement of Energy

Energy can move from one place to another. It can travel through space or matter. That’s why you can feel the warmth of a campfire and see its light. These forms of energy travel from the campfire to you.



Science Friday: Forecasting the Meltdown: The Aerial Snow Observatory

75% of Southern California's water supply comes from the snowpack in the Sierra Nevada Mountain Range. This video by Science Friday explains how NASA uses specialized instrumentation in the Airborne Snow Observatory to carefully measure the water content.



Summary

- Energy is the ability to do work.
- Energy cannot be created or destroyed. Energy can only change forms.
- Energy can change from one type to more than one type. For example, electric potential energy before a lightning strike can turn into light, sound, and heat.

Review

1. What is energy?
2. How does energy change from one form to another?
3. Figure out two examples in your life of when energy changes from one form to another.

This page titled 10.11: Electromagnetic Energy in the Atmosphere is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.12: Solar Energy on Earth



Just how important is this star?

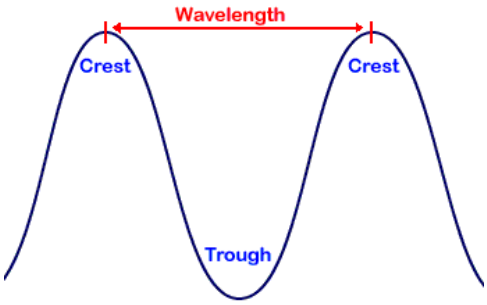
Almost all energy at Earth's surface comes from the Sun. The Sun’s energy warms the planet and the air around it. This causes the atmosphere to move and create weather. Sunlight also powers photosynthesis and life on Earth.

The Sun's Energy

Most of the energy at Earth's surface comes from the Sun. Solar energy travels in tiny packets that move in waves. The waves have different wavelengths. Waves with different wavelengths carry different amounts of energy.

Photons of Energy

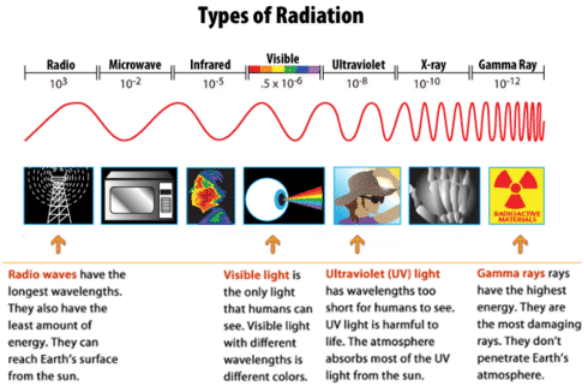
The Sun gives off energy in tiny packets called **photons**. Photons travel in waves. These waves make up **electromagnetic radiation**. The image below models a wave of light (**Figure** below). Notice the wavelength in the figure. Waves with shorter wavelengths have more energy.



This curve models a wave. Based on this figure, how would you define wavelength?

Electromagnetic Spectrum

Energy from the Sun has a wide range of wavelengths. The total range of energy is called the **electromagnetic spectrum** (**Figure** below).



Compare the wavelengths of radio waves and gamma rays. Which type of wave has more energy?

Visible light is the only light that humans can see. Different wavelengths of visible light appear as different colors. Radio waves have the longest wavelengths. They also have the least amount of energy. **Infrared light** has wavelengths too long for humans to see, but we can feel them as heat. The atmosphere absorbs the infrared light. **Ultraviolet (UV) light** is in wavelengths too short for humans to see. The most energetic UV light is harmful to life. The atmosphere absorbs most of this UV light from the Sun. Gamma rays have the highest energy, and they are the most damaging rays. Fortunately, gamma rays don't penetrate Earth's atmosphere.

Summary

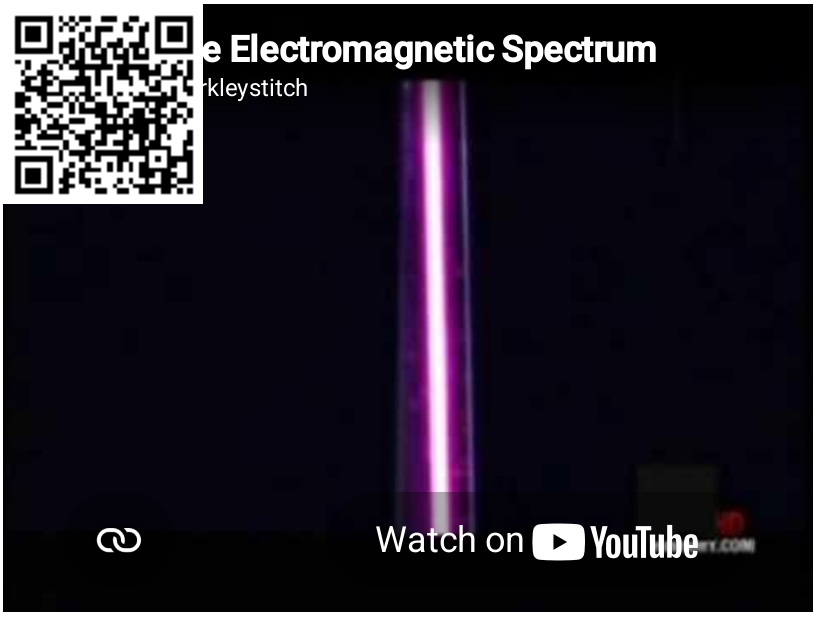
- Gamma rays have the most energy of any photons emitted by the sun while radio waves have the least. This range and the radiations within it make up the electromagnetic spectrum.
- Solar energy travels in photons. Photons travel in waves, which make up electromagnetic radiation.
- Visible light is the wavelengths of light humans can see.

Review

1. What is a photon? How does energy travel as photons?
2. What is visible light? What has longer wavelengths than visible light? Shorter wavelengths?
3. What is the electromagnetic spectrum?

Explore More

Use the resource below to answer the questions that follow.



1. What is the electromagnetic spectrum?
2. Which waves have the longest wavelengths?
3. What has the shortest wavelengths?
4. Why is the visible spectrum important?
5. Stars are far away yet astronomers can tell when they are made of hydrogen. How?

This page titled 10.12: Solar Energy on Earth is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.13: Thermal Energy Transfer in the Atmosphere



Can you see energy moving?

Energy constantly moves all around us! Anything that moves has kinetic energy, and you can see light energy and feel thermal energy in a chemical reaction or a campfire. Moving energy in the atmosphere sometimes makes itself visible in the way it moves air. In this photo, differences in temperature are causing air to move—in fantastic ways!

How Energy Moves Through the Atmosphere

Energy travels through space or material. Thermal energy is transferred in three ways: **radiation**, **conduction**, and **convection**.

Radiation

Radiation is the transfer of energy by waves. Energy can travel as electromagnetic waves through air or empty space. The Sun's energy travels through space by radiation. After sunlight heats the planet's surface, some heat radiates back into the atmosphere.

Conduction

In **conduction**, thermal energy is transferred from molecule to molecule by contact. Warmer molecules vibrate faster than cooler ones. They bump into the cooler molecules. When they do, they transfer some of their energy. Conduction happens mainly in the lower atmosphere. Can you explain why?

Convection

Convection is the transfer of thermal energy by a current. Convection happens in a liquid or a gas. Air near the ground is warmed by heat radiating from Earth's surface. The warm air is less dense, so it rises. As it rises, it cools. The cool air is dense, so it sinks to the surface. This creates a convection current (**Figure** below). Convection is the most important way that heat travels in the atmosphere.



Convection currents are the main way that heat moves through the atmosphere. Why does warm air rise?

https://k12.libretexts.org/@go/page/5490

403 ERROR

The request could not be satisfied.

Request blocked. We can't connect to the server for this app or website at this time. There might be too much traffic or a configuration error. Try again later, or contact the app or website owner.
If you provide content to customers through CloudFront, you can find steps to troubleshoot and help prevent this error by reviewing the CloudFront documentation.

```
Generated by cloudfront (CloudFront)
Request ID: 0XRG61fX887mmbX19ate-g55hStHzlL7cvC1L1DD7ZC9dLvxPU-6Ug==
```

Summary

- In conduction, heat moves from areas of more heat to areas of less heat. The substances must be in direct contact.
- In convection, materials move depending on their heat relative to nearby materials.
- In radiation, energy moves by waves.

Review

1. What is moving in conduction?
2. What is moving in convection?
3. What is radiation?

This page titled 10.13: Thermal Energy Transfer in the Atmosphere is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.14: Heat Budget of Planet Earth



How does heat on Earth resemble a household budget?

The thermal energy left on Earth is thermal energy in minus thermal energy out. If more energy comes into the system than goes out of the system, the planet warms. If less energy goes into the system than goes out of the system, the planet cools. Replace the word "money" for "thermal energy" and "on Earth" to "in your bank account" and you describe a household budget. Of course, Earth's heat budget is a lot more complex than a simple household budget.

Heat at Earth's Surface

About half of the solar radiation that strikes the top of the atmosphere is filtered out before it reaches the ground. This energy can be absorbed by atmospheric gases, reflected by clouds, or scattered. Scattering occurs when a light wave strikes a particle and bounces off in some other direction.

About 3% of the energy that strikes the ground is reflected back into the atmosphere. The rest is absorbed by rocks, soil, and water and then radiated back into the air as heat. These infrared wavelengths can be seen only by infrared sensors.



The Heat Budget

Because solar energy continually enters Earth's atmosphere and ground surface, is the planet getting hotter? The answer is no (although the next section contains an exception), because energy from Earth escapes into space through the top of the atmosphere. If the amount that exits is equal to the amount that comes in, then average global temperature stays the same. This means that the planet's heat budget is in balance. What happens if more energy comes in than goes out? If more energy goes out than comes in?

To say that the Earth's heat budget is balanced ignores an important point. The amount of incoming solar energy is different at different latitudes. Where do you think the most solar energy ends up and why? Where does the least solar energy end up and why?

See the **Table** below.

The Amount of Incoming Solar Energy

	Day Length	Sun Angle	Solar Radiation	Albedo
Equatorial Region	Nearly the same all year	High	High	Low
Polar Regions	Night 6 months	Low	Low	High

Note: Colder temperatures mean more ice and snow cover the ground, making albedo relatively high.

The difference in solar energy received at different latitudes drives atmospheric circulation.

Summary

- Incoming solar radiation is absorbed by atmospheric gases, reflected by clouds, or scattered.
- Much of the radiation that strikes the ground is radiated back into the atmosphere as heat.
- More solar radiation strikes the Equator than the poles.

Review

1. If the Sun suddenly started to emit more energy, what would happen to Earth's heat budget and the planet's temperature?
2. If more greenhouse gases were added to the atmosphere, what would happen to Earth's heat budget and the planet's temperature?
3. What happens to sunlight that strikes the ground?

Explore More

Use this resource to answer the questions that follow.



1. What does CERES measure?
2. What does the acronym CERES stand for?
3. What is the ideal radiation budget? Why?
4. How much of the Sun's radiation is reflected or absorbed by clouds.
5. What type of surfaces absorb the most energy?
6. Which regions are reflective?
7. What are scientists finding with CERES?
8. Why is the Earth warming?

9. What is a carbon footprint?
10. What happens to albedo when the ice caps melt?

This page titled 10.14: Heat Budget of Planet Earth is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.15: Solar Energy and Latitude

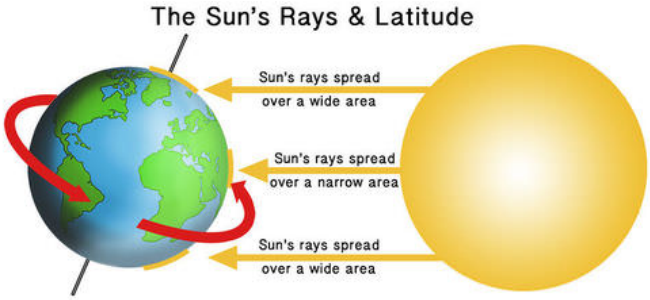


This is Antarctica. What season is this?

The Sun is always up, even in the middle of the night. That's the photo on the left. In the day, the Sun never gets too high in the sky. That's the photo on the right. So, this is summer. In the winter, it's just dark in Antarctica.

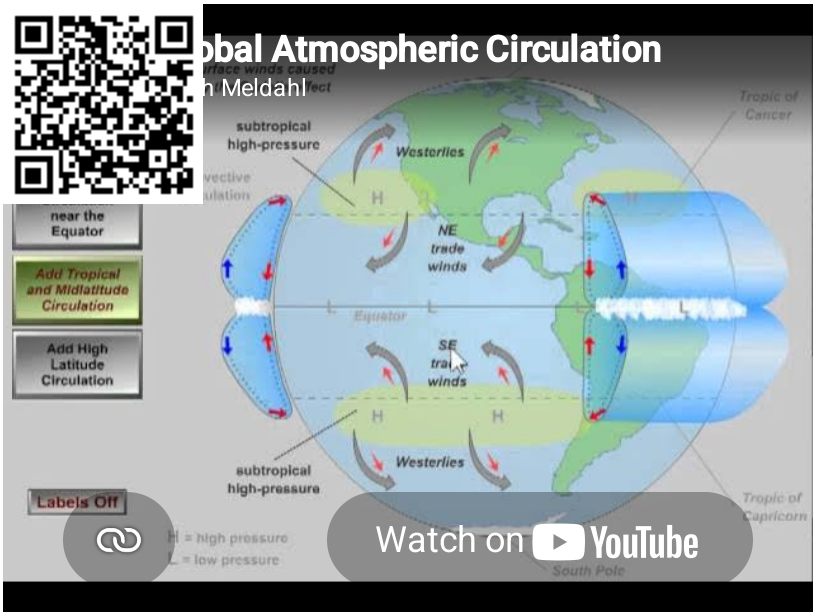
Energy and Latitude

Different parts of Earth's surface receive different amounts of sunlight (**Figure** below). The Sun's rays strike Earth's surface most directly at the Equator. This focuses the rays on a small area. Near the poles, the Sun's rays strike the surface at a slant. This spreads the rays over a wide area. The more focused the rays are, the more energy an area receives, and the warmer it is.



The lowest latitudes get the most energy from the Sun. The highest latitudes get the least.

The difference in solar energy received at different latitudes drives **atmospheric circulation**. Places that get more solar energy have more heat. Places that get less solar energy have less heat. Warm air rises, and cool air sinks. These principles mean that air moves around the planet. The heat moves around the globe in certain ways. This determines the way the atmosphere moves.



https://k12.libretexts.org/@go/page/5492

Summary

- A lot of the solar energy that reaches Earth hits the Equator.
- Much less solar energy gets to the poles.
- The difference in the amount of solar energy drives atmospheric circulation.

Review

1. The North Pole receives sunlight 24 hours a day in the summer. Why does it receive less solar radiation than the Equator?
2. What part of Earth receives the most solar radiation in a year? Why?
3. What makes the atmosphere move the way it does?

This page titled 10.15: Solar Energy and Latitude is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.16: Greenhouse Effect



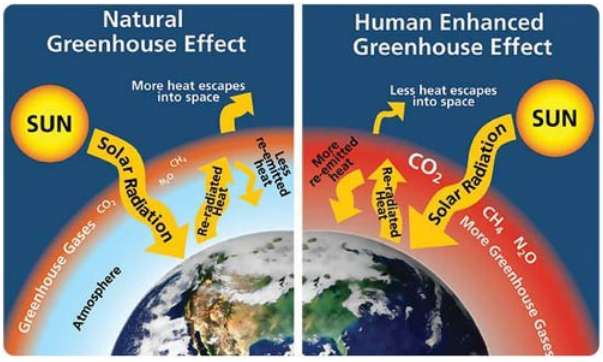
How does the atmosphere resemble a greenhouse?

Farmers use greenhouses to extend the growing season. A greenhouse traps thermal energy. Days that are too cool for a growing plant can be made to be just right. Similar to a greenhouse, greenhouse gases in the atmosphere keep Earth warm.

The Greenhouse Effect

When sunlight heats Earth's surface, some of the heat radiates back into the atmosphere. Some of this heat is absorbed by gases in the atmosphere. This is the **greenhouse effect**, and it helps to keep Earth warm. The greenhouse effect allows Earth to have temperatures that can support life.

Gases that absorb heat in the atmosphere are called **greenhouse gases**. They include carbon dioxide and water vapor. Human actions have increased the levels of greenhouse gases in the atmosphere (**Figure** below). The added gases have caused a greater greenhouse effect. How do you think this affects Earth's temperature?



Human actions have increased the natural greenhouse effect.

Like a blanket on a sleeping person, greenhouse gases act as insulation for the planet. The warming of the atmosphere is because of **insulation** by greenhouse gases. Greenhouse gases are the component of the atmosphere that moderate Earth's temperatures.

Greenhouse Gases

Greenhouse gases include CO_2, H_2O, methane, O_3, nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs). All are a normal part of the atmosphere except CFCs. The table below shows how each greenhouse gas naturally enters the atmosphere (**Table** below).

https://k12.libretexts.org/@go/page/5493

Greenhouse Gas	Source
Carbon dioxide	Respiration, volcanic eruptions, decomposition of plant material; burning of fossil fuels (driven by humans)
Methane	Decomposition of plant material under some conditions, biochemical reactions in stomachs
Nitrous oxide	Produced by bacteria
Ozone	Atmospheric processes
Chlorofluorocarbons	Not naturally occurring; made by humans

Different greenhouse gases have different abilities to trap heat. For example, one methane molecule traps 23 times as much heat as one CO_2 molecule. One CFC-12 molecule (a type of CFC) traps 10,600 times as much heat as one CO_2. Still, CO_2 is a very important greenhouse gas, because it is much more abundant in the atmosphere.



Summary

- Greenhouse gases include CO_2, H_2O, methane, O_3, nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs).
- Greenhouse gases trap heat in the troposphere. Some greenhouse gases can trap more heat than others.
- Levels of greenhouse gases in the atmosphere are increasing due to human activities.

Review

1. What is insulation? What effect does insulation have on global temperature?
2. What is the greenhouse effect?
3. How does Earth's atmosphere resemble a greenhouse?

This page titled 10.16: Greenhouse Effect is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.17: Atmospheric Processes- Challenge 3

1. Stratospheric ozone filters out ___.

all UVC rays, most UVB rays, and some UVA rays

2. The highest energy ultraviolet is ___, and the lowest energy ultraviolet is ___.

UVC; UVA

3. A heated iron is pressed against a shirt, warming it. Which type of energy transfer is occurring?

conduction

4. In the process of ___, substances in direct contact transfer thermal energy from areas of high energy to areas of low energy.

conduction

5. Solar energy coming through space is transferred by ___.

radiation

6. In regions where the Sun's rays hit the earth's surface at an angle, solar energy ___ and climate is ___.

spreads out; cool

7. ___ is the major movement of air in the atmosphere.

Atmospheric circulation

8. Which pole receives sunlight 24 hours a day in December?

South Pole

9. Use of CFCs, burning of fossil fuels, and growth in the cattle industry all contribute to the rise of ___ in the atmosphere.

greenhouse gases

10. CFCs do not occur ___ and are the result of ___.

naturally; human activity

11. Nitrogen oxide, a greenhouse gas, is produced mostly by ___.

bacteria

This page titled 10.17: Atmospheric Processes- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.18: Circulation in the Atmosphere



Where can you go to experience wind?

Wind is one of the most obviously dynamic features of our dynamic planet. For a long time Mt. Washington in New Hampshire was known as the windiest place on Earth. It no longer is called that, but it's still plenty windy. A wind speed of 231 miles per hour was recorded on the mountain in April 1934. In a 200 mph wind, you would not be able to stand up. Temperatures due to wind chill would be outrageously cold!

Atmospheric Circulation

Wind is just moving air. You can't really see it, but you can see its effects. Whether it's a gentle breeze or strong wind, you are most aware of air when it moves (**Figure** below). You can feel its molecules press against you. You can see things, like dirt and leaves, moving in the wind. And you can see object moving, like flags and trees, as a result of the wind.

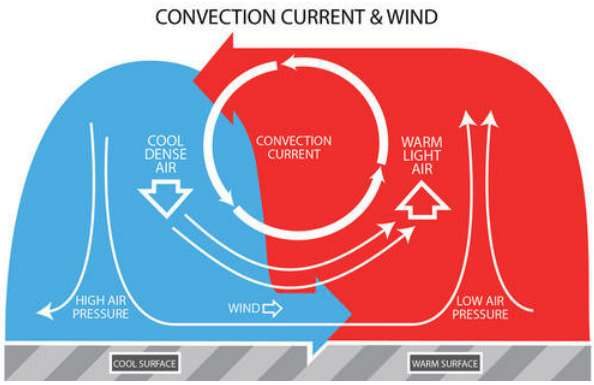


How can you tell the wind is blowing in these photos?

Why Air Moves

Air movement takes place in the troposphere. This is the lowest layer of the atmosphere. Air moves because of differences in heating. These differences create convection currents and winds (**Figure** below).

- Air in the troposphere is warmer near the ground. The warm air rises because it is light. The light, rising air creates an area of low air pressure at the surface.
- The rising air cools as it reaches the top of the troposphere. The air gets denser, so it sinks to the surface. The sinking, heavy air creates an area of high air pressure near the ground.
- Air always flows from an area of higher pressure to an area of lower pressure. Air flowing over Earth's surface is called **wind**. The greater the difference in pressure, the stronger the wind blows.



Differences in air temperature cause convection currents and wind.

Summary

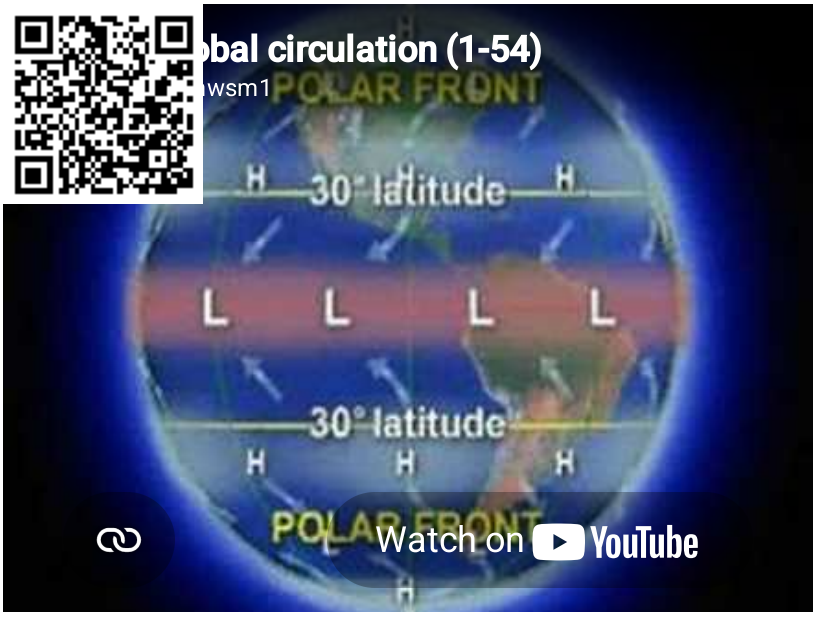
- Warm air rises because it is less dense. This creates an area of low pressure.
- Cool air sinks because it is denser. This creates an area of high pressure.
- Wind blows from areas of high pressure to areas of low pressure.

Review

1. Diagram and label the parts of a convection cell in the troposphere.
2. Why does warm air rise? Why does cool air sink?
3. What creates wind?

Explore More

Use the resource below to answer the questions that follow.



1. Where is insolation strongest?
2. What type of pressure occurs at the Equator? Why?
3. What type of pressure occurs at the poles? Why?
4. What are Hadley cells?
5. How do surface winds move?
6. What happens at the polar front?
7. How does air move differently at high altitudes?

This page titled 10.18: Circulation in the Atmosphere is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.19: Local Winds



Which large rainstorms are crucial for people in some parts of the world?

India, Pakistan, and other nations in southern Asia are great places to go to see monsoon rains. The region depends on the water they bring. Parts of the Southwestern United States also receive monsoon rains. These rains break the summer heat. They also provide water to desert plants. With winter rains and summer rains, these deserts are more lush than many.

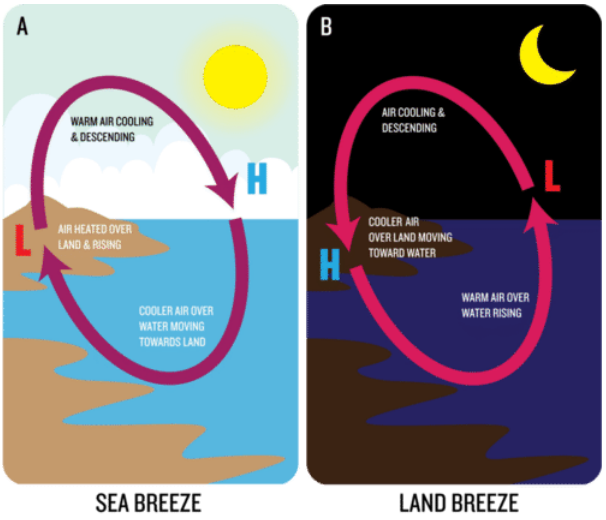
Local Winds

Local winds are winds that blow over a limited area. Local winds blow between small low and high pressure systems. They are influenced by local geography. Nearness to an ocean, lake, or mountain range can affect local winds. Some examples are found below. Local winds can affect the weather and climate of a region.

Land and Sea Breezes

Ocean water is slower to warm up and cool down than land. So the sea surface is cooler than the land in the daytime. It is also cooler than the land in the summer. The opposite is also true. The water stays warmer than the land during the night and the winter. These differences in heating cause local winds known as land and sea breezes (**Figure** below).

- A **sea breeze** blows from sea to land during the day or in summer. That's when air over the land is warmer than air over the water. The warm air rises. Cool air from over the water flows in to take its place.
- A **land breeze** blows from land to sea during the night or in winter. That's when air over the water is warmer than air over the land. The warm air rises. Cool air from the land flows out to take its place.

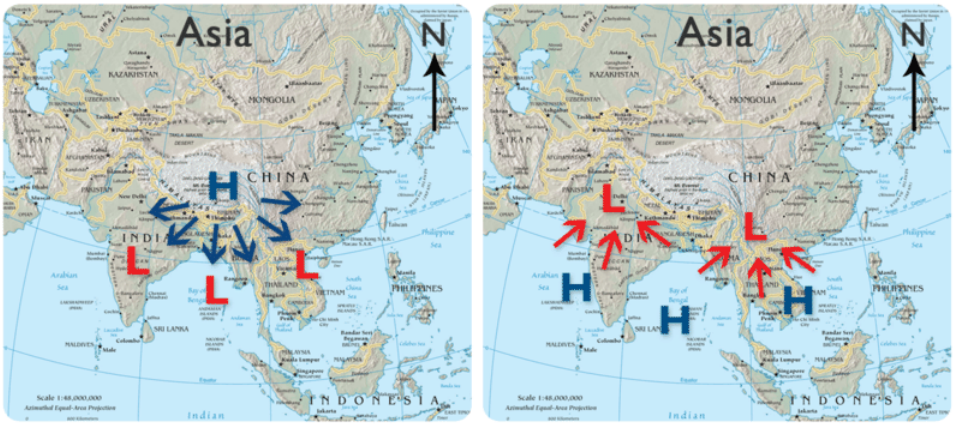


Land and sea breezes blow because of daily differences in heating.

Monsoons

Monsoons are like land and sea breezes, but on a larger scale. They occur because of seasonal changes in the temperature of land and water. In the winter, they blow from land to water. In the summer, they blow from water to land. In regions that experience monsoons, the seawater offshore is extremely warm. The hot air absorbs a lot of the moisture and carries it over the land. Summer monsoons bring heavy rains on land. Monsoons occur in several places around the globe. The most important monsoon in the

world is in southern Asia (**Figure** below). These monsoons are important because they carry water to the many people who live there.



Monsoons blow over southern Asia.

Mountain and Valley Breezes

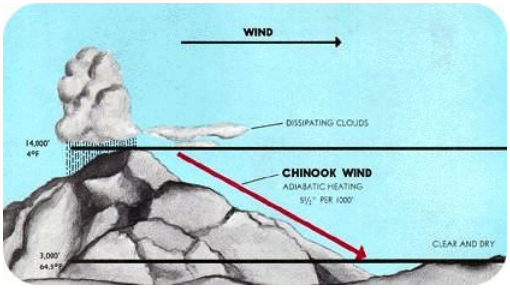
The air on a mountain slope warms more than the air over the nearby valley. The warm air rises and brings cool air up from below. This is a **valley breeze**. At night the mountain slope cools more than the air over the valley. The air flows downhill creating a **mountain breeze**.

Katabatic Winds

Katabatic winds move the same way as mountain and valley breezes. However, they are much stronger. Katabatic winds form over a high plateau that is surrounded by mountains. In winter, the plateau grows cold. Air sinks through the gaps in the mountains. Over Antarctica and Greenland, these winds are frigid.

Chinook Winds

Chinook winds (**Figure** below) occur when air is forced over a mountain range. Warm air rises over the Sierra Nevada in California, for example, because it is pushed eastward by the westerly winds. The air cools as it rises and precipitates. The air is now dry. It sinks down the far side of the mountains and may create strong winds. These Chinook winds are relatively warm. If there is snow, the winds may melt it quickly. The dry sinking air creates a **rainshadow effect**. Rainshadow effect is responsible for many of the world's deserts.



As air rises over a mountain it cools and loses moisture. The air warms by compression on the leeward side. The resulting warm and dry winds are Chinook winds. The leeward side of the mountain experiences rainshadow effect.

Santa Ana Winds

Santa Ana winds (**Figure** below) are responsible for many large fires in Southern California (**Figure** below). The Santa Ana winds arrive at the end of California's long summer drought season. Air east of the Sierra Nevada Mountains cools in late fall. This creates a high pressure zone. The air is then forced downhill through the deserts of the Southwest. It blows westward toward the ocean. The air is blocked by the San Gabriel and San Bernardino Mountains. So it is funneled rapidly through the mountain passes.

If a fire starts, it spreads quickly. The result is large-scale devastation. Long-term drought conditions and strong Santa Ana winds have fueled many destructive fires in Southern California including in recent years including in 2017, which saw 25 ongoing wildfires all the way into December.



The winds are especially fast through Santa Ana Canyon, for which they are named. Santa Ana winds blow dust and smoke westward over the Pacific from Southern California.



In October 2007, Santa Ana winds fueled many fires that together burned 426,000 acres of wild land and more than 1,500 homes in Southern California.

Desert Winds

High summer temperatures on the desert create high winds and monsoon storms. Strong winds in the desert can pick up dust and blow it around. A dust storm known as a **haboob** (**Figure** below) forms in the downdrafts on the front of a thunderstorm.



A haboob in the Phoenix metropolitan area, Arizona.

Summary

- Local winds blow between high pressure and low pressure areas.
- Winds blow up and down slope, on and off land and sea, through deserts or over mountain passes.
- Some local winds are well known in an area: haboobs in the desert, Santa Ana winds in Southern California, Chinook winds in Colorado.

Review

1. What causes local winds to blow?
2. Describe valley breezes and mountain breezes. How are they an example of how local winds form?
3. How do Chinook winds lead to rainshadow effect?

Explore More



1. What is the one sentence answer to the question what is wind?
2. What is air pressure?
3. Why are low pressure systems associated with bad weather?
4. Where does a high-pressure system come from?
5. Why doesn't wind blow in straight lines? How does wind blow?
6. Which direction is Coriolis deflection in the Northern Hemisphere? Which direction is Coriolis deflection in the Southern Hemisphere?

This page titled 10.19: Local Winds is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.20: Global Wind Belts

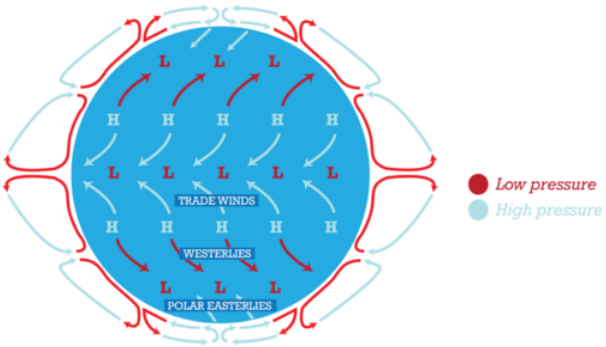


How did the "trade winds" get their name?

Not so long ago ships could sail only in the direction the wind was blowing, more-or-less. For centuries, a trip could be made or broken by how hard the wind blew. The trade winds were named because they were a reliable way to get across the ocean. Ships engaged in trade needed these winds to take or leave goods. The trade winds are one of the global wind belts.

Global Winds

Global winds are winds that occur in belts that go all around the planet (**Figure** below). Like local winds, global winds are caused by unequal heating of the atmosphere.



Global winds occur in belts around the globe.

Heating and Global Winds

Earth is hottest at the Equator and gets cooler toward the poles. The differences in heating create huge convection currents in the troposphere. At the Equator, for example, warm air rises up to the tropopause. When it can't rise any higher, it flows north or south.

By the time the moving air reaches 30°N or °S latitude, it has cooled somewhat. The cool air sinks to the surface. Then it flows over the surface back to the Equator. Other global winds occur in much the same way. There are three enormous convection cells north of the Equator and three south of the Equator.

Global Winds and the Coriolis Effect

Earth is spinning as air moves over its surface. This causes the Coriolis effect. Winds blow on a diagonal over the surface due to Coriolis effect. From which direction do the northern trade winds blow?

Without the Coriolis effect the global winds would blow north to south or south to north. But the Coriolis effect makes them blow northeast to southwest or the reverse in the Northern Hemisphere. The winds blow northwest to southeast or the reverse in the

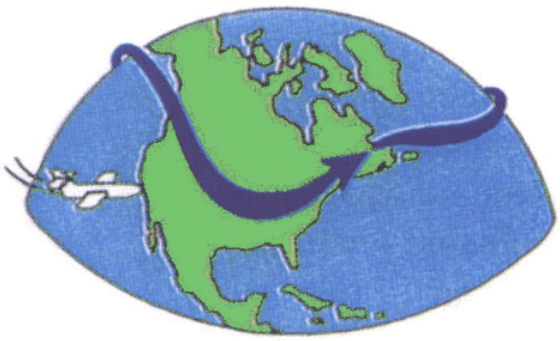
Southern Hemisphere.

The wind belts have names. The Trade Winds are nearest the Equator. The next belt is the westerlies. Finally are the polar easterlies. The names are the same in both hemispheres.

Jet Streams

Jet streams are fast-moving air currents high in the troposphere. They are also the result of unequal heating of the atmosphere. Jet streams circle the planet, mainly from west to east. The strongest jet streams are the polar jets. Pictured below is the northern polar jet (**Figure** below).

Northern Polar Jet Stream



This jet stream helps planes fly quickly from west to east over North America. How do you think it affects planes that fly from east to west?

Summary

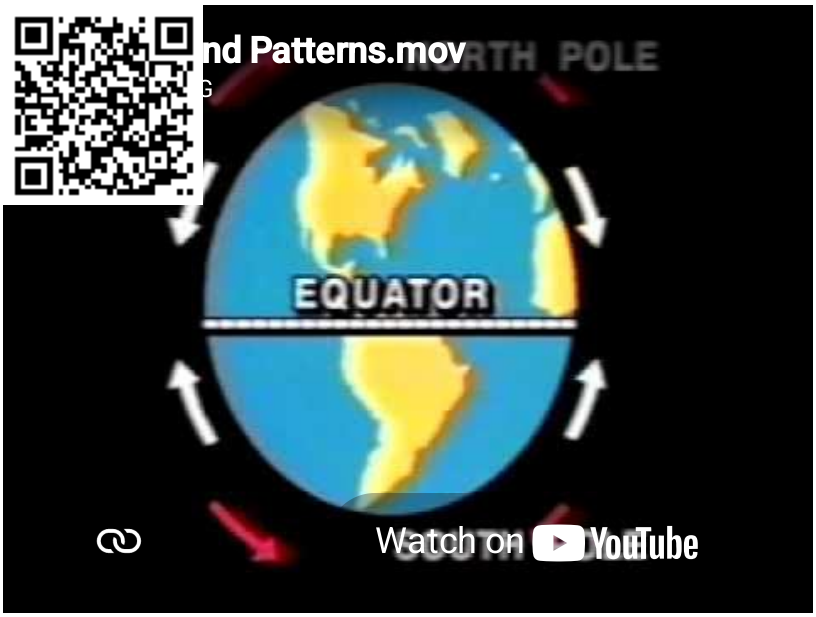
- Global winds blow from high to low pressure at the base of the atmospheric circulation cells.
- The globe has six atmospheric circulation cells. Three are north of the Equator and three are south. These cells have names.
- Jet streams are fast moving rivers of air going in opposite directions.

Review

1. What is a jet stream? Where are the strongest jet streams?
2. Which takes longer: a flight from San Francisco to Philadelphia or a flight from Philadelphia to San Francisco? Why did you make that choice?
3. Describe the locations of the major atmospheric convection cells. What creates them?

Explore More

Use the resource below to answer the questions that follow.



1. What creates wind?
2. What are monsoons?
3. What circumstances lead to summer monsoon winds?
4. What two factors determine the directions of the global winds?
5. In what direction does the Earth rotate?
6. Due to Coriolis effect, in what direction does wind curve in the Northern Hemisphere and in the Southern Hemisphere?
7. What are the Westerlies?

This page titled 10.20: Global Wind Belts is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.21: Atmospheric Processes- Challenge 4

1. At the equator, air is hit by solar energy more directly than elsewhere on the planet, warming and forming a ___.

low pressure zone

2. Warm air ___ at a ___ pressure zone; cool air ___ at a ___ pressure zone.

rises; low; sinks; high

3. Air flowing over Earth's surface is called ___. This can vary from a slight breeze to very strong conditions.

wind

4. Rain is common in ___ pressure regions due to rising air.

low

5. Sinking air ___.

causes evaporation

6. There are ___ major convection cells south of the equator.

three

7. During the day, mountain slopes warm more than valleys, causing warm air over the slopes to rise and draw up air from valleys. This produces a ___ breeze.

valley

8. Land breezes blow from land to sea in ___.

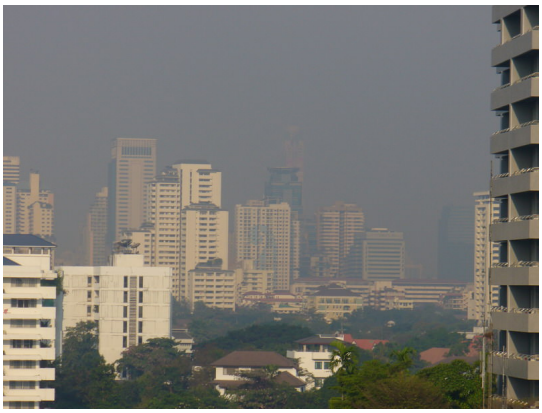
winter

9. Monsoon winds form when ___.

Hot air above land rises and sucks in warm, wet air from the sea.

This page titled 10.21: Atmospheric Processes- Challenge 4 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.22: Air Quality



What is this in the air?

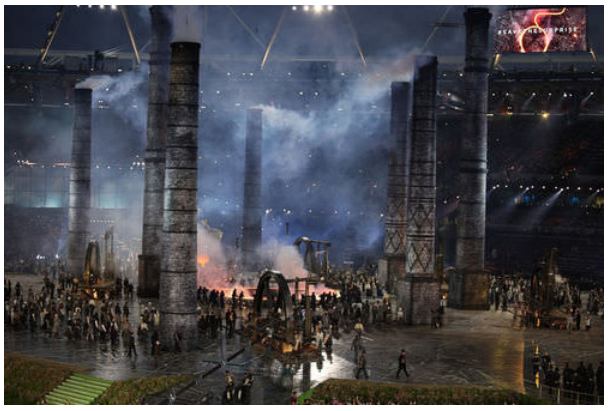
People have euphemisms for smog; sometimes it's fog, sometimes it's haze. It's hard to know sometimes whether the air is full of something natural, like water vapor, or something man-made, like CFCs. But in cities like this the air is often being marred by air pollution.

Air Quality

Pollutants include materials that are naturally occurring but are added to the atmosphere so that they are there in larger quantities than normal. Pollutants may also be human-made compounds that have never before been found in the atmosphere. Pollutants dirty the air, change natural processes in the atmosphere, and harm living things.

Problems with Air Quality

Air pollution started to be a problem when early people burned wood for heat and cooking fires in enclosed spaces such as caves and small tents or houses. But the problems became more widespread as humans began burning fossil fuels, such as coal, on a large scale during the Industrial Revolution (**Figure** below).



The 2012 Olympic Games in London opening ceremony contained a reenactment of the Industrial Revolution - complete with pollution streaming from smokestacks.

Photochemical Smog

Photochemical smog, a different type of air pollution, first became a problem in Southern California after World War II. The abundance of cars and sunshine provided the perfect setting for a chemical reaction between some of the molecules in auto exhaust or oil refinery emissions and sunlight (**Figure** below). Photochemical smog consists of more than 100 compounds, most importantly ozone.



Smog over Los Angeles as viewed from the Hollywood Hills.

The Clean Air Act

Terrible air pollution events in Pennsylvania and London, in which many people died, plus the recognition of the hazards of photochemical smog, led to the passage of the Clean Air Act in 1970 in the United States. The act now regulates 189 pollutants. The six most important pollutants regulated by the Act are ozone, particulate matter, sulfur dioxide, nitrogen dioxide, carbon monoxide, and the heavy metal lead. Other important regulated pollutants include benzene, perchloroethylene, methylene chloride, dioxin, asbestos, toluene, and metals such as cadmium, mercury, chromium, and lead compounds.

What is the result of the Clean Air Act? In short, the air in the United States is somewhat cleaner. Visibility is better and people are less incapacitated by industrial smog. However, despite the Act, industry, power plants, and vehicles put 160 million tons of pollutants into the air each year. Some of this smog is invisible and some contributes to the orange or blue haze that affects many cities.

Regional Air Quality

Air quality in a region is not affected just by the amount of pollutants released into the atmosphere in that location but by other geographical and atmospheric factors. Winds can move pollutants into or out of a region and a mountain range can trap pollutants on its leeward side. Inversions commonly trap pollutants within a cool air mass. If the inversion lasts long enough, pollution can reach dangerous levels.

Pollutants remain over a region until they are transported out of the area by wind, diluted by air blown in from another region, transformed into other compounds, or carried to the ground when mixed with rain or snow.

Table below lists the smoggiest cities in 2018. Fairbanks, Alaska is a surprise at #1. That ranking is due to particulates from people burning wood for warmth in winter. Fairbanks has very little ozone pollution because it has very few cars, and it is not very warm.

Seven of the 10 of the smoggiest cities are in California. Why do you think California cities are among those with the worst air pollution? The state has the right conditions for collecting pollutants including mountain ranges that trap smoggy air, arid and sometimes windless conditions, agriculture, industry, and lots and lots of cars.

Smoggiest U.S. Cities, 2018

Rank	City, State
1	Fairbanks, Alaska
2	Visalia-Porterville, California
3	Bakersfield-Delano, California
4	Los Angeles-Long Beach, California
5	Fresno-Madera, California
6	Modesto-Merced, California
7	El Centro, California
8 (tie)	Pittsburgh-New Castle-Weirton, Pennsylvania-Ohio-West Virginia
8 (tie)	Lancaster, Pennsylvania
10 (tie)	San Jose-San Francisco-Oakland, California
10 (tie)	Cleveland-Akron-Canton, Ohio

Summary

- Air is polluted by natural compounds in unnatural quantities or by unnatural compounds.
- Some pollutants enter the air directly and others are created by chemical reactions, such as those that are part of photochemical smog.
- Regions that are chronically polluted experience the release of a lot of pollutants into the air. The effects of pollution may also be amplified by geographical and atmospheric factors.

Review

1. How does photochemical smog differ from other types of air pollution?
2. What does the Clean Air Act regulate? what are the most important pollutants it regulates?
3. Why do parts of California have such bad air pollution?

1: Fairbanks, Alaska

This page titled 10.22: Air Quality is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.23: Types of Air Pollution



What is a pollution advisory?

Urban areas in sunny locations have pollution advisories. This happens when ozone levels get high. On these days, you should stay indoors or exercise early or late in the day. Drive less and avoid filling your tank.

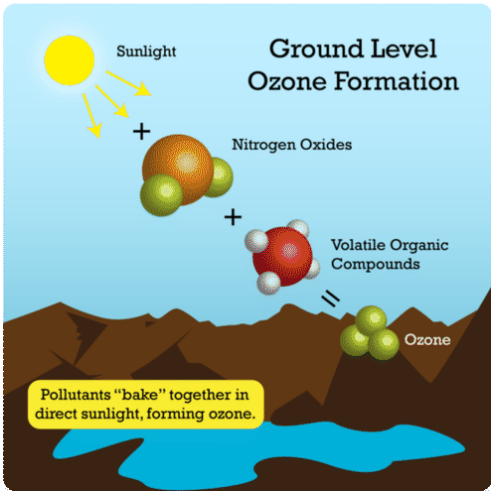
Air Pollutants

There are two main types of air pollutants: primary and secondary. Most air pollutants come from burning fossil fuels. Some come from burning forests. Some are due to the evaporation of chemicals.

Types of Air Pollutants

There are two basic types of pollutants in the air. They are known as primary pollutants and secondary pollutants.

- **Primary pollutants** enter the air directly. Some are released by natural processes, like ash from volcanoes. Most are released by human activities.
  - Carbon oxides are released when fossil fuels burn.
  - Nitrogen oxides form when nitrogen and oxygen combine at high temperatures. This occurs in hot exhausts from vehicles, factories, and power plants.
  - Sulfur oxides are produced when sulfur and oxygen combine. This happens when coal that contains sulfur burns.
  - Toxic heavy metals include mercury and lead. Mercury comes from smokestacks. Both metals have industrial uses.
  - Volatile organic compounds (VOCs) are carbon compounds, such as methane. VOCs are released by many human activities. Raising livestock, for example, produces a lot of methane.
  - **Particulates** are solid particles. These particles may be ash, dust, or even animal wastes. Many are released when fossil fuels burn.
- **Secondary pollutants** form from primary pollutants. Many occur as part of **photochemical smog**. This type of smog is seen as a brown haze in the air. Photochemical smog forms when certain pollutants have a chemical reaction in the presence of sunlight. Photochemical smog consists mainly of **ozone** (O_3). Ozone near the ground is a pollutant (**Figure** below). This ozone is harmful to humans and other living things. However, ozone in the stratosphere protects Earth from the Sun's harmful ultraviolet radiation.



Ozone forms near the ground as a secondary pollutant.

Sources of Air Pollutants

Most pollutants enter the air when fossil fuels burn. Some are released when forests burn. Others evaporate into the air.

Burning Fossil Fuels

Burning fossil fuels releases many pollutants into the air. These pollutants include carbon monoxide, carbon dioxide, nitrogen dioxide, and sulfur dioxide.

- Motor vehicles account for almost half of fossil fuel use.
- Power plants and factories account for more than a quarter of fossil fuel use (**Figure** below).
- Homes and other buildings burn fossil fuels.



Smoke stacks release a lot of pollutants into the air.

Burning Forests

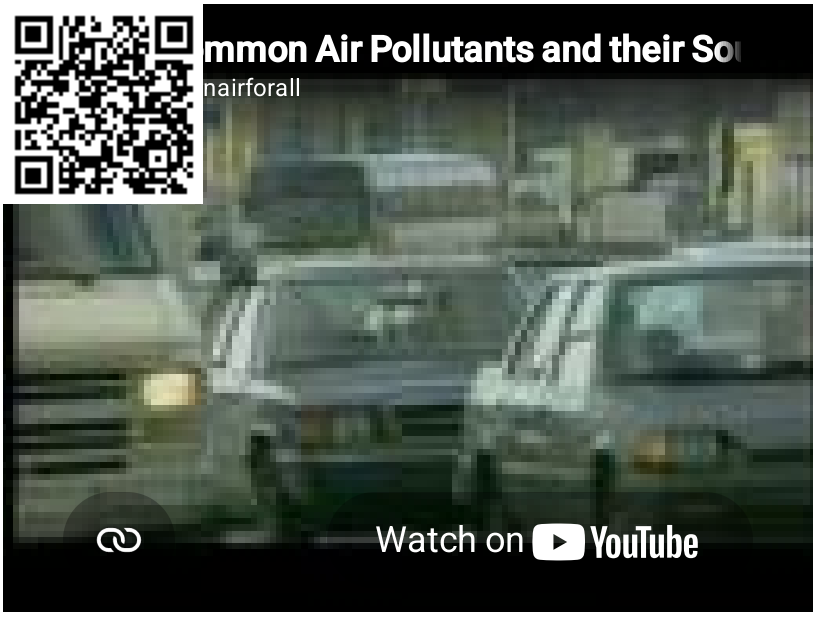
Millions of acres of forest have been cut and burned to make way for farming (**Figure** below). Burning trees produces most of the same pollutants as burning fossil fuels.



Cutting and burning trees to clear land for farming is called slash-and-burn agriculture. How does this affect the atmosphere?

Evaporation of VOCs

VOCs enter the air by evaporation. VOCs are found in many products, like paints and petroleum products. Methane is a VOC that evaporates from livestock waste and landfills.



Summary

- There are many types of primary pollutants, including carbon oxides, nitrogen oxides, sulfur oxides, particulates, lead, and volatile organic compounds.
- Secondary pollutants form from chemical reactions that occur when pollution is exposed to sunlight.
- Most pollutants enter the atmosphere from fossil fuel burning. Burning forests and evaporation of some chemicals account for most of the rest.

Review

1. How are primary and secondary pollutants different?
2. Why do fossil fuels account for so much air pollution?
3. What is ozone? Where is it harmful? Where is it beneficial?

This page titled 10.23: Types of Air Pollution is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.24: Effects of Air Pollution on the Environment



Why do we treat the atmosphere like a dump?

On a smoggy day, you're breathing garbage. Many human activities dump trash into the air. The trash is gases and particles, but it's still trash. Would we tolerate all this trash if it were in our houses?

Effects of Pollutants

Air pollution is harmful to human beings and other living things. About 22 million people die from air pollution each year. Breathing polluted air increases the risk of developing lung diseases, such as asthma and lung cancer. Breathing bad air also increases the chances of dying from other diseases. Children are most likely to be affected by air pollution. That's because their lungs are still developing and growing. Children also take in more air for their size than adults do. Some air pollutants damage the environment as well as the health of living things. The type of damage depends on the pollutant. Air pollution can also harm the environment.

Types of Pollutants

This concept explores the effects of different pollutants on the environment and human health. The pollutants include particulates, ozone, nitrogen oxides, sulfur oxides, carbon monoxide, heavy metals, and VOCs.

Particulates

Particulates cause lung diseases. They can also increase the risk of heart disease and the number of asthma attacks. Particulates block sunlight from reaching Earth's surface. This means there is less energy for photosynthesis. Less photosynthesis means that plants and phytoplankton produce less food. This affects whole ecosystems.

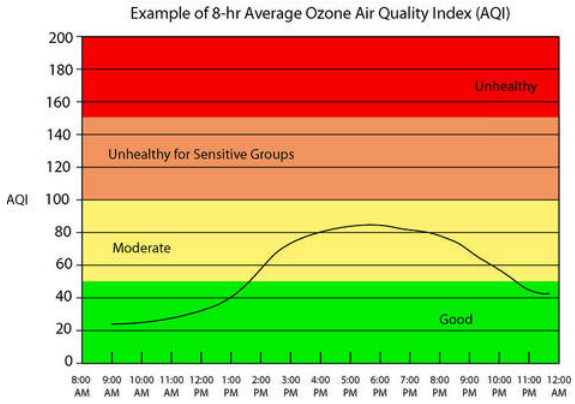
Ozone

The ozone in smog may damage plants. The effects of ozone add up over time. Plants such as trees, which normally live a long time, are most affected. Entire forests may die out if ozone levels are very high. Other plants, including crop plants, may also be damaged by ozone. Below, you can see evidence of ozone damage (**Figure** below).



Ozone damaged snap bean plants are shown on the left. Healthy snap bean plants are shown on the right.

The ozone in smog is also harmful to human health. The image below shows the levels of ozone to watch out for (**Figure** below). Some people are especially sensitive to ozone. They can be harmed by levels of ozone that would not affect most other people. These people include those with lung or heart problems.



The ozone air quality index gives the parts of ozone per million parts of air. How many parts of ozone are unhealthy for everyone?

Nitrogen and Sulfur Oxides

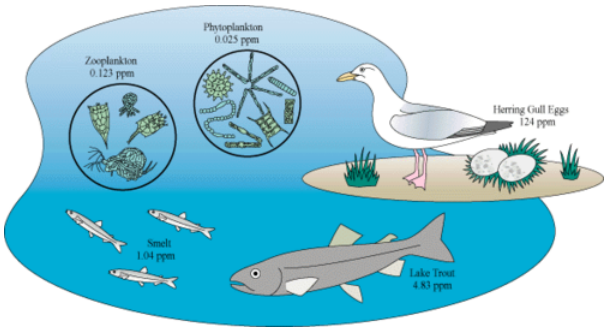
Both nitrogen and sulfur oxides are toxic to humans. These compounds can cause lung diseases or make them worse. Nitrogen and sulfur oxides form acid rain, which is described in the next concept.

Carbon Monoxide

Carbon monoxide (CO) is toxic to both plants and animals. CO is deadly to people in a confined space, such as a closed home. Carbon monoxide is odorless and colorless, so people can't tell when they are breathing it. That's why homes should have carbon monoxide detectors.

Heavy Metals

Heavy metals, such as mercury and lead, are toxic to living things. They can enter food chains from the atmosphere. The metals build up in the tissues of organisms by **bioaccumulation** (**Figure** below). Heavy metals accumulate as they are passed up a food chain. Imagine a low-level consumer eating a producer. That consumer takes in all of the heavy metals from all of the producers that it eats. Then a higher-level consumer eats the low-level consumer. The higher-level consumer accumulates all of the heavy metals from all of the lower-level consumers that it eats. In this way, an organism accumulates a lot of heavy metals. At high levels in the food chain, the heavy metals may become quite concentrated.



This diagram shows how mercury bioaccumulates. Compare the parts per million (ppm) of mercury in phytoplankton and gull eggs. Can you explain the difference?

The higher up a food chain that humans eat, the greater the levels of toxic metals they take in. That's why people should avoid eating too much large fish, such as tuna. Tuna are predators near the top of their food chains. They have been shown to contain high levels of mercury. In people, heavy metals can damage the brain and other organs. Unborn babies and young children are most affected. That's because their organs are still developing.

VOCs

VOCs are toxic to humans and other living things. In people, they can cause a wide range of problems. These can range from eye and nose irritation to brain damage and cancer. Levels of VOCs are often higher indoors than out. That's because they are released

by products such as paints, cleaning solutions, and building materials. How might you reduce your exposure to VOCs?



Summary

- An increase in particulates may have these effects. It may reduce photosynthesis, increase precipitation, and reduce temperatures.
- Ozone may damage native plants and some crop plants. Ozone may slow plant growth or damage leaves.
- Pollutants emitted into the air cause lung and other diseases in humans.

Review

1. Make a chart of each of the pollutants discussed in this concept. Add in the environmental effects of these pollutants. Then include the human health effects of these pollutants.
2. What time of day is the worst for ozone pollution? Can you think of why this is?
3. Describe bioaccumulation. What substances bioaccumulate?

This page titled 10.24: Effects of Air Pollution on the Environment is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.25: Causes of Air Pollution



Why don't we see emissions like this too often any more?

This photo of a power plant was taken before emission control equipment was added. Emissions are down since laws have been enacted to protect the air.

Causes of Air Pollution

Most air pollutants come from burning fossil fuels or plant material. Some are the result of evaporation from human-made materials. Nearly half (49%) of air pollution comes from transportation, 28% from factories and power plants, and the remaining pollution from a variety of other sources.

Fossil Fuels

Fossil fuels are burned in most motor vehicles and power plants. These non-renewable resources are the power for nearly all manufacturing and other industries. Pure coal and petroleum can burn cleanly and emit only carbon dioxide and water, but most of the time these fossil fuels do not burn completely and the incomplete chemical reactions produce pollutants. Few sources of these fossil fuels are pure, so other pollutants are usually released. These pollutants include carbon monoxide, nitrogen dioxide, sulfur dioxide, and hydrocarbons.

In large car-dependent cities such as Los Angeles and Mexico City, 80% to 85% of air pollution comes from motor vehicles (**Figure** below). Ozone, carbon monoxide, and nitrous oxides come from vehicle exhaust.



Auto exhaust like this means that the fuels is not burning efficiently.

A few pollutants come primarily from power plants or industrial plants that burn coal or oil. Sulfur dioxide (SO_2) is a major component of industrial air pollution that is released whenever coal and petroleum are burned. SO_2 mixes with H_2O in the air to produce sulfuric acid (H_2SO_4).

Mercury is released when coal and some types of wastes are burned. Mercury is emitted as a gas, but as it cools, it becomes a droplet. Mercury droplets eventually fall to the ground. If they fall into sediments, bacteria convert them to the most dangerous form of mercury: methyl mercury. Highly toxic, methyl mercury is one of the metal's organic forms.

Biomass Burning

Fossil fuels are ancient plants and animals that have been converted into usable hydrocarbons. Burning plant and animal material directly also produces pollutants. Biomass is the total amount of living material found in an environment. The biomass of a rainforest is the amount of living material found in that rainforest.

The primary way biomass is burned is for **slash-and-burn agriculture** (**Figure** below). The rainforest is slashed down and then the waste is burned to clear the land for farming. Biomass from other biomes, such as the savannah, is also burned to clear farmland. The pollutants are much the same as from burning fossil fuels: CO_2, carbon monoxide, methane, particulates, nitrous oxide, hydrocarbons, and organic and elemental carbon. Burning forests increases greenhouse gases in the atmosphere by releasing the CO_2 stored in the biomass and also by removing the forest so that it cannot store CO_2 in the future. As with all forms of air pollution, the smoke from biomass burning often spreads far and pollutants can plague neighboring states or countries.

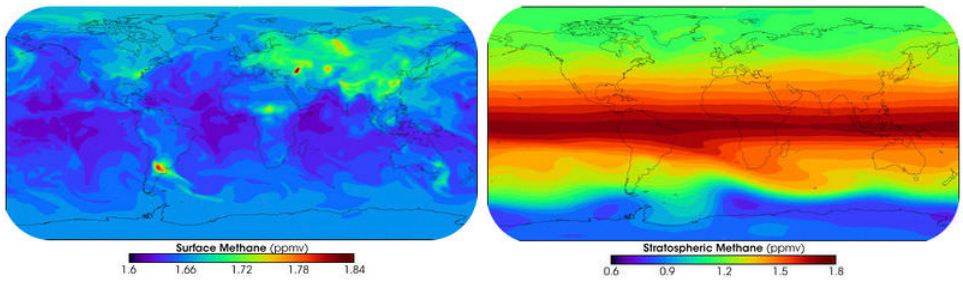


A forest that has been slash-and-burned to make new farmland.

Particulates result when anything is burned. About 40% of the particulates that enter the atmosphere above the United States are from industry and about 17% are from vehicles. Particulates also occur naturally from volcanic eruptions or windblown dust. Like other pollutants, they travel all around the world on atmospheric currents.

Evaporation

Volatile organic compounds (VOCs) enter the atmosphere by evaporation. VOCs evaporate from human-made substances, such as paint thinners, dry cleaning solvents, petroleum, wood preservatives, and other liquids. Naturally occurring VOCs evaporate off of pine and citrus trees. The atmosphere contains tens of thousands of different VOCs, nearly 100 of which are monitored. The most common is methane, a greenhouse gas (**Figure** below). Methane occurs naturally, but human agriculture is increasing the amount of methane in the atmosphere.



Methane forms when organic material decomposes in an oxygen-poor environment. In the top image, surface methane production is shown. Stratospheric methane concentrations in the bottom image show that methane is carried up into the stratosphere by the upward flow of air in the tropics.

Summary

- Most fossil fuels are dirty and release pollutants such as carbon monoxide, nitrogen dioxide, sulfur dioxide, and hydrocarbons.
- Burning plants and other biomass releases pollutants including carbon monoxide, methane, particulates, nitrous oxide, hydrocarbons, and organic and elemental carbon.
- Volatile organic compounds evaporate into the air and become pollutants.

Review

1. What is slash-and-burn agriculture and what pollutants does it release?
2. What are volatile organic compounds and why are they pollutants?
3. Name a compound that occurs in the atmosphere naturally but is a pollutant in excess amounts due to human activities.

This page titled 10.25: Causes of Air Pollution is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.26: Acid Rain

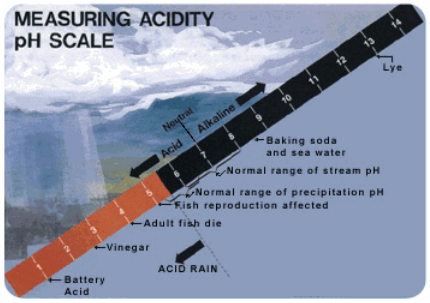


What would the artists think?

Notre Dame Cathedral in Paris opened in 1345. Construction took almost 200 years. For about 500 years, the cathedral was pristine. Yet this gargoyle has pits in it. The pits are caused by acid rain. Acid rain forms from pollutants from fossil fuel burning.

Acid Rain

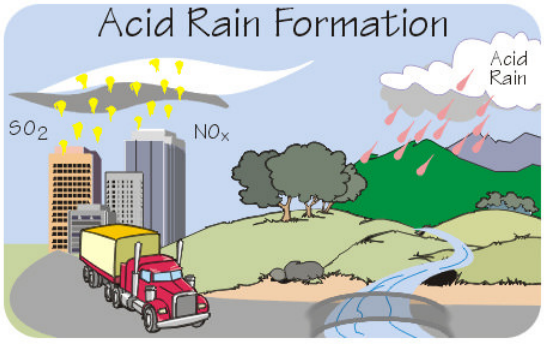
Acid rain is rain that has a pH less than 5 (**Figure** below). Acidity is measured on the **pH scale**. Lower numbers are more acidic, and higher numbers are less acidic (also called more **alkaline**). An **acid** has a pH of less than 7. The pH of normal rain is 5.6. It's slightly acidic because carbon dioxide in the air dissolves in rain. This forms carbonic acid, a weak acid.



This pH scale includes both normal and acid rain. At what pH do fish have problems reproducing?

How Acid Rain Forms

Acid rain forms when nitrogen and sulfur oxides in air dissolve in rain (**Figure** below). This forms nitric and sulfuric acids. Both are strong acids. Acid rain with a pH as low as 4.0 is now common in many areas. Acid fog may be even more acidic than acid rain. Fog with a pH as low as 1.7 has been recorded. That's the same pH as toilet bowl cleaner!



Nitrogen and sulfur oxides combine with rain to form acid rain.

https://k12.libretexts.org/@go/page/5503

Effects of Acid Rain

The image below shows some of the damage done by acid rain (**Figure** below). Acid rain ends up in soil and bodies of water. This can make them very acidic. The acid strips soil of its nutrients. These changes can kill trees, fish, and other living things. Acid rain also dissolves limestone and marble. This can damage buildings, monuments, and statues.



Acid rain has killed trees in this forest in the Czech Republic.

Summary

- Nitrogen and sulfur compounds emitted high into the atmosphere create acids. These acids may fall as acid rain.
- Acidity is measured on a pH scale. Rain that is 5.0 or less on that scale is considered acid rain.
- Acid rain weakens plants and animals and damages cultural treasures.

Review

1. Why does acid rain do a lot of damage far from where the smoke was released?
2. What damage does acid rain do to organisms? What damage does it do to cultural structures?
3. Describe the pH scale. What can you say about a liquid with a pH of 2.5? What about a liquid with a pH of 10.5?

Explore More

Use the resource below to answer the questions that follow.



1. What causes acid rain?
2. What two gases react with water to make acid rain?
3. Where relative to where the gases are emitted does acid rain strike?

4. What damage can acid rain cause?
5. How can we reduce acid rain?
6. What are scrubbers?
7. What is slurry?
8. How effective are scrubbers?

This page titled 10.26: Acid Rain is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.27: Ozone Depletion



Why can't the children in Punta Arenas go outside to play in the spring?

Punta Arenas, Chile, is the world's southernmost city. At such a high latitude, winters are exceedingly cold and dark. Unlike the children pictured above, the children in Punta Arenas must stay inside to avoid the cold. Of course, they look forward to spring when they can go out to play. But some years, it is too dangerous for the children to go outside. The ozone hole has moved north. Too much of the Sun's harmful UV radiation gets through.

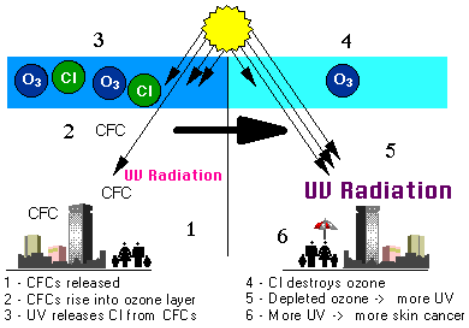
Loss of High-Level Ozone

Ozone near the ground harms human health. Ground-level ozone is a pollutant. But the ozone layer in the stratosphere protects us from harmful solar rays. That's why people were alarmed in the 1980s to learn that there was a hole in the ozone layer.

Cause of Ozone Loss

What's destroying the ozone layer? The chief cause is chlorofluorocarbons (CFCs). These are human-made chemicals that contain the element chlorine (Cl). In the past, CFCs were widely used in spray cans, refrigerators, and many other products. CFCs are stable compounds that can remain in the atmosphere for hundreds of years.

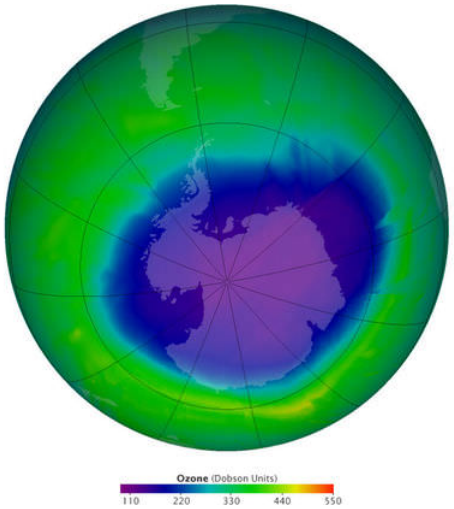
Once CFCs are in the air, they float up into the stratosphere. What happens next is pictured below (**Figure** below). Sunlight breaks apart the molecules. This releases their chlorine ions (Cl). The free chlorine ions may then combine with oxygen ions in ozone. This breaks down the ozone molecules into an oxygen molecule and an oxygen ion. One CFC molecule can break down as many as 100,000 ozone molecules in this way! These forms of oxygen do not protect the planet from ultraviolet radiation.



CFCs break down ozone in the stratosphere.

Ozone Hole

Most ozone loss it taking place over the South Pole and Antarctica. This is the location of the ozone hole. The **ozone hole** is a region in the stratosphere where there is less ozone than normal. Conditions are just right for ozone destruction because it is exceedingly cold. The ozone hole is also seasonal. The hole forms during the early part spring in the Southern Hemisphere and then grows northward (**Figure** below). The ozone layer is also thinner over the Northern Hemisphere.



The hole in the ozone layer occurs over Antarctica. How do you think the hole in the ozone layer could affect life on Earth?

Effects of Ozone Loss

With less ozone in the stratosphere, more UV rays reach the ground. More UV rays increase skin cancer rates. Just a 1 percent loss of ozone causes a 5 percent increase in skin cancer. More UV rays also harm plants and phytoplankton. As a result, they produce less food. This may affect entire ecosystems.

Protecting the Ozone Layer

The Montreal Protocol is a worldwide agreement on air pollution. It focuses on CFCs. It was signed by many countries in 1987. It controls almost 100 chemicals that can damage the ozone layer. Its aim is to return the ozone layer to its normal state.

The Montreal Protocol has been effective in controlling CFCs. By 1995, few CFCs were still being used. But the ozone hole kept growing for several years after that because of the CFCs already in the atmosphere. It peaked in 2006. Since then, it has been somewhat smaller. The Montreal Protocol is a shining example of how nations can come together to solve a global environmental problem.

Summary

- CFCs float up into the stratosphere where they break apart. The chlorine pulls an oxygen ion off of an ozone molecule and destroys it.
- The ozone hole forms over Antarctica in the spring.
- Ozone loss increases the amount of high-energy ultraviolet radiation that strikes Earth. This can cause ecological and health problems.

Review

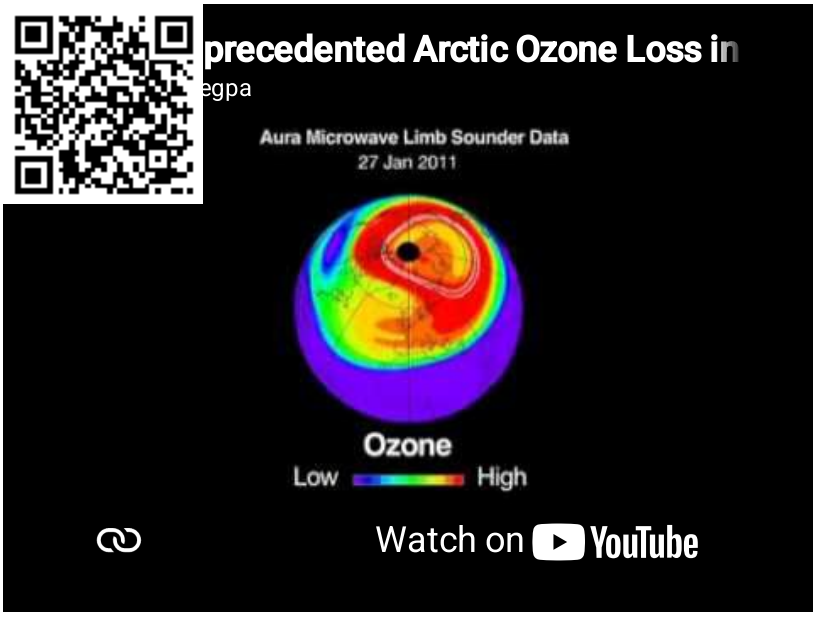
1. How do CFCs destroy ozone?
2. What is the ozone hole, and where is it found?
3. What effect does the ozone hole have on life, especially human life?

Explore More

Use the resources below to answer the questions that follow.



1. What is the purpose of the ozone layer?
2. Why is the ozone layer so fragile?
3. How much did ozone decrease between 1979 and 1993? Where scientists surprised by this?
4. Which satellite was launched to study the ozone? When?



5. What caused this ozone loss?

This page titled 10.27: Ozone Depletion is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.28: Reducing Air Pollution



Can a car run on hydrogen?

Yes! But so far this is not feasible for more than just a few models. A major problem with hydrogen cars is the lack of hydrogen fuel. Many ways to reduce pollution are being developed. What can you do to help?

The Clean Air Act

Air quality is a measure of the pollutants in the air. More pollutants mean poorer air quality. Poor air quality started to become a serious problem after the Industrial Revolution. Factories burned coal for energy. Gasoline burned by cars and trucks added greatly to air pollution. By the mid-1900s, air quality in many big cities was very bad. Incidents in London and in U.S. cities alerted people to the extent of the problem. It was clear that air quality needed to be protected.

In 1970 in the U.S., the Clean Air Act was passed. It limits what can be released into the air. The air in the U.S. is slightly cleaner now than it was 50 years ago. But air pollution has not gone away. Vehicles, factories, and power plants still release more than 150 million tons of pollutants into the air each year.

Reducing Pollutants from Fossil Fuels

There are two basic types of strategies for reducing pollution from fossil fuels:

1. Use less fossil fuel.
2. Prevent pollutants from entering the air.

Use Less Fossil Fuel

We can reduce our use of fossil fuels in several ways:

- Conserve fossil fuels. For example, turning out lights when we aren't using them saves electricity. Why does this help? A lot of the electricity we use comes from coal-burning power plants.
- Use fossil fuels more efficiently. For example, driving a fuel-efficient car lets you go farther on each gallon of gas. This can add up to a big savings in fossil fuel use.
- Keep up with technology. Hybrid cars run on electricity that would be wasted during braking. These cars use gas only as a backup fuel. As a result, they produce just 10 percent of the air pollution produced by regular cars.

Keep Air Free of Pollutants

Some of the pollutants from fossil fuels can be filtered out of exhaust before it is released into the air (**Figure** below). Other pollutants can be changed to harmless compounds before they are released. Two widely used technologies are scrubbers and catalytic converters.

- Scrubbers are used in factories and power plants. They remove particulates and waste gases from exhaust before it is released to the air.
- Catalytic converters are used on motor vehicles. They break down pollutants in exhaust to non-toxic compounds. For example, they change nitrogen oxides to harmless nitrogen and oxygen gases.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



Before catalytic converters were required, cars spewed a lot of pollutants into the air.

Increase Alternative Energy Sources

Developing alternative energy sources is important. What are some of the problems facing wider adoption of alternative energy sources?

- The technologies are still being developed. This includes sources of alternative energy, like solar and wind.
- Solar and wind are still expensive relative to fossil fuels, but their costs are rapidly decreasing. Some renewable energy sources are now cheaper than fossil fuels. Still, the technology needs to advance so that the price continues to fall.
- Some areas get low amounts of sunlight and are not suited for solar. Others do not have much wind. It is important that regions develop what best suits them. The desert Southwest will need to develop solar. The Great Plains can use wind energy. Perhaps some locations will rely on nuclear power.

Ways You Can Reduce Air Pollution

Everyone can help to reduce air pollution. Just use less fossil fuels! How can you do this?

- Ride a bike or walk instead of driving.
- Take a bus or carpool.
- Buy a fuel efficient car.
- Turn off lights and appliances when they are not in use.
- Use energy efficient light bulbs and appliances.
- Buy fewer things that are manufactured using fossil fuels.

All these actions reduce the amount of energy that power plants need to produce.





Summary

- Catalytic converters reduce pollution from cars.
- To reduce air pollution, either use less fossil fuels, or clean emissions before they enter the air.
- Different types of clean energy can be developed for different locations. Some regions are suited for solar, others for wind, etc.

Review

1. Why is the Clean Air Act important?
2. Why is it important to develop alternative energy sources?
3. What can you do to reduce the amount of air pollution you produce?

This page titled 10.28: Reducing Air Pollution is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

10.29: Atmospheric Processes- Challenge 5

1. Unlike secondary pollutants, ___ pollutants are released directly into the air by natural processes or, more often, human activities.

primary

2. ___ is a heavy metal that can cause brain damage or blood poisoning and can still be found in some old paints.

Lead

3. ___ are solid particles such as ash, dust, and fecal matter.

Particulates

4. Emission control devices placed on power plants to comply with the Clean Air Act have ___ coming from smokestacks.

reduced the amount of pollution that we see

5. Nearly half of all pollution comes from ___.

transportation

6. If fossil fuels like coal and petroleum are not pure, they may ___.

produce pollutants

7. In the process of ___, toxic heavy metals in the atmosphere can enter food chains by building up in consumers' tissues.

bioaccumulation

8. ___ can cause lung diseases, increase the risk of heart disease, and trigger asthma attacks.

Particulates

9. ___ in the troposphere reduces productivity and harms the leaves of plants.

Ozone

10. Which chemicals can neutralize the effects of acid rain?

Carbonates

11. ___ is used to treat bodies of water affected by acid rain.

Lime kiln dust

12. Poor nations experience acid rain and ___.

may experience crop damage that they can't control

13. The ozone layer in the stratosphere, which protects us from UV rays, is being depleted, mostly by the increase of ___.

chlorofluorocarbons (CFCs)

14. Ozone in the stratosphere ___, while ozone in the troposphere ___.

protects Earth's surface from UV radiation; is a pollutant

This page titled 10.29: Atmospheric Processes- Challenge 5 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

11: Weather

11.1: Introduction to Weather
11.2: Humidity
11.3: Clouds
11.4: Fog
11.5: Precipitation
11.6: Air Masses
11.7: Fronts
11.8: Weather- Challenge 1
11.9: Thunderstorms
11.10: Tornadoes
11.11: Cyclones
11.12: Hurricanes
11.13: Blizzards
11.14: Heat Waves and Droughts
11.15: Weather- Challenge 2
11.16: Collecting Weather Data
11.17: Predicting Weather
11.18: Weather Maps
11.19: Weather- Challenge 3

This page titled 11: Weather is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.1: Introduction to Weather



What's the weather like?

The United States is a big country. With two coasts and a large land mass in between, there's a chance for every kind of weather. In the next few sections we'll visit places that have the type of weather we're interested in studying.

What Is Weather?

All **weather** takes place in the atmosphere. Nearly all of it in the lower atmosphere. **Weather** refers to the conditions of the atmosphere at a given time and place. **Climate** is the average of weather over a long time.

Imagine your grandmother who lives in a distant place calls you up. She asks what your weather is like today. What would you say? Is it warm or cold? Sunny or cloudy? Calm or windy? Clear or rainy? What features of weather are important to mention?

A location’s weather depends on:

- air temperature.
- air pressure.
- fog.
- humidity.
- cloud cover.
- precipitation.
- wind speed and direction.

All of these characteristics are directly related to the amount of energy that is in the system, and where that energy is. The ultimate source of this energy is the Sun.

Weather is what we experience from day to day, or minute to minute. Weather can change rapidly.

What Causes Weather?

Weather occurs because of unequal heating of the atmosphere. The source of heat is the Sun. The general principles behind weather can be stated simply:

- The Sun heats Earth’s surface more in some places than in others.
- Where it is warm, heat from the Sun warms the air close to the surface. If there is water at the surface, it may cause some of the water to evaporate.
- Warm air is less dense, so it rises. When this happens, more dense air flows in to take its place. The flowing surface air is wind.
- The rising air cools as it goes higher in the atmosphere. If it is moist, the water vapor may condense. Clouds may form, and precipitation may fall.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



Science Friday: Snowflake Safari

Next snowstorm, grab a magnifying glass and look carefully at snowflakes. Bullet rosettes, stellar plates and capped columns are just a few of the many varieties of snow crystals. In this video by Science Friday, physicist Kenneth Libbrecht shares secrets about snowflakes.



Summary

- A region's weather depends on its air temperature, air pressure, humidity, precipitation, wind speed and direction, and other factors.
- Climate is the long-term average of weather.
- Weather can change in minutes, but climate changes very slowly.

Review

1. Compare and contrast weather and climate.
2. What factors account for a location's weather?
3. Describe how unequal heating causes weather.

This page titled 11.1: Introduction to Weather is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.2: Humidity



Would you rather spend a summer day in Phoenix or in Houston?

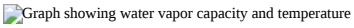
People who live in Phoenix, Arizona, are told that summer isn't so bad because "it's a dry heat." What does that mean? Imagine that both Phoenix and Houston have a temperature of 90°F. In Phoenix, the relative humidity is 20%. In Houston, the relative humidity is 90%. So in Phoenix it feels like it's 90°F. But in Houston it feels like it's 122°F! Of course in Phoenix in July, the average high temperature is 106°F. That's hot, dry or not!

Humidity

Humidity is the amount of water vapor in the air. High humidity increases the chances of clouds and precipitation.

Relative Humidity

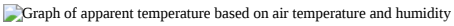
Humidity usually refers to **relative humidity**. This is the percent of water vapor in the air relative to the total amount the air can hold. How much water vapor can the air hold? That depends on temperature. Warm air can hold more water vapor than cool air (**Figure** below).



How much water vapor can the air hold when its temperature is 40° C?

Humidity and Heat

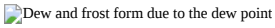
People often say, “it’s not the heat but the humidity.” Humidity can make a hot day feel even hotter. When sweat evaporates, it cools your body. But when the air contains as much water vapor as it can hold, water condenses on your skin just as fast as it evaporates, providing no cooling benefit. The **heat index** (**Figure** below) is a measure of what the temperature feels like because of the humidity.



How hot does it feel when the air temperature is 90°F? It depends on the humidity.

Dew Point

You’ve probably noticed dew on the grass on a summer morning. Why does dew form? Remember that the land heats up and cools down fairly readily. So when night comes, the land cools. Air that was warm and humid in the daytime also cools over night. As the air cools, it can hold less water vapor. Some of the water vapor condenses on the cool surfaces, such as blades of grass. The temperature at which water vapor condenses is called the **dew point**. If this temperature is below freezing, ice crystals of frost form instead of dew (**Figure** below). The dew point occurs at 100 percent relative humidity. Can you explain why?



The grass on the left is covered with dew. The grass on the right is covered with frost. The difference is the temperature of the grass.

Science Friday: Snowflake Safari

Next snowstorm, grab a magnifying glass and look carefully at snowflakes. Bullet rosettes, stellar plates and capped columns are just a few of the many varieties of snow crystals. In this video by Science Friday, physicist Kenneth Libbrecht shares secrets about snowflakes.

LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



Summary

- Air reaches its dew point when humidity increases or temperature decreases.
- Water droplets form when the air reaches 100% humidity. If the temperature is cold enough, frost will form.
- Relative humidity is how the air feels at its temperature and humidity.

Review

1. What is humidity? What is relative humidity?
2. Explain what heat index is.
3. Why does water come out of the air at its dew point?

Explore More

Use the resource below to answer the questions that follow.



1. What is humidity?
2. What is water vapor?
3. What is absolute humidity?
4. What two factors does relative humidity consider?
5. What are you likely to see when the humidity is 100%?

This page titled 11.2: Humidity is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.3: Clouds



Where should you go if you don't want to see the Sun?

The Pacific Northwest has the most days of heavy cloud cover. 62% of days have more than three-quarters of the sky covered in clouds in Seattle. Conditions are nearly the same in Portland, Oregon. If you want to see the most sunshine, the least cloudy cities are in Arizona.

Clouds

Clouds form when air in the atmosphere reaches the dew point. Clouds may form anywhere in the troposphere. Clouds that form on the ground are called fog.

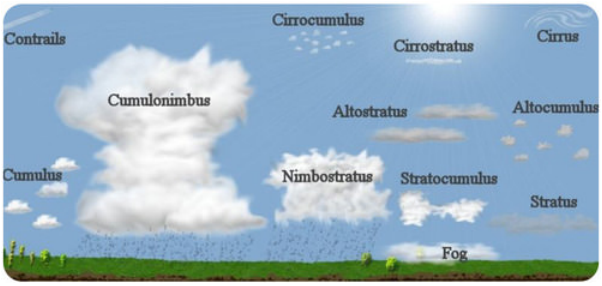
How Clouds Form

Clouds form when water vapor condenses around particles in the air. The particles are specks of matter, such as dust or smoke. Billions of these tiny water droplets come together to make up a cloud. If the air is very cold, ice crystals form instead of liquid water.

Classification of Clouds

Clouds are classified on the basis of where and how they form. Three main types of clouds are cirrus, stratus, and cumulus; there are other types of clouds as well (**Figure** below).

- **Cirrus clouds** form high in the troposphere. Because it is so cold they are made of ice crystals. They are thin and wispy. Cirrus clouds don't usually produce precipitation, but they may be a sign that wet weather is coming.
- **Stratus clouds** occur low in the troposphere. They form in layers that spread horizontally and may cover the entire sky like a thick blanket. Stratus clouds that produce precipitation are called nimbostratus. The prefix *nimbo-* means "rain."
- **Cumulus clouds** are white and puffy. Convection currents make them grow upward, and they may grow very tall. When they produce rain, they are called cumulonimbus.



Find the cirrus, cirrostratus, and cirrocumulus clouds in the figure. What do they have in common? They all form high in the troposphere. Clouds that form in the mid troposphere have the prefix "alto-", as in altocumulus. Where do stratocumulus clouds form?

Clouds and Temperature

Clouds can affect the temperature on Earth's surface. During the day, thick clouds block some of the Sun's rays. This keeps the surface from heating up as much as it would on a clear day. At night, thick clouds prevent heat from radiating out into space. This keeps the surface warmer than it would be on a clear night.



Science Friday: Growing Snowflakes in a Bottle

Ever dreamed about making your own snowflakes? It turns out you can, using materials that you can easily obtain. In this video by ScienceFriday, physicist Ken Libbrecht describes how to build your own snowflake in a plastic bottle.



Summary

- Water vapor condenses on particles in the air to form clouds.
- Clouds block sunlight in the day. Clouds trap heat in the atmosphere at night.
- Cloud types include cirrus, stratus, and cumulus.

Review

1. What happens to turn water vapor into a cloud?
2. What effects do clouds have on temperature?
3. Compare and contrast cirrus, stratus, and cumulus clouds.

This page titled 11.3: Clouds is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.4: Fog



Where is the most famous fog in the U.S.?

San Francisco, the City by the Bay, is known for its fog. There's an old joke: "I spent the coldest winter of my life in San Francisco one summer." That's because of the fog! There is a big difference in temperature between the two sides of the city. On the Pacific side, where there is fog, temperatures are low. On the bay side, where there isn't fog, temperatures are much higher.

Fog

Fog (**Figure** below) is a cloud on the ground. Fog forms when humid air near the ground cools below its dew point. Each type of fog forms in a different way.

- **Radiation fog** forms at night. Skies are clear, and the relative humidity is high. The ground cools as temperature goes down. Air near the ground cools below its dew point. Tule fog is an extreme form of radiation fog. This type of fog strikes the Central Valley of California in winter.
- **Advection fog** is famous in San Francisco, California. Warm, moist air comes in from the Pacific Ocean. The air blows over the cold California current. When the air cools below its dew point, fog forms. Sea breezes bring the fog onshore.
- **Steam fog** appears in autumn when cool air moves over a warm lake. Water evaporates from the lake surface. As the water vapor cools, it condenses. The fog appears like steam.
- Warm humid air travels up a hillside and cools below its dew point to create **upslope fog**.



(a) Tule fog in the Central Valley of California. (b) Advection fog in San Francisco. (c) Steam fog over a lake in Algonquin Park, Canada. (d) Upslope fog around the peaks of the Sanqing Mountains in China.

Fog levels are declining along the California coast as climate warms. The change in fog may have big ecological changes for the state.



Summary

- Fog forms when there is a difference in temperature between the land and the air.

Review

1. Why does fog form?
2. What makes tule fog distinctive?
3. Compare and contrast the different types of fog.

This page titled 11.4: Fog is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.5: Precipitation



Want to stay dry? Don't go to these places!

The wettest locations in the world are in Mawsynram and Cherrapunji in India. Monsoon rains result in more than 460" of rain annually. The wettest place in the United States with 404" on average is on Maui (Big Bog). The wettest place in the continental United States is Langlois, Oregon with a mere 122" per year.

Precipitation

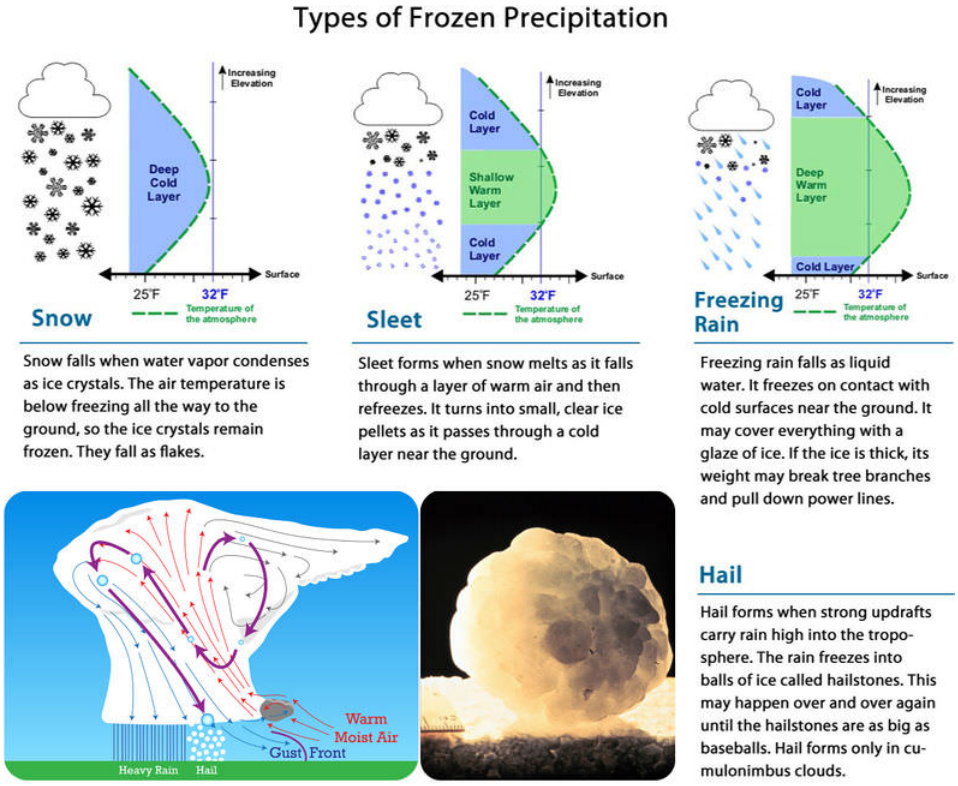
Clouds are needed for precipitation. **Precipitation** is water that falls from the sky. This may fall as liquid water, mostly as **rain**. It may fall also as frozen water, such as snow.

Why Precipitation Falls

Millions of water molecules in a cloud must condense to make a single raindrop or snowflake. The drop or flake falls when it becomes too heavy for updrafts to keep it aloft. As a drop or flake falls, it may collect more water and get larger.

Types of Precipitation

Why does it snow instead of rain? Air temperature determines which type of precipitation falls. Rain falls if the air temperature is above freezing (0° C or 32° F). Frozen precipitation falls if the air or ground is below freezing. Frozen precipitation may fall as **snow**, **sleet**, or **freezing rain**. Below, you can see how the different types form (**Figure** below).



Frozen precipitation may fall as snow, sleet, or freezing rain.

Summary

- Precipitation falls when it gets too heavy to stay in a cloud.
- Rain droplets caught up in air currents within a cloud get larger by the addition of condensed droplets until they are too heavy and they fall.
- If the ground is very cold, rain can freeze to become sleet or glaze.

Review

1. Why do raindrops form and fall to the ground?
2. Why does hail only come from cumulonimbus clouds?
3. How does sleet form?

Explore More

Use the resource below to answer the questions that follow.



1. What is precipitation?
2. What is the most common form of precipitation?
3. What is hail?
4. What is sleet?
5. What is snow?

This page titled 11.5: Precipitation is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.6: Air Masses



Pick an air mass!

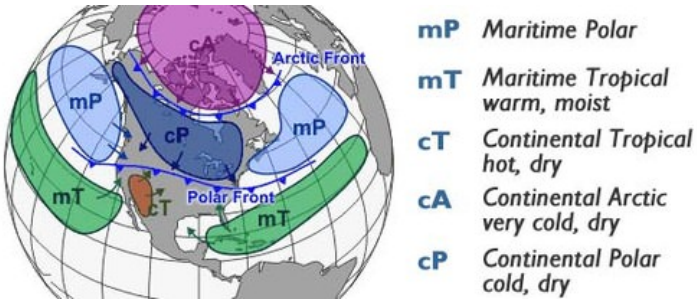
A cold, dry air mass forms over the interior of Alaska. The mountain is Mt. McKinley in Denali National Park. A warm wet air mass forms over the ocean. It sneaks onto the coastal area. Which region would you like to visit?

Air Masses

An **air mass** is a large body of air that has about the same conditions throughout. For example, an air mass might have cold, dry air. Another air mass might have warm, moist air. The characteristics of an air mass depend on where the air mass formed. The air must stay over that location long enough to pick up those characteristics.

Formation of Air Masses

Most air masses form over polar or tropical regions. They may form over continents or oceans. Air masses are moist if they form over oceans. They are dry if they form over continents. Air masses that form over oceans are called maritime air masses. Those that form over continents are called continental air masses. The image below shows air masses that form over or near North America (**Figure** below).



North American air masses.

An air mass takes on the conditions of the area where it forms. For example, a continental polar air mass has cold, dry air. A maritime polar air mass has cold, moist air. Which air masses have warm, moist air? Where do they form?

Movement of Air Masses

When a new air mass moves over a region it brings its characteristics to the region. This may change the area's temperature and humidity. Moving air masses cause the weather to change when they contact different conditions. For example, a warm air mass moving over cold ground may cause an inversion.

Why do air masses move? Winds and jet streams push them along. Cold air masses tend to move toward the Equator. Warm air masses tend to move toward the poles. The Coriolis effect causes them to move on a diagonal. Many air masses move toward the northeast over the U.S. This is the same direction that global winds blow.



Further Reading

Fronts

Summary

- An air mass has roughly the same temperature and humidity.
- Air masses form over regions where the air is stable for a long enough time. The air takes on the characteristics of the region.
- Air masses move when they are pushed by high level winds.

Review

1. What is an air mass?
2. Why do air masses form where the air stays in one place for a while?
3. What happens when an air mass moves over a new region?

This page titled 11.6: Air Masses is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.7: Fronts



What happens when one air mass meets another?

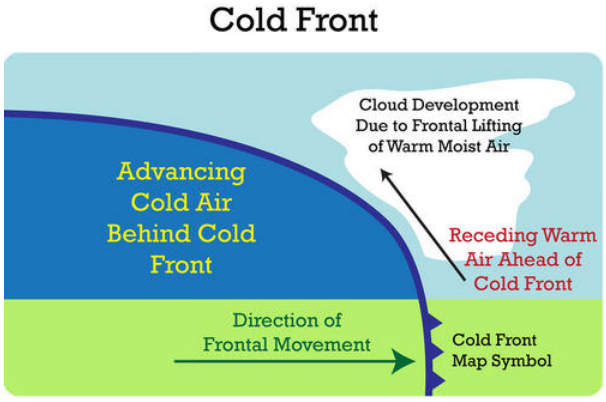
This sight is common when one air mass meets another. You can almost see one air mass being pushed up over the other. When two air masses meet, the result is often a storm. Have you been to the Midwestern United States in the spring? This is a common sight.

Fronts

When cold air masses move south from the poles, they run into warm air masses moving north from the tropics. The boundary between two air masses is called a **front**. Air masses usually don't mix at a front. The differences in temperature and pressure cause clouds and precipitation. Types of fronts include cold, warm, occluded, and stationary fronts.

Cold Fronts

A **cold front** forms when a cold air mass runs into a warm air mass (**Figure** below). The cold air mass moves faster than the warm air mass. So the cold air mass lifts the warm air mass out of its way. As the warm air rises, its water vapor condenses. Clouds form, and precipitation falls. If the warm air is very humid, precipitation can be heavy. Temperature and pressure differences between the two air masses cause winds. Winds may be very strong along a cold front.



Cold fronts often bring stormy weather.

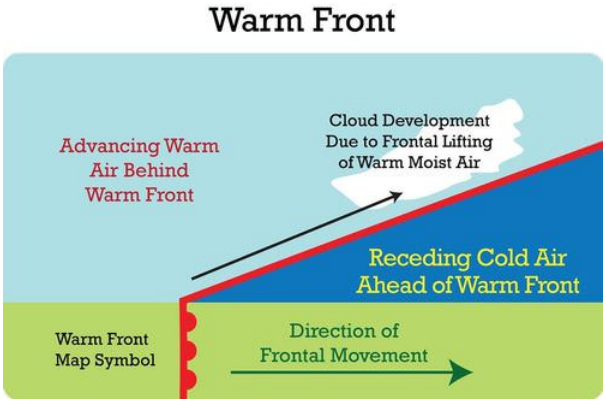
As the fast-moving cold air mass keeps advancing, so does the cold front. Cold fronts often bring sudden changes in the weather. There may be a thin line of storms right at the front that moves as it moves. In the spring and summer, the storms may be thunderstorms and tornadoes. In the late fall and winter, the storms may bring snow. After a cold front passes, the cold air mass behind it brings cooler temperatures. The air is likely to be less humid as well. Can you explain why?

Warm Fronts

When a warm air mass runs into a cold air mass, it creates a **warm front** (**Figure** below). The warm air mass is moving faster than the cold air mass. The warm air mass then flows up over the cold air mass. As the warm air rises, it cools. This brings about clouds

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

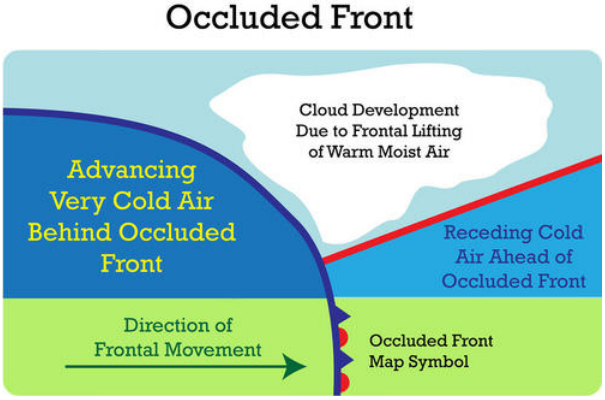
and sometimes light precipitation. Warm fronts move slowly and cover a wide area. After a warm front passes, the warm air mass behind it brings warmer temperatures. The warm air is also likely to be more humid.



Warm fronts generally bring cloudy weather.

Occluded Fronts

In an **occluded front**, a warm air mass becomes trapped between two cold air masses. The warm air is lifted up above the cold air (**Figure** below). Cloudy weather and precipitation along the front are typical.



How does an occluded front differ from a warm or cold front?

Stationary Fronts

Sometimes two air masses stop moving when they meet. These stalled air masses create a **stationary front**. Such a front may bring clouds and precipitation to the same area for many days.

Summary

- Much of the weather occurs at fronts, where air masses meet.
- In a warm front, a warm air mass slides over a cold air mass. In a cold front, a cold air mass slides under a warm air mass.
- An occluded front has three air masses: cold, warm, and cold.

Review

1. What characteristics give warm fronts and cold fronts their names?
2. Describe a warm front. What weather is found with a warm front?
3. Describe a cold front. What weather is found with a cold front?
4. How does an occluded front form?

Explore More

Use the resource below to answer the questions that follow.



1. What is a front?
2. How does a cold front form?
3. What forms along a cold front?
4. How does a warm front form?
5. What type of clouds form at warm fronts?
6. What type of precipitation is produced from a warm front?
7. What is a stationary front?
8. What type of weather can occur at an occluded front?

This page titled 11.7: Fronts is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.8: Weather- Challenge 1

1. ___ is weather averaged over a long period of time.

Climate

2. As rising air cools, any water vapor within it begins to ___.

condense

3. Dew forms when humid air cools overnight. If the temperature falls below freezing, ___ will form instead.

frost

4. The ___ index is a measure of what the temperature feels like because of the humidity.

heat

5. Why does humidity affect how hot it feels?

High humidity prevents sweat from evaporating and cooling our bodies

6. The most important condition necessary for cloud formation is ___.

the presence of condensation nuclei

7. Clouds are commonly classified by ___.

altitude

8. ___ clouds are white and puffy.

Cumulus

9. Within an air mass, ___ and ___ are nearly the same.

temperature and humidity

10. An air mass described by the symbol mTk formed over ___.

the ocean in a tropical region and is moving over warmer ground

11. Air masses form primarily in ___.

high pressure, polar and tropical zones

12. When a cold air mass collides with a warm air mass and lifts the warm air mass out of the way, a ___ forms. The rising warm air causes clouds to form.

cold front

13. The leading edge of an air mass is called a ___.

front

This page titled 11.8: Weather- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.9: Thunderstorms



How do you get struck by lightning?

An average of 55 people die from lightning strikes each year in the United States. Here's your best chance for being struck by lightning, according to NASA. Go golfing on a July Sunday at around 4 pm, especially in Florida. The golf club up in the air acts as a lightning rod. The late afternoon in July is a great time for thunderstorms. Florida is prone to thunderstorms, and Sunday is a day on which a lot of people like to golf. In other words, don't do these things!

Thunderstorms

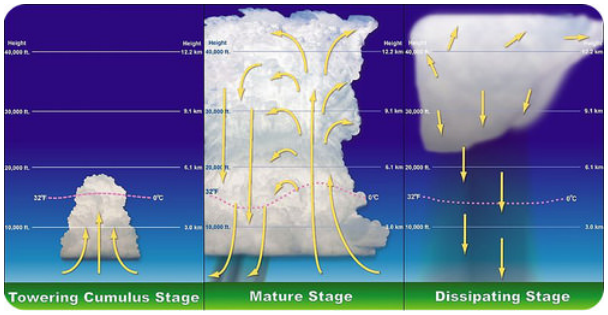
Thunderstorms are are known for their heavy rains and lightning. In strong thunderstorms, hail and high winds are also likely. Thunderstorms are very common. Worldwide, there are about 14 million of them each year! In the U.S., they are most common—and strongest—in the Midwest.

Thunderstorm Formation

Thunderstorms form when the ground is really hot (**Figure** below). The air near the ground becomes very warm and humid. This is true in some locations in late afternoon or early evening in spring and summer. The warm air rises rapidly, which creates strong updrafts. When the rising air cools, its water vapor condenses. The updrafts create tall cumulonimbus clouds. Winds blow the cloud top sideways. This makes the well-known anvil shape of a cloud known as a thunderhead (**Figure** below). Water droplets and ice fly up through the cloud. When these droplets get heavy enough, they fall. This starts a downdraft. A convection cell develops within the cloud. A mature thunderstorm produces gusty winds, lightning, heavy rain, and hail.



A thunderhead is a cumulonimbus cloud.



Formation and disappearance of a thunderstorm.

Lightning and Thunder

During a thunderstorm, some parts of a thunderhead become negatively charged. Other parts become positively charged. The difference in charge creates lightning. **Lightning** (**Figure** below) is a huge release of electricity. Lightning can jump between oppositely charged parts of the same cloud, between one cloud and another, or between a cloud and the ground. Lightning blasts the air with energy. The air heats and expands so quickly that it explodes. This creates the loud sound of **thunder**.

Do you know why you always hear the boom of thunder after you see the flash of lightning? It's because light travels faster than sound. If you count the seconds between seeing lightning and hearing thunder, you can estimate how far away the lightning was. A lapse of five seconds is equal to about a mile.

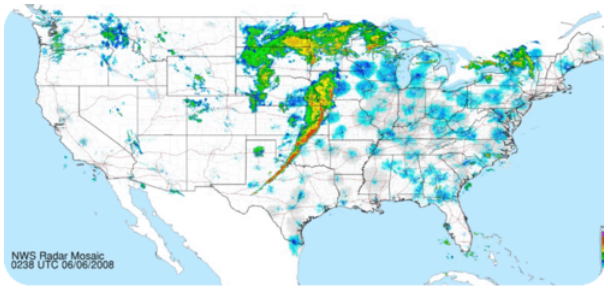


Lightning flashes during a thunderstorm

The End

The downdrafts cool the air at the base of the cloud. The air is no longer warm enough to rise. Convection shuts down and the thunderhead runs out of energy. A thunderstorm usually ends only 15 to 30 minutes after it begins. New thunderstorms may start in the same area.

Many thunderstorms form individually. During some seasons, they form in **squall lines**, long lines of thunderstorms, along a cold front. Squall lines form in spring and early summer in the Midwestern United States. This is because the maritime tropical (mT) air mass from the Gulf of Mexico meets the continental polar (cP) air mass from Canada (**Figure** below).



Cold air from the Rockies collided with warm, moist air from the Gulf of Mexico to form this squall line.

Summary

- Thunderstorms grow where ground temperatures are extremely high.
- Convection in the cloud causes raindrops or hailstones to grow. Downdrafts ultimately end convection.
- Squall lines are long lines of thunderstorms that form along a cold front.

Review

1. Why are thunderstorms so common?
2. What is the energy source that feeds a thunderstorm?
3. What two atmospheric processes lead to the formation of the anvil-shaped clouds?
4. What causes a thunderstorm to end?

Explore More

Use the resource below to answer the questions that follow.



1. What causes thunderstorms to develop?
2. What determines the severity of the storm?
3. What causes the air to rise?
4. What causes the air mass to cool? What happens to this rising cooler air?
5. What causes lightning and thunder?

This page titled 11.9: Thunderstorms is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.10: Tornadoes



Where do you go to see a tornado? Tornado Alley!

Tornadoes are deadly serious. The deadliest in recent years killed 158 people in Joplin, Missouri in 2011. More than 550 people died in the United States from tornadoes that year. The deadliest tornado on record killed 629 people in 1926. This "tri-state" tornado raced across Missouri, Illinois, and Indiana.

Tornadoes

Severe thunderstorms have a lot of energy and strong winds. This allows them to produce tornadoes. A **tornado** (**Figure** below) is a funnel-shaped cloud of strong whirling winds. The funnel moves along the ground, destroying everything in its path. As it moves, it loses energy. Before this happens, it may have gone up to 25 kilometers (16 miles). Fortunately, tornadoes are narrow. They may be only 150 meters (500 feet) wide. Tornadoes are also called twisters.



Tornadoes are small but mighty storms.

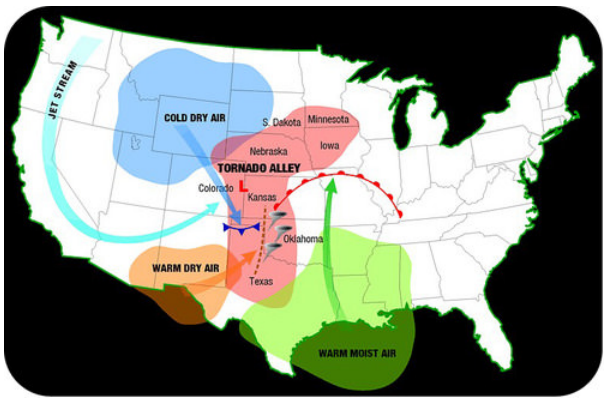
Classifying Tornadoes

The winds of a tornado can reach very high speeds. The faster the winds blow, the greater the damage they cause. Wind speed and damage are used to classify tornadoes (**Table** below).

F-Scale Rating	Wind Speed (kilometers per hour)	Wind Speed (miles per hour)	Damage
F0	64-116	40-72	Light - tree branches fall and chimneys may collapse
F1	117-180	73-112	Moderate - mobile homes, autos pushed aside
F2	181-253	113-157	Considerable - roofs torn off houses, large trees uprooted
F3	254-332	158-206	Severe - houses torn apart, trees uprooted, cars lifted
F4	333-419	207-260	Devastating - houses leveled, cars thrown
F5	420-512	261-318	Incredible - structures fly, cars become missiles
F6	>512	>318	Maximum tornado wind speed

Tornado Alley

Look at the map below (**Figure** below). It shows where the greatest number of tornadoes occur in the U.S. Tornadoes can happen almost anywhere in the U.S., but only this area is called "Tornado Alley." Why do so many tornadoes occur here? This is where warm air masses from the south run into cold air masses from the north.



Tornadoes are most common in the central part of the U.S.

Damage

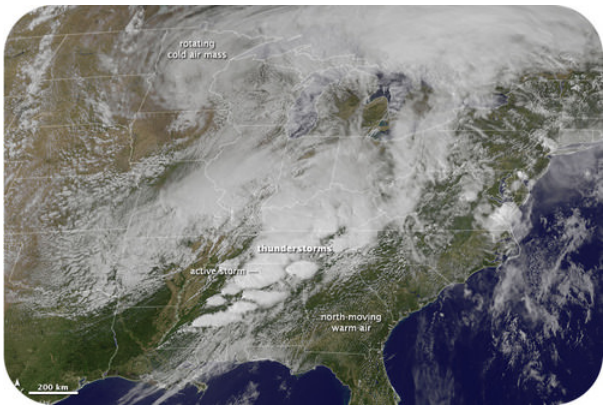
A tornado strikes only a small area, but it can still destroy everything in its path. Most injuries and deaths from tornadoes are caused by flying debris (**Figure** below). In the United States, an average of 90 people are killed by tornadoes each year. The most violent two percent of tornadoes account for 70% of the deaths by tornadoes.



Tornado damage that occurred in the City of Murfreesboro, TN when it was struck by an F-4 tornado.

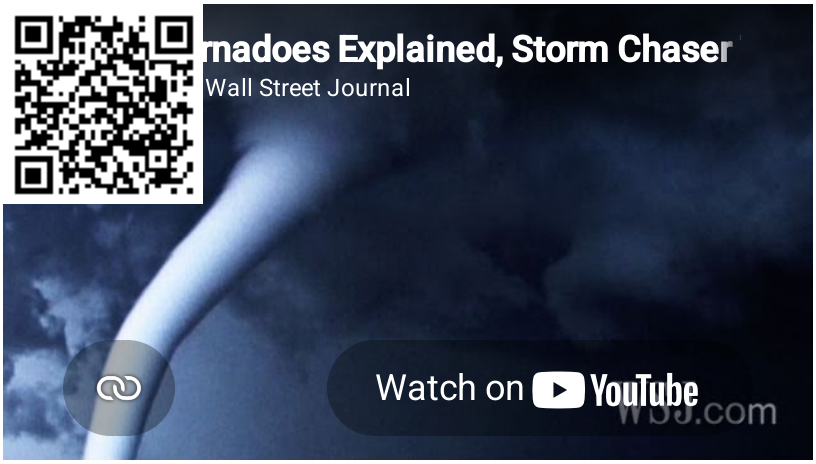
April 2011

Late April 2011 saw the deadliest set of tornadoes in more than 25 years. There were more than 150 tornadoes reported throughout one day! Severe thunderstorms came about when two very different air masses met. A warm moist air mass blew north from the Atlantic Ocean and Gulf of Mexico (mT). It rammed into a cold polar air mass (cP) that the was sitting over the region. In addition, the jet stream was blowing strongly in from the west (**Figure** below).



April 27-28, 2011. The cold air mass is shown by the mostly continuous clouds. The warm air mass is indicated by small low clouds. Thunderstorms are indicated by bright white patches.

Everyone in the region was told that tornadoes were possible. But it's impossible to know exactly where and when a tornado will touch down. The path it will take is unknown, because tornado movement is not very predictable.



Summary

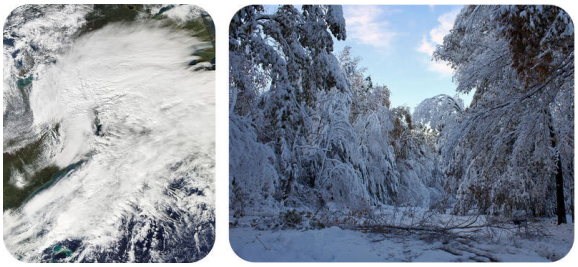
- A tornado is a whirling funnel of air extending down from a cumulonimbus cloud.
- The Fujita scale measures tornado intensity based on wind speed and damage.
- Tornadoes can only be predicted over a wide region.

Review

1. What causes the tornadoes of Tornado Alley?
2. Draw a diagram showing why tornadoes strike the middle of the U.S.
3. What circumstances led to all the tornadoes in April 2011?

This page titled 11.10: Tornadoes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.11: Cyclones



Did you go out on Halloween in 2011?

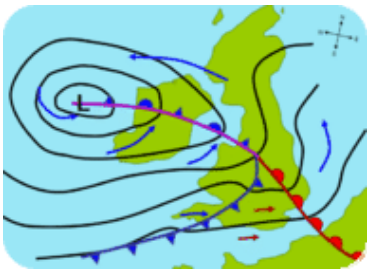
If you did, you probably don't live in the northeastern United States. In much of the region, Halloween was postponed in 2011. A large and early nor'easter struck the area. The massive storm dropped as much as 32 inches of snow. It caused over three million people to lose power. In all, 39 people died.

Mid-Latitude Cyclones

Cyclones can be the most intense storms on Earth. A **cyclone** is a system of winds that rotate around a low pressure center. The swirling air rises and cools. This creates clouds and precipitation.

Mid-latitude cyclones form at the polar front. Two very different air masses blow past each other in opposite directions. The Coriolis effect causes winds to strike the polar front at an angle. Warm and cold fronts form next to each other.

Most winter storms in the middle latitudes, including most of the United States and Europe, are caused by mid-latitude cyclones (**Figure** below).



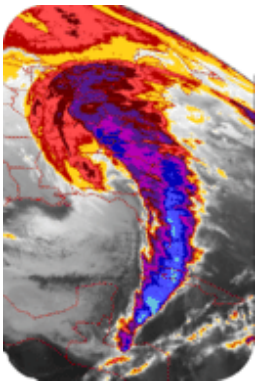
A hypothetical mid-latitude cyclone affecting the United Kingdom. The arrows point the wind direction and its relative temperature; L is the low pressure area. Notice the warm, cold, and occluded fronts.

The warm air at the cold front rises and creates a low pressure cell. Winds rush into the low pressure. This creates a rising column of air. The air twists, rotating counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. Since the rising air is moist, rain or snow falls.

Mid-latitude cyclones form in winter in the mid-latitudes. The storms move eastward with the westerly winds. These two- to five-day storms can reach 1,000 to 2,500 km (625 to 1,600 miles) in diameter. They can produce winds up to 125 km (75 miles) per hour.

Nor'easters

Mid-latitude cyclones are especially fierce in the mid-Atlantic and New England states. They are called **nor’easters** because they come from the northeast. About 30 nor’easters strike the region each year (**Figure** below).



The 1993 “Storm of the Century” was a nor’easter that covered the entire eastern seaboard of the United States.

Summary

- A cyclone is a system of winds rotating around an area of low pressure.
- A mid-latitude cyclone forms at the polar front. This occurs when the temperature difference between air masses is very large.
- Nor'easters are mid-latitude cyclones that come from the northeast.

Review

1. What is a cyclone?
2. What are the motions of air in a mid-latitude cyclone?
3. What is a nor'easter?

This page titled 11.11: Cyclones is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.12: Hurricanes

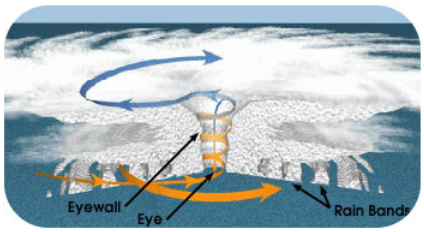


Ever been to The Big Easy?

New Orleans, Louisiana, is a city unlike any other. The city is known for its Cajun food, jazz music, and full out celebration of Mardi Gras. Residents love the city with a great intensity. Yet, many people who evacuated before Hurricane Katrina have not returned. The population is nearly 30% lower than it was in August 2005. Many sections of the city have still not recovered.

Hurricanes

Tornadoes may also come from hurricanes. A **hurricane** (**Figure** below) is an enormous storm with high winds and heavy rains. Hurricanes may be hundreds of kilometers wide. They may travel for thousands of kilometers. The storm's wind speeds may be greater than 251 kilometers (156 miles) per hour. Hurricanes develop from tropical cyclones. Hurricanes are called typhoons in the Pacific.



A cross-sectional view of a hurricane.

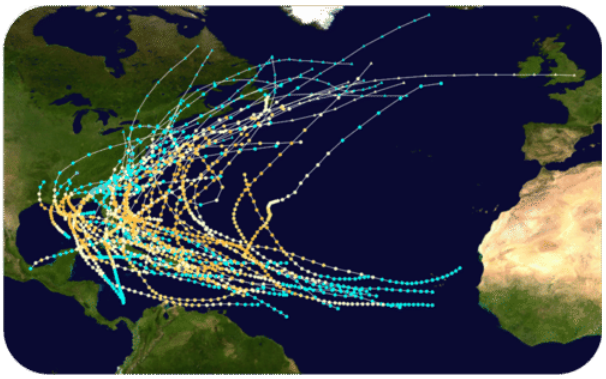
Hurricane Formation

Hurricanes are cyclones. Since they form in the tropics, they are called tropical cyclones. These storms form over very warm ocean water in summer and autumn. The temperature of the sea surface must be 28°C (82°F) or higher. The air above the water warms and rises. This forms a low pressure cell. The air begins to rotate around the low pressure cell. Water vapor condenses. If conditions are right, the storm will build into a hurricane in two to three days.

Hurricanes are huge and produce high winds. Rainfall can be as high as 2.5 cm (1") per hour. The total rainfall can be 20 billion metric tons daily. The enormous amounts of energy released could equal the total annual electrical power consumption of the United States. That's from just one storm. Hurricanes can also generate tornadoes.

Hurricanes move with the prevailing winds. In the Northern Hemisphere, they originate in the trade winds and are blown to the west. When they reach the westerlies, they switch direction. So they travel toward the north or northeast. You can look at a map of hurricane tracks to see this happen (**Figure** below). Hurricanes may cover 800 km (500 miles) in one day.

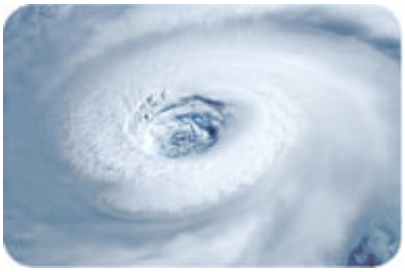
CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



Track map of all hurricanes that have achieved Category 3 intensity in the Atlantic basin, without reaching higher intensities. The points show the location of the storm at 6-hour intervals. The colour represents the storm's maximum sustained wind speeds as classified in the Saffir-Simpson Hurricane Scale, and the shape of the data points represent the nature of the storm (see source link).

The Eye of a Hurricane

At the center of a hurricane is a small area where the air is calm and clear. This is called the eye of the hurricane (**Figure** below). The eye forms at the low-pressure center of the hurricane. Air in the eye rises upward.



The eye of this hurricane is easy to see from space.

The End

Since hot water gives a hurricane its energy, the storm will grow stronger as long as it stays over the warm ocean. If it goes ashore or moves over cooler water, it is cut off from the hot water energy. This causes the storm to lose strength and slowly fade away.

Hurricanes typically last for five to ten days. The winds push them until they are over cooler water or land. When a hurricane disintegrates, it is replaced with intense rains and tornadoes.

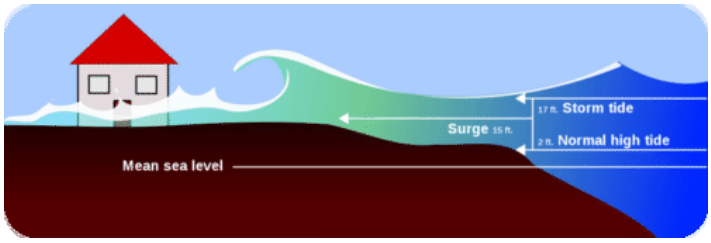
Classifying Hurricanes

Like tornadoes, hurricanes are classified on the basis of wind speed and damage (**Table** below).

Category	Wind Speed (kilometers per hour)	Wind Speed (miles per hour)	Damage
1 (weak)	119-153	74-95	Above normal; no real damage to structures
2 (moderate)	154-177	96-110	Some roofing, door, and window damage; considerable damage to vegetation, mobile homes, and piers
3 (strong)	178-209	111-130	Some buildings damaged; mobile homes destroyed
4 (very strong)	210-251	131-156	Complete roof failure on small residences; major erosion of beach areas; major damage to lower floors of structures near shore
5 (devastating)	>251	>156	Complete roof failure on many residences and industrial buildings; some complete building failure

Damage

So much rain falling so fast causes some of the damage from a hurricane. But a lot of the damage is caused by storm surge. **Storm surge** is very high water located in the low pressure eye of the hurricane. The very low pressure of the eye allows the water level to rise above normal sea level. Storm surge can cause flooding when it reaches land (**Figure** below). High winds do a great deal of damage in hurricanes. High winds can also create very big waves. If the large waves are atop a storm surge, the high water can flood the shore. If the storm happens to occur at high tide, the water will rise even higher.



Storm surge can cause serious flooding.

There are about 100 hurricanes around the world each year. There are many smaller tropical storms and tropical depressions. As people develop coastal regions, property damage from storms continues to rise. However, scientists are becoming better at predicting storms. Fatalities are decreasing. The one major exception was Hurricane Katrina.

Hurricane Katrina

The 2005 Atlantic hurricane season was unprecedented. The hurricane season was longer than normal, and there were many more storms. The damage from the storms was the greatest in history. The total cost was estimated at more than $128 billion. There were more than 2,280 deaths.

Hurricane Katrina was both the most destructive hurricane and the most deadly. When the levees that protect the city broke, much of the city was flooded (**Figure** below). The hurricane was the costliest natural disaster in U.S. history. Nearly 2,000 people died, and damage was estimated at over $80 billion.



Flooding in New Orleans after Hurricane Katrina caused the levees to break. Water poured into the city.



Further Reading

Tornadoes

Cyclones

Summary

- Hurricanes are cyclones that form in tropical latitudes. They are called tropical cyclones.
- Hurricanes have high winds that blow around a low pressure zone. In the low pressure zones, air moves upward. This is the eye of the hurricane.
- The damage hurricanes cause is due largely to storm surge. High wind speeds and rain also cause damage.
- Hurricane Katrina was so damaging because the levees that protected New Orleans broke.

Review

1. What is a hurricane? What is the eye of a hurricane?
2. How does a hurricane form?
3. Where does the storm get its energy?
4. What is storm surge?
5. Under what circumstances does a hurricane die?
6. Why was Hurricane Katrina so damaging?

Explore More

Use the resources below to answer the questions that follow.



1. What are hurricanes?
2. Where do most hurricanes begin to form?
3. How does a hurricane start and build so large?
4. What direction do hurricanes spin?
5. What is the eye?
6. What are typhoons and cyclones?

This page titled 11.12: Hurricanes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.13: Blizzards



Where are the snowiest cities in the United States?

Eight of the top ten cities with the highest average snowfall are in upstate New York. This region gets so much snow because it is on the leeward side of the Great Lakes. The area receives lake-effect snow. If you plan to visit in winter, strap on your snow shoes!

Winter Storms

Like hurricanes, winter storms develop from cyclones. But in the case of winter storms, the cyclones form at higher latitudes. In North America, cyclones often form when the jet stream dips south in the winter. This lets dry polar air pour south. At the same time, warm moist air from the Gulf of Mexico flows north. When the two air masses meet, the differences in temperature and pressure create strong winds and heavy precipitation. Blizzards and lake-effect snow storms are two types of winter storms that occur in the U.S.

Blizzards

A **blizzard** (**Figure** below) is a snow storm that has high winds. To be called a blizzard, a storm must have winds greater than 56 kilometers (35 miles) per hour and visibility of ¼ mile or less because of wind-blown snow.



Blizzard in Washington, D.C. Blizzards are unusual in Washington, D.C. Do they ever occur where you live?

Blizzards are dangerous storms. The wind may blow the snow into deep drifts. Along with the poor visibility, the snow drifts make driving risky. The wind also makes cold temperatures more dangerous. The greater the wind speed, the higher the windchill. **Windchill** is what the temperature feels like when the wind is taken into account. It depends on air temperature and wind speed (**Figure** below). Higher windchill will cause a person to suffer frostbite and other harmful effects of cold sooner than if the wind isn't blowing.

NWS Windchill Chart

Wind (mph) \ Temperature (°F)	Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5		36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10		34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15		32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20		30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25		29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30		28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35		28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40		27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45		26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50		26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55		25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60		25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times: 30 minutes, 10 minutes, 5 minutes

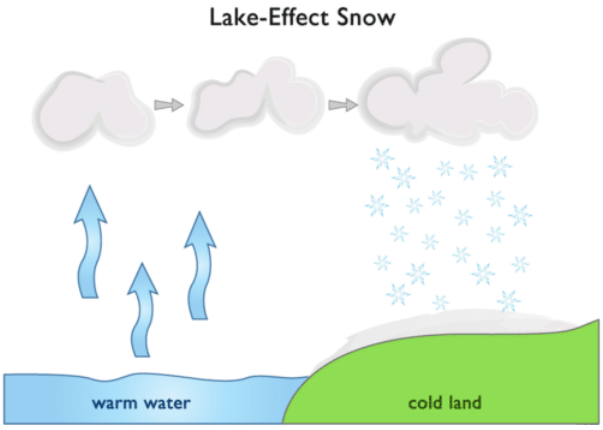
Wind Chill (°F) = $35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$

Where, T= Air Temperature (°F) V= Wind Speed (mph) Effective 11/01/01

Windchill temperatures may be very low in blizzards because of the high wind speeds. How long does it take for frostbite to occur when the air temperature is 0° F and the wind speed is 55 miles per hour?

Lake-Effect Snow

Some places receive very heavy snowfall just about every winter. If they are near a lake, they may be getting **lake-effect snow**. The image below shows how lake-effect snow occurs (**Figure** below). Winter winds pick up moisture as they pass over the relatively warm waters of a large lake. When the winds reach the cold land on the other side, the air cools. Since there was so much moisture in the air, it can drop a lot of snow. More than 254 centimeters (100 inches) of snow may fall in a single lake-effect storm!



Lake-effect snow falls on the east side of lakes in North America. These snows are heaviest on the east sides of the Great Lakes.

Summary

- Blizzards are often part of a mid-latitude cyclone. The jet stream brings cold air into contact with warm moist air.
- The difference in pressure between the air masses brings about strong winds.
- Cold polar air absorbs moisture as it travels over the Great Lakes. The air cools when it goes back over land and then dumps snow. This creates lake-effect snow.

Review

1. What is the difference between a snowstorm and a blizzard?
2. Under what circumstances does a blizzard form?
3. What two conditions cause the largest blizzards?
4. What causes lake-effect snow?

This page titled 11.13: Blizzards is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.14: Heat Waves and Droughts



Is the current drought like the Dust Bowl?

The worst heat wave in U.S. history came in 1936. The already struggling Midwest was hit hard by extreme temperatures and drought. Soil lost moisture so it blew away. Crops were destroyed, and more than 5,000 people died. The Western US is currently suffering with drought with different, but severe, consequences.

Heat Waves

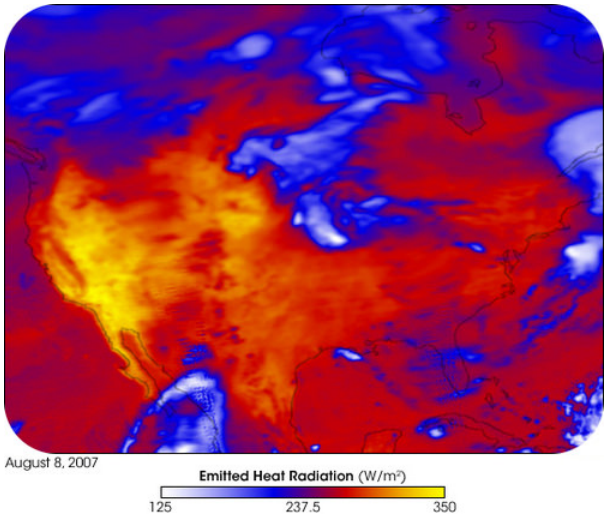
A **heat wave** is different depending on its location. A region has a heat wave if it has more than five consecutive days of temperatures that are more than 9°F (5°C) above average. A heat wave in Portland, Oregon might be just an average warm week in Phoenix, Arizona.

Heat waves have increased in frequency and duration in recent years. The summer 2011 North American heat wave brought record temperatures across the Midwestern and Eastern United States. Many states and localities broke records for temperature and for the most days above 100°F.

Causes

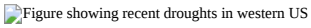
A high pressure cell sitting over a region with no movement is the likely cause of a heat wave.

What do you think caused the heat wave in the image below (**Figure** below)? A high pressure zone kept the jet stream farther north than normal for August.



A heat wave over the United States as indicated by heat radiated from the ground. The bright yellow areas are the hottest, and the blue and white are coolest.

Droughts


Figure showing recent droughts in western US

Drought has many consequences. Recent droughts in the western US have weakened trees, making them vulnerable to the spread of beetles, which kill them. Entire forests are now brown with dead trees. When trees and brush are dry, wildfires spread more easily. California and other western states have experienced devastating wildfires in recent years.

Droughts also depend on what is normal for a region. A region that gets significantly less precipitation than normal for an extended period of time is in drought. The Southern United States is experiencing an ongoing and prolonged drought.

Drought has many consequences. When soil loses moisture it may blow away. This happened during the Dust Bowl in the United States in the 1930s. Forests may be lost, dust storms may become common, and wildlife are disturbed. Wildfires become much more common during times of drought.

Summary

- A heat wave or a drought is defined as conditions different from normal in a region.
- A heat wave is caused when a warm high-pressure cell sits over a region.
- Drought may have extremely severe consequences. The severity depends on its duration and intensity.

Review

1. How is a heat wave defined?
2. How is a drought defined?
3. How does the position of the jet stream cause a heat wave?

Explore More

Use the resources below to answer the questions that follow.



1. What will happen if the world's average temperature increases by 3 degrees?
2. What will become the norm in Europe and the Mediterranean?
3. What happened in the summer of 2003?
4. How many people died in Europe that summer?
5. Why was this catastrophe, caused or exacerbated by global warming, unique?

Tags recommended by the template: article:topic

This page titled 11.14: Heat Waves and Droughts is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.15: Weather- Challenge 2

1. Electrical charge separations in cumulonimbus clouds generate electric potentials, which are released as electricity in the form of ___.

lightning

2. A thunderstorm will end when ___.

downdrafts cool the base of the cloud and shut down convection

3. Thunder arises from ___.

rapidly expanding air heated explosively by lightning

4. When a warm air mass rises at a cold front, a ___ pressure cell is created.

low

5. Mid-latitude cyclones form at the ___ when the temperature difference between two air masses is ___.

polar front; large

6. Hurricanes get their energy from the ___ water they form and travel over.

warm

7. Hurricane Katrina caused so much damage to New Orleans because ___.

it broke the levees that protected the city

8. The Saffir-Simpson Scale measures hurricane intensity, ranging from ___.

1-5, with 1 being the weakest

9. Snow storms, sleet, and cold winds occur in ___.

blizzards

10. Blizzards are most common in winter when the jet stream has moved ___.

south

11. Buffalo and Rochester, New York, are the snowiest metropolitan areas in the U.S. because they are downwind from ___.

The Great Lakes

12. A ___ happens when a region gets significantly less precipitation than normal for an extended period of time.

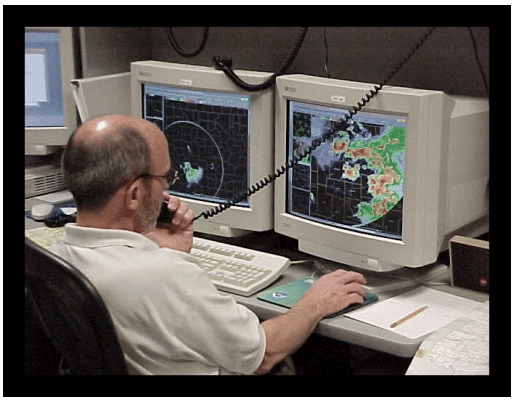
drought

13. A period of excessively hot weather in a particular region for a prolonged period of time is a ___.

heat wave

This page titled 11.15: Weather- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.16: Collecting Weather Data



What does a meteorologist need before he or she can forecast the weather?

Data! A meteorologist needs data about the current conditions. There are many types of instruments available for collecting that data. According to the World Meteorological Organization (WMO), a 5-day weather forecast today is as reliable as a 2-day forecast was 20 years ago.

Predicting the Weather

Weather is very difficult to predict. That's because it's very complex, and many factors are involved. Slight changes in even one factor can cause a big change in the weather. Still, certain "rules of thumb" generally apply. These "rules" help meteorologists forecast the weather. For example, low pressure is likely to bring stormy weather. So if a center of low pressure is moving your way, you can expect a storm.

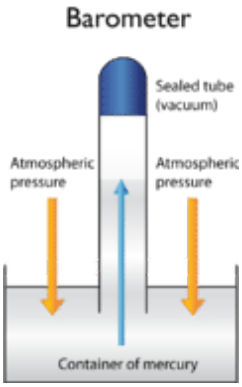
People often complain when the weather forecast is wrong. Weather forecasts today, however, are much more accurate than they were just 20 years ago. Scientists who study and forecast the weather are called meteorologists. How do they predict the weather?

The first thing they need is data. Their data comes from various instruments.

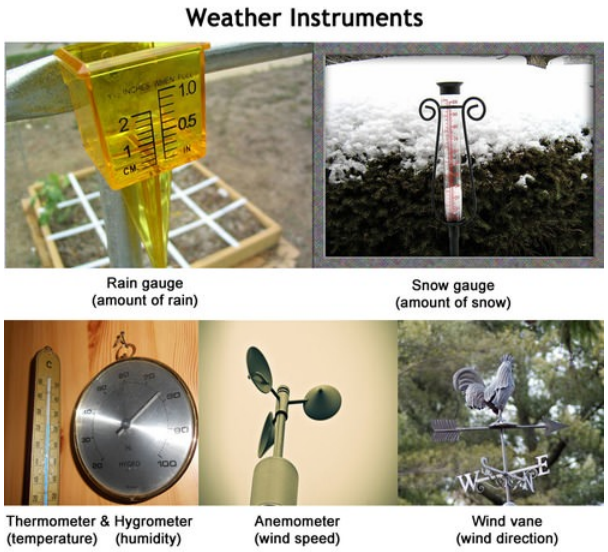
Weather Instruments

Weather instruments measure weather conditions. One of the most important conditions is air pressure, which is measured with a **barometer** (**Figure** below). There are also a number of other commonly used weather instruments (**Figure** below):

- A **thermometer** measures temperature.
- An **anemometer** measures wind speed.
- A **rain gauge** measures the amount of rain.
- A **hygrometer** measures humidity.
- A **wind vane** shows wind direction.
- A **snow gauge** measures the amount of snow.



The greater the air pressure outside the tube, the higher the mercury rises inside the tube. Mercury can rise in the tube, because there's no air pressing down on it.



Some of the most commonly used weather instruments.

Collecting Data

Weather instruments collect data from all over the world at thousands of weather stations. Many are on land, but some float in the oceans on buoys. There's probably at least one weather station near you.

Other weather devices are needed to collect weather data in the atmosphere. They include weather balloons, satellites, and **radar** (**Figure** below).



Weather stations collect data on land and sea. Weather balloons, satellites, and radar collect data in the atmosphere.

Weather stations contain many instruments for measuring weather conditions. The **weather balloon** (**Figure** above) will rise into the atmosphere until it bursts. As it rises, it will gather weather data and send it to the surface. Many **weather satellites** orbit Earth. They constantly collect and transmit weather data from high above the surface. A radar device sends out radio waves in all directions. The waves bounce off water in the atmosphere and then return to the sender. The radar data shows where precipitation is falling. It's raining in the orange-shaded area shown above.

Using Computers

What do meteorologists do with all that weather data? They use it in weather models. The models analyze the data and predict the weather. The models require computers. That's because so many measurements and calculations are involved.

Summary

- Various instruments measure weather conditions: thermometers measure air temperature, and barometers measure air pressure.
- Satellites monitor weather from above.
- Radar is used to monitor precipitation.

Review

1. What can a barometer tell you about the coming weather?
2. Why is weather prediction better than it used to be?
3. What is the purpose of a weather satellite?

Explore More

Use the resource below to answer the questions that follow.



1. Why is weather difficult to predict?
2. What is the Afternoon Constellation? What does it do?
3. What are the three important characteristics of clouds?
4. What are the basic shapes of clouds?
5. What is fog?
6. Why is it important to study clouds?
7. What will Cloudsat do?

This page titled 11.16: Collecting Weather Data is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.17: Predicting Weather



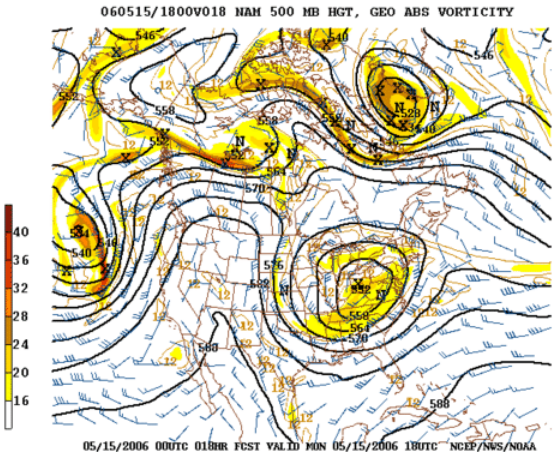
Does a picnic bring rain?

Weather forecasts are better than they ever have been. According to the World Meteorological Organization (WMO), a 5-day weather forecast today is as reliable as a 2-day forecast was 20 years ago. Now there's no excuse to be rained out on a picnic!

Numerical Weather Prediction

The most accurate weather forecasts are made by advanced computers, with analysis and interpretation added by experienced meteorologists. These computers have up-to-date mathematical models that can use much more data and make many more calculations than would ever be possible by scientists working with just maps and calculators. Meteorologists can use these results to give much more accurate weather forecasts and climate predictions.

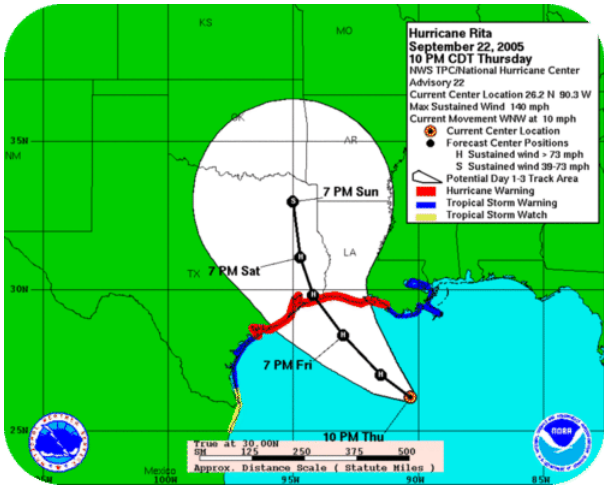
In Numerical Weather Prediction (NWP), atmospheric data from many sources are plugged into supercomputers running complex mathematical models (**Figure** below). The models then calculate what will happen over time at various altitudes for a grid of evenly spaced locations. The grid points are usually between 10 and 200 kilometers apart. Using the results calculated by the model, the program projects weather further into the future. It then uses these results to project the weather still further into the future, as far as the meteorologists want to go. Once a forecast is made, it is broadcast by satellites to more than 1,000 sites around the world.



A weather forecast using numerical weather prediction.

NWP produces the most accurate weather forecasts, but as anyone knows, even the best forecasts are not always right.

Weather prediction is extremely valuable for reducing property damage and even fatalities. If the proposed track of a hurricane can be predicted, people can try to secure their property and then evacuate (**Figure** below).



By predicting Hurricane Rita's path, it is likely that lives were saved.

Further Reading

Collecting Weather Data

Summary

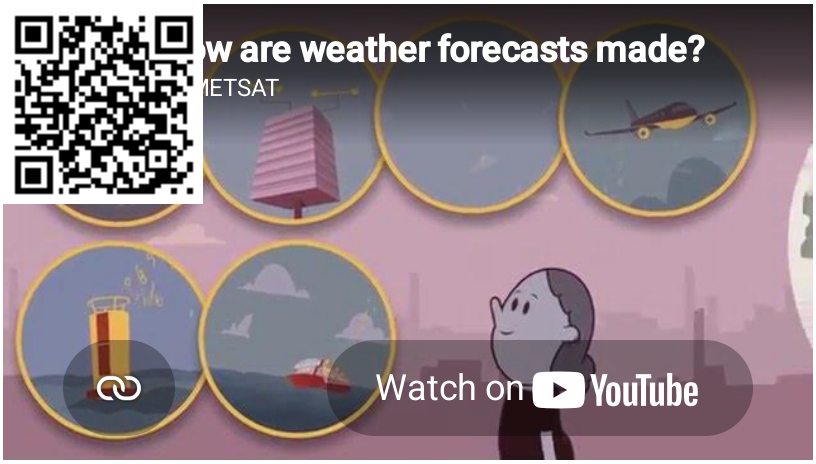
- Meteorologists use computers to crank data through mathematical models to forecast the weather.
- Numerical weather prediction calculates what will happen to conditions horizontally and vertically over an area.
- Weather forecasts can go further into the future than ever.

Review

1. What is numerical weather prediction?
2. Even with numerical weather prediction, meteorologists have a difficult time predicting the path of a hurricane more than a day or two into the future. Why?
3. One popular online weather prediction site goes 10 days out and another goes 15 days out. Why the discrepancy?

Explore More

Use this resource to answer the questions that follow.



1. Explain how scientists monitor weather above Earth.
2. What is numerical weather prediction?
3. What is the purpose of the Meteor Satellite?

This page titled 11.17: Predicting Weather is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.18: Weather Maps

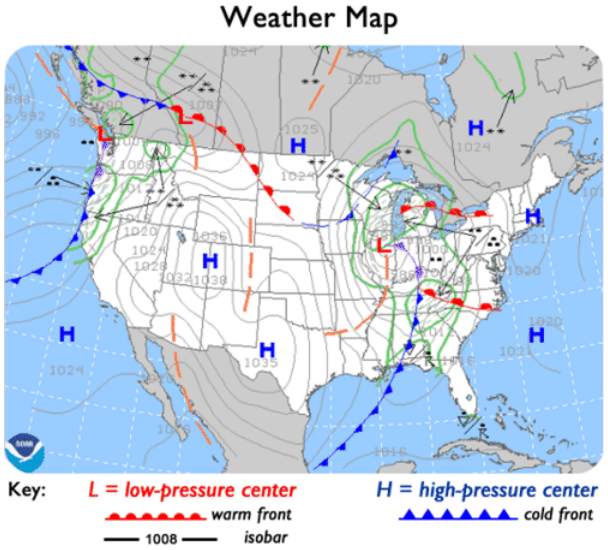


What can a weather map tell you about the weather?

A lot! A weather map indicates all sorts of things to let you know the forecast. It also may have some cute graphics associated with it.

Weather Maps

You may have seen weather maps like the one pictured below (**Figure** below). A **weather map** shows weather conditions for a certain area. The map may show the actual weather on a given day. It may show the predicted weather for some time in the future. Some weather maps show many weather conditions. Others show a single condition.



This weather map shows air pressure contours. Which state has the lowest air pressure shown on the map?

Air Pressure Maps

The weather map pictured above (**Figure** above) shows air pressure. The lines on the map connect places that have the same air pressure. Air pressure is measured in a unit called the millibar. **Isobars** are the lines that connect the points with the same air pressure. The map also shows low- and high-pressure centers and fronts. Find the cold front on the map. This cold front is likely to move toward the northeast over the next couple of days. How could you use this information to predict what the weather will be on the East Coast?

Other Weather Maps

Instead of air pressure, weather maps may show other weather conditions. For example, a temperature map might show the high and low temperatures of major cities. The map may have **isotherms**, lines that connect places with the same temperature.

Summary

- Weather maps graphically depict weather conditions.
- Isobars are lines of constant pressure.
- Isobars indicate pressure cells.

Review

1. What are the gray lines on the weather map pictured above?
2. How are high- and low-pressure centers indicated on a weather map?
3. What do the blue and red hatched lines indicate on the map?

Tags recommended by the template: article:topic

This page titled 11.18: Weather Maps is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

11.19: Weather- Challenge 3

1. A ___ measures air pressure.

barometer

2. A ___ measures temperature.

thermometer

3. One reason that weather predictions are more accurate now than they were 20 years ago is that ___.

meteorologists can now collect much more and far better data

4. ___ models are used to predict weather.

Mathematical

5. In the process of ___, a supercomputer takes atmospheric data and calculates what will happen to weather conditions horizontally and vertically.

Numerical Weather Prediction (NWP)

6. Lines of equal temperature that connect places on weather maps are called ___.

isotherms

7. Lines joining places of equal air pressure on a weather map are known as ___.

isobars

8. Isotachs can be used to locate ___.

jet streams

This page titled 11.19: Weather- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

12: Climate

12.1: Weather vs. Climate
12.2: Effect of Latitude on Climate
12.3: Effect of Atmospheric Circulation on Climate
12.4: Effect of Continental Position on Climate
12.5: Effect of Altitude and Mountains on Climate
12.6: Climate- Challenge 1
12.7: Climate Zones and Biomes
12.8: Tropical Moist Climates
12.9: Dry Climates
12.10: Temperate Climates
12.11: Continental Climates
12.12: Polar Climates
12.13: Climate- Challenge 2
12.14: Climate Change in Earth History
12.15: Short-Term Climate Change
12.16: Carbon Cycle and Climate
12.17: Global Warming
12.18: Causes and Effects of Global Warming
12.19: Impact of Continued Global Warming
12.20: Reducing Greenhouse Gas Pollution
12.21: Climate- Challenge 3

This page titled 12: Climate is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.1: Weather vs. Climate



Where in Hawaii do you want to go?

Look at a list of cities with the best climate in the United States. Hawaii is well represented. Now look at a list of cities with the worst climate in the United States. (You know where this is going, don't you?) Yes, Hawaii is also represented. Kona and Hilo are both on the Big Island. Hilo is on the windward side where the trade winds bring in moisture from the Pacific. Kona is on the leeward side, beyond the high volcanic mountains. This city lies within the rain shadow. Guess which city is more popular with tourists?

What is Climate?

Almost anything can happen with the weather. Climate, however, is more predictable. **Climate** is the long-term average of weather in a particular spot. Good climate is why we choose to vacation in Hawaii in February (usually on the leeward side). Of course, the weather is not guaranteed to be good! A location's climate considers the same characteristics as its weather. These are its air temperature, humidity, wind speed and direction, and the type, quantity, and frequency of precipitation. For climate, these things are averaged over time.

During the mid- to late-twentieth century, California received an enormous influx of new residents. Many of these people came from the northeastern United States. They were sick of the cold, snow, and rain. Southern California, especially near the coast, has a nearly perfect climate. The average lows and highs in San Diego year round are in the 50s, 60s, and 70s (**Figure** below).



A bike path along Mission Bay in San Diego, California.

The climate for a particular place is steady. Changes occur only very slowly. Climate is determined by many factors, including the angle of the Sun, the likelihood of cloud cover, and the air pressure. All of these factors are related to the amount of solar energy that hits that location over time.

The climate of a region depends on its position relative to many things. These factors are described in the next sections.

Summary

- Climate is the long-term average of weather.
- Climate changes very slowly.
- Climate depends on a number of factors such as air temperature, humidity, wind speed and direction, and the type, quantity, and frequency of precipitation.

Review

1. What is climate?
2. Why did California receive a large influx of new residents?
3. How does climate change?
4. What factors determine climate?

Explore More

Use the resource below to answer the questions that follow.



1. What is the difference between weather and climate?
2. Describe a temperate climate.
3. Where are arid climates found?
4. What creates a climate system?
5. What drives climate?
6. What do greenhouse gases do?
7. What are the main greenhouse gases?
8. What would Earth be like without the greenhouse effect?

This page titled 12.1: Weather vs. Climate is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.2: Effect of Latitude on Climate





Do you want to be a Snowbird?

A Snowbird is usually a person who is retired. Like a migrating bird, they go where the weather is good. A snowbird may spend summers "at home" in Michigan or New York. But they travel to Arizona or Florida to spend their winters in the Sun and warmth. What would a reverse snowbird be? A person who spent summers in the 100+ degree heat and winters in the sub-0 cold. Brrrr....

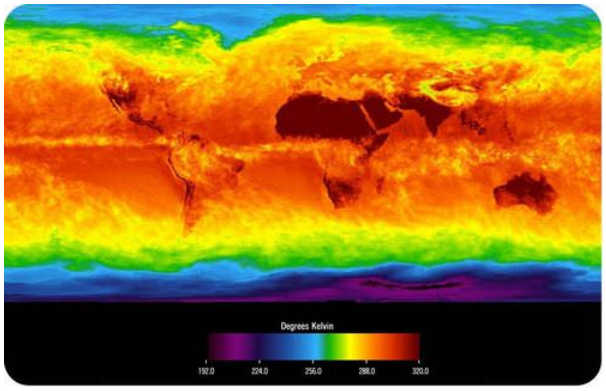
Latitude and Climate

Latitude is the distance north or south of the Equator. It's measured in degrees, from 0° to 90°. Several climate factors vary with latitude.

Latitude and Temperature

Temperature changes with latitude (**Figure** below).

- At the Equator, the Sun's rays are most direct. This is where temperatures are highest.
- At higher latitudes, the Sun's rays are less direct. The farther an area is from the Equator, the lower its temperature.
- At the poles, the Sun's rays are least direct. Much of the area is covered with ice and snow, which reflect a lot of sunlight. Temperatures are lowest here.



Temperature varies with latitude. If you look closely you can see that other factors influence temperature. Mountain ranges, for example, are cooler than they should be for their latitude.



(a) Austin, Texas; (b) Wichita, Kansas; (c) Fargo, North Dakota; (d) Manitoba, Canada.



Map of North America showing the locations of four cities that lie along the same longitude.

Austin, Texas; Wichita, Kansas; Fargo, North Dakota; and Thompson, Manitoba in Canada all roughly lie on the 97° west longitude line (**Figure** above and **Figure** above). But they run the length of the North America from 30°N in Austin, to 38°N in Wichita, to 47°N in Fargo, and to 56°N in Thompson. Other factors affect their climate, but all four cities are inland.

	July Avg. High	July Avg. Low	January Avg. High	January Avg. Low
Austin	96	74	62	41
Wichita	93	70	43	22
Fargo	82	60	18	0
Thompson	73	48	-3	-20

The table above shows the variation in high and low temperatures that are due primarily to latitude (**Table** above). Which latitude would you prefer?

Summary

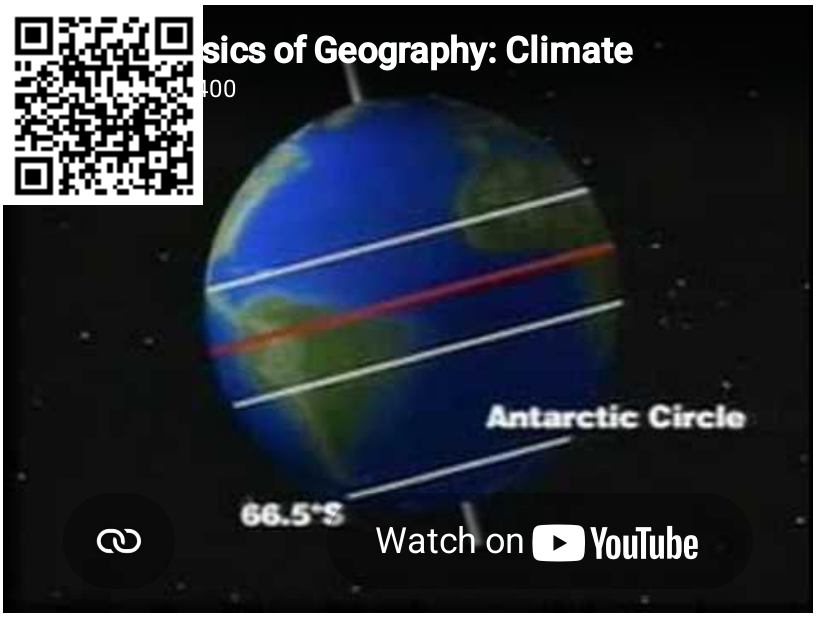
- Latitude affects the amount of solar radiation a place receives.
- The amount of solar radiation a place receives is greatest at the Equator and lessens toward the poles.
- Latitude is not the only factor that determines the temperature of a region.

Review

1. How do you explain the variation in temperature from Austin, Texas, to Thompson, Manitoba, Canada?
2. What are two reasons that solar radiation is different at different latitudes?
3. Look at the map of temperature versus latitude around the globe. Why are the bands not straight across?

Explore More

Use the resource below to answer the questions that follow.



1. What influences does the Sun have on a region's climate?
2. Does the tilt of Earth's axis of rotation influence climate?
3. What is latitude?
4. What is the Equator and what is the climate there like?
5. What is the Tropic of Cancer and the Tropic of Capricorn?
6. What is the climate of the area between the Tropic of Cancer and Tropic of Capricorn?
7. What are the middle latitudes? What is the climate like in this region generally?
8. Describe the polar regions.
9. What is elevation? How does elevation affect climate?
10. Besides the amount of precipitation a region gets, what else about precipitation affects climate?
11. How do wind and water currents affect climate?

This page titled 12.2: Effect of Latitude on Climate is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.3: Effect of Atmospheric Circulation on Climate



Would you like to go to the horse latitudes?

Imagine you're on a sailing ship that's carrying horses among other cargo. You want to go from Spain to northern South America. For a smooth ride west, you need to get the ship into the trade winds. But where the trade winds and the westerlies meet is a zone where air flows vertically downward. It's hard to get through there in a sailing ship. So your ship gets stuck. For weeks. There's no more water or food for the horses so you throw them overboard. Some people think this is where the horse latitudes got their name.

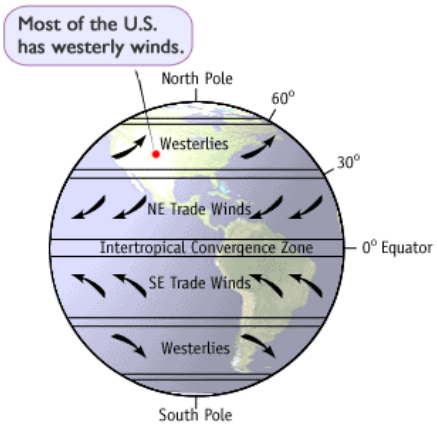
More Effects of Latitude on Climate

We saw that the amount of solar radiation an area receives depends on its latitude. The amount of solar radiation affects the temperature of a region. Latitude has other effects on climate.

Latitude and Prevailing Winds

Global air currents cause global winds. The figure below shows the direction that these winds blow (**Figure** below). Global winds are the prevailing, or usual, winds at a given latitude. The winds move air masses, which causes weather.

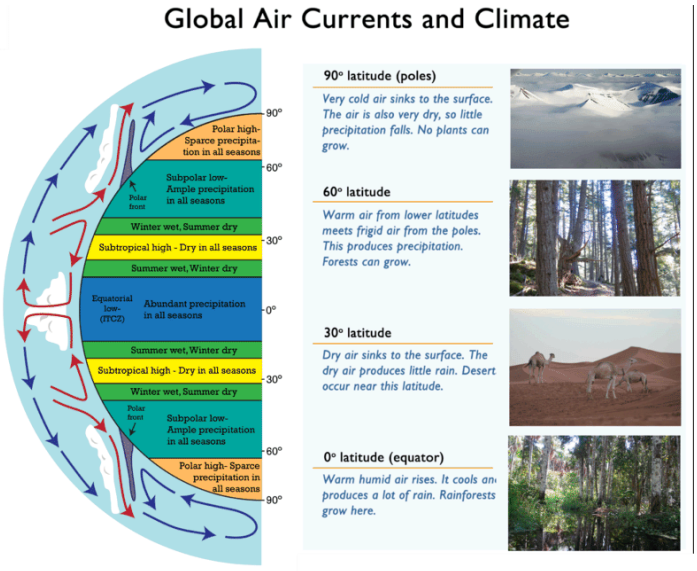
The direction of prevailing winds determines which type of air mass usually moves over an area. For example, a west wind might bring warm moist air from over an ocean. An east wind might bring cold dry air from over a mountain range. Which wind prevails has a big effect on the climate. What if the prevailing winds are westerlies? The westerlies blow from nearer the Equator to farther from the Equator. How would they affect the climate?



The usual direction of the wind where you live depends on your latitude. This determines where you are in the global wind belts.

Latitude and Precipitation

Global air currents affect precipitation. How they affect it varies with latitude (**Figure** below). Where air rises, it cools and there is precipitation. Where air sinks, it warms and causes evaporation. These patterns are part of the global wind belts.



Global air currents are shown on the left. You can see how they affect climate on the right.

"Five Factors that Affect Climate" takes a very thorough look at what creates the climate zones. The climate of a region allows certain plants to grow, creating an ecological biome.



Summary

- Prevailing winds are the result of atmospheric circulation cells. They influence the climate of a region.
- Rising and sinking air can influence the precipitation of a region.
- Atmospheric circulation cells create the general climate of a region.

Review

1. What are prevailing winds? How do they affect climate?
2. Where is there not much wind?
3. How do atmospheric circulation cells affect precipitation?

This page titled 12.3: Effect of Atmospheric Circulation on Climate is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.4: Effect of Continental Position on Climate



Is latitude making the difference in weather in these three cities?

No. These three cities are at the same latitude. They are San Francisco, California; Wichita, Kansas; and Virginia Beach, Virginia. Proximity to the ocean is important. Also important is the direction the winds are blowing at this location.

Oceans and Climate

When a place is near an ocean, the water can have a big effect on the climate.

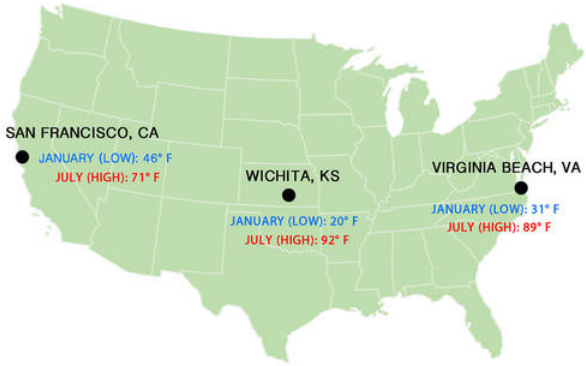
Coastal and Inland Climates

Places at the same latitude may have very different climates if one is on a coast and one is inland.

- On the coast, the climate is influenced by warm moist air from the ocean. A coastal climate is usually mild. Summers aren't too hot, and winters aren't too cold. Precipitation can be high due to the moisture in the air. This is a **maritime climate**.
- Farther inland, the climate is influenced by cold or hot air from the land. This air may be dry, because it comes from over land. An inland climate is usually more extreme. Winters may be very cold, and summers may be very hot. Precipitation can be low. This is a **continental climate**.

The Influence of the Ocean

The ocean has a big effect on climate. This is obvious when you compare the temperatures of these three cities. Each of these cities is located at 37°N latitude, within the westerly winds (**Figure** below).

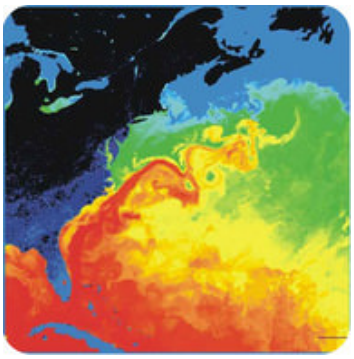


How does the ocean influence the climate of these three cities?

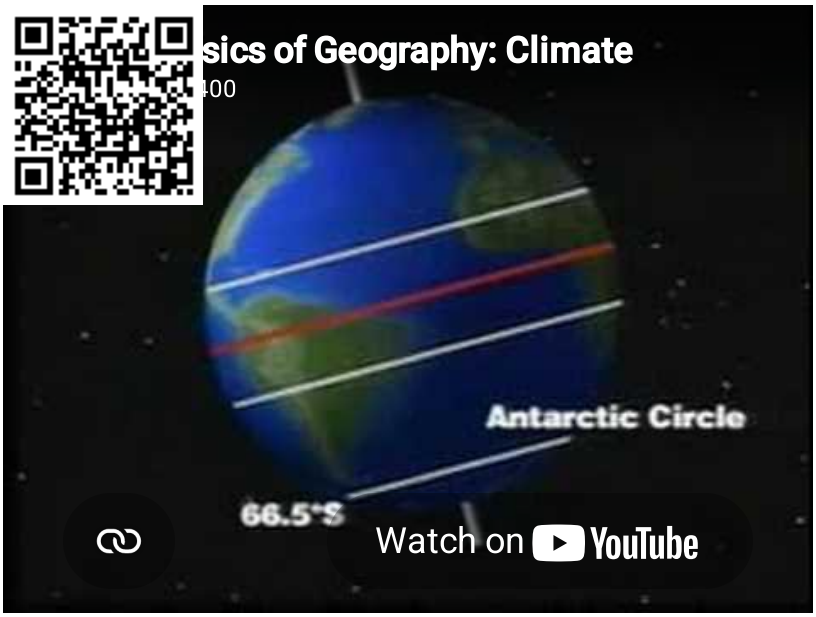
The climate of San Francisco is influenced by the Pacific Ocean. The cool California current comes from the north. Upwelling brings cold water from the deep. So the water offshore is cold. Virginia Beach is near the Atlantic Ocean. But its temperatures are more like Wichita than San Francisco. Why is the climate in Virginia Beach less influenced by the ocean than San Francisco? *Hint*: Think about the direction the winds are going at that latitude. The weather in San Francisco comes from over the Pacific Ocean. Much of the weather in Virginia comes from the continent.

Ocean Currents and Climate

Ocean currents carry warm or cold water throughout the world's oceans. They help to even out the temperatures in the oceans. This also affects the temperature of the atmosphere and the climate around the world. Currents that are near shore have a direct impact on climate. They may make the climate much colder or warmer. Examples of this are pictured below (**Figure** below).



The Gulf Stream moves warm equatorial water up the western Pacific and into northern Europe. The warm water raises temperatures in the British Isles.



Summary

- A maritime climate is influenced by a nearby ocean. A continental climate is influenced by nearby land.
- The temperature of offshore currents affect nearby land areas.
- A maritime climate is less extreme than a continental climate, because the ocean moderates temperatures.

Review

1. Describe a maritime climate. What location has a maritime climate?
2. Describe a continental climate. What location has a continental climate?
3. San Francisco and Virginia Beach are both near an ocean. Why are their climates so different?

This page titled 12.4: Effect of Continental Position on Climate is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.5: Effect of Altitude and Mountains on Climate



How much does the climate vary across Washington State?

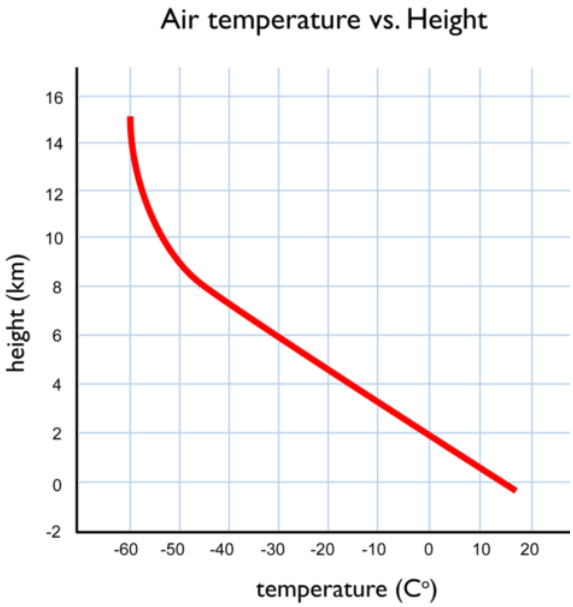
The first photo is of Olympic National Park by the Pacific Ocean. The area is wet; very, very wet. Moving eastward, you find Mt. Baker, one of the Cascades volcanoes. The climate on the mountain is very different from the climate near the ocean. It is extremely cold with abundant snowfall in winter. The third photo is of eastern Washington. Much of the land is farmed. The climate is much drier for two reasons. Can you determine what they are?

Mountains and Climate

Did you ever hike or drive up a mountain? Did you notice that it was cooler near the top? Climate is not just different on a mountain. Just having a mountain range nearby can affect the climate.

Altitude and Temperature

Air temperature falls at higher altitudes (**Figure** below). Why does this happen? Since air is less dense at higher altitudes, its molecules are spread farther apart than they are at sea level. These molecules have fewer collisions, so they produce less heat.



Air temperature drops as you go higher.

Look at the mountain pictured below (**Figure** below). The peak of Mount Kilimanjaro, Tanzania (Africa, 3° south latitude) is 6 kilometers (4 miles) above sea level. At 3°S, it's very close to the Equator. At the bottom of the mountain, the temperature is high year round. How can you tell that it's much cooler at the top?

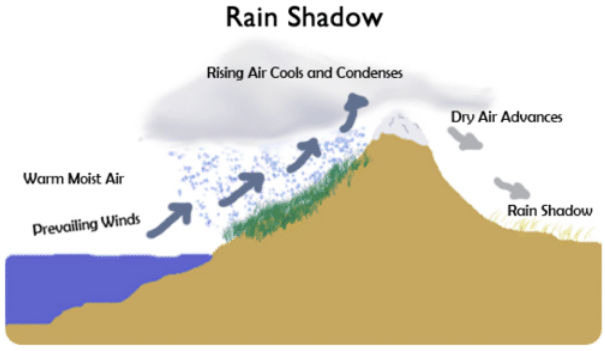
https://k12.libretexts.org/@go/page/5532



Mount Kilimanjaro has very different climates at the top and bottom.

Mountains and Precipitation

Mountains can also affect precipitation. Mountains and mountain ranges can cast a **rain shadow**. As winds rise up the windward side of a mountain range, the air cools and precipitation falls. On the other side of the range, the leeward side, the air is dry, and it sinks. So there is very little precipitation on the leeward side of a mountain range. The figure below shows how this happens (**Figure** below).



What role do prevailing winds play in a rain shadow?

Summary

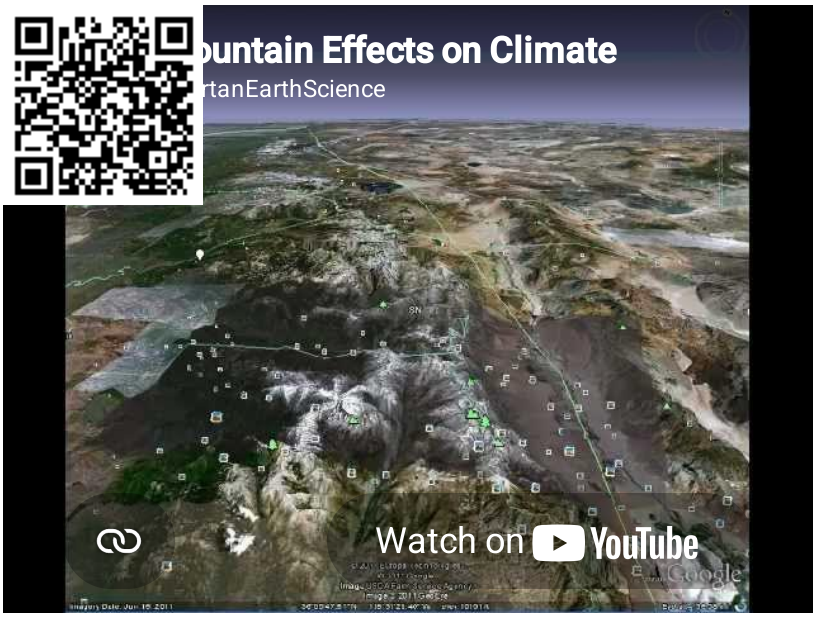
- Where air is denser, the air temperature is higher.
- Rainshadow effect occurs on the leeward side of a mountain range.
- Maritime air may become stuck on the windward side of a mountain range. For this reason it is unable to bring cooler air farther inland.

Review

1. Why does an increase in altitude cause a change in temperature?
2. What is rain shadow effect?
3. What are the two ways that a mountain range can affect climate?

Explore More

Use the resource below to answer the questions that follow.



1. What does wind do as it goes up and over a mountain range?
2. What is the climate on the windward side of a mountain range like?
3. What is the climate on the leeward side of a mountain like?
4. What are rain shadow deserts?
5. What are the characteristics (wind, precipitation, vegetation) seen on the windward side of the Sierra Nevada Mountains?
6. What are the characteristics (wind, precipitation, vegetation) seen on the leeward side of the Sierra Nevada Mountains?

This page titled 12.5: Effect of Altitude and Mountains on Climate is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.6: Climate- Challenge 1

1. A location's average wind speed and direction, humidity, and air temperature can describe the location's ___.

climate

2. ___ is the long-term average of weather for a region.

Climate

3. The ___ receives the most solar radiation over the course of a year.

equator

4. At the ___ the Sun never rises very high in the sky.

poles

5. The Intertropical Convergence Zone is also known as the ___.

Doldrums

6. Winds blowing from the sub-tropical high pressure zones to the sub-polar low pressure zones are the ___.

westerlies

7. Winds are caused primarily by ___.

pressure differences

8. Coastal ___ brings cold, deep water up to the ocean surface off of California, which contributes to the cool coastal temperatures.

upwelling

9. A continental climate is more extreme than a coastal climate and has ___ winters and ___ summers.

cold; hot

10. Why is Mount Kilimanjaro covered by snow at the peak even though it is located near the equator?

it's very tall--temperature decreases with altitude in the troposphere

11. The Great Basin, which includes the Bonneville Salt Flats of Utah, is ___ because ___.

very dry; it is in the rainshadow of the Sierra Nevada Mountains

12. Air pressure and air temperature ___ with increasing altitude.

decrease

This page titled 12.6: Climate- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.7: Climate Zones and Biomes

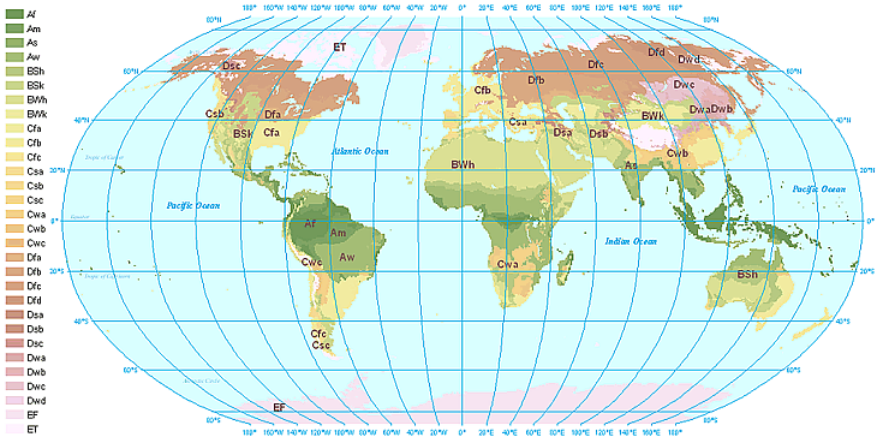


How are altitude and latitude similar?

The top of Mt. Humphreys (top), the highest point in Arizona, is 12,637 feet (3,852 m). Only a few plants can live in this harsh environment. The life zone is tundra. Tundra is also seen in high latitudes, like Denali National Park in Alaska (bottom). Denali is at 63° north.

Major Climate Types

Major climate types are based on temperature and precipitation. Latitude plays an important role in determining the climate of a region. However, many other factors play a role in climate. Oceans and mountain ranges influence climate in the same ways worldwide (**Figure** below). You can see where the climate types are on the map, and then read about them below.



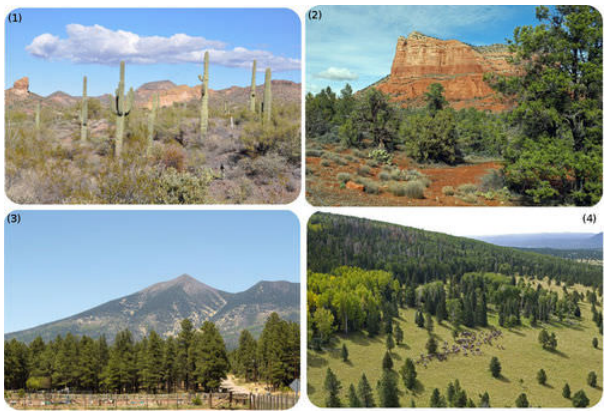
Find where you live on the map. What type of climate do you have?

Temperature and precipitation determine what types of plants can grow in an area. Animals and other living things depend on plants. So each climate is associated with certain types of living things. A major type of climate and its living things make up a **biome**. As you read about the major climate types below, find them on the map above (**Figure** above).

Altitude and Latitude

Altitude mimics latitude in climate zones. Climates and biomes typical of higher latitudes may be found at high altitudes.

Arizona is a state with a large elevation change. In the late 1800s, C. Hart Merriam noticed that the plant life changed with altitude in the same way it changes with latitude. So on a trip from Phoenix up to the top of the mountain, you could see all of these life zones (**Figure** below):



(1) Lower Sonoran, sea level to 4,000 feet: cactus, desert scrub. (2) Upper Sonoran, 4,000 to 7,000: pinyon-juniper. (3) Transition, 7,000 to 8,000 feet: Ponderosa Pine, some scrub; the snow-capped peak is Mt. Humphreys. (4) Lower Boreal, 8,000 to 11,000: Douglas fir, spruce; Douglas fir and Ponderosa pine are found together in some forests. (5) Upper Boreal, above 11,000 alpine tundra; see Mt. Humphreys above.

Microclimates

Climate conditions in a small area may be different from those of the surroundings. The climate of the small area is called a **microclimate**. The microclimate of a valley may be cool relative to its surroundings since cold air sinks. The ground surface may be hotter or colder than the air a few feet above it. This is because rock and soil gain and lose heat readily. Different sides of a mountain will have different microclimates. In the Northern Hemisphere, a south-facing slope receives more solar energy than a north-facing slope. Each side supports different amounts and types of vegetation.

Further Reading

Tropical Moist Climates

Dry Climates

Temperate Climates

Continental Climates

Polar Climates

Summary

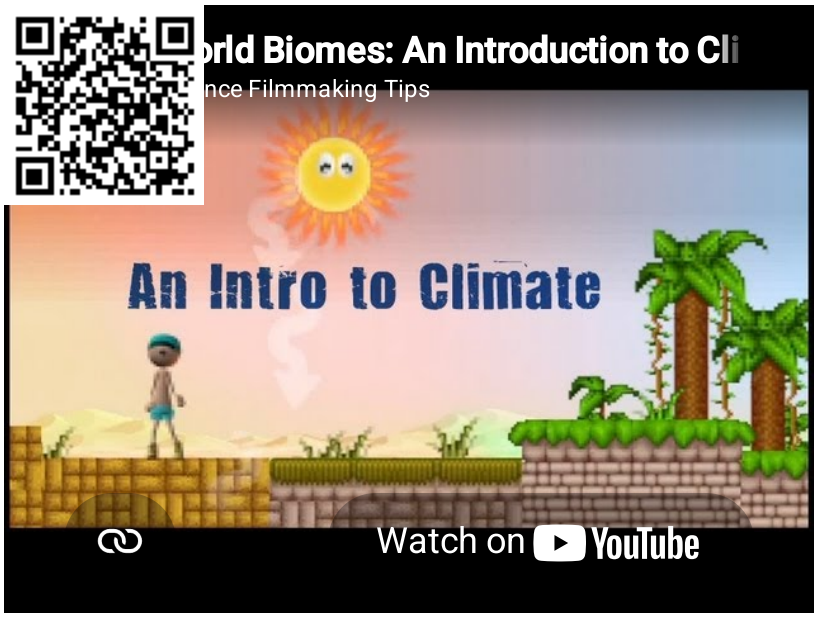
- Altitude and latitude produce similar climate zones and life zones.
- A biome is a climate zone and the plants and animals that live in it.
- A microclimate has different climate conditions from the surrounding regions.

Review

1. What factors determine a climate type?
2. How does a biome relate to a climate zone?
3. Why would a region have its own microclimate, different from the surrounding climate?
4. How are altitude and latitude similar for producing life zones?

Explore More

Use the resource below to answer the questions that follow.



1. What determines the characteristics of the Moab desert?
2. Where are deserts often found?
3. Why are the poles cold?
4. How can the ocean heat the land?
5. How does the mean temperature at Reykjavik, Iceland compare with a similar latitude in Alaska?
6. What brings the warm temperatures to Iceland?
7. How do greenhouse gases affect climate?
8. What are the principal factors in determining climate?

This page titled 12.7: Climate Zones and Biomes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.8: Tropical Moist Climates



What kind of climate is this?

Whether a place is wet all year round or dry for some time really affects what can grow there. In the tropics, places that are wet year round have lush vegetation. Places that are dry some of the time are much less lush.

Tropical Climates

Tropical climates are found around the Equator. As you'd expect, these climates have warm temperatures year round. The warm air rises at the Equator. As it rises, it cools, causing it to rain. Tropical climates may be very wet, or wet and dry.

Tropical Wet Climate

Tropical wet climates occur at or very near the Equator. They have high rainfall year round. **Tropical rainforests** (**Figure** below) grow in this type of climate.



A tropical rainforest in Borneo, Indonesia.

Tropical Wet and Dry Climate

Tropical wet and dry climates occur between 5° and 20° latitude and receive less rainfall. Most of the rain falls in a single season. The rest of the year is dry. Few trees can withstand the long dry season, so the main plants are grasses (**Figure** below). Wildlife thrive on these grasslands.



Africa is famous for its grasslands and their wildlife.



Summary

- Tropical climates are found at or near the Equator. Because warm air rises at the Equator, there is a lot of rain.
- Tropical wet climates get rain year round. Tropical rainforests grow in this climate zone.
- Tropical wet and dry climates have a rainy season and a dry season. The vegetation is largely grass.

Review

1. How does atmospheric circulation lead to there being rainforests in the tropics?
2. How does a tropical wet climate differ from a tropical wet and dry climate?
3. How do the differences in tropical climates lead to differences in vegetation?

This page titled 12.8: Tropical Moist Climates is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.9: Dry Climates



How do plants that evolved in different places end up being so similar?

Organisms evolve to fit the conditions they are in. There are only so many ways to minimize the use of water. Plants in arid climates evolve very similar structures to lessen water use. They also have structures to protect themselves from the Sun. The cactus on the right is from South America. The cactus on the left is from North America. These plants are just one of many examples of organisms evolving under very similar conditions and turning out to be very similar.

Dry Climates

Dry climates receive very little rainfall. They also have high rates of evaporation. This makes them even drier.

Deserts

The driest climates are **deserts**. Most occur between about 15° and 30° latitude. This is where dry air sinks to the surface in the global circulation cells. Deserts receive less than 25 centimeters (10 inches) of rain per year. They may be covered with sand dunes or be home to sparse but hardy plants. With few clouds, many deserts have hot days and cool nights.



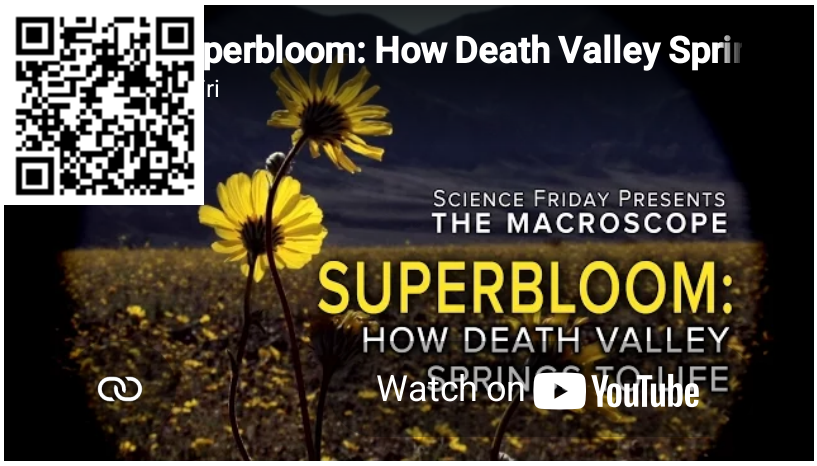
Some deserts receive a small amount of rain during the winter and again during the summer. This is enough to keep plants alive as in the left photo. Some deserts receive very little rain or rain only one season a year. These deserts have few plants as in the right photo.

Steppes

Other dry climates get a little more precipitation. They are called **steppes**. These regions have short grasses and low bushes (**Figure** below). Steppes occur at higher latitudes than deserts. They are dry because they are in continental interiors or rain shadows.

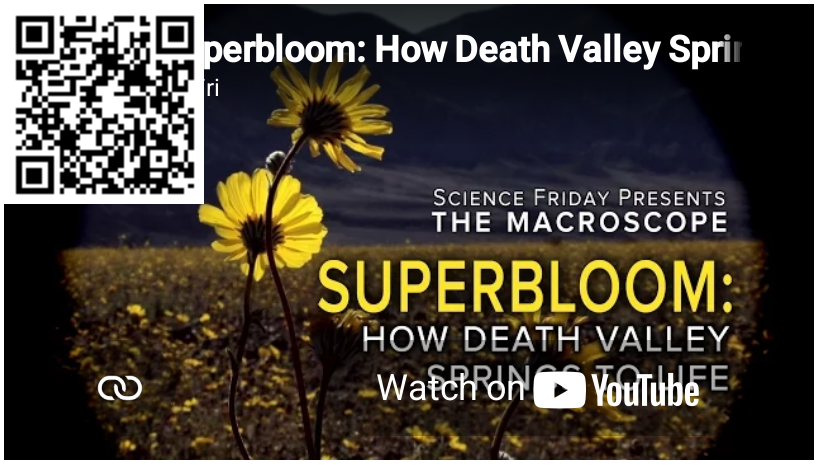


A steppe in Mongolia.



Science Friday: Superbloom: How Death Valley Springs to Life

A massive seed bank of desert wildflowers lies beneath Death Valley. This video by Science Friday shows that when heavy winter rains soak deep into the soil, these hidden wonders spring to life, in an event called a “superbloom”.



Summary

- Deserts receive very little rainfall. They are often home to very unusual and well adapted plants.
- Steppes receive more rain than deserts. They are higher and have grasses and scrub.
- Plants adapt to local conditions. If conditions are the same but the plants are far apart, they may still be very similar.

Review

1. What is the reason that an arid desert has so little rainfall?
2. What is the reason that a steppe has so little rainfall?
3. What is the difference between a desert and a steppe in vegetation?
4. What adaptations do arid climate zone plants have to the dry conditions?

This page titled 12.9: Dry Climates is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.10: Temperate Climates



What do these photos have in common? What's different?

Both photos have grapevines and old-looking stone buildings. The Sun is shining. The photo on the right is in California, where wine has become an enormous business in recent decades. On the left is an ancient village in Tuscany in Italy. These locations both have a Mediterranean climate, which is good for wine, olive oil, artichokes, and an tremendous number of other agricultural products.

Temperate Climates

Temperate climates have moderate temperatures. These climates vary in how much rain they get and when the rain falls.

Mediterranean Climate

Mediterranean climates are found on the western coasts of continents. The latitudes are between 30° and 45°. The coast of California has a Mediterranean climate. Temperatures are mild, and rainfall is moderate. Most of the rain falls in the winter, and summers are dry. To make it through the dry summers, short woody plants are common (**Figure** below).



A manzanita bush in San Mateo County, California

Marine West Coast Climate

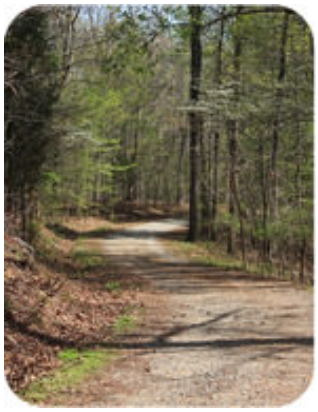
Marine west coast climates are also found on the western coasts of continents. They occur between 45° and 60° latitude. The coast of Washington State has this type of climate. Temperatures are mild, and there's plenty of rainfall all year round. Dense fir forests grow in this climate (**Figure** below).



Hoh rainforest in Olympic National Park, Washington

Humid Subtropical Climate

Humid subtropical climates are found on the eastern sides of continents between about 20° and 40° latitude. The southeastern U.S. has this type of climate. Summers are hot and humid, but winters are chilly. There is moderate rainfall throughout the year. Pine and oak forests grow in this climate (**Figure** below).



Duke Forest in Durham, North Carolina

Summary

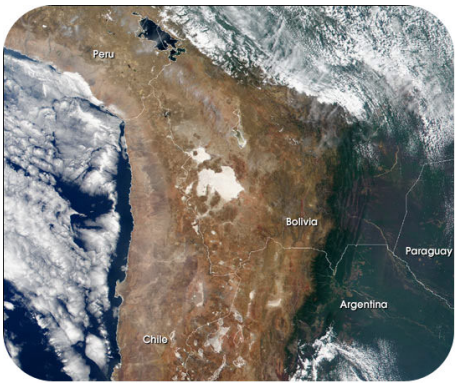
- Different temperate climates are at different latitudes. The latitude a climate depends on where it is on a continent.
- The Mediterranean climate has wet winters and dry summers.
- The marine west coast climate gets lots of rain from the nearby ocean.
- In the humid subtropical climate, summers are wet but winters are very cold.

Review

1. At what latitudes do these three climate types occur?
2. What types of plants are found in each of the three climate types above?
3. What is difficult about plants trying to survive in a Mediterranean climate? How do they do that?

This page titled 12.10: Temperate Climates is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.11: Continental Climates



Where don't you go to experience a continental climate?

There are no continental climates in the Southern Hemisphere. Can you guess why? Continental climates are between 40° and 70°. The southern continents at this latitude are too narrow. All of their inland areas are close enough to a coast to be affected by the ocean!

Continental Climates

Continental climates are found in inland areas. They are too far from oceans to experience the effects of ocean water. Continental climates are common between 40° and 70° north latitude.

Humid Continental Climate

Humid continental climates are found between 40° and 60° north latitude. The northeastern U.S. has this type of climate. Summers are warm to hot, and winters are cold. Precipitation is moderate, and it falls year round. Deciduous trees grow in this climate (**Figure** below). They lose their leaves in the fall and grow new ones in the spring.



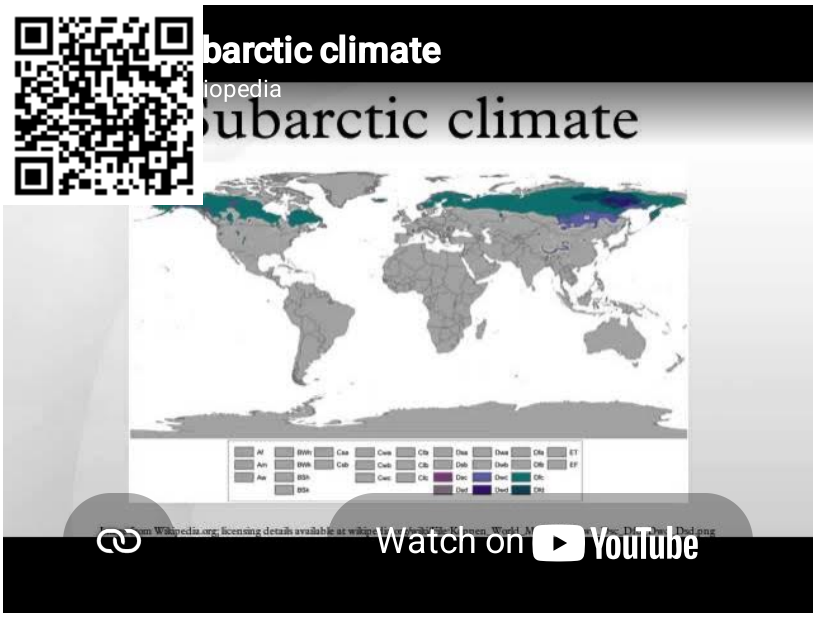
The deciduous forests of Vermont begin to lose their leaves in the fall

Subarctic Climate

Subarctic climates are found between 60° and 70° north latitude. Much of Canada and Alaska have this type of climate. Summers are cool and short. Winters are very cold and long. Little precipitation falls, and most of it falls during the summer. Conifer forests grow in this climate (**Figure** below).



A conifer forest in Jasper National Park, Alberta, Canada.



Summary

- Continental climates are far enough way from the ocean that there is no influence.
- Deciduous trees are common in humid continental climates. Conifer forests grow in the subarctic.
- Humid continental climates have warm winters and cold summers. Subarctic climates have cool short summers and very cold winters.

Review

1. What is the main features of a continental climate?
2. What are the temperature and precipitation conditions of the two climates described here?
3. What is the difference in trees in the two climate types described here?

This page titled 12.11: Continental Climates is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.12: Polar Climates



What types of animals live here?

The polar climate is harsh. Plants are small and low to the ground. What types of animals can live under these conditions? In alpine areas, small mammals that seek protection in rocks are common. The marmot on the left is an example. Large animals must be prepared to live exposed to frigid cold. Musk ox live in the farthest north parts of North America and Greenland. Additionally, large animals like caribou can migrate to more hospitable places in winter.

Polar Climates

Polar climates are found near the North and South Poles. They also occur on high mountains at lower latitudes. The summers are very cool, and the winters are frigid. Precipitation is very low because it's so cold. The growing season is very short. **Tundra** refers to areas with permafrost. **Permafrost** is a lower layer of soil that is permanently frozen. Tundra also refers to a treeless plain with small plants. You can see examples of polar climates pictured below.

Polar Tundra

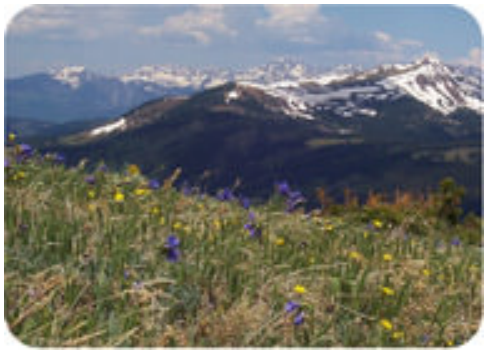
The polar tundra climate (**Figure** below) occurs near the poles. Tundra climates have permafrost. Permafrost is layer of ground below the surface that is always frozen, even in the summer. Only small plants, such as mosses, can grow in this climate.



Polar tundra in the Northwest Territories, Canada.

Alpine Tundra

The alpine tundra climates (**Figure** below) occurs at high altitudes at any latitude. They are also called highland climates. These regions are very cold because they are so far above sea level. The alpine tundra climate is very similar to the polar tundra climate.



Alpine Tundra in the Rockies, Colorado.

https://k12.libretexts.org/@go/page/5539

Ice Caps

Ice caps are areas covered with thick ice year round. Ice caps are found only in Greenland and Antarctica. Temperatures and precipitation are both very low. What little snow falls usually stays on the ground. It doesn't melt because it's too cold.



Summary

- Tundra is land with permafrost, no trees, and small hardy plants.
- Permafrost is land with permanently frozen soil.
- Tundra is found near the poles and up on high mountains.

Review

1. What is permafrost? Where do you think it is found?
2. What is tundra? Why is tundra found at the polar regions and in the high mountains?
3. What are ice caps? How does the ice accumulate?

This page titled 12.12: Polar Climates is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.13: Climate- Challenge 2

1. There are ___ major climate types according to the Köppen classification system.

five

2. Dry climates occur within ___ or in ___ when found at higher altitudes.

continents; rainshadows

3. The average annual rainfall in a tropical moist climate is at least ___ per year.

150 cm

4. The constant rain of a tropical wet climate allows ___ to grow.

rainforests

5. The aridity of the tropical ___ and ___ climate allows only grasses to grow, rather than trees.

wet; dry

6. Atmospheric circulation produces the year-round rain that characterizes the wet climates of the tropical ___.

rainforests

7. ___ receive more rain than deserts, but they are still dry; they occur at higher altitudes and have grasses and scrub.

Steppes

8. A treeless plain with small plants is a ___.

tundra

9. Areas covered with thick ice year round are known as ___ and are found only in Greenland and Antarctica.

ice caps

10. ___ is a lower layer of soil that is permanently frozen.

permafrost

This page titled 12.13: Climate- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.14: Climate Change in Earth History



How important was the Pleistocene ice age to human evolution?

Climate is dynamic; climate has changed through Earth's history. Climate has changed a lot during the time humans have been evolving. As the climate got colder, people learned to hunt more since plants became scarce in the winter. Better hunting required better tools. Better tools helped to spur on the evolution of culture.

How Earth's Climate Changes

Earth's climate has changed many times through Earth's history. Over much of Earth's past, the climate was warmer than it is today. Picture in your mind dinosaurs roaming the land. They're probably doing it in a pretty warm climate (**Figure** below)!



Dinosaurs thrived during one of the warmest periods in Earth's history.

But ice ages also occurred many times in the past. An **ice age** is a period when temperatures are cooler than normal. This causes glaciers to spread to lower latitudes. Scientists think that ice ages occurred at least six times over the last billion years alone. How do scientists learn about Earth's past climates?

The last major ice age took place in the Pleistocene. This epoch lasted from 2 million to 14,000 years ago. Earth's temperature was only 5° C (9° F) cooler than it is today. But glaciers covered much of the Northern Hemisphere. Below, you can see how far south they went (**Figure** below). Clearly, a small change in temperature can have a big impact on the planet. Humans lived during this ice age.



Pleistocene glaciers covered an enormous land area. Chicago is just one city that couldn't have existed during the Pleistocene.

Why Climate Changes

Several natural processes may affect Earth’s temperature. They range from sunspots to Earth’s wobble.

- **Sunspots** are storms on the Sun. When the number of sunspots is high, the Sun gives off more energy than usual. Still, there is little evidence for climate changing along with the sunspot cycle.
- Plate movements cause continents to drift closer to the poles or the Equator. Ocean currents also shift when continents drift. All these changes can affect Earth’s temperature.
- Plate movements trigger volcanoes. A huge eruption could spew so much gas and ash into the air that little sunlight wouldn't reach the surface for months or years. This could lower Earth’s temperature.
- A large **asteroid** hitting Earth would throw a lot of dust into the air. This could block sunlight and cool the planet.
- Earth goes through regular changes in its position relative to the Sun. Its orbit changes slightly. Earth also wobbles on its axis of rotation. The planet also changes its **axial tilt**, the angle of its axis of rotation. These changes can affect Earth’s temperature.

Summary

- Earth's climate has been warmer and colder, but mostly warmer, through Earth history.
- Many natural processes change Earth's climate. These include sunspots, plate tectonics, volcanism, asteroid impacts, and Earth's motions.
- The Pleistocene Ice Age lasted from 2 million to 14,000 years ago. Earth’s temperature was only 5° C (9° F) cooler than it is today.

Review

1. How has climate changed in the past 14,000 years?
2. How can the Sun change Earth's climate?
3. What is an ice age? When was the most recent?

Explore More

Use the resource below to answer the questions that follow.



This video deals with the time period at the end of the Paleozoic, called the Permian, 250,000,000 years ago. At that time there was a great mass extinction. Since it was so long ago, scientists must use many types of evidence to determine its cause.

1. What were therapsids? What was their great accomplishment?
2. What occurred 250 million years ago?
3. What natural disaster occurred at around the same time?
4. How much warming did Peter Ward calculate could have happened as a result of this natural disaster? What evidence did he use for his calculation?
5. Did this explain the mass extinction at the end of the Permian? Why or why not?
6. What happened during the first phase of the extinction?
7. What happened during the second phase of the extinction?
8. What happened during the third phase of the extinction?
9. What increased between the marine extinction and the final land extinction? What caused this?
10. In all, what caused the Earth's temperature to rise by 10 degrees?
11. How long did it take for life to recover? What animals came to dominate the Earth?

This page titled 12.14: Climate Change in Earth History is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.15: Short-Term Climate Change



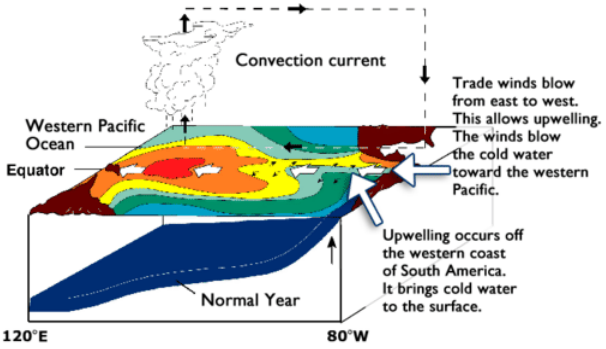
What are short term climate changes?

El Niño and La Niña bring about dramatic changes in climate for a year or two. In some locations, one brings rain and the other brings drought. In California, for example, El Niño years are full of snow and rain. La Niña years tend toward drought. These variations can bring tremendous changes to living creatures. Humans are also affected; for example, erosion from storms may be very high some years.

Short-Term Climate Change

You've probably heard of El Niño and La Niña. These terms refer to certain short-term changes in climate. The changes are natural and occur in cycles, lasting from days to years. El Niño and La Niña are not the only short-term climate changes. Others include the Pacific decadal oscillation and the North Atlantic oscillation. El Niño and La Niña are the most noticeable and discussed.

To understand El Niño and La Niña, you first need to know what happens in normal years (**Figure** below).

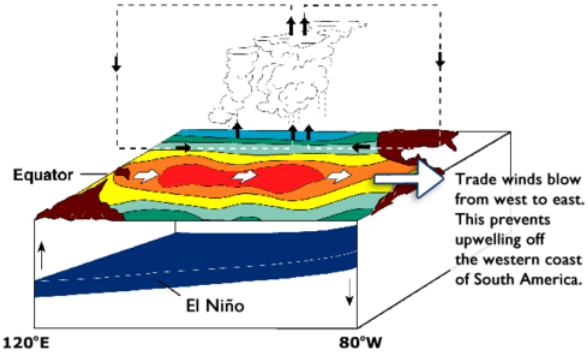


This diagram represents the Pacific Ocean in a normal year. North and South America are the brown shapes on the right.

El Niño

During an **El Niño**, the western Pacific Ocean is warmer than usual. This causes the trade winds to change direction. The winds blow from west to east instead of east to west (**Figure** below). The change in the trade winds also causes the jet streams to be north of their normal location. The warm water travels east across the Equator, too. Warm water piles up along the western coast of South America. This prevents upwelling. Why do you think this is true?

These changes in water temperature, winds, and currents affect climates worldwide. The changes usually last a year or two. Some places get more rain than normal. Other places get less. In many locations, the weather is more severe.



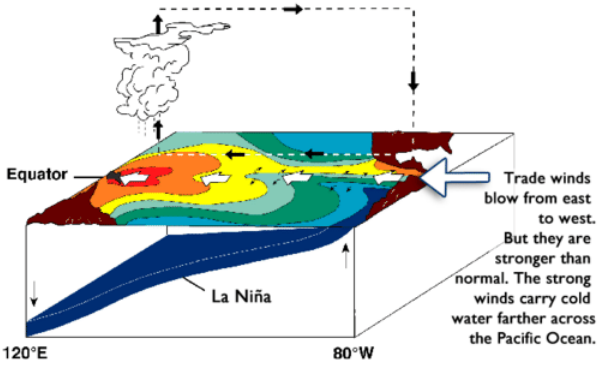
How do you think El Niño affects climate on the western coast of South America?

This ABC News video explores the relationship of El Niño to global warming. El Niño is named as the cause of strange weather across the United States in the winter of 2007.



La Niña

La Niña (**Figure** below) generally follows El Niño. It occurs when the Pacific Ocean is cooler than normal. The trade winds are like they are in a normal year. They blow from east to west. But in a La Niña, the winds are stronger than usual. More cool water builds up in the western Pacific. These changes can also affect climates worldwide.



How do you think La Niña affects climate on the western coast of South America?

https://k12.libretexts.org/@go/page/5542

Some scientists think that global warming is affecting the cycle of El Niño and La Niña. These short-term changes seem to be cycling faster now than in the past. They are also more extreme.

Further Reading

Long-Term Climate Change

Summary

- El Niño and La Niña are two examples of short-term climate changes lasting one to a few years.
- In an El Niño, the trade winds reverse direction, as do the equatorial surface currents. This causes warm water to pool off of South America and stop upwelling.
- A La Niña is like normal conditions only more so.

Review

1. In which direction does wind blow during an El Niño event?
2. In which direction does current go during an El Niño event?
3. How is a La Niña different from an El Niño?
4. During an El Niño, what happens to life off the coast of South America and why?

This page titled 12.15: Short-Term Climate Change is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.16: Carbon Cycle and Climate



What is a diamond?

Carbon takes all sorts of forms as an element and as a compound. A diamond is just carbon, pure carbon. A diamond is good for cutting things, but it's not good for breathing or building proteins out of, yet other forms of carbon are. Carbon is essential for life on Earth and, as carbon dioxide, it is an important atmospheric gas.

The Carbon Cycle

Carbon is a very important element to living things. As the second most common element in the human body, we know that human life without carbon would not be possible. Protein, carbohydrates, and fats are all part of the body and all contain carbon. When your body breaks down food to produce energy, you break down protein, carbohydrates, and fat, and you breathe out carbon dioxide.

Carbon occurs in many forms on Earth. The element moves through organisms and then returns to the environment. When all this happens in balance, the ecosystem remains in balance too.

Short-Term Cycling of Carbon

The short term cycling of carbon begins with carbon dioxide (CO_2) in the atmosphere.

Photosynthesis

Through photosynthesis, the inorganic carbon in carbon dioxide plus water and energy from sunlight is transformed into organic carbon (food) with oxygen given off as a waste product. The chemical equation for photosynthesis is:

$$\underset{\text{carbon dioxide}}{6\ CO_2} + \underset{\text{water}}{6\ H_2O} + \text{Energy from sunlight} \rightarrow \underset{\text{glucose (sugar)}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\ O_2}$$

Respiration

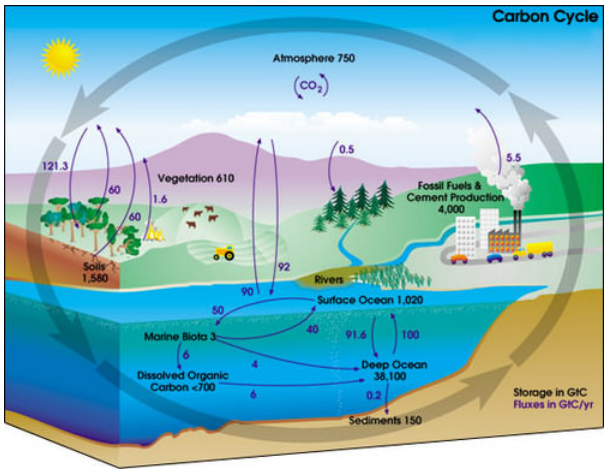
Plants and animals engage in the reverse of photosynthesis, which is respiration. In respiration, animals use oxygen to convert the organic carbon in sugar into food energy they can use. Plants also go through respiration and consume some of the sugars they produce.

The chemical reaction for respiration is:

$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$ + useable energy

Photosynthesis and respiration are a gas exchange process. In photosynthesis, CO_2 is converted to O_2; in respiration, O_2 is converted to CO_2.

Remember that plants do not create energy. They change the energy from sunlight into chemical energy that plants and animals can use as food (**Figure** below).



The carbon cycle shows where a carbon atom might be found. The black numbers indicate how much carbon is stored in various reservoirs, in billions of tons ("GtC" stands for gigatons of carbon). The purple numbers indicate how much carbon moves between reservoirs each year. The sediments, as defined in this diagram, do not include the ~70 million GtC of carbonate rock and kerogen.

Long-Term Carbon Cycling

Carbon Sinks and Carbon Sources

Places in the ecosystem that store carbon are reservoirs. Places that supply and remove carbon are **carbon sources** and **carbon sinks**, respectively. If more carbon is provided than stored, the place is a carbon source. If more carbon dioxide is absorbed than is emitted, the reservoir is a carbon sink. What are some examples of carbon sources and sinks?

- Carbon sinks are reservoirs where carbon is stored. Healthy living forests and the oceans act as carbon sinks.
- Carbon sources are reservoirs from which carbon can enter the environment. The mantle is a source of carbon from volcanic gases.

A reservoir can change from a sink to a source and vice versa. A forest is a sink, but when the forest burns it becomes a source.

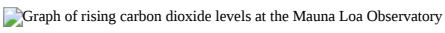
The amount of time that carbon stays, on average, in a reservoir is the residence time of carbon in that reservoir.

Atmospheric Carbon Dioxide

Remember that the amount of CO_2 in the atmosphere is very low. This means that a small increase or decrease in the atmospheric CO_2 can have a large effect.

By measuring the composition of air bubbles trapped in glacial ice, scientists can learn the amount of atmospheric CO_2 at times in the past. Of particular interest is the time just before the Industrial Revolution, when society began to use fossil fuels. That value is thought to be the natural content of CO_2 for this time period; that number was 280 parts per million (ppm).

By 1958, when scientists began to directly measure CO_2 content from the atmosphere at Mauna Loa volcano in the Pacific Ocean, the amount was 316 ppm (**Figure** below). In 2018, the atmospheric CO2 content crossed over to 410 ppm.



The amount of CO_2 in the atmosphere has been measured at Mauna Loa Observatory since 1958. The blue line shows yearly averaged CO_2. The red line shows seasonal variations in CO_2.

This is an increase in atmospheric CO_2 of 40% since the before the Industrial Revolution. About 65% of that increase has occurred since the first CO_2 measurements were made on Mauna Loa Volcano, Hawaii, in 1958.

Human Actions Impact the Carbon Cycle

Humans have changed the natural balance of the carbon cycle because we use coal, oil, and natural gas to supply our energy demands. Fossil fuels are a sink for CO_2 when they form, but they are a source for CO_2 when they are burned.

The equation for combustion of propane, a simple hydrocarbon, looks like this:

$$\underset{\text{propane}}{C_3H_8} + \underset{\text{oxygen}}{5\ O_2} \rightarrow \underset{\text{carbon dioxide}}{3\ CO_2} + \underset{\text{water}}{4\ H_2O}$$

The equation shows that when propane burns, it uses oxygen and produces carbon dioxide and water. So when a car burns a tank of gas, the amount of CO_2 in the atmosphere increases just a little. Added over millions of tanks of gas and coal burned for electricity in power plants and all of the other sources of CO_2, the result is the increase in atmospheric CO_2 seen in the **Figure** above.

The second largest source of atmospheric CO_2 is **deforestation** (**Figure** below). Trees naturally absorb CO_2 while they are alive. Trees that are cut down lose their ability to absorb CO_2. If the tree is burned or decomposes, it becomes a source of CO_2. A forest can go from being a carbon sink to being a carbon source.



This forest in Mexico has been cut down and burned to clear forested land for agriculture.

Why the Carbon Cycle is Important

Why is such a small amount of carbon dioxide in the atmosphere even important? Carbon dioxide is a greenhouse gas. Greenhouse gases trap thermal energy that would otherwise radiate out into space, which warms Earth. These gases were discussed in the chapter Atmospheric Processes.

Summary

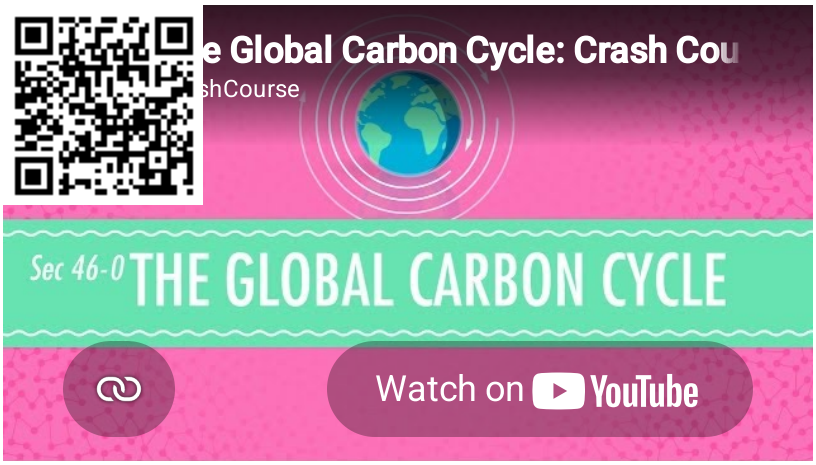
- Carbon is essential for life as part of proteins, carbohydrates, and fats.
- The amount of carbon dioxide in the atmosphere is extremely low, but it is extremely important since carbon dioxide is a greenhouse gas, which helps to keep Earth's climate moderate.
- The amount of carbon dioxide in the atmosphere is rising, a fact that has been documented on Mauna Loa volcano since 1958.

Review

1. What does it mean to say that photosynthesis and respiration are gas exchange processes?
2. How do scientists learn about carbon levels in the past?
3. How do human activities affect the carbon cycle?

Explore More

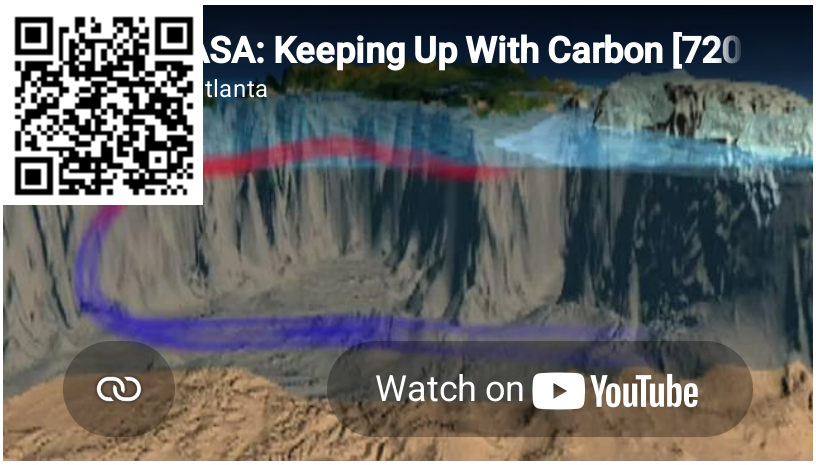
Use this resource to answer the questions that follow.



1. What do greenhouse gases do?
2. Where did most of the carbon dioxide that was present in the early atmosphere go?
3. What did the early plants add to the atmosphere and why was that important? What else did they create?
4. What do organisms do with the organic carbon?
5. What are the two major things that carbon does?
6. What is the 30 second version of the carbon cycle?
7. What does carbon fixation do with carbon dioxide?
8. How do organisms use the carbohydrates produced by carbon fixing reactions?
9. What is cellular respiration the reverse of?
10. After the organisms metabolize carbohydrates, how is the carbon released back into the environment?
11. What happens when carbon dioxide mixes with water and what does it cause?
12. What happens to the carbonate ions in the marine environment?
13. What happens when shell building organisms die? What happens if those organisms are buried deeply?
14. How much carbon is wrapped up in fossil fuels compared to the total amount of carbon?
15. Where does the carbon dioxide go that is released from fossil fuels? Where does the excess carbon dioxide go?

Resources





Tags recommended by the template: article:topic

This page titled 12.16: Carbon Cycle and Climate is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.17: Global Warming

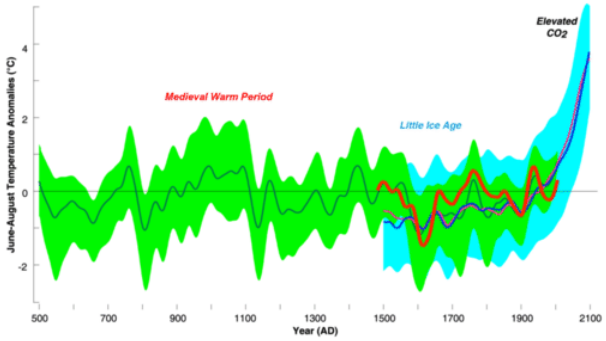


How can things change so quickly?

Glaciers and ice sheets are melting. This can be seen clearly in photographs. The glaciers advanced during the Pleistocene ice age. They have been melting back since then, except for during the Little Ice Age. However, the rate of melting has increased tremendously in recent decades.

Temperature Variations

Since the end of the Pleistocene, Earth's temperature has risen. The image below shows how it changed over just the last 1500 years (**Figure** below). The Medieval Warm Period was a time of somewhat higher average temperatures. The Little Ice Age was a time of somewhat lower average temperatures. But for each time, the anomaly (the difference from average temperature) was less than 1° C (1.8° F). Still, the overall trend is slightly upward.



Earth's temperature. Different sets of data all show an increase in temperature since about 1880 (the Industrial Revolution).

Recent Temperature Trends

Since the mid 1800s, Earth has warmed up quickly (**Figure** below). By end the of 2017, 17 of the 18 hottest years on record have all occurred since 1998! This temperature rise is what is usually meant by **global warming**.



Earth's temperature (1850–2007). Earth has really heated up over the last 150 years. Do you know why?

Summary

- Average global temperature has been rising since the end of the ice ages.
- The largest temperature rise has been in the past two decades.

- The rise in Earth's temperature since the late 19th century is referred to as global warming.

Review

1. What have been the temperature trends in the past 1500 years?
2. How is the rise in temperatures in the past two decades different from the rise since of the past 1500 years?
3. What is global warming?

Explore More

Use the resource below to answer the questions that follow.



1. How much has the global temperature risen in the last century?
2. What is the major human activity that contributes to global warming and why?
3. What is the greenhouse effect?
4. Is average global temperature rising? What is your evidence?
5. Which greenhouse gases are at their highest levels in history? When was the last time they were as high?
6. What do researchers predict will happen?
7. What can we do now to slow the rise in temperatures?

This page titled 12.17: Global Warming is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.18: Causes and Effects of Global Warming



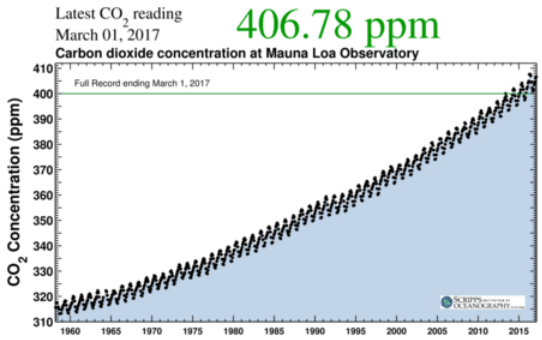
What is the human cost of warmer temperatures?

Many lands are marginal for farming. When rainfall is normal or high, the lands can produce. When rainfall is low, no crops grow. Drought makes marginal lands unsuitable for farming. Drought can also make good lands more difficult to farm. These changes will increase as temperatures warm.

Causes of Global Warming

The average global temperature has been rising since the end of the Pleistocene, with some ups and downs, of course. Rising temperatures are natural for this time period. But natural causes cannot explain all the warming that's been happening. There is some other factor at work.

Recent **global warming** is due mainly to human actions. The actions involve releasing greenhouse gases into the atmosphere. Remember that greenhouse gases keep the atmosphere warm? And that carbon dioxide is a greenhouse gas? When humans burn fossil fuels, carbon dioxide is released into the atmosphere. The more carbon dioxide in the atmosphere, the better the atmosphere can trap heat. In other words, an increase in greenhouse gases leads to greater greenhouse effect. The result is increased global warming. Pictured below is the increase in carbon dioxide since 1960 (**Figure** below).



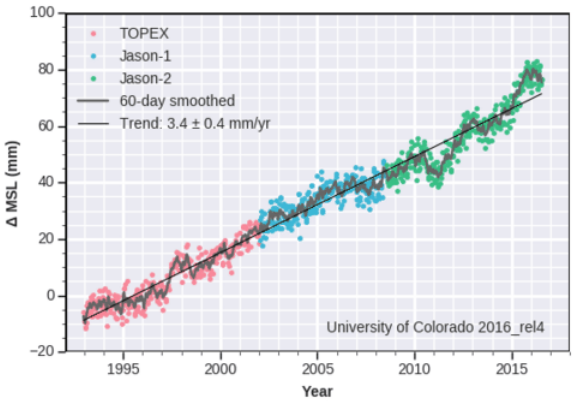
How much more carbon dioxide was in the air in 2010 than in 1960?

Burning forests also releases carbon dioxide into the atmosphere. Other human activities release greenhouse gases into the atmosphere. For example, growing rice and raising livestock both produce methane.

Effects of Global Warming

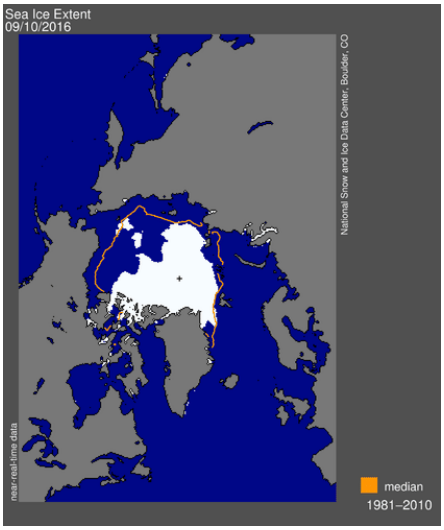
There are already many effects of global warming being seen. As Earth has gotten warmer, sea ice has melted. This has raised the level of water in the oceans about 3 mm per year. The rate of sea level rise is now accelerating and might be more than 10 mm per year in 2100. Although this doesn't sound like much, added together over the years it can be a lot. The greatest danger from flooding will be when storm surge is added to the top of higher sea levels.

LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



The overall trend in sea level since 1870; it has risen about 9 inches.

The extent of Arctic sea ice in summer has been decreasing rapidly. The ice pictured below is the sea ice minimum in 2016 (**Figure** below). The yellow line is the median minimum ice extent for 1981–2010.



The sea ice minimum for 2016 (pictured) was the third lowest on record, with 2012 as the lowest. 2017 was slightly higher, although records have not been updated.

Other effects of global warming include more extreme weather. Earth now has more severe storms, floods, heat waves, and droughts than it did just a few decades ago. Many living things cannot adjust to the changing climate. Coral reefs in many parts of the world are struggling to survive. Species are moving uphill where temperatures are cooler. Those at the top of the mountain are being run off. Migration and egg-laying behaviors in birds are off of their normal. There are many more examples of the effects of changing climate.



Summary

- Greenhouse gases trap heat in the atmosphere. Burning fossil fuels and other human activities release greenhouse gases into the atmosphere.
- Greenhouse gas levels in the atmosphere are increasing. Global temperatures are increasing.
- Changes due to increasing temperatures are seen around the globe. Living organisms and humans are also affected.

Review

1. What do you expect to happen if you increase the amount of greenhouse gases in the atmosphere?
2. What has happened to the level of carbon dioxide in the atmosphere in the past several decades (use numbers and units)?
3. What has happened to sea level since 1870 (use numbers and units)?
4. What are some of the effects of climate change that are already being seen?

This page titled 12.18: Causes and Effects of Global Warming is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.19: Impact of Continued Global Warming



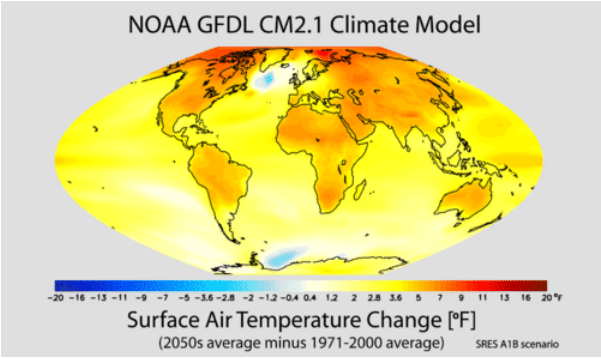
“The land is part of me...”

"The future kind of scares me, just thinking about how we're going to survive." says 18-year old Harlie Potter, an Inuit living in the autonomous area of Nunatsiavut in Newfoundland, Canada. Native people in the Arctic see changes much more than people in lower latitudes. Warming is occurring more rapidly in the polar regions.

How Will Climate Change in the Future?

Earth’s temperature will keep rising unless greenhouse gas emissions are curbed. The temperature in 2100 may be as much as 5° C (9° F) higher than it was in 2000. Is 5° C (9° F) a lot? It's more than the increase in temperature from the the times of maximum ice during the Pleistocene to now. Since the end of the Pleistocene, the temperature has only risen about 4° C. That's just 4° C from abundant ice to the moderate climate we have today. How might a 5° C increase in temperature affect Earth in the future?

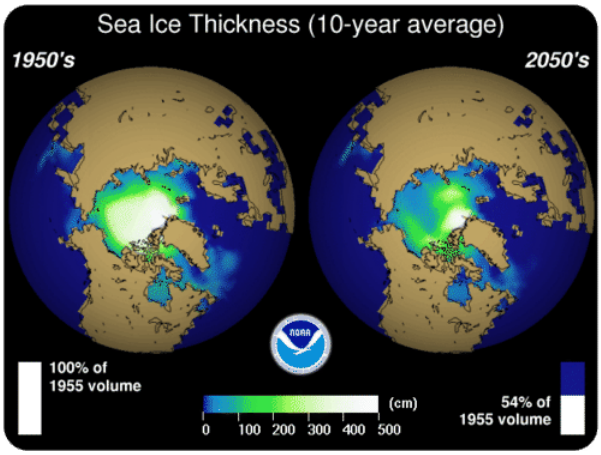
Warming will affect the entire globe by the end of this century. The map in **Figure** below shows how much temperatures will change in different regions based on the Coupled Climate 2.1 model. In what place is the temperature increase the greatest? Where in the United States is the temperature increase the highest?



The Arctic will experience the greatest temperature changes.

What Will Happen?

As temperature rises, more sea ice will melt. The figure below shows how much less sea ice there may be in 2050 if temperatures keep going up (**Figure** below). This would cause sea level to rise even higher. Some coastal cities could be underwater. Millions of people would have to move inland. How might other living things be affected?



In the 2050s, there may be only half as much sea ice as there was in the 1950s.

Weather will become more extreme. Heat waves and droughts will become more frequent and more intense. The Midwestern United States will become hot and dry. This will make growing food more difficult. Cropland worldwide will be affected. Hurricanes may become more severe.

Plants and animals will move or die out. Some will thrive in a warmer world, but most will not. The biosphere may become quite different.

These are only a few of the impacts warmer temperatures will have. The vast majority of scientists agree that this is what is happening.

Summary

- Global temperatures will increase. Some locations like the Arctic and Amazon will experience a greater increase.
- Sea level will rise and some coastal cities may be submerged.
- Weather will become more extreme. Crops and some plants and animals may not be able to survive the warmer temperatures.

Review

1. Pretend that the temperature today is 5° C (9° F) higher than yesterday. Now consider an increase of 5° C (9° F) in average global temperature. How are these two scenarios different?
2. Why is a rise in sea level significant?
3. What will plants and animals do as temperature rises?

Explore More

Use the resource below to answer the questions that follow.



1. Climate has always been changing. Why is it something to worry about now?
2. Describe the changes that could be seen if the Earth warms by one degree.
3. Describe the effects of two degrees of warming.
4. What changes will occur with three degrees of warming?
5. Describe the consequences of four degrees of warming.

This page titled 12.19: Impact of Continued Global Warming is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.20: Reducing Greenhouse Gas Pollution



What can the polar bear do?

Polar bears evolved to hunt from ice. As arctic ice melts, polar bears are having a harder time finding food. Polar bears can adapt to finding food in other locations, like garbage dumps--unhealthy and unsustainable food sources. But they can't do anything about reducing global warming. Humans are responsible for greenhouse gas emissions, so humans can reduce those emissions. It's not too late to get started.

Climate Regulations

The Clean Air Act of 1970 was crucial for reducing air pollution in the United States. The Clean Water Act of 1970 did the same for reducing water pollution. The Montreal Protocol was even more important in some ways. This treaty was the first time many countries came together to solve a problem. They created a good plan for reducing substances that destroy the ozone layer.

A treaty similar to the Montreal Protocol is needed for regulating greenhouse gases. The Kyoto Protocol was passed in 1997. The Protocol focused on controlling greenhouse gas emissions. Many nations signed the protocol, but not all. The United States, which at the time was the largest emitter of greenhouse gases, did not. The U.S. is currently the second largest emitter of greenhouse gases after China. Other treaties have been worked on but there has not been much progress. There are many people, organizations and nations that think that this is too vague and too slow.

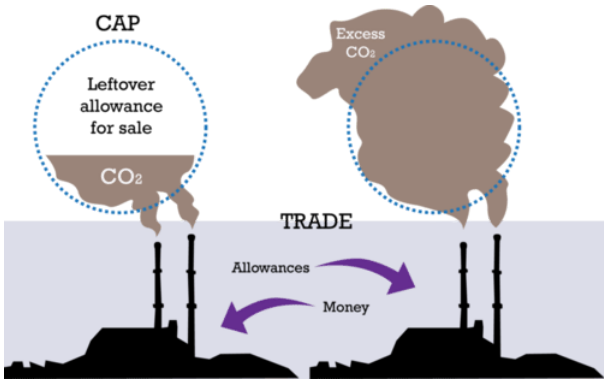
A stricter agreement must be reached very soon. By doing nothing we are actively harming the earth—continuing to raise greenhouse gas levels and failing to prepare for the coming environmental changes. Efforts to limit greenhouse gas emissions are mired in politics. Meanwhile, crucial time is being lost.

Ways to Reduce Carbon Dioxide Emissions

There are several possible ways to encourage organizations to reduce carbon dioxide emissions. They include cap-and-trade systems, carbon taxes, and carbon sequestration.

- In a **cap-and-trade system**, each nation is given a cap on carbon dioxide emissions. This is the most carbon dioxide the country is allowed to emit. Sometimes a nation may need to go over its cap. In that case, it can trade with another nation that is below its cap. Below, you can see how this works (**Figure** below).
- **Carbon taxes** are taxes placed on products that produce carbon dioxide. An example of this is gasoline for your car. The taxes encourage people to use less fossil fuel. This naturally reduces carbon dioxide emissions.
- **Carbon sequestration** captures carbon dioxide as it is emitted by a power plant before it enters the atmosphere. The carbon dioxide is then stored in another form. Carbon is sequestered naturally by forests. Trees take in carbon dioxide for photosynthesis. Artificial methods of sequestering carbon underground are being researched. This is just one of the geoengineering methods that are being researched for reducing carbon dioxide.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



This diagram shows how a cap-and-trade system works.

New technologies can be developed. Renewable energy sources emit fewer or no greenhouse gases. These sources are discussed in the chapter *Natural Resources*.

What You Can Do

Reducing the amount that temperatures will rise will take all nations working together. But individuals can make a difference. What can you do? Many of the same things that you do to reduce air pollution.

- Walk, ride a bike, or take a bus.
- Turn electrical appliances off.
- Reduce consumption of products and packaging.
- Unplug cell phones and other chargers when not in use.
- Use compact fluorescent light bulbs.
- Use directed lighting.
- Be aware: take shorter showers, do not use more boiling water than needed, etc.
- BE INVOLVED! Learn more about climate change. Talk with people about the problem and what they can do. Write letters to the editor or to politicians. It's your world and your future.

Summary

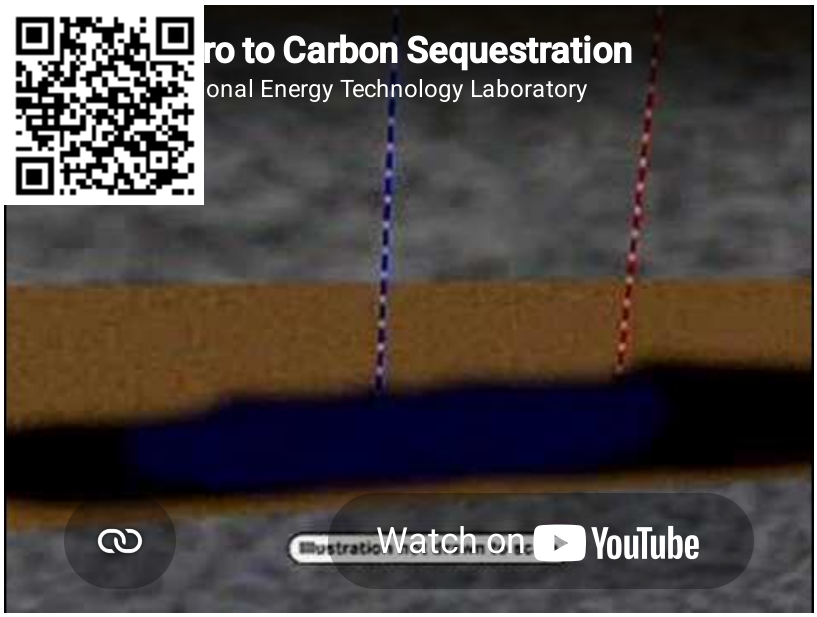
- A cap-and-trade system gives nations a cap on the greenhouse gas emissions. Those that have a higher cap than they need can trade with a nation that needs more.
- A carbon tax taxes carbon emissions to encourage conservation.
- Carbon capture and sequestration is a geoengineering solution. This method removes excess carbon dioxide from the atmosphere and stores it.

Review

1. Why is a treaty between nations needed so that we can reduce greenhouse gas emissions? Why is there a problem getting a treaty that will work?
2. How does a cap-and-trade system work? Could it work for cities or businesses in the same way it does for nations?
3. What is carbon sequestration? Does it prevent carbon dioxide from being emitted? Does it keep carbon dioxide from entering the atmosphere?

Explore More

Use the resource below to answer the questions that follow.



1. What is the purpose of carbon sequestration?
2. What are the three pillars of the Global Climate Change Initiative?
3. What is CCS?
4. What is CCS being used for today?
5. How is CCS done?
6. What type of stone is carbon dioxide pumped into? Why?
7. Why are cap rocks important? How do scientists know cap rocks work?

This page titled 12.20: Reducing Greenhouse Gas Pollution is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

12.21: Climate- Challenge 3

1. The average global temperature during glacial periods was ___ less than the current average global temperature.

5.5°C (10°F)

2. The Vikings colonized Greenland during the ___and were forced out during the ___.

Medieval Warm Period; Little Ice Age

3. The Little Ice Age lasted for a period of ___ years.

500

4. ___ is a byproduct of photosynthesis.

Oxygen

5. Carbon is the ___ most common element in the human body.

second

6. ___ are a natural source for the release of carbon dioxide in the atmosphere.

volcanoes

7. Warmer temperatures are causing coral reefs to ___, eventually killing them.

turn white

8. Temperatures have been rising since ___, but the ___ is increasing.

the end of the Pleistocene; rate of increase

9. One negative impact of modern technology is that ___.

the level of pollution is increasing

10. If the amount of ___ gases in the atmosphere continues to increase, more thermal energy will be trapped in the atmosphere, and global temperatures will continue to rise.

greenhouse

11. An increase in the occurrence of severe storms, floods and droughts, and effects on the seasonality of animals are all consequences of ___.

climate change

12. Atmospheric carbon dioxide concentration has increased by ___ over the last fifty years.

80 ppm

13. Marine organisms with carbonate shells will struggle growing because of ___.

ocean acidification

14. Water shortages will become a problem in some areas because ___.

reduced snowpack and earlier springs due to global warming will reduce water availability from snowmelt

15. The increase in average global temperature seen in the past two decades was caused by ___.

burning of fossil fuels by humans

This page titled 12.21: Climate- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

13: Weathering and Soils

13.1: Weathering and Erosion
13.2: Mechanical Weathering
13.3: Chemical Weathering
13.4: Influences on Weathering
13.5: Weathering and Soils- Challenge 1
13.6: Soil Characteristics
13.7: Soil Formation
13.8: Soil Horizons and Profiles
13.9: Types of Soils
13.10: Soil Erosion
13.11: Avoiding Soil Loss
13.12: Weathering and Soils- Challenge 2

This page titled 13: Weathering and Soils is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

13.1: Weathering and Erosion



Why are these rocks different?

The rock seen on the left is being mined in a quarry. What are the features of the rock? The rock seen on the right is exposed in an outcrop. How do the features of these rocks differ? The rock in the quarry is being exposed to the elements for the first time. It is not weathered. The rock in the outcrop has been weathering for many thousands of years. Can you identify the weathering features?

Weathering

Weathering changes solid rock into pieces. These pieces are called sediments. Sediments are described in the chapter *Earth's Materials and Crust*. Sediments are different sizes of rock particles. Boulders are sediments; so is gravel. At the other end, silt and clay are also sediments. Weathering may also cause the minerals at the Earth's surface to change form. The new minerals that form are stable at the Earth's surface. There are two types of weathering, mechanical and chemical. These are discussed in both Mechanical Weathering and Chemical Weathering.

Weathering Takes Time

No one can watch for millions of years as mountains are built. And no one can watch as those same mountains gradually are worn away. But imagine a new sidewalk or road. The new road is smooth and even. Over hundreds of years, it will completely disappear. What happens to that road over one or two years? What changes would you see (**Figure** below)? What forces of weathering wear down that road, or rocks or mountains over time?



One bad winter can cause a road to weather. The potholes in this road will need to be fixed.

Erosion

Erosion moves sediments after they have formed. The sediments are transported away from the place where they form. There are several agents of erosion. Flowing water moves and deposits sediments. Water erodes far more material than any other erosional agent. Wind is important as an agent of erosion. This is especially true in arid climates. Ice, in glaciers, can erode enormous quantities of sediments. Gravity as a force of erosion pulls material downhill.

Many types of landforms are created by the erosion of sediments. Some are described later in this chapter.

Deposition

Sediments are deposited in an environment of deposition. This can be a sand dune, beach, lake, river bend, or a great number of other locations. Scientists can figure out the environment of deposition of a sedimentary rock by looking at the size of sediments

and the sedimentary features in the rock.

Many types of landforms are created by the deposition of sediments. Some are described later in this chapter.

Changing Landscapes

Plate tectonics forces work to build huge mountains and other landscapes. Conversely, the forces of weathering gradually wear down those rocks and landscapes. Together with erosion, tall mountains turn into hills and even plains. The Appalachian Mountains along the east coast of North America were once as tall as the Himalayas.

Further Reading

Influences on Weathering

Soil Characteristics

Summary

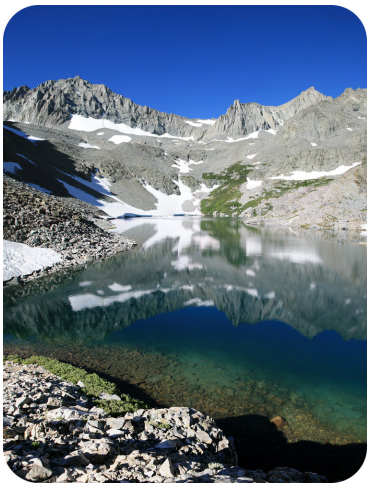
- Weathering breaks down Earth's materials into smaller pieces.
- Erosion transports those pieces to other locations.
- Weathering and erosion modify Earth's surface landscapes over time.

Review

1. What is weathering?
2. How is weathering different from erosion?
3. Why does weathering take so much time?
4. What are some of the agents of erosion?

This page titled 13.1: Weathering and Erosion is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

13.2: Mechanical Weathering



Why is mechanical weathering so important here?

The high mountains of the Sierra Nevada are made of granite. The climate is cold. Mechanical weathering dominates the weathering here. Can you find signs of mechanical weathering in the photo? Can you see evidence of chemical weathering in the photo? Why is mechanical weathering so much more important than chemical weathering here? How is mechanical weathering altering the landscape in the high Sierra?

Mechanical Weathering

Mechanical weathering breaks rock into smaller pieces. These smaller pieces are just like the bigger rock; they're just smaller! The rock has broken without changing its composition. The smaller pieces have the same minerals in the same proportions. You could use the expression “a chip off the old block“ to describe mechanical weathering! The main agents of mechanical weathering are water, ice, and wind.

Ice Wedging

Rocks can break apart into smaller pieces in many ways. **Ice wedging** is common where water goes above and below its freezing point (**Figure** below). This can happen in winter in the mid-latitudes or in colder climates in summer. Ice wedging is common in mountainous regions like the Sierra Nevada pictured above.

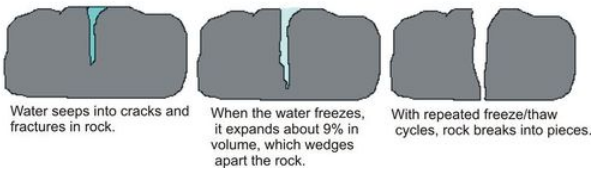


Diagram showing ice wedging.

This is how ice wedging works. When liquid water changes into solid ice, it increases in volume. You see this when you fill an ice cube tray with water and put it in the freezer. The ice cubes go to a higher level in the tray than the water. You also may have seen this if you put a can of soda into the freezer so that it cools down quickly. If you leave the can in the freezer too long, the liquid expands so much that it bends or pops the can. (For the record, water is very unusual. Most substances get smaller when they change from a liquid to a solid.)

Ice wedging happens because water expands as it goes from liquid to solid. When the temperature is warm, water works its way into cracks in rock. When the temperature cools below freezing, the water turns to ice and expands. The ice takes up more space. Over time, this wedges the rock apart. Ice wedging is very effective at weathering. You can find large piles of broken rock at the base of a slope. These rocks were broken up by ice wedging. Once loose, they tumbled down the slope.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Abrasion

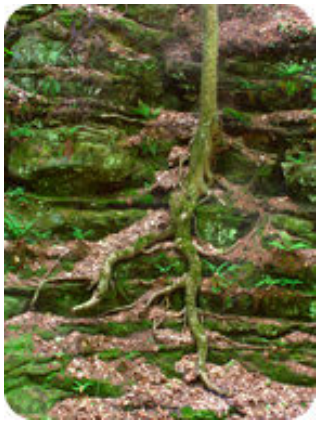
Abrasion is another type of mechanical weathering. With abrasion, one rock bumps against another rock. Gravity causes abrasion as a rock tumbles down a slope. Moving water causes abrasion; it moves rocks so that they bump against one another (**Figure** below). Strong winds cause abrasion by blasting sand against rock surfaces. Finally, the ice in glaciers cause abrasion. Pieces of rock embedded in ice at the bottom of a glacier scrape against the rock below. If you have ever collected beach glass or pebbles from a stream, you have witnessed the work of abrasion.



Water flowing through river or beach cobbles causes them to hit each other. This contact causes abrasion, which makes the rocks round.

Plants and Animals in Mechanical Weathering

Sometimes plants or animals cause mechanical weathering. This can happen slowly. A plant's roots grow into a crack in rock. As the roots grow larger, they wedge open the crack (**Figure** below). Burrowing animals can also cause weathering. By digging for food or creating a hole to live, in the animal may break apart rock.



The large roots of this tree can break apart rock. This is mechanical weathering.

Humans and Mechanical Weathering

Today, human beings do a lot of mechanical weathering whenever we dig or blast into rock. This is common when we build homes, roads, and subways, or quarry stone for construction or other uses.

Summary

- Mechanical weathering breaks down existing rocks and minerals.
- Mechanical weathering keeps the chemical makeup of materials the same.
- Ice wedging, abrasion, and some actions of living organisms and humans bring about mechanical weathering.

Review

1. Describe the process of ice wedging. In what environment is ice wedging most likely to happen?
2. Describe the process of abrasion.
3. How do plants and animals cause mechanical weathering?

Explore More

Use this resource to answer the questions that follow.



1. What is physical weathering?
2. How do trees break down solid rock?
3. What causes the most common type of physical weathering?
4. What percent does water expand?
5. How does water break apart a rock?

This page titled 13.2: Mechanical Weathering is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

13.3: Chemical Weathering



Why is the rock different colors on the surface and in the interior?

This rock is at South Mountain Park in the Phoenix metropolitan area. The climate is often hot and arid. What colors are the rock in this photo? What color is the surface of the rock? What color is the interior? Why do you think there are differences in color between the surface and the interior of this rock? How is chemical weathering altering the landscape?

Chemical Weathering

Chemical weathering is different than mechanical weathering. The minerals in the rock change their chemical makeup. They become a different type of mineral or even a different type of rock. Chemical weathering works through chemical reactions that change the rock.

No Longer Stable

Most minerals form deep within Earth's crust. At these depths, temperatures and pressures are much higher than at the surface. Minerals that were stable deeper in the crust are not stable under surface conditions. That's why chemical weathering happens. Minerals that formed at higher temperature and pressure change into minerals that are stable at the surface.

Agents of Chemical Weathering

There are many agents of chemical weathering. Remember that water was a main agent of mechanical weathering. Well, water is also an agent of chemical weathering. That makes it a double agent! Carbon dioxide and oxygen are also agents of chemical weathering. Each of these is discussed below.

Water

Water is an amazing molecule. It has a very simple chemical formula, H_2O. It is made of just two hydrogen atoms bonded to one oxygen atom. Water is remarkable in terms of all the things it can do. Lots of things dissolve easily in water. Some types of rock can even completely dissolve in water (**Figure** below)! Other minerals change by adding water into their structure. **Hydrolysis** is the name of the chemical reaction between a compound and water.



Weathered rock in Walnut Canyon near Flagstaff, Arizona.

Carbon Dioxide

Carbon dioxide (CO_2) combines with water as raindrops fall through the air. This makes a weak acid, called carbonic acid. This happens so often that carbonic acid is a common, weak acid found in nature. This acid works to dissolve rock. It eats away at

sculptures and monuments. While this is normal, more acids are made when we add pollutants to the air. Any time we burn any fossil fuel, it adds nitrous oxide to the air. When we burn coal, rich in sulfur, it adds sulfur dioxide to the air. As nitrous oxide and sulfur dioxide react with water, they form nitric acid and sulfuric acid. These are the two main components of acid rain. Acid rain accelerates chemical weathering.

Oxygen

Oxygen strongly reacts with elements at the Earth's surface. This process is called **oxidation**. You are probably most familiar with the rust that forms when iron reacts with oxygen. Many minerals are rich in iron. Red rocks are full of iron oxides (**Figure** below). As iron changes into iron oxide, the iron oxides can also make red color in soils.



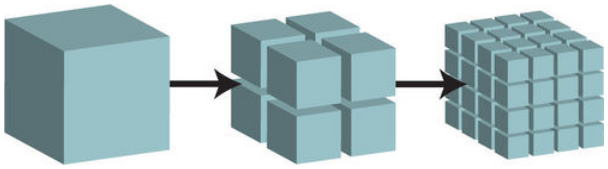
The red rocks of Monument Valley are due to the oxidation of iron in the rock.

Plants and Animals

Plants and animals also cause chemical weathering. As plant roots take in nutrients, they remove elements from the minerals. This causes a chemical change in the rock.

Mechanical Weathering and Chemical Weathering

Mechanical weathering increases the rate of chemical weathering. As rock breaks into smaller pieces, the surface area of the pieces increases. With more surfaces exposed, there are more places for chemical weathering to occur (**Figure** below). Let's say you wanted to make some hot chocolate on a cold day. It would be hard to get a big chunk of chocolate to dissolve in your milk or hot water. Maybe you could make hot chocolate from some smaller pieces like chocolate chips, but it is much easier to add a powder to your milk. This is because the smaller the pieces are, the more surface area they have. Smaller pieces dissolve more easily.



As rock breaks into smaller pieces, overall surface area increases.

Mechanical weathering may increase the rate of chemical weathering.

Summary

- Chemical weathering changes the composition of a mineral to break it down.
- Water chemically weathers rock in hydrolysis.
- Carbon dioxide chemically weathers rock by creating acids.
- Oxygen chemically weathers rock by combining with a metal.

Review

1. What is hydrolysis?
2. How does carbon dioxide lead to chemical weathering?

3. How does mechanical weathering increase the effectiveness of chemical weathering processes?
4. How do plants contribute to chemical weathering?

Explore More

Use the resource below to answer the questions that follow.



1. What is chemical weathering?
2. What are the three ways chemical weathering occurs?
3. What is oxidation? What does it produced?
4. What is carbonation? What does it create?
5. What is hydration? What does it do?
6. In what type of environment is chemical weathering most likely to occur?

This page titled 13.3: Chemical Weathering is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

13.4: Influences on Weathering



How is weathering different in these two places?

Weathering varies for a lot of reasons. If you compare these two photos, one reason stands out. On the left, there is a lot of plant life. On the right, not so much. Why is the amount of plant life so different? The left is a rainforest, with a warm and wet climate. The right is a desert, with a warm and dry climate. Climate is very important for causing weathering. The way a landscape is modified depends on the climate of the region and other factors.

Rock and Mineral Type

Some types of minerals weather easily. Some types of minerals are very resistant to weathering. Some minerals in a rock might completely dissolve in water. This leaves behind the more resistant minerals, which are released from the rock. A beautiful example of this effect is the "Stone Forest" in China, shown in the video below:



Rocks also weather differently. Igneous rocks are usually solid and are more resistant to weathering. Intrusive igneous rocks weather slowly because it is hard for water to penetrate them. Sedimentary rocks usually weather more easily. For example, limestone dissolves in weak acids like rainwater.

Different types of sedimentary rocks can weather differently. This will lead to differential erosion. In the photo of the Grand Canyon, some layers create cliffs. These are hard rocks that do not weather easily. Rock layers that resist weathering and erosion form the top of the canyon and the top of features. Softer layers form slopes. These are rocks that weather more easily (**Figure** below).



The rocks in this photo of the Grand Canyon are all sedimentary. Hard rocks that are resistant to weathering form cliffs. Softer rocks that weather more easily form slopes.

Climate

Climate is the temperature plus precipitation of an area over a long period of time. Climate affects chemical weathering. Chemical weathering increases as:

- Temperature increases. Chemical reactions are faster at higher temperatures.
- Precipitation increases. Chemical reactions increase when there is more water. Since water increases both mechanical and chemical weathering, more water strongly increases weathering.

Look at how temperature and precipitation change weathering. What type of climate has the lowest weathering rate? A cold, dry climate. A warm, wet climate has the highest weathering rate.

Vegetation

Plants increase mechanical and chemical weathering. Plant roots may enter cracks in rock and break it apart. Plant debris may increase the amount of acid in water. The warmer and wetter a climate is, the more plants it will have. Bacteria also grow more in warm, wet regions. So, warm, wet climates have more weathering from biological processes.

Resources from Weathering

Weathering may concentrate some resources. In tropical climates, chemical weathering can be intense. Some minerals dissolve and water carries them away. This leaves behind the materials that are not soluble. **Bauxite** is aluminum oxide that collects this way. Bauxite is our main source of aluminum ore.

Summary

- Different minerals and rocks weather at different rates under the same conditions.
- Different temperature and precipitation will cause the same materials to weather differently.
- Vegetation increases weathering, both mechanical and chemical.

Review

1. Why are igneous rocks more resistant to weathering than sedimentary rocks?
2. What types of rocks weather most readily? Why?
3. What types weather least readily? Why?
4. What climate types cause more intense weathering? What climate types cause less intense weathering?
5. How do plants increase both types of weathering?
6. How does bauxite form? What resource comes from bauxite?

This page titled 13.4: Influences on Weathering is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

13.5: Weathering and Soils- Challenge 1

1. A river picks up sediments from its banks and moves them with the current. This is an example of ___.

erosion

2. ___ is the breakdown of solid rocks into sediments.

Weathering

3. ___ is the process by which sediments are removed from a given location, such as a rock face or riverbank.

Erosion

4. ___ occurs when a rock is scraped by rocks or other particles.

Abrasion

5. Scratches from rocks in a moving glacier are signs of ___.

abrasion

6. Mechanical weathering is a ___ process.

physical

7. Acid rain, oxygen, and water can all cause ___.

chemical weathering

8. Dissolution of calcite, rusting of iron-based minerals, and potassium feldspar losing its potassium are all examples of ___.

chemical weathering

9. Quartz sand is very common on beaches because ___.

quartz is resistant to weathering, so it is left behind after other minerals erode away

10. Water increases chemical weathering because ___.

it facilitates chemical reactions

11. The rate of water percolation, the temperature at which weathering takes place, and the type of rock all influence ___.

the rate of weathering

This page titled 13.5: Weathering and Soils- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

13.6: Soil Characteristics



How does soil resemble weathered rock?

The same processes that weather rock create soil. A large part of soil is weathered rock! If weathering processes didn't exist on earth we would have no soil. Earth wouldn't be a very good place to live. There would be very limited plant life and not much way to grow crops.

The Importance of Soil

You learned in the previous concept that weathering produces sediment. Weathering also produces soil.

People could not live on earth without soil! Your life and the lives of many land organisms depend on soil. **Soil** is only a very thin layer over solid rock. Yet, it is the place where reactions between solid rock, liquid water and air take place. Soil anchors plant roots and provides them with water and nutrients. We get wood, paper, cotton, medicines, and even pure water from soil. So soil is a very important resource. Our precious soil needs to be carefully managed and cared for. If we don’t take care of the soil we have, we may not be able to use it in the future.

Characteristics of Soil

Soil is a complex mixture of different materials.

- Some of them are **inorganic**. Inorganic materials are made from non-living substances like pebbles and sand.
- Soil also contains bits of **organic** materials from plants and animals.

In general, about half of the soil is made of pieces of rock and minerals. The other half is organic materials.

In some soils, the organic portion is entirely missing. This is true of desert sand. At the other extreme, a soil may be completely organic. Peat, found in a bog or swamp, is totally organic soil. Organic materials are necessary for a soil to be fertile. The organic portion provides the nutrients needed for strong plant growth.

Soil Texture

The inorganic portion of soil is made of many different size particles. These different size particles are present in different proportions. The sizes and proportions of particles determines some of the properties of the soil.

- Water can flow easily through a **permeable** soil. Spaces between the inorganic particles are large and well connected. Sandy or silty soils are permeable, water-draining types of soils.
- Soils with lots of very small spaces are water-holding soils. When clay is present in a soil, the soil holds together more tightly. Clay-rich soil can hold more water.
- When a soil contains a mixture of grain sizes, the soil is called a **loam** (**Figure** below).

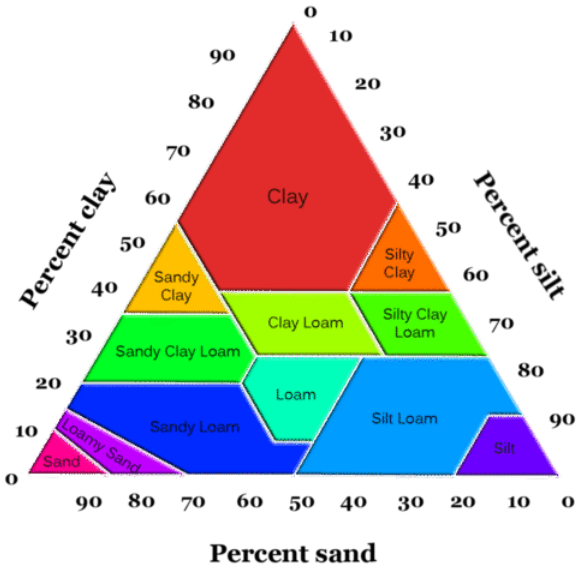
CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



Two layers of soil are shown here. A sandy soil is at the bottom. A soil with more clay is at the top.

Classification

Soil scientists classify soil by measuring the percentage of sand, silt, and clay. They plot this information on a triangular diagram. Each size particle is at one corner (**Figure** below). The soil type is then known from the location on the diagram. At the top, a soil would be clay; at the left corner, it would be sand; at the right corner, it would be silt. Soils in the lower middle with less than 50% clay are loams.



Soil types by particle size.

Soil: The Ecosystem

We can think about soil as a living resource. Soil is an ecosystem all by itself! In the spaces of soil are millions of living organisms. These include earthworms, ants, bacteria, and fungi. (**Figure** below).



Earthworms and insects are important residents of soils.

Further Reading

Soil Formation

Soil Horizons and Profiles

Types of Soils

Soil Erosion

Avoiding Soil Loss

Summary

- Soil reflects the interactions between the lithosphere, atmosphere, hydrosphere, and biosphere.
- Permeable soils allow water to flow through.
- The proportions of silt, clay, and sand allow scientists to classify soil type.

Review

1. What are the inorganic materials that make up a soil?
2. What are the organic materials that make up a soil?
3. In what environment are there no organic materials in soils? What soils are nearly all organic?
4. How are living organisms important to soil?

Explore More

Use the resource below to answer the questions that follow.



1. Why is soil important?
2. How many different types of soils are there? What is the composition of average soil?
3. What is humus?
4. What does the amount of humus determine?
5. How can texture affect plant growth?
6. What type of soil do farmers prefer?
7. How much soil being lost each year in the U.S.?
8. Describe the different types of erosion.

This page titled 13.6: Soil Characteristics is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

13.7: Soil Formation



How are these two soils different?

What color is the soil on the left? What color is the soil on the right? Why do you think they differ so much in color? Which soil do you think is better for growing things? See below to find out!

Soil Formation

How well soil forms and what type of soil forms depends on several different factors, which are described below.

Soil development takes a very long time. It may take hundreds or even thousands of years to form the fertile upper layer of soil. Soil scientists estimate that in the very best soil forming conditions, soil forms at a rate of about 1mm/year. In poor conditions, it may take thousands of years!

Weathering

Soil formation requires weathering. Where there is less weathering, soils are thinner. However, soluble minerals may be present. Where there is intense weathering, soils may be thick. Minerals and nutrients would have been washed out.

Climate

Climate is the most important factor determining soil type. Given enough time, a climate will produce a particular type of soil. The original rock type does not matter. Two rocks of the same type will form a different soil type in each different climate. This is true because most rocks on Earth are made of the same eight elements. When the rock breaks down to become soil, the soil is the same.

The same climate factors that lead to high weathering also produce more soil.

- More rain weathers minerals and rocks more. Rain allows chemical reactions, especially in the top layers of the soil.
- More rain can dissolve more rock. More rain can carry away more material. As material is carried away, new surfaces are exposed. This also increases the rate of weathering.
- Higher temperatures increase the rate of chemical reactions. This also increases soil formation.
- In warmer regions, plants and bacteria grow faster. Plants and animals weather material and produce soils. In tropical regions, where temperature and precipitation are consistently high, thick soils form. Arid regions have thin soils.

Soil type also influences the type of vegetation that can grow in the region. We can identify climate types by the types of plants that grow there.

Parent Rock

The original rock is the source of the inorganic portion of the soil. Mechanical weathering breaks rock into smaller pieces. Chemical reactions change the rock's minerals.

Soil may form in place or from material that has been moved.

- **Residual soil** forms in place. The underlying rock breaks down to form the layers of soil above it. Only about one-third of the soils in the United States are residual.
- **Transported soil** has come in from somewhere else. Sediments can be transported into an area by glaciers, wind, water, or gravity. Soils form from the loose particles that have been transported and deposited.

Slope

Weathered material washes off steep slopes and so does not stay in place to form soil. Soil forms where land areas are flat or gently undulating.

Time

Soils thicken as the amount of time available for weathering increases. The longer the amount of time that soil remains in a particular area, the thicker it will be.

Biological Activity

Biological activity produces the organic material in soil. **Humus** forms from the remains of plants and animals. It is an extremely important part of the soil. Humus coats the mineral grains. It binds them together into clumps that hold the soil together. This gives the soil its structure. Soils with high humus are better able to hold water. Soils rich with organic materials hold nutrients better and are more fertile. These soils are more easily farmed.

The color of soil indicates its fertility. Black or dark brown soils are rich in nitrogen and contain a high percentage of organic materials. Soils that are nitrogen poor and low in organic material might be gray, yellow, or red (**Figure** below). Soil with low organic material is not good for growing plants.



This sandy soil shows evidence of very little organic activity. Plants grow, but are far apart and short-lived. This means that little soil can form. The soil that's there has little organic content.

Summary

- Many factors affect soil formation. Some are climate, rock type, slope, time, and biological activity. Differences in these factors may produce different types of soil.
- Soil type determines what can grow in a region.
- Humus is the decayed remains of living organisms. Humus makes soil fertile.

Review

1. Why is climate more important than rock type for determining the type of soil that forms?
2. How would you create a very thick, organic-rich soil?
3. How would you create a very thin, sandy soil?
4. Why is time important for soil formation?

Explore More

Use the resource below (start at 0:50) to answer the questions that follow.



1. What does soil start as? What changes that material?
2. What is really important in creating a good soil?
3. What makes up soil texture?
4. What types of soil holds water? What type holds air?
5. What does a gardener need to do to the soil to make it better for growing plants?

This page titled 13.7: Soil Formation is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

13.8: Soil Horizons and Profiles



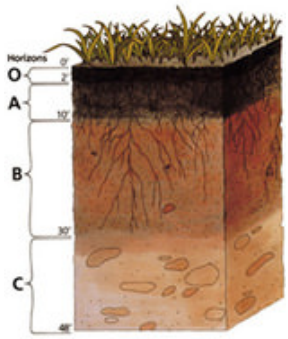
What's beneath your car tires?

Beneath an asphalt road is this incredible soil profile. Can you identify the horizons? There are some clues in the photo that can help you identify the climate type. What type of climate would produce this soil?

Soil Horizons and Profiles

Soil develops over time and forms soil horizons. **Soil horizons** are different layers of soil with depth. The most weathering occurs in the top layer. This layer is most exposed to weather! It is where fresh water comes into contact with the soil. Each layer lower is weathered just a little bit less than the layer above. As water moves down through the layers, it is able to do less work to change the soil. This is because the chemical reactions have already occurred.

If you dig a deep hole in the ground, you may see each of the different layers of soil. All together, the layers are a **soil profile**. Each horizon has its own set of characteristics (**Figure** below). In the simplest soil profile, a soil has three horizons.



In this diagram, a cross-section of soil shows different soil layers.

Topsoil

The first horizon is the “A“ horizon. It is more commonly called the **topsoil**. The topsoil is usually the darkest layer of the soil. It is the layer with the most organic material. Humus forms from all the plant and animal debris that falls to or grows on the ground. The topsoil is also the region with the most biological activity. Many organisms live within this layer. Plant roots stretch down into this layer. The roots help to hold the topsoil in place. Topsoil is needed to grow most crops (**Figure** below).



Good topsoil is great for growing plants.

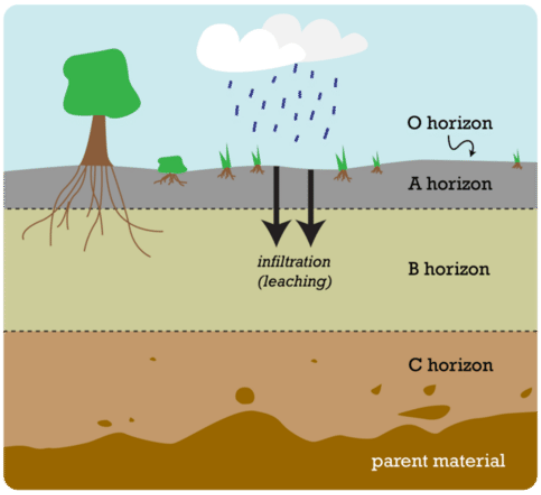
Topsoil usually does not have very small particles like clay. Clay-sized particles are carried to lower layers as water seeps down into the ground. Many minerals dissolve in the fresh water that moves through the topsoil. These minerals are carried down to the lower layers of soil.

Subsoil

Below the topsoil is the "B" horizon. This is also called the **subsoil**. Soluble minerals and clays accumulate in the subsoil. Because it has less organic material, this layer is lighter brown in color than topsoil. It also holds more water due to the presence of iron and clay. There is less organic material in this layer.

C Horizon

The next layer down is the "C" horizon. The **C horizon** is made of partially altered bedrock. There is evidence of weathering in this layer. Still, it is possible to identify the original rock type from which this soil formed (**Figure** below).



This image shows the various soil horizons.

Not all climate regions develop soils. Arid regions are poor at soil development. Not all regions develop the same soil horizons. Some areas develop as many as five or six distinct layers. Others develop only a few.

Summary

- Soil horizons are layers within a soil. Different soil horizons show different amounts of alteration.
- Soil profiles reveal the different layers of soil.
- Soil layers include topsoil, subsoil, and the C horizon.
- Topsoil has the highest proportion of organic material. Topsoil is essential for farming.

Review

1. What is topsoil? Why is topsoil so important for growing plants?
2. How does weathering produce soil?
3. Why does the C horizon most resemble the parent material?

Explore More

Use the resource below to answer the questions that follow.



1. What are the two main components of the A horizon and what is different about them?
2. What is in the O-horizon? What is its more common name?
3. What distinguishes the E-horizon from the horizons above and below?
4. In what regions do soils have an E-horizon?
5. What are the characteristics of the B-horizon?
6. How does the C-horizon differ from the other horizons?
7. What is below the C-horizon?

This page titled 13.8: Soil Horizons and Profiles is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

13.9: Types of Soils



Where would you rather grow crops?

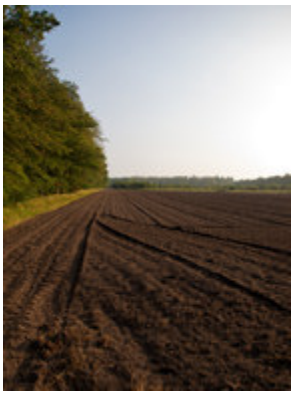
The soil on the left is in Tuscany in Italy. Tuscany is known best for growing grapes for wine and olives for olive oil. The soil on the right is in China. It is the soil that remained when rainforest trees were removed. Do you know which soil would be better for crops?

Types of Soils

For soil scientists, there are thousands of types of soil! Soil scientists put soils into very specific groups with certain characteristics. Each soil type has its own name. Let's consider a much simpler model, with just three types of soil. These types are based on climate. Just remember that there are many more than just these three types.

Pedalfer

One important type of soil forms in a **deciduous forest**. In these forests, trees lose their leaves each winter. Deciduous trees need lots of rain — at least 65 cm of rainfall per year. Deciduous forests are common in the temperate, eastern United States. The type of soil found in a deciduous forest is a **pedalfer** (**Figure** below). This type of soil is usually dark brown or black in color and very fertile.



The soil beneath a deciduous forest is a pedalfer. These soils are very fertile.

Pedocal

Pedocal soil forms where grasses and brush are common (**Figure** below). The climate is drier, with less than 65 cm of rain per year. With less rain, there is less chemical weathering and organic material, and the soils are slightly less fertile.



Grassland soils are less rich than soils in more humid regions.

Laterite

A third important type of soil is **laterite**. Laterite forms in tropical areas. Temperatures are warm and rain falls every day (**Figure** below). So much rain falls that chemical weathering is intense. All soluble minerals are washed from the soil. Plant nutrients get carried away. There is practically no humus. Laterite soils are often red in color from the iron oxides. If laterites are exposed to the Sun, they bake as hard as a brick.



Laterite soils, which are found beneath rainforests, are not good for growing crops.

Summary

- Pedalfer is the soil common in deciduous forests. Pedalfer is dark brown and fertile.
- Pedocal is the soil common in grasslands. The more arid climate increases calcium in the soil. Pedocal is not as fertile.
- Laterite forms in tropical rain forests. Chemical weathering strips the soils of their nutrients. When the forest is removed the soil is not very fertile.

Review

1. What is pedocal? How much chemical weathering leads to this soil type and why?
2. What is the plant life found with pedocal soils? How much organic material do they contain?
3. What is pedalfer? How much chemical weathering leads to this soil type and why?
4. What is the plant life found with pedalfer soils?
5. What is laterite? How much chemical weathering leads to this soil type and why?
6. What is the plant life found with laterite soils?
7. If a forest is leveled so that a laterite soil is exposed to the Sun, what happens to it?

Explore More

Use the resources below to answer the questions that follow.



1. What is laterite?
2. Where is it found?
3. What zones are in laterite? What process or lack of that process produces each zone?
4. How does an ore body with a high amount of metals form in these soils?

This page titled 13.9: Types of Soils is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

13.10: Soil Erosion



Could it happen again?

Farmers were forced off their lands during the **Dust Bowl** in the 1930s. The rains stopped, and the topsoil blew off these former grasslands. This scene was repeated throughout the central United States. During long droughts, some people wonder if another dust bowl could come.

Causes of Soil Erosion

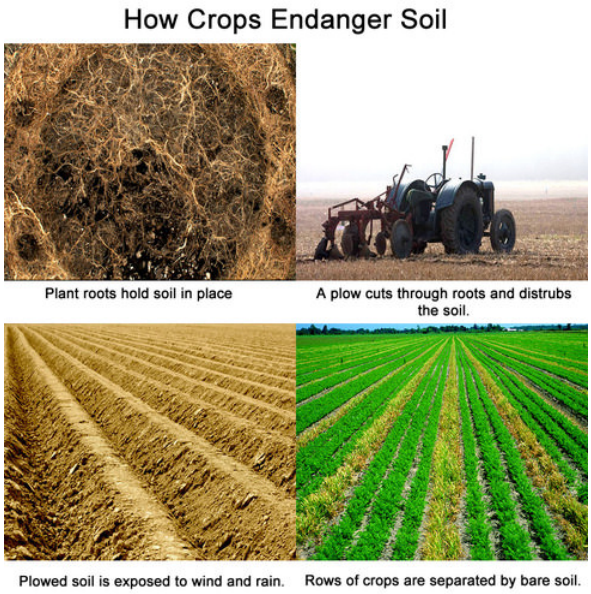
The same agents that erode landscapes also erode soil. They are water, wind, ice, or gravity. Running water is the leading cause of soil erosion. Water is abundant and has a lot of power. Wind is also a leading cause of soil erosion. Wind can pick up soil and blow it far away.

Activities that remove vegetation, disturb the ground, or allow the ground to dry are activities that increase erosion. What are some human activities that increase soil erosion?

Farming

The photos below (**Figure** below) show how farming practices can increase soil erosion. Plant roots penetrate the soil and keep it from eroding. Plowing turns over bare soil and cuts through plant roots. Bare soil is exposed to wind and water. In the past, farmers always plowed fields before planting.

The problem doesn't stop with plowing. Crops are usually planted in rows with bare soil in between the rows. In places where crops grow only during part of the year, the land may be bare for a few months.



Farming leaves some soil exposed to erosion.

The soil that is most likely to erode is the nutrient-rich topsoil. The loss of topsoil degrades the farmland.

Grazing

As pictured below (**Figure** below), some grazing animals, especially sheep and goats, eat grass right down to the roots. They may even pull the grass entirely out of the ground. Grazing animals can kill the grass. They may thin it out so much that it offers little protection to the soil. If animals are kept in the same place too long, the soil may become completely bare. The bare soil is easily eroded by wind and water.



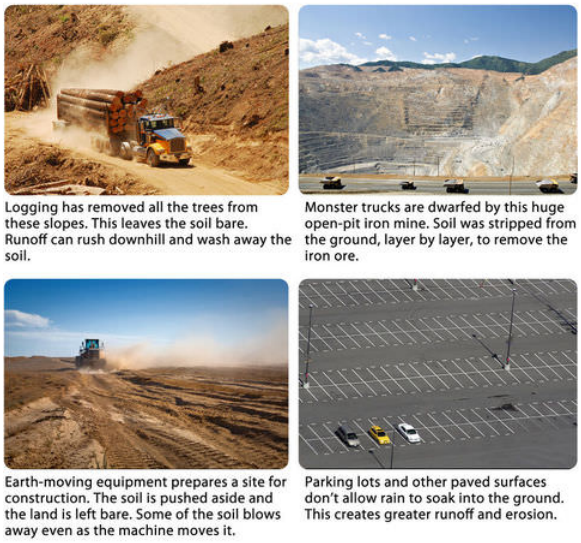
Sheep and goats can damage plants and leave the soil bare.

Logging, Mining, and Construction

Other human actions that put soil at risk include logging, mining, and construction. You can see examples of each below (**Figure** below).

- When forests are cut down, the soil is suddenly exposed to wind and rain. Without trees, there is no **leaf litter** to cover the ground and protect the soil. When leaf litter decays, it adds humus and nutrients to the soil.
- Mining and construction strip soil off the ground and leave the land bare.
- Paved roads and parking lots prevent rainwater from soaking into the ground. This increases runoff and the potential for soil erosion.

Logging, Mining, and Construction



Logging has removed all the trees from these slopes. This leaves the soil bare. Runoff can rush downhill and wash away the soil.

Monster trucks are dwarfed by this huge open-pit iron mine. Soil was stripped from the ground, layer by layer, to remove the iron ore.

Earth-moving equipment prepares a site for construction. The soil is pushed aside and the land is left bare. Some of the soil blows away even as the machine moves it.

Parking lots and other paved surfaces don't allow rain to soak into the ground. This creates greater runoff and erosion.

Logging, mining, construction, and paving surfaces are some of the ways that soil erosion increases.

Recreation

Even things that people do for fun can expose soil to erosion. For example, overuse of hiking trails can leave bare patches of soil. Off-road vehicles cause even more damage; examples of this are pictured below (**Figure** below).



What's fun for people may be bad for soil. Off-road vehicles can destroy plants and leave the ground bare. This sets up the soil for erosion.

Soil erosion is a natural occurrence. However, human activities have greatly accelerated soil erosion. In some locations, soil may now be eroding about 10 times faster than its natural rate. Since Europeans settled in the United States, approximately one-third of the topsoil has eroded away.

Summary

- Soil erosion is a natural process, but human activities can increase it.
- The main agents of soil erosion are water and wind.
- Soil erosion is more likely where the ground has been disturbed. Farming, grazing animals, logging, mining, construction, and recreational activities can do this.

Review

1. What are the agents of soil erosion?
2. How does farming accelerate soil erosion?
3. How does grazing accelerate soil erosion?
4. What is common about the human activities that increase soil erosion, such as logging, hiking, or driving an off-road vehicle?

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

5. What happens when the rate of soil erosion increases?
6. Which layer of soil is usually lost?

Explore More

Use the resource below to answer the questions that follow.



1. Why was the steel plow important?
2. What was needed during World War I?
3. Why was the soil of this region particularly vulnerable to erosion?
4. What had occurred by 1929?
5. What happened in 1930? What was the problem with replacing prairie grasses with crops?
6. What was a black blizzard?
7. How could the Dust Bowl have been prevented?
8. How has this region survived more recent droughts? Think about other sections you've studied, what might another reason be?

This page titled 13.10: Soil Erosion is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

13.11: Avoiding Soil Loss



Why did someone cut designs into this hillside?

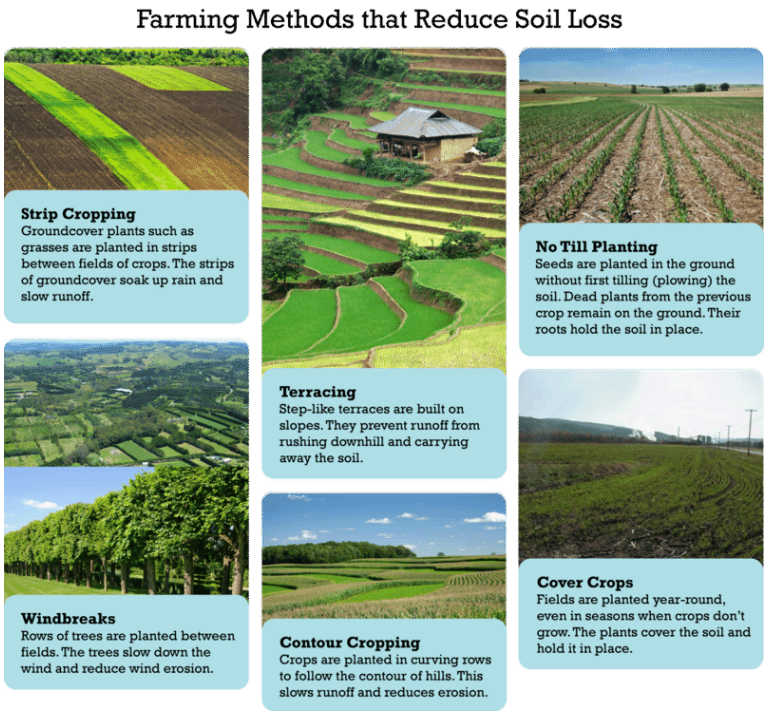
Although the hillside is interesting, that's not why this was done. Terracing prevents soil erosion on a hillside that is being farmed. Many techniques can be utilized to reduce soil erosion.

Preventing Soil Erosion

Soil is a renewable resource, but it can take thousands of years to form. That’s why people need to do what they can to prevent soil erosion.

Farming Methods That Reduce Soil Erosion

The Dust Bowl taught people that soil could be lost by plowing and growing crops. New ways of farming were developed to protect the soil. Some of the methods are described below (**Figure** below).



There are many farming methods that help prevent soil erosion.

Other Ways to Reduce Soil Erosion

There are several other ways to help prevent soil loss. Some of them are pictured below (**Figure** below).

- Prevent overgrazing. Frequently move animals from field to field. This gives the grass a chance to recover.

- Avoid logging steep hillsides. Cut only a few trees in any given place. Plant new trees to replace those that are cut down.
- Reclaim mine lands. Save the stripped topsoil and return it to the land. Once the soil is in place, plant trees and other plants to protect the bare soil.
- Use barriers to prevent runoff and soil erosion at construction sites. Plant grass to hold the soil in place.
- Develop paving materials that absorb water and reduce runoff.
- Restrict the use of off-road vehicles, especially in hilly areas.



Taking steps to control erosion can help save soil.



Summary

- Soil is a renewable resource. Sometimes it is lost faster than it can be replaced.
- Farming methods that can reduce soil erosion include terracing, contour cropping, windbreaks, and no-till planting.
- Caution with grazing, recreational activities and reclaiming used lands can help reduce soil erosion.

Review

1. Why is it so important to reduce soil erosion?
2. What are some of the agricultural practices that can reduce soil erosion?
3. How can soil erosion be reduced where trees are logged?
4. Why should a forest be replaced if it is logged?

This page titled 13.11: Avoiding Soil Loss is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

13.12: Weathering and Soils- Challenge 2

1. Soil that is so rich in organic matter that it can be burned is called ___.

peat

2. Any material through which water (or any other liquid or gas) can move through is ___.

permeable

3. The rock and mineral contents of soil are ___, while humus is organic.

inorganic

4. In a soil profile, deeper horizons are ___ altered and ___ like the original rock.

less; more

5. Iron oxide and clay accumulate in the ___ of the soil profile.

subsoil

6. ___ has the highest proportion of organic matter in the soil profile.

Topsoil

7. ___ can bake as hard as a brick if exposed to the Sun.

Laterite

8. The rate of soil formation under ideal conditions--intermediate topography, proper climate, and a good balance of organisms--is ___.

1 mm/year

9. ___ forms in tropical rainforests.

Laterite

10. To reduce erosion in cities, ___.

include green spaces where plants can grow

11. Crop rotation, planting nutrient-rich cover crops, and alternating the types of crops planted in each row all help prevent ___.

soil erosion

12. Preventing soil erosion ___ crop yields and ___ existing ecosystems.

improves; protects

This page titled 13.12: Weathering and Soils- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

14: Erosion and Deposition

14.1: Erosion by Streams
14.2: Deposition by Streams
14.3: Erosion by Groundwater
14.4: Deposition by Groundwater
14.5: Erosion and Deposition- Challenge 1
14.6: Erosion by Waves
14.7: Deposition by Waves
14.8: Protecting Shorelines
14.9: Erosion by Wind
14.10: Deposition by Wind
14.11: Erosion and Deposition- Challenge 2
14.12: Erosion by Glaciers
14.13: Deposition by Glaciers
14.14: Landforms from Erosion and Deposition
14.15: Erosion and Deposition- Challenge 3

This page titled 14: Erosion and Deposition is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

14.1: Erosion by Streams



What's different about these landscapes?

Both of these rivers run through Yellowstone National Park. The Firehole River is a tributary of the Madison. In this photo, it's flowing over flat ground. The Yellowstone River on the right is cascading over Yellowstone Falls. Which river is doing more erosion? In what direction is the stream eroding?

Erosion by Surface Water

Water that flows over Earth's surface includes runoff, streams, and rivers. All these types of flowing water can cause erosion and deposition.

Erosion by Runoff

When a lot of rain falls in a short period of time, much of the water is unable to soak into the ground. Instead, it runs over the land. Gravity causes the water to flow from higher to lower ground. As the runoff flows, it may pick up loose bits of soil and sand.

Runoff causes more erosion if the land is bare. Plants help hold the soil in place. The runoff water pictured below (**Figure** below) is brown because it eroded soil from a bare, sloping field. Can you find evidence of erosion by runoff where you live? What should you look for?



Runoff has eroded small channels through this bare field.

Much of the material eroded by runoff is carried into bodies of water, such as streams, rivers, ponds, lakes, or oceans. Runoff is an important cause of erosion. That's because it occurs over so much of Earth's surface.

Erosion by Streams

Streams erode sediment from their banks. They pick up and transport sediments.

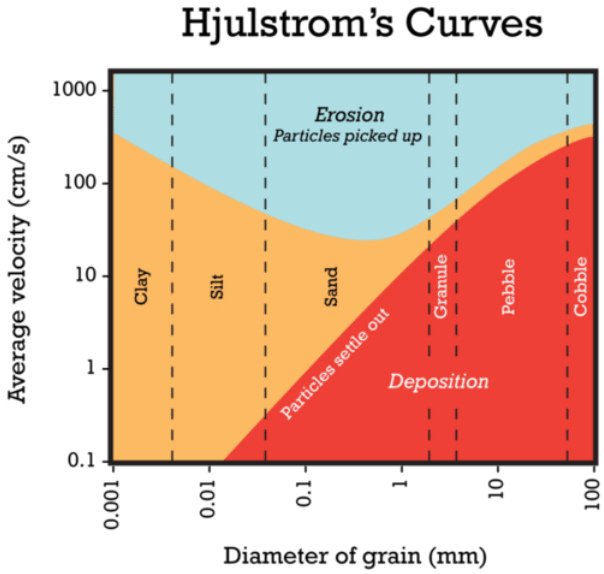


A stream in the desert rushes past its banks. The power of the water erodes the cliff face.

As a stream erodes its banks, it creates a V-shaped valley (**Figure** above). This contrasts with the U-shaped valleys created by glaciers.

Erosion and Water Speed

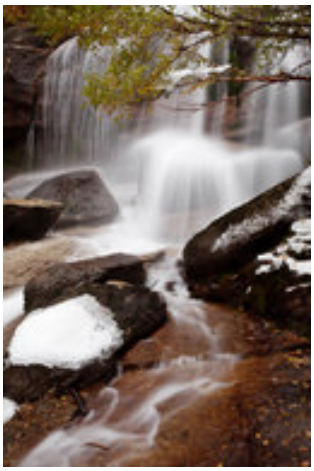
Erosion by a stream depends on the velocity of the water. Fast water erodes more material than slow water. Eventually, the water deposits the materials. As water slows, larger particles are deposited first. As the water slows even more, smaller particles are deposited. The graph pictured below (**Figure** below) shows how water velocity and particle size influence erosion and deposition.



Flowing water erodes or deposits particles depending on how fast the water is moving. It also depends on how big the particles are.

Erosion in the Mountains

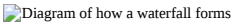
Streams often start in mountains, where the land is very steep (**Figure** below). A mountain stream flows very quickly because of the steep slope. This causes a lot of erosion and very little deposition. The rapidly falling water digs down into the stream bed and makes it deeper. It carves a narrow, V-shaped channel.



This mountain stream is in Whitney Portal in the Sierra Nevada of California. The slope is so steep that water cascades down in a waterfall.

How Waterfalls Form

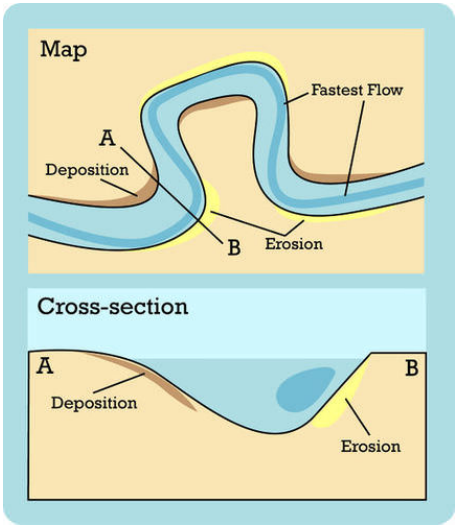
Mountain streams may erode waterfalls. A waterfall forms where a stream flows from an area of harder to softer rock (**Figure** below). The water erodes the softer rock faster than the harder rock. This causes the stream bed to drop down, like a step. This creates a waterfall. As erosion continues, the waterfall gradually moves upstream.



How a waterfall forms and moves. Why does a waterfall keep moving upstream?

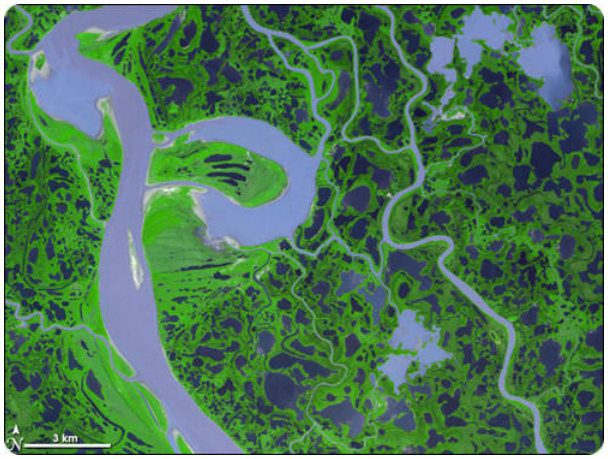
Erosion by Slow-Flowing Rivers

Streams eventually run onto flatter ground. Rivers flowing over gentle slopes erode the sides of their channels more than the bottom. Large curves, called **meanders**, form because of erosion and deposition by the moving water. The curves are called meanders because they slowly "wander," or meander, over the land. Below, you can see how this happens (**Figure** below).



Meanders form because water erodes the outside of curves and deposits eroded material on the inside. Over time, the curves shift position.

As meanders erode from side to side, they create a **floodplain**. This is a broad, flat area on both sides of a river. Eventually, a meander may become cut off from the rest of the river. This forms an **oxbow lake** (**Figure** below).



An oxbow lake forms in the Mackenzie River Delta, Canada.

Science Friday: The Lollipop Hypothesis

Ever wondered how many licks it takes to reach the center of a lollipop? Mathematicians at NYU's applied mathematics lab have designed experiments to determine this. Find out in this video by Science Friday.

403 ERROR

The request could not be satisfied.

Request blocked. We can't connect to the server for this app or website at this time. There might be too much traffic or a configuration error. Try again later, or contact the app or website owner.
If you provide content to customers through CloudFront, you can find steps to troubleshoot and help prevent this error by reviewing the CloudFront documentation.

```
Generated by cloudfront (CloudFront)
Request ID: ZfYoQx_X78lOGcq0ruJhm8NIfCbSpifJBCa62wp5rQxp4uH-Kdwa2w==
```

g

Deposition by Streams

Summary

- Faster water carries more and larger sediment.
- Streams erode their banks to create V-shaped valleys.
- A river on flat ground meanders. When a meander is cut off it may become an oxbow lake.
- A floodplain is where the extra water goes when the river is in flood.

Review

1. Where along a meander does a river erode its banks? Where does it deposit sediment? Why?
2. How does a waterfall form?
3. How does stream erosion in the high mountains differ from that on flatter ground?
4. How does erosion by runoff differ from stream erosion?

This page titled 14.1: Erosion by Streams is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

14.2: Deposition by Streams

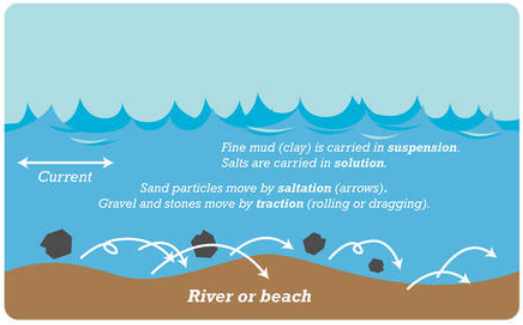


Why is there a pile of rocks in that stream?

A river meanders, causing erosion on one side of its bank. On the other side, sediments are deposited. In this photo of a meander, where is there erosion and where is there deposition?

Sediment Transport

Sediments move differently when carried by water, depending on their size; this is illustrated below (**Figure** below).



How flowing water moves particles. How particles are moved by flowing water depends on their size.

Sediments are carried as:

- **Dissolved load**: Dissolved ions are carried in the water. These ions usually travel all the way to the ocean.
- **Suspended load**: Sediments carried as solids as the stream flows are suspended load. The stream's velocity determines the size of particles that can be carried (**Figure** below).



The Connecticut River is brown from the sediment it carries. The river drops the sediment offshore into Long Island Sound.

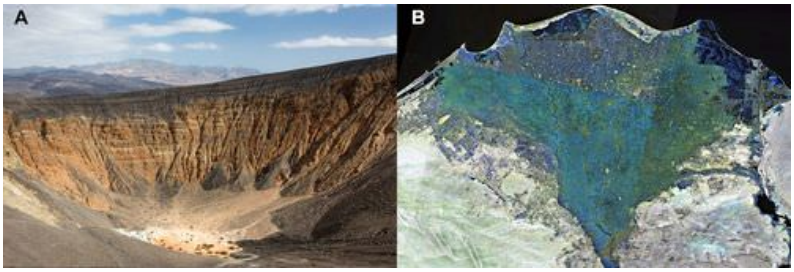
- **Bed load**: Some particles are too large to be carried as suspended load. These sediments are bumped and pushed along the stream bed as bed load. Bed load sediments do not move continuously. This intermittent movement is called **saltation**. Streams with high velocities that flow down steep slopes cut down into the stream bed. The sediments that travel as bed load do a lot of the downcutting.

Deposition by Streams and Rivers

When a stream or river slows down, it starts dropping its sediments. Larger sediments are dropped in steep areas, but smaller sediments can still be carried. Smaller sediments are dropped as the slope becomes less steep.

Alluvial Fans

In arid regions, a mountain stream may flow onto flatter land. The stream comes to a stop rapidly. The deposits form an **alluvial fan** (**Figure** below).



(A) Alluvial fans in Death Valley, California (B) Nile River Delta in Egypt

Deltas

Deposition also occurs when a stream or river empties into a large body of still water. In this case, a **delta** forms. A delta is shaped like a triangle. It spreads out into the body of water. An example is pictured below (**Figure** above).

Deposition by Flood Waters

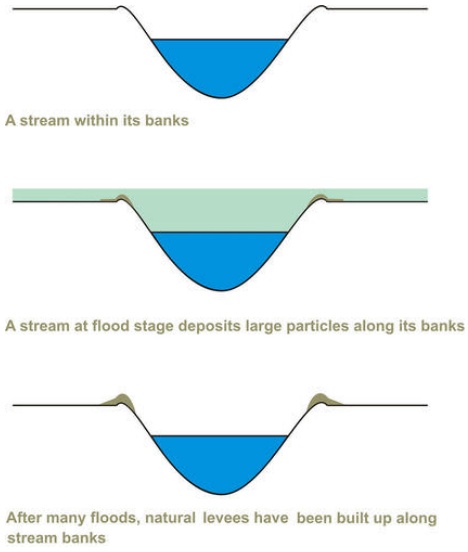
A flood occurs when a river overflows it banks. This might happen because of heavy rains.

Floodplains

As the water spreads out over the land, it slows down and drops its sediment. If a river floods often, the floodplain develops a thick layer of rich soil because of all the deposits. That's why floodplains are usually good places for growing plants. For example, the Nile River in Egypt provides both water and thick sediments for raising crops in the middle of a sandy desert.

Natural Levees

A flooding river often forms natural levees along its banks. A **levee** (**Figure** below) is a raised strip of sediments deposited close to the water's edge. Levees occur because floodwaters deposit their biggest sediments first when they overflow the river's banks.



This diagram shows how a river builds natural levees along its banks.

Summary

- Streams carry dissolved ions and sediments. The sizes of the sediments a stream can carry, its competence, depend on the stream's velocity.
- Particles that are too large to be suspended move along the stream bed by saltation.
- Rivers deposit sediments on levees, floodplains, and in deltas and alluvial fans.

Review

1. If the amount of water in a stream in flood starts to go down, what will happen to sediments the stream is carrying? What will be deposited and where?
2. What happens when a river floods? How are natural levees created?
3. How do alluvial fans form?

Explore More

Use this resource (watch up to 8:00) to answer the questions that follow.



1. What type of structure is the Lighthouse? What is that?
2. What is the rock that eroded away? Why was it removed?
3. What did the canyon start out as? What happened to make the canyon?
4. What rock type is most of the rock in this canyon? Why is that important?
5. What is the river doing now?
6. What is the major agent of erosion in the canyon? What is second?

This page titled 14.2: Deposition by Streams is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

14.3: Erosion by Groundwater



What resources does a coastal city need?

Tulum is a walled city that was once inhabited by the Maya people. Tulum is on the Yucatan Peninsula of Mexico. The beautiful blue Caribbean supplied the Maya with abundant fish. What else would the Maya people have needed? Fresh water is found in cenotes, sinkholes that are common in the Yucatan limestone.

Groundwater Erosion

Some water soaks into the ground. It travels down through tiny holes in soil. It seeps through cracks in rock. The water moves slowly, pulled deeper and deeper by gravity. Water in an underground rock or sediment layer is **groundwater**. Underground water can also erode and deposit material.

Rainwater absorbs carbon dioxide (CO_2) as it falls. The CO_2 combines with water to form carbonic acid. The slightly acidic water is especially good at dissolving limestone. Groundwater creates landforms by dissolving away rock.

Florida is unique for groundwater erosion. The state is extremely flat and made mostly of limestone. Due to the wet climate, groundwater surfaces in many locations. In the Everglades, rivers create a wide floodplain, and groundwater comes to the surface (**Figure** below).



A cypress forest in Everglades National Park needs water to thrive.

Caves

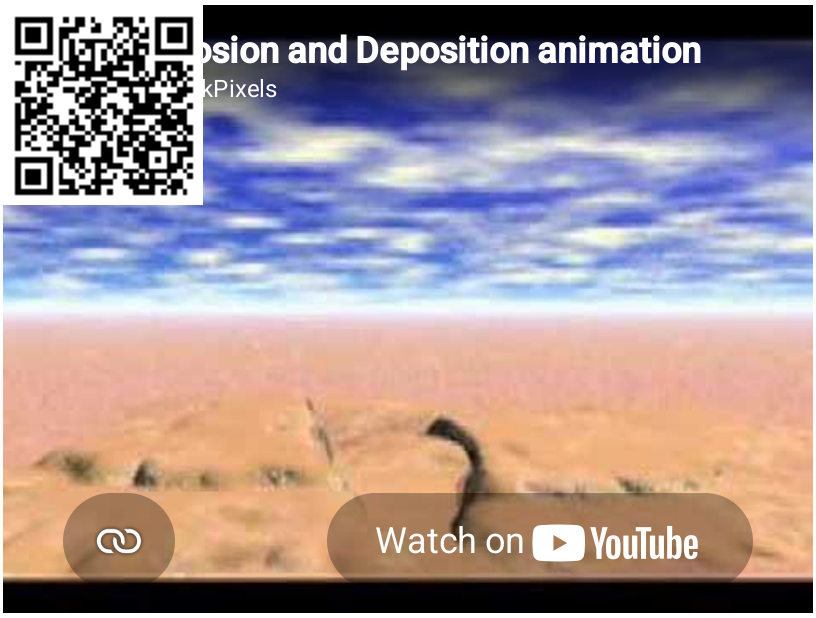
Caves are one of the types of landforms created by groundwater erosion. Working slowly over many years, groundwater travels along small cracks. The water dissolves and carries away the solid rock. This gradually enlarges the cracks. Eventually, a cave, like the one pictured in the **Figure** below, may form.



The Tham Luang Cave in Thailand

Sinkholes

As erosion by groundwater continues, the ceiling of a cave may collapse. The rock and soil above it sink into the ground. This forms a **sinkhole** on the surface. Some sinkholes are large enough to swallow up a home or several homes in a neighborhood.



Further Reading

Deposition by Groundwater

Summary

- Groundwater erodes rock beneath the ground surface. Limestone is a carbonate and is most easily eroded.
- Groundwater dissolves minerals and carries the ions in solution.
- Groundwater erosion creates caves and sinkholes.

Review

1. How does groundwater erode rock?
2. Why is groundwater acidic?
3. How does a cave become a sinkhole?

Explore More

Use the resource below to answer the questions that follow.



1. What is needed to create caves, like Kartchner Caverns?
2. When were they discovered? When did this area become a state park?
3. How long did it take the caverns to form?
4. How are hollow areas created in the limestone?
5. How do the interesting features like stalactites form?
6. Why is protecting the caves important?

This page titled 14.3: Erosion by Groundwater is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

14.4: Deposition by Groundwater



Where would you look for a spectacular cave like this one?

Groundwater dissolves minerals and rocks into ions. Groundwater deposits those ions into different types of structures. Limestone caves are the best place to see these structures. Water erodes the cave, and the deposits form structures like stalactites and stalagmites. The cave pictured here is Carlsbad Caverns in New Mexico.

Cave Deposits

Caves are known for their spectacular mineral structures. Caves are likely to be found in limestone where the groundwater level has gone down. This exposes the cave and its features. **Stalactites** are beautiful icicle-like formations. They form as water containing calcium carbonate drips from the ceiling of a cave. The word "stalactite" has a "c," and it forms from the ceiling. **Stalagmites** form as calcium carbonate drips from the ceiling to the floor of a cave. The stalagmite grow upward. The "g" in "stalagmite" means it forms on the ground. You can see examples of both stalactites and stalagmites below (**Figure** below).



Stalactites hang from the ceiling and stalagmites rise from the floor of a cave. The two together form a column.

If a stalactite and stalagmite join together, they form a **column**. One of the wonders of visiting a cave is to witness the beauty of these amazing and strangely captivating structures.

Giant Crystals

Some of the largest, and most beautiful, natural crystals can be found in the Naica mine, in Mexico. These gypsum crystals were formed over thousands of years. Groundwater that is rich in calcium and sulfur flowed through an underground cave. Check it out:



Summary

- Groundwater dissolves minerals and carries the ions in solution.
- Groundwater deposits the material in caves as stalactites, stalagmites, and columns.
- Giant crystals may be found in caves.

Review

1. How does water create depositional features in a cave?
2. What are stalactites, stalagmites, and columns?
3. Where is the groundwater in a cave we can visit?

This page titled 14.4: Deposition by Groundwater is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

14.5: Erosion and Deposition- Challenge 1

1. Runoff would be massive on a ___.

steep, bare slope

2. As water slows, ___ particles are deposited first.

larger

3. A broad, flat area on both sides of a river is a ___.

floodplain

4. Sediments carried as small solids in the flow of a stream make up the ___ load.

suspended

5. Ions carried by a river make up the ___ load.

dissolved

6. A ___ is a raised strip of sediments deposited close to the water's edge.

natural levee

7. When the ceiling of a cave collapses, a ___ forms on the surface.

sinkhole

8. Groundwater travels along small cracks, dissolving and carrying away the solid rock. Over time this forms a ___.

cave

9. The large and beautiful crystals of the Naica mine in Mexico are made of ___.

gypsum

10. ___ hang from the ceiling of caves, and ___ rise from the ground. Together, they form ___.

Stalactites; stalagmites; columns

11. ___ are the best places to see stalactites and stalagmites.

Limestone caves

This page titled 14.5: Erosion and Deposition- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

14.6: Erosion by Waves

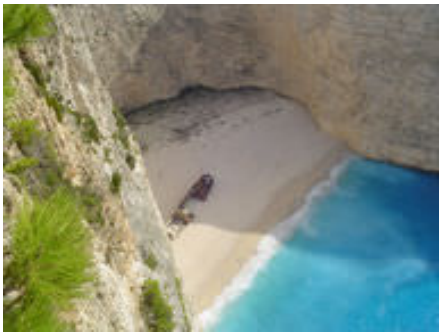


Is this erosion or deposition?

The power of the ocean modifies landforms by erosion and deposition. Landforms modified by both erosion and deposition are seen in this photo. The cliff is being eroded by incoming waves. The beach is being created as sand is being deposited.

Wave Erosion

Wave energy does the work of erosion at the shore. Waves erode sediments from cliffs and shorelines. The sediment in ocean water acts like sandpaper. Over time, they erode the shore. The bigger the waves are and the more sediment they carry, the more erosion they cause (**Figure** below).



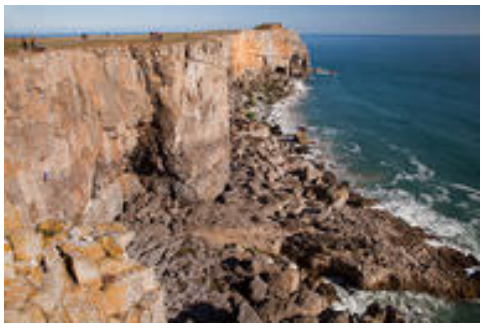
Waves erode sediment from sea cliffs. The sediment is then deposited on beaches. These sandy cliffs are in Greece.

Wave refraction either concentrates wave energy or disperses it. In quiet water areas, such as bays, wave energy is dispersed. This allows sand to be deposited. Land that sticks out into the water is eroded by the strong wave energy. The wave energy concentrates its power on the **wave-cut cliff**.

Landforms From Wave Erosion

Erosion by waves can create unique landforms (**Figure** below).

- **Wave-cut cliffs** form when waves erode a rocky shoreline. They create a vertical wall of exposed rock layers.
- **Wave-cut platforms** are level areas formed by wave erosion. Since these platforms are above sea level, it means that either sea level was higher relative or the rock was lower.



A wave-cut platform is exposed in Pembrokeshire, South Wales.

- **Sea arches** form when waves erode both sides of a cliff. They create a hole in the cliff, like the one pictured below (**Figure** below).



A sea arch creates a natural bridge in California.

- **Sea stacks** form when waves erode the top of a sea arch. This leaves behind pillars of rock.

Sediment Transport

Rivers carry sediments from the land to the sea. Sometimes the sediments are deposited in a delta. But if the waves are powerful, the water will transport the sediments along the coastline. Sediments eroded from cliffs near the shoreline may also be transported.

Wave Refraction

Most waves approach the shore at an angle. The part of the wave that is nearer the shore reaches shallow water sooner than the part that is farther out. The shallow part of the wave "feels" the bottom first. This slows down the inshore part of the wave and makes the wave "bend." This bending is called **refraction**.

Most waves strike the shore at an angle.This creates longshore currents, which move roughly parallel to the shoreline.

Further Reading

Deposition by Waves

Protecting Shorelines

Summary

- Ocean waves have a tremendous amount of energy and so they may do a great deal of erosion.
- Some landforms created by erosion are platforms, arches, and sea stacks.
- Longshore currents are created because water approaches the shore at an angle.

Review

1. What are the two ways an increase in wave energy will increase coastal erosion?
2. How does wave refraction work as a wave approaches a shoreline?
3. Does all the sand at a beach come from currents and waves bringing it in?

Explore More

Use the resource below to answer the questions that follow.



1. What is coastal erosion?
2. What is accretion?
3. What causes erosion to increase?
4. How does rock type affect the rate of erosion? How does this affect the appearance of the coastline?
5. What are the four ways coastal erosion happens?
6. Why are rates of erosion expected to increase?

This page titled 14.6: Erosion by Waves is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

14.7: Deposition by Waves

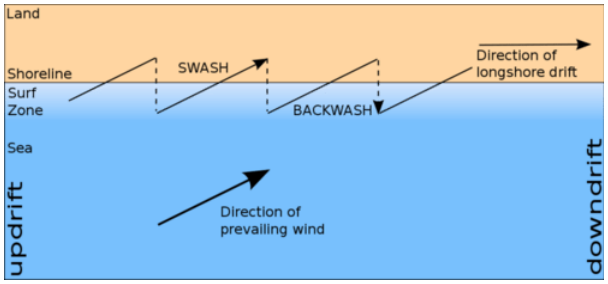


Which came first: erosion or deposition?

Both erosion and deposition are seen in this photo. The beach sands were deposited, but waves are now eroding them away. At the shore, there's always a battle between the two types of forces. What happens when deposition is greater than erosion? What happens when erosion is greater than deposition?

Wave Deposition

The transport of sediments by longshore currents is called **longshore drift**. Longshore drift is created in this way: Sediment is moved up the beach by an incoming wave. The wave approaches at an angle to the shore. Water then moves straight offshore. The sediment moves straight down the beach with it. The sediment is again picked up by a wave that is coming in at an angle. So longshore drift moves sediment along the shore. This zig-zag motion can be seen in **Figure** below.



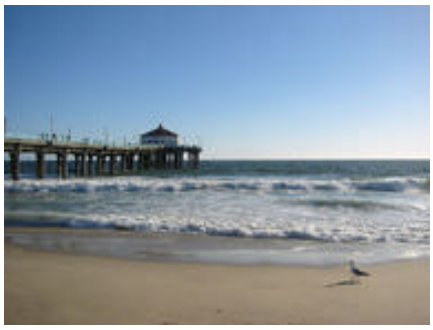
Longshore drift carries particles of sand and rock down a coastline.

Landforms Deposited by Waves

Longshore drift continually moves sand along the shore. Deposition occurs where the water motion slows. The smallest particles, such as silt and clay, are deposited away from shore. This is where the water is calmer. Larger particles are deposited onshore. This is where waves and other motions are strongest.

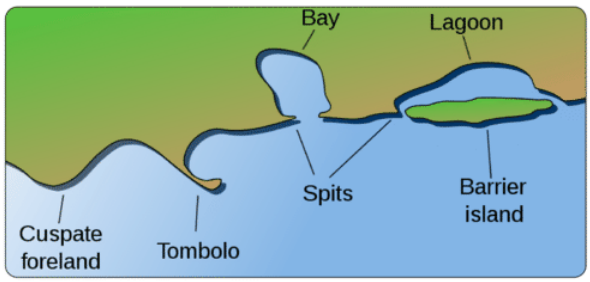
In relatively quiet areas along a shore, waves deposit sand. Sand forms a **beach** (**Figure** below).

https://k12.libretexts.org/@go/page/5569



Manhattan Beach in Southern California has a pier coming off of a sandy beach.

Waves also move sand from the beaches on shore to bars of sand offshore as the seasons change. In the summer, waves have lower energy so they bring sand up onto the beach. In the winter, higher energy waves bring the sand back offshore.



Examples of features formed by wave-deposited sand.

A **spit** is a ridge of sand that extends away from the shore. The end of the spit may hook around toward the quieter waters close to shore.

Waves may also deposit sediments to form sandbars and **barrier islands**. Pictured below are examples of these landforms (**Figure** below); also, an example of all the different landforms waves create (**Figure** above).



A barrier island is a long strip of sand. The sand naturally moves in the local currents. People try to build on barrier islands.

In its natural state, a barrier island acts as the first line of defense against storms such as hurricanes. A natural barrier island is a vegetated sandy areas in which sand can move. When barrier islands are developed, hurricanes damage houses and businesses. A large hurricane brings massive problems to the urbanized area.



Summary

- The shore may have a lot of sediment washed from land or eroded from cliffs. The sediment is transported by currents.
- Transported sand will eventually be deposited on beaches, spits, or barrier islands.

Review

1. What processes cause spits and barrier islands to form?
2. What is longshore drift?
3. Describe how sediment moves along the shore.
4. What function does a barrier island in its natural state serve?

This page titled 14.7: Deposition by Waves is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

14.8: Protecting Shorelines



Why do you see man-made structures on some beaches?

When you go to a beach, you may see man-made structures like these. Most attempt to keep the sand where people want the sand to be. A smaller number keeps the sand from coming into an area where it is not wanted.

Protecting Shorelines

Shores are attractive places to live and vacation. But development at the shore is at risk of damage from waves. Wave erosion threatens many homes and beaches on the ocean. This is especially true during storms, when waves may be much larger than normal. People build several types of structures to protect beaches.

Breakwaters

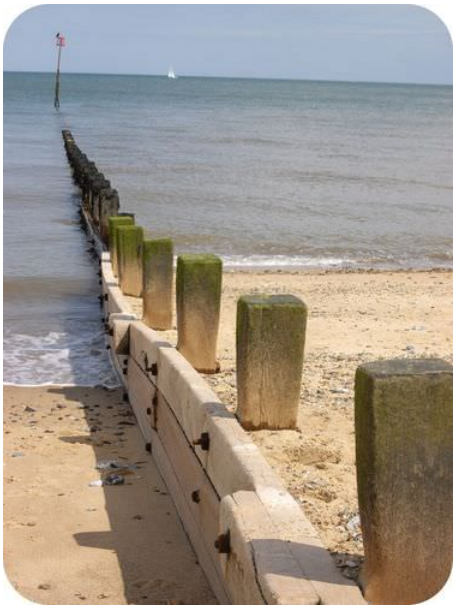
Barrier islands provide natural protection to shorelines. Storm waves strike the barrier island before they reach the shore. People also build artificial barriers, called **breakwaters**. Breakwaters also protect the shoreline from incoming waves. The breakwater pictured below (**Figure** below) runs parallel to the coast like a barrier island.



This rocky breakwater protects the beach at Tenerife in the Canary Islands, Spain.

Groins

Longshore drift can erode the sediment from a beach. To keep this from happening, people may build a series of groins. A **groin** (**Figure** below) is wall of rocks or concrete. The structure juts out into the ocean perpendicular to the shore. A groin stops the longshore movement of sand. Sand collects on the up-current side of the groin. Sand on opposite of side of the groin erodes. This reduces beach erosion.



This groin slows sand on the up-current side. Can you determine which way the water is moving based on where the sand is collecting?

Seawalls

A seawall is also parallel to the shore. However, a seawall is built onshore. **Seawalls** (**Figure** below) protect the shore from incoming waves.



This seawall protects a shore in Vancouver.

Does Protection Work?

People do not always want to choose safe building practices, and instead choose to build a beach house right on the beach. Protecting development from wave erosion is difficult and expensive. The only foolproof way to prevent damage from erosion is to build away from shorelines.

Protection does not always work. The northeastern coast of Japan was protected by anti-tsunami seawalls. Yet waves from the 2011 tsunami that resulted from the Tōhoku earthquake washed over the top of some seawalls and caused others to collapse. Japan is now planning to build even higher seawalls to prepare for any future (and inevitable) tsunami.

Summary

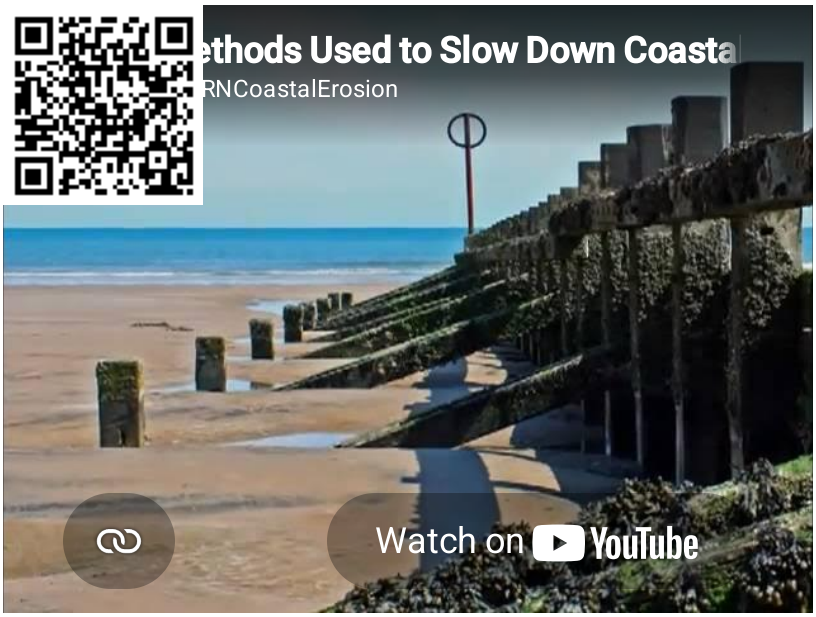
- People love the shore, so they develop these regions and then must protect them.
- Seawalls and breakwaters are built parallel to the shore.
- Groins are built perpendicular to the shore. They trap sand.

Review

1. How does a groin protect a beach?
2. How does a seawall protect a beach?
3. How does a breakwater protect a beach?
4. What are the downsides of protecting beaches with engineering solutions?

Explore More

Use the resource below to answer the questions that follow.



1. What are the two methods to slow down coastal erosion?
2. What is a sea wall? What does it protect the shore from?
3. What is a jetty? What does it protect the shore from?
4. What is a groin? What does it protect the shore from?
5. What are breakwaters? What do they protect the shore from?
6. Why don't people like most of the methods to prevent coastal erosion?
7. What is beach nourishment?
8. What problems does beach nourishment cause?

This page titled 14.8: Protecting Shorelines is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

14.9: Erosion by Wind



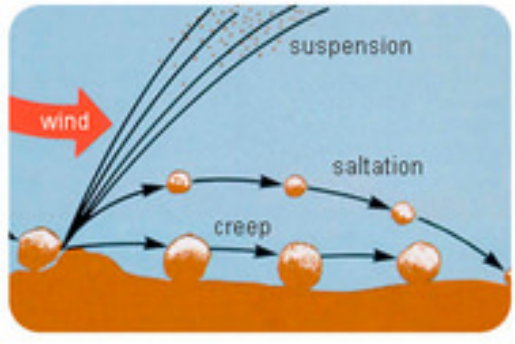
Is wind the greatest erosional force in the desert?

Wind can do remarkable things. It can erode rock to make beautiful shapes. Wind has eroded this rock so that it looks like a rabbit. This limestone formation is in the Sahara Desert in Egypt. Water is the most important erosional force even in the desert. But wind makes its mark in many ways.

Sediment Transport by Wind

Like flowing water, wind picks up and transports particles. Wind carries particles of different sizes in the same ways that water carries them (**Figure** below).

- Tiny particles, such as clay and silt, move by **suspension**. They hang in the air, sometimes for days. They may be carried great distances and rise high above the ground.
- Larger particles, such as sand, move by **saltation**. The wind blows them in short hops. They stay close to the ground.
- Particles larger than sand move by **creep**. The wind rolls or pushes them over the surface. They stay on the ground.



Wind transports particles in different ways depending on their size.

Wind Erosion

Dust storms (**Figure** below) are more common in dry climates. The soil is dried out and dusty. Plants may be few and far between. Dry, bare soil is more easily blown away by the wind than wetter soil or soil held in place by plant roots.



When winds whip up in the desert, they can create tremendous dust storms.

Deflation

Wind blows small particles away. As a result, the ground surface gets lower and rockier; this is called **deflation**. The rocks that are left are called **desert pavement**. Desert pavement is a surface covered by gravel-sized particles that are not easily moved by wind.

Abrasion

Did you ever see workers sandblasting a building to clean it? Sand is blown onto the surface to scour away dirt and debris. Wind-blown sand has the same effect. It scours and polishes rocks and other surfaces. Wind-blown sand may carve rocks into interesting shapes (**Figure** below). This form of erosion is called abrasion. It occurs any time rough sediments are blown or dragged over surfaces. Can you think of other ways abrasion might occur?



This incredible rock formation in Utah is the result of wind erosion.

Desert Varnish

Exposed rocks in desert areas often develop a dark brown or black coating called **desert varnish** (**Figure** below). Wind transports clay-sized particles that chemically react with other substances at high temperatures. The coating is formed of iron and manganese oxides.



Ancient people carved these petroglyphs into desert varnish at Sego Canyon, Utah.

Further Reading

Deposition by Wind

Summary

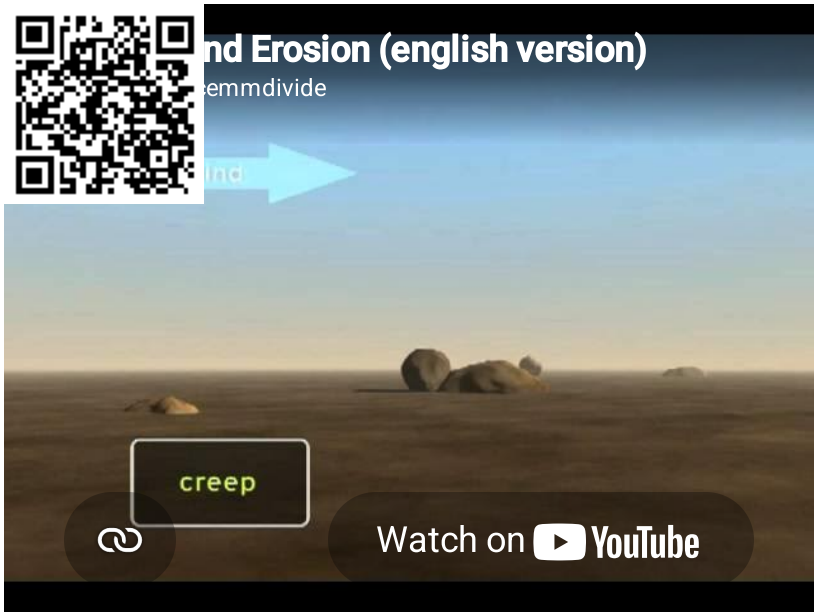
- Wind moves sediments by suspension, saltation, or creep.
- In deserts, wind picks up small particles and leaves behind larger rocks. This forms desert pavement.
- Moving sand may sand blast rocks and other materials causing abrasion.

Review

1. How does desert varnish form?
2. Why are dust storms more common in deserts than in wetter regions?
3. How does wind transport the smallest sediments? How does wind transport sand? How does wind transport particles somewhat larger than sand?

Explore More

Use the resource below to answer the questions that follow.



1. Why is soil erosion a problem?
2. How does wind erosion occur? What is the relationship between wind speed and the amount of erosion?
3. What are the three types of wind erosion?
4. What type of wind erosion moves 50% of the soil?
5. What is creep?
6. What is saltation?
7. What is suspension?
8. When is suspension easily seen?
9. What has accelerated erosion?

This page titled 14.9: Erosion by Wind is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

14.10: Deposition by Wind




How does deposition by wind modify landscapes?

On the right is a desert mountain in Arizona. The surface in the foreground is desert pavement. How did wind modify this landscape? On the left is a desert mountain with sand dunes in Death Valley, California. How did wind modify this landscape? Erosion and deposition by wind leave very different landscapes behind.

Wind Deposition

Like water, when wind slows down it drops the sediment it's carrying. This often happens when the wind has to move over or around an obstacle. A rock or tree may cause wind to slow down. As the wind slows, it deposits the largest particles first. Different types of deposits form depending on the size of the particles deposited.

Sand Dunes

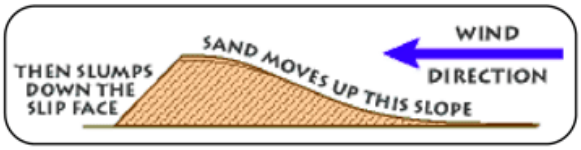
When the wind deposits sand, it forms small hills. These hills are called **sand dunes** (**Figure** below). For sand dunes to form, there must be plenty of sand and wind. Sand dunes are found mainly in deserts and on beaches.



A runner strides across sand dunes. Sand is picked up by her foot as it leaves the dune.

How Sand Dunes Form

What causes a sand dune to form? It starts with an obstacle, such as a rock. The obstacle causes the wind to slow down. The wind then drops some of its sand. As more sand is deposited, the dune gets bigger. The dune becomes the obstacle that slows the wind. This causes more sand to drop. The hill takes on the typical shape of a sand dune (**Figure** below).



A sand dune has a gentle slope on the side the wind blows from. The opposite side has a steep slope. This side is called the slip face.

Migration of Sand Dunes

Once a sand dune forms, it may slowly migrate over the land. The wind moves grains of sand up the gently sloping side of the dune. This is done by saltation. When the sand grains reach the top of the dune, they slip down the steeper side. The grains are pulled by gravity. The constant movement of sand up and over the dune causes the dune to move along the ground. A dune moves in the same direction that the wind usually blows. Can you explain why?

Loess

When the wind drops fine particles of silt and clay, it forms deposits called **loess** (**Figure** below). Loess deposits form vertical cliffs. Loess can become a thick, rich soil. That's why loess deposits are used for farming in many parts of the world.



Loess hills in Missouri are home to the Squaw Creek Wildlife Refuge.

Seafloor Mud

Fine-grained mud in the deep ocean comes from silts and clays brought from the land by wind. The particles are deposited on the sea surface. they slowly settle to the deep ocean floor, forming brown, greenish, or reddish clays. Volcanic ash may also settle on the seafloor.

Summary

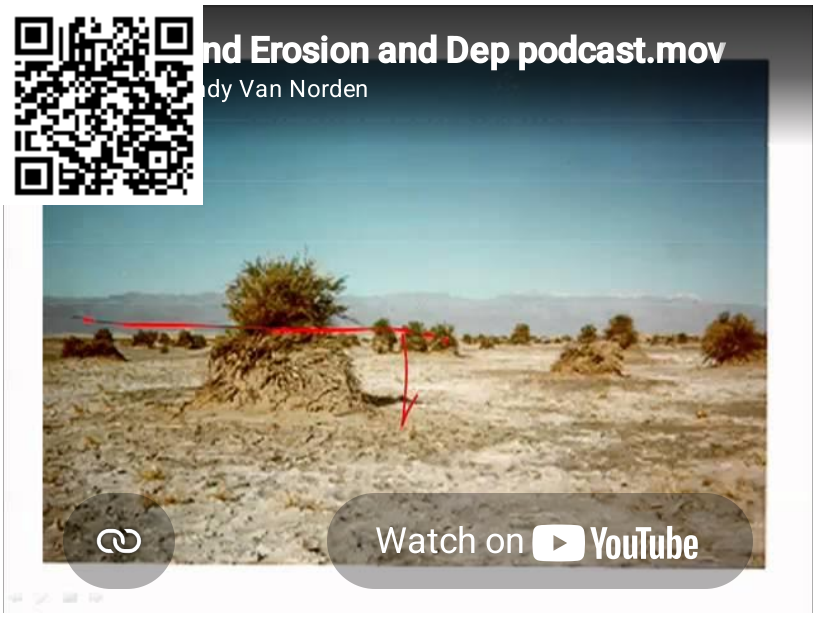
- The sand is transported until it is deposited in a sand dune.
- Sand is blown up a slope. Gravity pulls it down the other side. This is how dunes migrate.
- Loess is very fine wind-blown deposits.

Review

1. Describe how wind deposits sediments as it slows.
2. Describe how sand dunes move.
3. What is loess?

Explore More

Use the resource below to answer the questions that follow.



1. What size particles can wind move and why can't it move other sizes?
2. Why does wind erosion and deposition occur mostly in deserts?
3. Why does a stony pavement form in some desert areas?
4. What is a ventifact? Why is the ventifact in the video narrower at the base than the top?
5. What are sand dunes? Why are they usually made of quartz?
6. What is cross bedding?

This page titled 14.10: Deposition by Wind is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

14.11: Erosion and Deposition- Challenge 2

1. Pillars of rock left behind by wave erosion are known as ___.

sea-stacks

2. When wave action forms a hole in a cliff, it creates a ___.

sea arch

3. ___ are level areas formed by wave erosion.

wave-cut platforms

4. During the winter, sand is ___ from beaches, while during the summer, sand is generally ___ on beaches.

eroded; deposited

5. Deposition occurs when water motion ___.

slows down

6. In general, erosion is greater than deposition on beaches during the ___.

winter

7. A potential problem with groins is that ___.

beaches on the down-current side may be starved of sand

8. ___ are essentially artificial barrier islands.

Breakwaters

9. Seawalls are built ___, while breakwaters are built ___.

onshore; offshore

10. Wind pushes large sediments along the ground in a process known as ___.

creep

11. Wind moves small sediments in the air by ___.

suspension

12. Wind carries intermediate-sized sediments close to the ground by ___.

saltation

13. A sand dune has a ___ slope on the side from which wind blows, and a ___ slope on the opposite side.

gentle; steep

14. Sand dunes form when an obstacle forces wind to ___.

slow down and deposit sand

15. As wind slows, it deposits ___ particles first.

large

This page titled 14.11: Erosion and Deposition- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

14.12: Erosion by Glaciers



In what ways is this glacier creating distinctive landforms?

This glacier is modifying the landscape it's flowing through. Glaciers erode and deposit telltale landforms. They show the direction a glacier flowed and how far it advanced. They create fantastic and unique features in mountain areas. Did glaciers leave clues where you live? If you live in the northern part of the United States, you might be able to find some. Would you know what to look for?

Erosion by Glaciers

Like flowing water, flowing ice erodes the land and deposits the material elsewhere. Glaciers cause erosion in two main ways: plucking and abrasion.

- **Plucking** is the process by which rocks and other sediments are picked up by a glacier. They freeze to the bottom of the glacier and are carried away by the flowing ice.
- **Abrasion** is the process in which a glacier scrapes underlying rock. The sediments and rocks frozen in the ice at the bottom and sides of a glacier act like sandpaper. They wear away rock. They may also leave scratches and grooves that show the direction the glacier moved. These grooves are called **glacial striations**.

Valley Glaciers

Valley glaciers create several unique features through erosion.

- As a valley glacier flows through a V-shaped river valley, it scrapes away the sides of the valley. It carves a U-shaped valley with nearly vertical walls (**Figure** below).



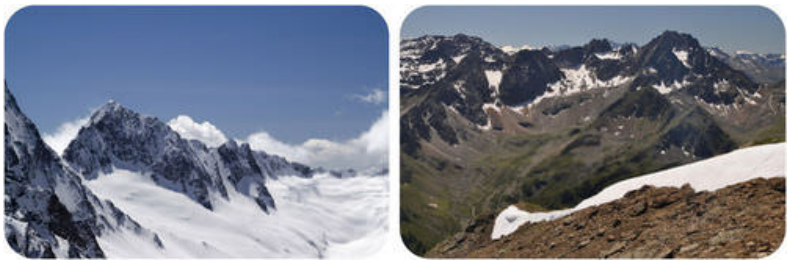
The glacier on the left is carving out the sides of a valley. The U-shaped valley on the right is what will be left when the glacier melts away.

- A **hanging valley** was cut off from the main valley by a larger glacier (**Figure** below).



The waterfall on the right flows through a glacial valley. A larger glacier carved the valley the water falls into. There is a waterfall because this is a hanging valley.

- A **cirque** is a rounded hollow carved near the top of a mountain by a glacier (**Figure** below). This is where the glacier begins. The highest cliff of a cirque is called the headwall.



On the left, there are several cirques where glaciers are originating. A glacier melted and left behind cirques in the mountains on the right.

- An **arête** is a jagged ridge that remains when cirques form on opposite sides of a mountain. A low spot in an arête is called a col.
- A **horn**, like the one pictured below (**Figure** below), is a sharp peak that is left behind when glaciers erode all sides of a mountain.



The Matterhorn in Switzerland is the classic glacial horn.



Further Reading

Deposition by Glaciers

Landforms from Erosion and Deposition by Gravity

Summary

- Glaciers are incredibly powerful agents of erosion.
- Valley glaciers create very distinctive landforms like horns, cirques, and hanging valleys.
- Glaciers pluck rocks from valley walls. This turns a V-shaped river valley into a U-shaped glacial valley.

Review

1. Why do glacial striations show the direction a glacier moved?
2. Describe how these erosional features form: hanging valley, cirque, arete, and horn.
3. How does plucking create a U-shaped valley?

This page titled 14.12: Erosion by Glaciers is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

14.13: Deposition by Glaciers



How could those rocks on the glacier modify the landscape?

Glaciers modify the landscape by erosion. They also modify the landscape by deposition. Glaciers carry an enormous amount of material and dump it. The features they leave behind show where they were and what happened as they were melting away.

Deposition by Glaciers

As glaciers flow, mechanical weathering loosens rocks on the valley walls. These rocks falls onto the glacier. Glaciers can carry rocks of any size, from giant boulders to silt. The glacier may carry the rocks for many kilometers over many years. Glaciers deposit the sediment when they melt. They drop and leave behind whatever was once frozen in their ice.

Erratics

Giant rocks carried by a glacier are eventually dropped. These **glacial erratics**, like the one pictured below (**Figure** below), are noticeable because they are huge. Also, they are usually a different rock type from the surrounding bedrock.



These glacial erratics at Yosemite National Park was deposited by a glacier.

Glacial Till

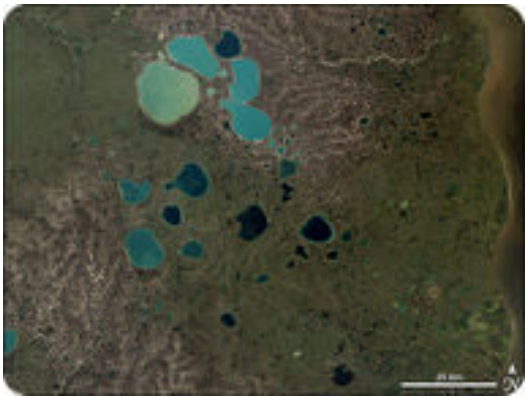
The material dropped by a glacier is usually a mixture of particles and rocks of all sizes. This unsorted pile is called **glacial till**. Water from the melting ice may form lakes or other water features. The **figure** below shows some of the landforms glaciers deposit when they melt.

- A **moraine** is sediment deposited by a glacier. A ground moraine is a thick layer of sediments left behind by a retreating glacier. An end moraine is a low ridge of sediments deposited at the end of the glacier. It marks the greatest distance the glacier advanced.



The hikers are standing on a moraine. What erosional feature is the hikers looking at?

- A **drumlin** is a long, low hill of sediments deposited by a glacier. Drumlins often occur in groups called drumlin fields. The narrow end of each drumlin points in the direction the glacier was moving when it dropped the sediments.
- An **esker** is a winding ridge of sand deposited by a stream of meltwater. Such streams flow underneath a retreating glacier.
- A **kettle lake** occurs where a chunk of ice was left behind in the till of a retreating glacier. When the ice melted, it left a depression. The meltwater filled it to form a lake. You can see examples of kettle lakes below (**Figure** below).



Kettle lakes are found where ice sheets once covered the land. These are in Siberia.

Varves

Several types of stratified deposits form in glacial regions but are not formed directly by the ice. **Varves** form where lakes are covered by ice in the winter. Dark, fine-grained clays sink to the bottom of the lake in winter. Melting ice in the spring brings running water that deposits lighter colored sands. Each alternating dark/light layer represents one year of deposits.



Summary

- Glaciers dump glacial till. Glacial moraines outline a glacier's extent.
- Drumlins, eskers, and kettle lakes are features made of glacial till.
- Varves form in lakes covered by ice. Varves are useful to scientists for understanding climate.

Review

1. Describe how these depositional features form: moraine, drumlin, esker, and kettle lake.
2. Why are varves important to scientists?
3. Why does the presence of glacial till mean there was a glacier in the area?

This page titled 14.13: Deposition by Glaciers is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

14.14: Landforms from Erosion and Deposition



What can cause devastation four months after a volcanic eruption?

Four months after Mt. Merapi in Indonesia erupted, there was more devastation. Rain continually washed ash down-slope in massive ash flows. Residents were unable to live well under these conditions.

Landforms and Gravity

Gravity is responsible for erosion by flowing water and glaciers. That's because gravity pulls water and ice downhill. These are ways gravity causes erosion indirectly. But gravity also causes erosion directly. Gravity can pull soil, mud, and rocks down cliffs and hillsides. This type of erosion and deposition is called **mass wasting**. It may happen suddenly. Or it may occur very slowly, over many years.

Landslides

Landslides are the most dramatic, sudden, and dangerous types of mass wasting. Landslides are sudden falls of rock; by contrast, avalanches are sudden falls of snow.

Weathered material may fall away from a cliff because there is nothing to keep it in place. Rocks that fall to the base of a cliff make a **talus slope**. Sometimes as one rock falls, it hits another rock, which hits another rock, and begins a landslide.

A landslide can be very destructive (**Figure** below). It may bury or carry away entire villages. Air trapped under the falling rocks acts as a cushion that keeps the rock from slowing down. Landslides can move as fast as 200 to 300 km/hour.



This landslide in California in 2008 blocked Highway 140.

Landslides often occur on steep slopes in dry or semi-arid climates. The California coastline, with its steep cliffs and years of drought punctuated by seasons of abundant rainfall, is prone to landslides. Wet soil becomes slippery and heavy. Earthquakes often trigger landslides. The shaking ground causes soil and rocks to break loose and start sliding.

Mudflows and Lahars

A **mudflow** is the sudden flow of mud down a slope because of gravity. Mudflows occur where the soil is mostly clay. Like landslides, mudflows usually occur when the soil is wet. Wet clay forms very slippery mud that slides easily. Mudflows follow river channels, washing out bridges, trees, and homes that are in their path.

A **lahar** is mudflow that flows down a composite volcano (**Figure** below). Ash mixes with snow and ice melted by the eruption to produce hot, fast-moving flows. The lahar caused by the eruption of Nevado del Ruiz in Colombia in 1985 killed more than 23,000 people.



A lahar is a mudflow that forms from volcanic ash and debris. This lahar comes off of Tunguragua volcano in Ecuador.

Slump and Creep

Less dramatic types of mass wasting move Earth materials slowly down a hillside. **Slump** is the sudden movement of large blocks of rock and soil down a slope. (**Figure** below). All the material moves together in big chunks. Slumps may happen when a layer of slippery, wet clay is underneath the rock and soil on a hillside. Or they may occur when a river (or road) undercuts a slope. Slump leaves behind crescent-shaped scars on the hillside.



Slump material moves as a whole unit, leaving behind a crescent shaped scar.

Creep is the very slow movement of rock and soil down a hillside. Creep occurs so slowly you can't see it happening. You can see only the effects of creep after years of movement (**Figure** below). The slowly moving ground causes trees, fence posts, and other structures on the surface to tilt downhill.



As the hillside moves down slope a tree tries to stand up straight. The tree ends up with a bent trunk.

Prevention and Awareness

Landslides cause $1 billion to $2 billion of damage in the United States each year. Mass wasting is responsible for traumatic and sudden loss of life and homes in many areas of the world.

Some communities have developed landslide warning systems. Around San Francisco Bay, the National Weather Service and the U.S. Geological Survey use rain gauges to monitor soil moisture. If soil becomes saturated, the weather service issues a warning. Earthquakes, which may occur on California's abundant faults, can also trigger landslides.

To be safe from landslides:

- Be aware of your surroundings. Notice changes in the natural world.
- Look for cracks or bulges in hillsides, tilting of decks or patios, or leaning poles or fences when rainfall is heavy. Sticking windows and doors can indicate ground movement. This is because soil pushes slowly against a house and knocks windows and doors out of alignment.
- Look for landslide scars. Landslides are most likely to happen where they have occurred before.
- Plant vegetation and trees on the hillside around your home. This helps hold the soil in place.
- Help to keep a slope stable by building retaining walls. Installing good drainage in a hillside may keep the soil from getting saturated.

Summary

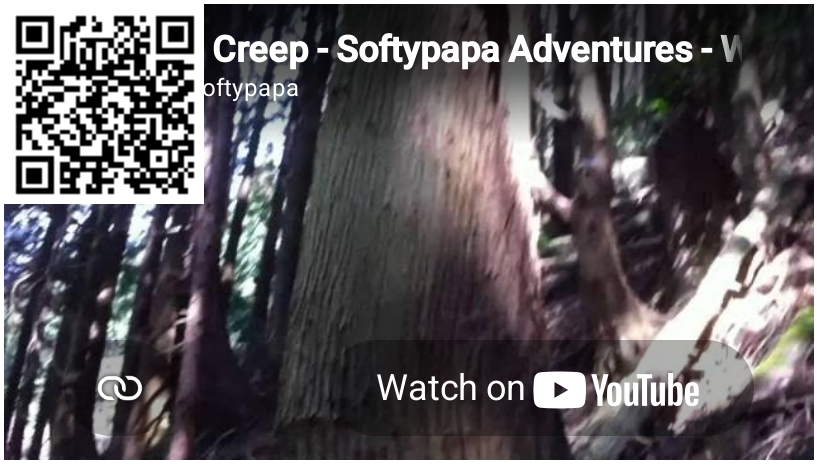
- Landslides are sudden and massive falls of rock down a slope. Landslides may be very destructive or even deadly. Slump and creep are slower types of mass wasting.
- Mudflows or lahars, which are volcanic mudflows, are mass movements that contain a lot of water.
- Mass wasting is more likely to occur on slopes that are wet, have weak rock, or are undercut. An earthquake or other ground shaking can trigger a landslide.
- To avoid being in a landslide, be aware of signs in a hillside, such as cracks or bulges and old landslide scars. To keep a slope stable, install good drainage or build retaining walls.

Review

1. What factors make it more likely that a place will have a landslide?
2. Pretend that you are going to buy a house on a hill. How do you know if the house might slide or creep down the hill?
3. What can be done to prevent landslides?
4. How is a landslide different from a mudflow? How is a lahar different from a mudflow?

Explore More

Use the resources below to answer the questions that follow.



1. What is creep?
2. How do trees compensate for creep?

This page titled 14.14: Landforms from Erosion and Deposition is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

14.15: Erosion and Deposition- Challenge 3

1. A jagged ridge that remains when cirques form on opposite sides of a mountain is an ___.

arête

2. A ___ is a sharp peak left behind when glaciers erode all sides of a mountain.

horn

3. A rounded hollow carved by a glacier near the top of a mountain is a ___.

cirque

4. An ___ marks the greatest extent of a glacier.

end moraine

5. Low hills of sediment deposited by a glacier are known as ___.

drumlins

6. A ___ can form when a chunk of ice is left behind in the till of a retreating glacier.

kettle lake

7. Rocks falling onto the base of a cliff form a ___.

talus slope

8. The speed of landslides varies from ___ to ___ km/hour.

200; 300

9. Landslides are most likely to occur in a ___ year that was preceded by ___ years.

wet; dry

This page titled 14.15: Erosion and Deposition- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

15: Understanding Earth's History

15.1: How Fossilization Creates Fossils
15.2: Types of Fossilization
15.3: Earth History and Clues from Fossils
15.4: Understanding Earth's History- Challenge 1
15.5: Principles of Relative Dating
15.6: Determining Relative Ages
15.7: Correlation Using Relative Ages
15.8: Geologic Time Scale
15.9: Understanding Earth's History- Challenge 2
15.10: Tree Rings, Ice Cores, and Varves
15.11: Radioactive Decay as a Measure of Age
15.12: Radiometric Dating
15.13: Age of Earth
15.14: Understanding Earth's History- Challenge 3

This page titled 15: Understanding Earth's History is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

15.1: How Fossilization Creates Fossils



How do you find fossils?

In lots of places, you can go on a field trip to find fossils. The fossils are found in rock layers. You can break apart the rock layers and find the fossils.

What Are Fossils?

Fossils are preserved remains or traces of organisms that lived in the past. Most preserved remains are hard parts, such as teeth, bones, or shells. Hard parts are less likely to be destroyed before they can become fossils. Even so, a very tiny percentage of living things become fossils. These types of fossils are called **body fossils** (**Figure** below, **Figure** below, and **Figure** below).



The preserved remains of an ammonite.



The preserved remains of an Archaeopteryx, a type of dinosaur.



A group of preserved trilobites, a variety of ancient marine arthropods.

Preserved traces can include footprints, burrows, or even wastes. Examples of these types of fossils, called **trace fossils** are picture below (**Figure** below and **Figure** below).



The preserved trace of a dinosaur footprint, originally in mud.



A preserved trace: burrows made by prehistoric worms.

Summary

- Fossils are the remains or traces of living organisms.
- Body fossils are usually hard parts, such as bones, teeth, and shells.
- Trace fossils are the traces of organisms, not parts of them. Trace fossils include footprints, feces, and burrows.

Review

1. Give three examples of body fossils.
2. Give three examples of trace fossils.
3. Why are most fossils of hard-bodied organisms?

Explore More

Use the resource below to answer the questions that follow.



1. What do paleontologists study and what is that thing?
2. At least how old are most fossils?
3. What are trace fossils? What are a few examples?
4. What can be learned from trace fossils?
5. What are mold fossils?
6. How do resin fossils?
7. What are body fossils?
8. How do body fossils form?
9. If body fossils form beneath layers of sediment, how do they end up at the surface where they can be found?

This page titled 15.1: How Fossilization Creates Fossils is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

15.2: Types of Fossilization



Where could you find the best fossils?

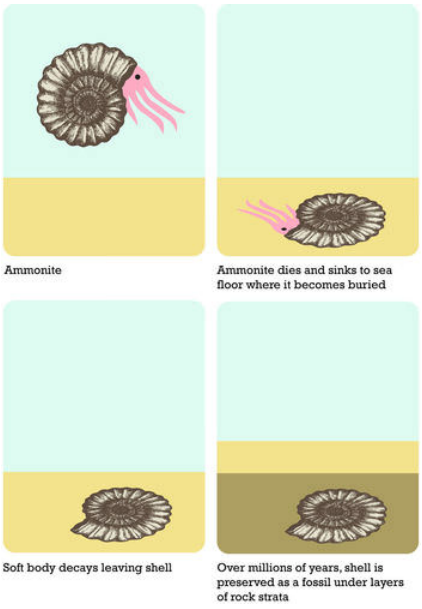
The best fossils would probably be ones that you could get DNA from. DNA holds the genes of an organisms. The genes could tell scientists a lot about what the organisms was really like. Where could you find a fossil with DNA? How about a melting glacier? You might be able to find a creature that had been frozen into the ice for a long time. A frozen animal would be very well preserved!

How Fossils Form

The process by which remains or traces of living things become fossils is called **fossilization** (**Figure** below). Most fossils are preserved in sedimentary rocks.

Fossils in Sedimentary Rock

Most fossils form when a dead organism is buried in sediment. Layers of sediment slowly build up. The sediment is buried and turns into sedimentary rock. The remains inside the rock also turn to rock. The remains are replaced by minerals. The remains literally turn to stone. This type of fossilization is called **permineralization**.



Fossilization. This flowchart shows how most fossils form.

Other Ways Fossils Form

Fossils may form in other ways. With complete preservation, the organism doesn't change much. As pictured below (**Figure** below), tree sap may cover an organism and then turn into **amber**. The original organism is preserved so that scientists might be able to study its DNA. Organisms can also be completely preserved in tar or ice.



Complete Preservation. This spider looks the same as it did the day it died millions of years ago!

Molds and casts are another way organisms can be fossilized. A **mold** is an imprint of an organism left in rock. The organism's remains break down completely. Rock that fills in the mold resembles the original remains. The fossil that forms in the mold is called a **cast** (**Figure** below). Molds and casts usually form in sedimentary rock. With **compression** (**Figure** below), an organism's remains are put under great pressure inside rock layers. This leaves behind a dark stain in the rock.



Molds and Casts. A mold is a hole left in rock after an organism's remains break. A cast forms from the minerals that fill that hole and solidify.



Compression. A dark stain is left on a rock that was compressed. These leaves were fossilized by compression.

Why Fossilization Is Rare

It’s very unlikely that any given organism will become a fossil. The remains of many organisms are consumed. Remains also may be broken down by other living things or by the elements. Hard parts, such as bones, are much more likely to become fossils. But even they rarely last long enough to become fossils. Organisms without hard parts are the least likely to be fossilized. Fossils of soft organisms, from bacteria to jellyfish, are very rare.

Summary

- Very few fossils preserve soft parts. Insects may be preserved in amber. Insects and other animals may be preserved in ice.
- Some fossils are created when minerals replace the organic material. This is called permineralization.
- A fossil may be in the form of a mold. A mold is the depression left in the shape of the material.
- A fossil may be preserved as a cast. A cast is the rocky material that fills the mold.

Review

1. Why are there so few fossils of soft parts?
2. A snail shell is buried in mud. The shell is filled with mineral-rich water. What type of fossilization has occurred?
3. Compare and contrast molds and casts.
4. Why is fossilization rare?

Explore More

Use the resource below to answer the questions that follow.



1. What are fossils?
2. What type of rocks are fossils found in?
3. What are sediments?
4. How does a bone from a dead organism harden to become a fossil?
5. What happens as the bone is buried?
6. What factors exposed the rock layers with the fossils in it?

This page titled 15.2: Types of Fossilization is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

15.3: Earth History and Clues from Fossils



How could there be seashells at 20,000 feet?

Shell beds are found high in the Andes Mountains. How did they get there? This is more evidence that Earth is a dynamic planet! The rock that is on top of the mountains was once beneath the sea. Due to plate tectonics, the mountains rose slowly above the ocean. This process took a really long time. This is one way we know that Earth is really old!

Learning from Fossils

Of all the organisms that ever lived, only a tiny number became fossils. Still, scientists learn a lot from fossils. Fossils are our best clues about the history of life on Earth.

Fossil Clues

Fossils give clues about major geological events. Fossils, like the one pictured below (**Figure** below), can also give clues about past climates. Here are just a few examples.

- Fossils of ocean animals are found at the top of Mt. Everest. Mt. Everest is the highest mountain on Earth. These fossils show that the area was once at the bottom of a sea. The seabed was later uplifted to form the Himalaya mountain range.
- Fossils of plants are found in Antarctica. Currently, Antarctica is almost completely covered with ice. The fossilized plants show that Antarctica once had a much warmer climate.



What can we learn from fossil clues like this fish fossil found in the Wyoming desert?

Index Fossils

Fossils are used to determine the ages of rock layers. **Index fossils** are the most useful for this. Index fossils are of organisms that lived over a wide area. They lived for a fairly short period of time. An index fossil allows a scientist to determine the age of the rock it is in.

Trilobite fossils (**Figure** below) are common index fossils. Trilobites were widespread marine animals. They lived between 500 and 600 million years ago. Rock layers containing trilobite fossils must be that age. Different species of trilobite fossils can be used to narrow the age even more.



Trilobites are good index fossils. Why are trilobite fossils useful as index fossils?



Further Reading

Principles of Relative Dating

Determining Relative Ages

Correlation Using Relative Ages

Summary

- Fossils tell a lot about the environment during the time they were deposited.
- Climate is one important thing that can be indicated by fossils. This is because organisms have specific conditions in which they can live.
- An index fossil must be distinctive, widespread, and short-lived. It indicates a specific period of time.

Review

1. How do fossils help geologists learn about the geological history of an area?
2. How is an index fossil used to identify a time period?
3. Why are the fossils of marine organisms sometimes found in rock units at the tops of high mountains? What does this tell you about the geological history of an area?

Explore More

Use the resource below to answer the questions that follow.



1. Why is the paleoecologist collecting samples?
2. What does he want to create from the fossil evidence?
3. How is this similar to forensic science?
4. What do they look for to understand insect feeding?
5. What has been discovered from these fossils?
6. What question does this raise for the scientists?

This page titled 15.3: Earth History and Clues from Fossils is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

15.4: Understanding Earth's History- Challenge 1

1. Why are the La Brea Tar Pits in Los Angeles, California, an exception?

they formed under unusual circumstances

2. Hard-shelled marine organisms ___ more often than organisms with soft tissues in exposed environments.

fossilize

3. Amber is ___.

fossilized tree sap

4. When insects fossilize, it is usually in ___.

amber

5. A bone dissolves and leaves behind a space in a rock called a ___, which fills with minerals to form a ___in the original shape of the organism.

mold; cast

6. ___ can be used to identify a specific period of time.

Index fossils

7. At the time of the fossilization of coal, the temperature of Antarctica was ___.

warm

8. Compared with fossils in younger rocks, fossils in older rocks are ___.

less similar to modern organisms

This page titled 15.4: Understanding Earth's History- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

15.5: Principles of Relative Dating



Where's a good place to see geology?

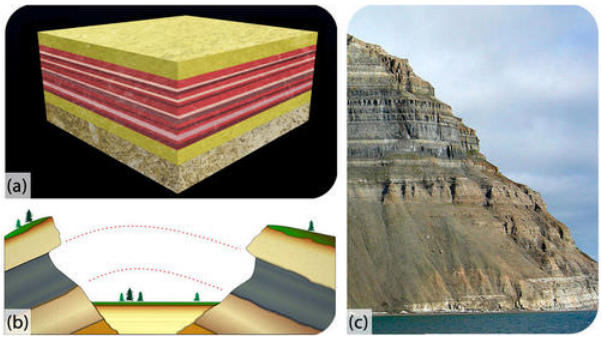
The Southwestern United States is a fantastic place to see geology. The arid climate means that that the rocks are not covered by vegetation. In many places, especially the national parks, the formations are fantastic. The rocks themselves are very interesting. The principles discussed below are easily seen around the Southwest.

Relative Age Dating

Early geologists had no way to determine the absolute age of a geological material. If they didn't see it form, they couldn't know if a rock was one hundred years or 100 million years old. What they could do was determine the ages of materials relative to each other. Using sensible principles they could say whether one rock was older than another. They could also determine when a process occurred relative to those rocks.

Laws of Stratigraphy

The study of rock strata is called **stratigraphy**. The laws of stratigraphy can help scientists understand Earth's past. The laws of stratigraphy are usually credited to a geologist from Denmark named Nicolas Steno. He lived in the 1600s. The laws are illustrated in **Figure** below; refer to the figure as you read about Steno's laws below.



(a) Original horizontality. (b) Lateral continuity. (c) Superposition.

Law of Superposition

Superposition refers to the position of rock layers and their relative ages (**Figure** below). **Relative age** means age in comparison with other rocks, either younger or older. The relative ages of rocks are important for understanding Earth's history. New rock layers are always deposited on top of existing rock layers. Therefore, deeper layers must be older than layers closer to the surface. This is the law of superposition.



Superposition. The rock layers at the bottom of this cliff are much older than those at the top. What force eroded the rocks and exposed the layers?

Law of Lateral Continuity

Rock layers extend laterally, or out to the sides. They may cover very broad areas, especially if they formed at the bottom of ancient seas. Erosion may have worn away some of the rock, but layers on either side of eroded areas will still “match up.”

The Grand Canyon (**Figure** below) is a good example of lateral continuity. You can clearly see the same rock layers on opposite sides of the canyon. The matching rock layers were deposited at the same time, so they are the same age.



Lateral Continuity. Layers of the same rock type are found across canyons at the Grand Canyon.

Law of Original Horizontality

Sediments were deposited in ancient seas in horizontal, or flat, layers. If sedimentary rock layers are tilted, they must have moved after they were deposited.

Law of Cross-Cutting Relationships

Rock layers may have another rock cutting across them, like the igneous rock pictured below (**Figure** below). Which rock is older? To determine this, we use the law of cross-cutting relationships. The cut rock layers are older than the rock that cuts across them.



Cross-cutting relationships in rock layers. The rock layers at the bottom are cut off by the rock layers that are higher up. Which layers are older and which are younger?

Unconformities

Geologists can learn a lot about Earth's history by studying sedimentary rock layers. But in some places, there's a gap in time when no rock layers are present. A gap in the sequence of rock layers is called an **unconformity**.

Look at the rock layers pictured below (**Figure** below); they show a feature called Hutton's unconformity. The unconformity was discovered by James Hutton in the 1700s. Hutton saw that the lower rock layers are very old. The upper layers are much younger. There are no layers in between the ancient and recent layers. Hutton thought that the intermediate rock layers eroded away before the more recent rock layers were deposited.

Hutton's discovery was a very important event in geology! Hutton determined that the rocks were deposited over time. Some were eroded away. Hutton knew that deposition and erosion are very slow. He realized that for both to occur would take an extremely long time. This made him realize that Earth must be much older than people thought. This was a really big discovery! It meant there was enough time for life to evolve gradually.



Hutton's unconformity, in Scotland.

Summary

- Sediments are deposited horizontally. This is original horizontality.
- The oldest sedimentary rocks are at the bottom of the sequence. This is the law of superposition.
- Rock layers are laterally continuous.This is the law of lateral continuity.
- Rock B cuts across rock A. Rock A must be older. This is the principle of cross-cutting relationships.
- A gap in a rock sequence is an unconformity.

Review

1. How do Steno's laws help geologists to decipher the geological history of a region?
2. Why does the principle of lateral continuity work?

3. How could you recognize the existence of an unconformity?

Explore More

Use the resource below to answer the questions that follow.



1. What is superposition?
2. How can the age of the layers be determined?
3. How does volcanic ash help scientists to determine the age of a rock sequence?
4. What are the radioactive elements?
5. If a radiometric age can be determined is there any use for a relative age? Why or why not?

This page titled 15.5: Principles of Relative Dating is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

15.6: Determining Relative Ages



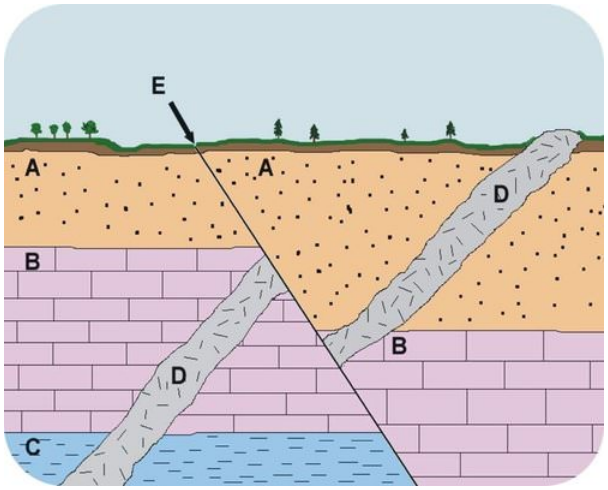
What are the relative ages of these rocks?

This photo shows rock layers and a fault—the fault is the large diagonal crack running through this rock. These features can tell us several things about relative age. Unless the rock was turned over somehow, we can assume that the layers on top are younger than the layers on the bottom. Since the fault separates the layers, we can tell that the fault occurred after all the layers were deposited.

Determining the Relative Ages of Rocks

Steno's principles are essential for determining the relative ages of rocks and rock layers. Remember that in relative dating, scientists do not determine the exact age of a fossil or rock. They look at a sequence of rocks to try to decipher when an event occurred relative to the other events represented in that sequence. The **relative age** of a rock, then, is its age in comparison with other rocks. (1) Do you know which rock is older and which is younger? (2) Do you know how old the rock's layers are in years? For relative ages, you know #1 but not #2.

In some cases, it is very tricky to determine the sequence of events that leads to a certain formation. In the picture below, can you figure out what happened in what order (**Figure** below)? Write it down and then check the following paragraphs.



A geologic cross section: Sedimentary rocks (A-C), igneous intrusion (D), fault (E).

The principle of cross-cutting relationships states that a fault or intrusion is younger than the rocks that it cuts through. The fault cuts through all three sedimentary rock layers (A, B, and C) and also the intrusion (D). So the fault must be the youngest feature. The intrusion (D) cuts through the three sedimentary rock layers, so it must be younger than those layers. By the law of superposition, C is the oldest sedimentary rock, B is younger and A is still younger.

The full sequence of events is:

1. Layer C formed.
2. Layer B formed.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

3. Layer A formed.
4. After layers A-B-C were present, intrusion D cut across all three.
5. Fault E formed, shifting rocks A through C and intrusion D.
6. Weathering and erosion created a layer of soil on top of layer A.

Summary

- The oldest rock units lie beneath the younger ones.
- By the principle of cross-cutting relationships (and common sense), we know that something must exist before something else can cut across it.
- The history of a section of rocks can be deciphered using the principles outlined in this concept.

Review

1. What is relative age? How does it differ from absolute age?
2. Why do the principles of relative dating not indicate the absolute age of a rock unit?
3. Can you think of a way a rock unit with an older fossil could be above a rock until with a younger fossil? Describe the scenario.

Explore More

Use the resource below to answer the questions that follow.



1. Look at that geologic cross section. Do you think it's possible to determine the geological processes that led to the creation of those rocks in those locations in those orders?
2. How long a period of Earth history is represented by that diagram?
3. What is an unconformity? What causes it?
4. What was the first thing that happened to create the first rock layer?
5. What forces and processes create the mountains and valleys seen in the region?
6. When lava erupts, does it create a layer similar to a sedimentary rock?

This page titled 15.6: Determining Relative Ages is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

15.7: Correlation Using Relative Ages



How would you correlate two rock units?

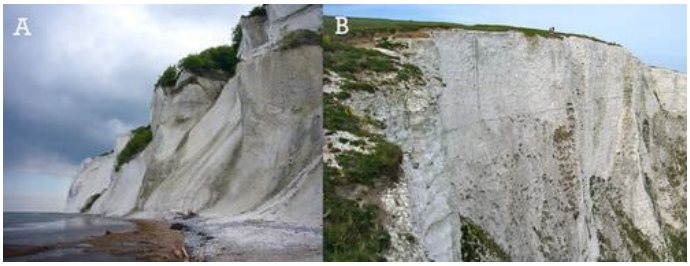
On a field trip in the southwestern United States you would see some very unique rock layers. You might see a distinctive whitish rock unit that looks like sand dunes. This rock is the Navajo Sandstone. The first photo is from the Valley of Fire near Las Vegas, Nevada. The second is from Capitol Reef National Park in Utah. These sites are roughly 250 miles apart. Sand dunes stretched across this part of the country during the Mesozoic.

Matching Rock Layers

When rock layers are in the same place, it's easy to give them relative ages. But what if rock layers are far apart? What if they are on different continents? What evidence is used to match rock layers in different places?

Widespread Rock Layers

Some rock layers extend over a very wide area. They may be found on more than one continent or in more than one country. They are matched up by **correlation**. For example, the famous White Cliffs of Dover are on the coast of southeastern England. These distinctive rocks are matched by similar white cliffs in France, Belgium, Holland, Germany, and Denmark (**Figure** below). It is important that this chalk layer goes across the English Channel. The rock is so soft that the Channel Tunnel connecting England and France was carved into it!



Chalk Cliffs. (A) Matching chalk cliffs in Denmark and (B) in Dover, U.K.

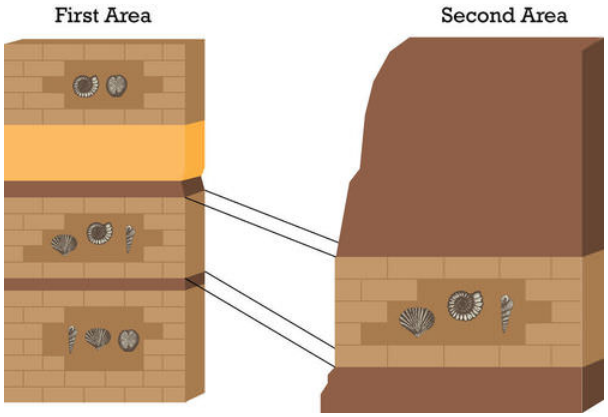
Key Beds

Like index fossils, key beds are used to match rock layers. A **key bed** is a thin layer of rock. The rock must be unique and widespread. For example, a key bed from around the time that the dinosaurs went extinct is very important. A thin layer of clay was deposited over much of Earth's surface. The clay has large amount of the element iridium. Iridium is rare on Earth but common in asteroids. This unusual clay layer has been used to match rock up layers all over the world. It also led to the hypothesis that a giant asteroid struck Earth and caused the dinosaurs to go extinct.

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

Using Index Fossils

Index fossils are commonly used to match rock layers in different places (**Figure** below). If two rock layers have the same index fossils, then they're probably about the same age.



Using Index Fossils to match rock layers. Rock layers with the same index fossils must have formed at about the same time. The presence of more than one type of index fossil provides stronger evidence that rock layers are the same age.

Summary

- A single rock unit contains the story of the geology of that location. To understand the geology of a region, scientists use correlation.
- To correlate rock units, something distinctive must be present in each. This can include an index fossil, a unique rock type, a key bed, or a unique sequence of rocks.
- A key bed can be global. An example is the iridium layer that was deposited at the time of the Cretaceous-Tertiary extinctions.

Review

1. What features must the iridium layer at the time of the dinosaur extinction need to be a key bed?
2. To be more certain that fossils can be used to correlate rock layers, what is needed?
3. What is the process of correlation?

Explore More

Use the resource below to answer the questions that follow.



1. In what type of rock were the leaf fossils found? How is this type of rock formed?
2. Why is this volcanic ash unique?
3. How does the lapilli tuff form?
4. What does the lapilli tuff allow scientists to do?

This page titled 15.7: Correlation Using Relative Ages is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

15.8: Geologic Time Scale



Why would you want to name time?

When you refer to events in the history of your life you often link it to a time period. "When I was in kindergarten..." might be the start of your story. It helps scientists to have names to refer to events in Earth history. For this reason, they developed the geologic time scale.

The Geologic Time Scale

Earth formed 4.5 billion years ago. Geologists divide this time span into smaller periods. Many of the divisions mark major events in life history.

Dividing Geologic Time

Divisions in Earth history are recorded on the **geologic time scale**. For example, the Cretaceous ended when the dinosaurs went extinct. European geologists were the first to put together the geologic time scale. So, many of the names of the time periods are from places in Europe. The Jurassic Period is named for the Jura Mountains in France and Switzerland, for example.

Putting Events in Order

To create the geologic time scale, geologists correlated rock layers. Steno's laws were used to determine the relative ages of rocks. Older rocks are at the bottom, and younger rocks are at the top. The early geologic time scale could only show the order of events. The discovery of radioactivity in the late 1800s changed that. Scientists could determine the exact age of some rocks in years. They assigned dates to the time scale divisions. For example, the Jurassic began about 200 million years ago. It lasted for about 55 million years.

Divisions of the Geologic Time Scale

The largest blocks of time on the geologic time scale are called “eons.” Eons are split into “eras.” Each era is divided into “periods.” Periods may be further divided into “epochs.” Geologists may just use “early” or “late.” An example is “late Jurassic,” or “early Cretaceous.” Pictured below is the geologic time scale (**Figure** below).

EON	ERA	PERIOD	MILLIONS OF YEARS AGO
Phanerozoic	Cenozoic	Quaternary	1.6
		Tertiary	66
	Mesozoic	Cretaceous	138
		Jurassic	205
		Triassic	240
	Paleozoic	Permian	290
		Pennsylvanian	330
		Mississippian	360
		Devonian	410
		Silurian	435
		Ordovician	500
		Cambrian	570
Proterozoic	Late Proterozoic Middle Proterozoic Early Proterozoic		2500
Archean	Late Archean Middle Archean Early Archean		3800?
Pre-Archean			

The Geologic Time Scale.



Further Reading

Radioactive Decay as a Measure of Age

Radiometric Dating

Summary

- The geologic time scale divides Earth history into named units. Naming time periods makes it easier to talk about them.
- The units of the time scale are separated by major events in Earth or life history.
- In the geologic time scale, time units are divided and subdivided into smaller pieces.

Review

1. Why do Earth scientists need a geologic time scale?
2. Why are some units of the geologic time scale longer and some shorter?
3. What did the discovery of radioactivity do to change the geological time scale?

This page titled 15.8: Geologic Time Scale is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

15.9: Understanding Earth's History- Challenge 2

1. If the same sedimentary rock layer is found on either side of a valley, ___.

the rocks formed in the same environment, and the valley was cut into the rock later

2. The principle of original horizontality states that ___.

sediments are deposited in horizontal layers

3. If a fault cuts through an entire sequence of rock layers, the fault is ___ than the rock sequence.

younger

4. If rock P cuts across rock Q, than rock P is ___ than rock Q.

younger

5. The relative age of a rock is ___.

the age of the rock relative to other rocks and geologic structures

6. A key bed must ___.

be very distinctive

7. Fossils of microorganisms are called ___.

microfossils

8. The thin layer of clay with a high concentration of iridium correlates with ___.

the extinction of the dinosaurs and other organisms at the end of the Cretaceous

10. If Earth's history is condensed into one calendar year, dinosaurs appear ___.

in mid-December

11. The geologic time scale was originally based ___.

entirely on relative dating

12. We live in the Holocene Epoch, which is encompassed by ___.

the Phanerozoic Eon, the Cenozoic Era, and the Quaternary Period

---

This page titled 15.9: Understanding Earth's History- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

15.10: Tree Rings, Ice Cores, and Varves



How could you tell the age of this ruin?

Mesa Verde in Southwestern Colorado is the site of beautiful cliff dwellings. The people who inhabited these dwellings are long gone. If you go there you will hear the history of the area, complete with dates. How do archeologists know when the people lived here? How do they know the ages of the structures there? Tree ring dating is extremely useful for finding the age of ancient structures.

Tree Ring Dating

Cut into a tree and you can see its rings. In some locations, the summer growth band is light-colored and the winter band is dark. Each light-dark band represents one year. You can tell how long the tree lived by counting the number of **tree rings** (**Figure** below). Age dating by tree rings is called **dendrochronology**.



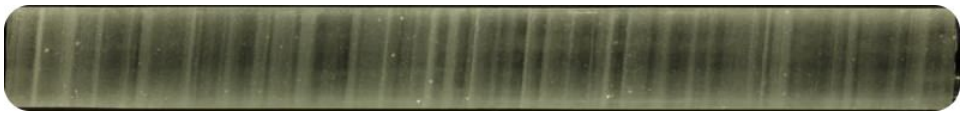
Cross-section showing growth rings.

You can tell other things from tree rings too. In a good year a tree will produce a wide ring. A summer drought will produce a smaller ring. These variations will appear in all trees in a region. The same pattern can be found in all the trees in the area. This pattern helps scientist to identify a particular time period.

Scientists have records of tree rings going back over the past 2,000 years. By matching up patterns they can tell when a tree (or a piece of wood from one) lived. Wood fragments from old buildings and ancient ruins can be age dated. The outermost ring gives the date when the tree died.

Ice Cores

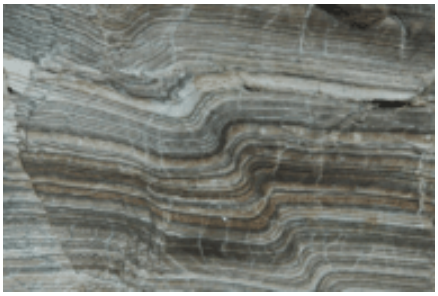
Other processes create yearly layers that can be used for dating. On a glacier, snow falls in winter. In summer, dust accumulates. This leads to a snow-dust annual pattern. This pattern can be seen down into the ice (**Figure** below). Scientists drill deep into ice sheets. **Ice cores** can be hundreds of meters long. The ice cores show how the environment has changed. Gas bubbles in the ice can be analyzed to show how atmospheric gases have changed. This can yield clues about climate. Long ice cores have allowed scientists to create a record of polar climate going back hundreds of thousands of years.



Ice core section showing annual layers.

Varves

Lake sediments also have an annual pattern. This is easy to see in lakes that are located at the end of glaciers. The glacier melts rapidly in the summer. This produces a thick deposit of sediment in the lake. Thin, clay-rich layers are deposited in the winter. The resulting layers are called **varves**. Varves give scientists clues about past climate conditions (**Figure** below). A warm summer might result in a very thick sediment layer. A cooler summer might yield a thinner layer. Like tree rings, these patterns can be used to identify time periods.



Ancient varve sediments in a rock outcrop.

Summary

- Where conditions vary seasonally, trees develop distinctive rings. Ice contains more or less dust. Lake sediments show more or less clay.
- Tree rings, ice cores, and varves indicate the environmental conditions at the time they were made.
- The distinctive patterns of tree rings, ice cores, and varves go back thousands of years. They can be used to determine the time they were made.

Review

1. Why are these three dating methods considered absolute age dating?
2. Describe how tree rings indicate time. Do the same for ice cores and varves.
3. Describe how tree rings, ice cores, and varves indicate what was going on in the environment when they formed.

Explore More

Use the resources below to answer the questions that follow.



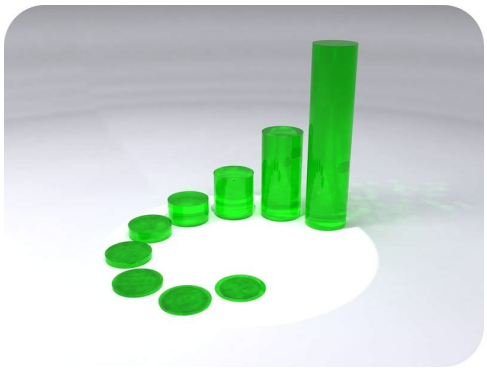
1. What do annual tree rings tell scientists?
2. What can be learned from tree rings?
3. What do tree rings indicate about the lost colony of Roanoke, Virginia?
4. What type of trees do scientists look for? Why?



5. What is trapped in the ice cores and when it it from?
6. How long have ice cores been studied?
7. What can be learned from ice cores?
8. What circumstances make the best ice cores? What is a good location to obtain cores like this?
9. How much would sea level rise if the Greenland ice sheet melted?

This page titled 15.10: Tree Rings, Ice Cores, and Varves is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

15.11: Radioactive Decay as a Measure of Age



When do you stop counting?

Pretend that the large green cylinder is a parent isotope. Now you can visualize the decay of the parent to the daughter. It's easy to see that the second cylinder is half the size of the first. The third is half the size of the second. But when the cylinders get small, the differences are much harder to see. At some point, there is too little of the parent left. That isotope pair is no longer useful for dating.

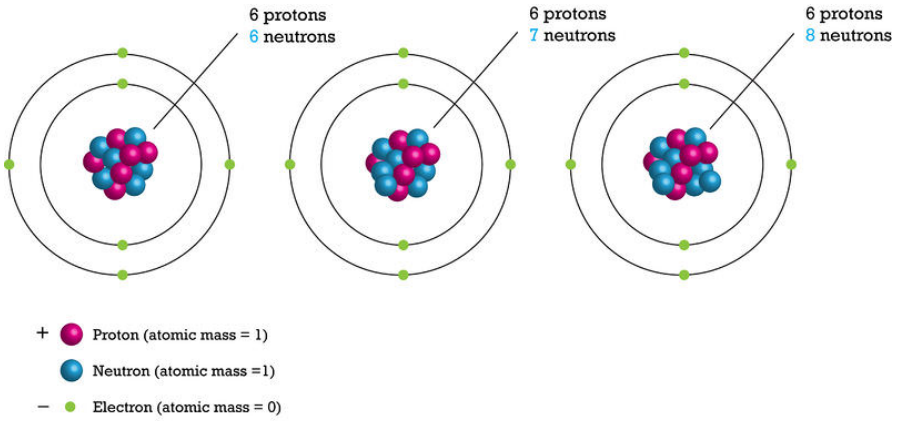
Radioactive Decay

Radioactive decay is the breakdown of unstable elements into stable elements. To understand this process, recall that the atoms of all elements contain the particles protons, neutrons, and electrons.

Isotopes

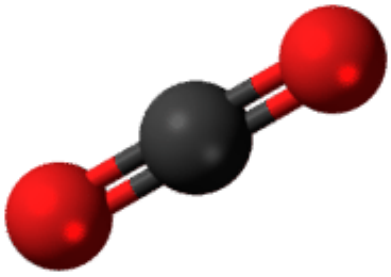
An element is defined by the number of protons it contains. All atoms of a given element contain the same number of protons. The number of neutrons in an element may vary. Atoms of an element with different numbers of neutrons are called **isotopes**.

Consider carbon as an example. Two isotopes of carbon are shown below (**Figure** below). Compare their protons and neutrons. Both contain six protons. But carbon-12 has six neutrons and carbon-14 has eight neutrons.



Isotopes are named for their number of protons plus neutrons. If a carbon atom had seven neutrons, what would it be named?

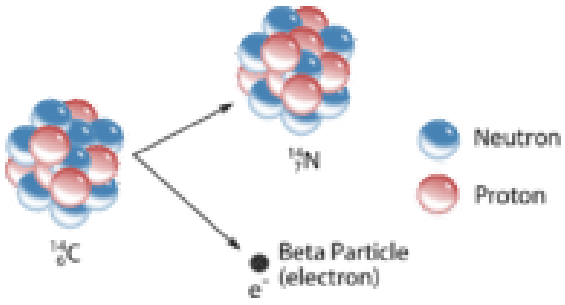
Almost all carbon atoms are carbon-12. This is a stable isotope of carbon. Only a tiny percentage of carbon atoms are carbon-14. carbon-14 is unstable. It is a **radioactive isotope** of carbon. Pictured below is carbon dioxide (**Figure** below), which forms in the atmosphere from carbon-14 and oxygen. Neutrons in cosmic rays strike nitrogen atoms in the atmosphere. The nitrogen forms carbon-14. Carbon in the atmosphere combines with oxygen to form carbon dioxide. Plants take in carbon dioxide during photosynthesis. In this way, carbon-14 enters food chains.



Carbon-14 forms in the atmosphere. It combines with oxygen and forms carbon dioxide. How does carbon-14 end up in fossils?

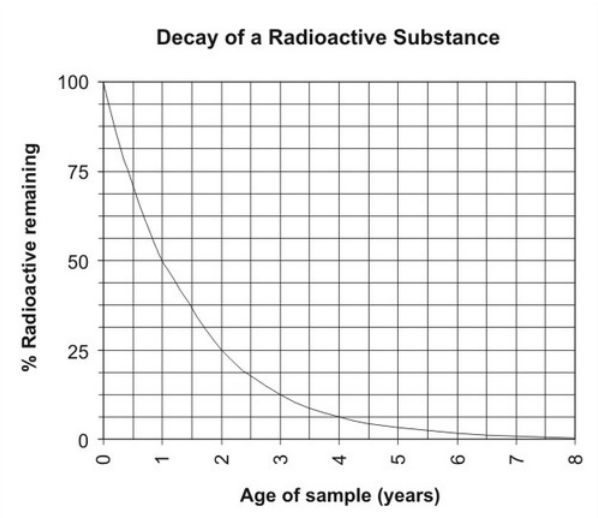
Decay of Unstable Isotopes

Like other unstable isotopes, carbon-14 breaks down, or decays. The original atoms are called the **parent isotopes**. For carbon-14 decay, each carbon-14 atom loses a beta particle, or a neutron that splits into a proton and an electron. It changes to a stable atom of nitrogen-14. The stable atom at the end is the **daughter product** (**Figure** below).



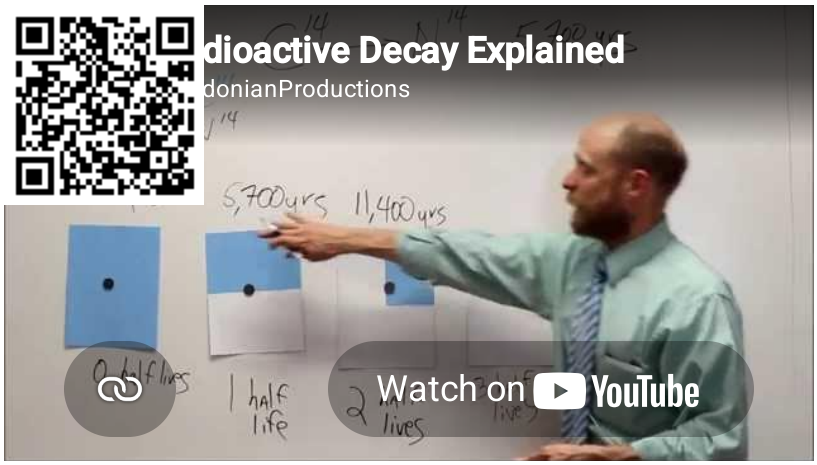
Unstable isotopes, such as carbon-14, decay by losing atomic particles. They form different, stable elements when they decay.

The decay of an unstable isotope to a stable element occurs at a constant rate. This rate is different for each parent-daughter isotope pair. The decay rate is measured in a unit called the half-life. The **half-life** is the time it takes for half of a given amount of an isotope to decay. For example, the half-life of carbon-14 is 5,730 years. Imagine that you start out with 100 grams of carbon-14. In 5,730 years, half of it decays. This leaves 50 grams of carbon-14. Over the next 5,730 years, half of the remaining amount will decay. Now there are 25 grams of carbon-14. How many grams will there be in another 5,730 years? The figure below graphs the rate of decay of a substance (**Figure** below).



The rate of decay of a radioactive substance is constant over time.

https://k12.libretexts.org/@go/page/5910



Summary

- A half-life is the time it takes for half of the parent isotopes of an element to change to the daughter product.
- With alpha decay, the nucleus loses two protons and two neutrons.
- Carbon-14 has a half-life of 5,730 years.

Review

1. What makes an isotope radioactive? Are all isotopes radioactive?
2. What is a parent isotope and a daughter product?
3. Describe half-life. Use an example.

This page titled 15.11: Radioactive Decay as a Measure of Age is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

15.12: Radiometric Dating



Can wood give an age in another way?

In the section on tree ring dating, there was a photo of a ruin at Mesa Verde National Park. This photo is also from Mesa Verde. In archeological sites, wood can be dated by tree rings. It can also be dated by radiometric dating. Carbon-14 dating is very useful for ruins that contain wood. If the tree died around the time the ladder was created, then carbon-14 can tell the age of the ladder. If the ladder was built for the site, then that age will be the age of the archeological site.

Radiometric Dating

The rate of decay of unstable isotopes can be used to estimate the absolute ages of fossils and rocks. This type of dating is called **radiometric dating**.

Carbon-14 Dating

The best-known method of radiometric dating is **carbon-14 dating**. This method is also called radiocarbon dating. A living thing takes in carbon-14 (along with stable carbon-12). As the carbon-14 decays, it is replaced with more carbon-14. After the organism dies, it stops taking in carbon. That includes carbon-14. The carbon-14 that is in its body continues to decay. So the organism contains less and less carbon-14 as time goes on. We can estimate the amount of carbon-14 that has decayed by measuring the amount of carbon-14 to carbon-12. We know how fast carbon-14 decays. With this information, we can tell how long ago the organism died.

Carbon-14 has a relatively short half-life. It decays quickly compared to some other unstable isotopes. So carbon-14 dating is useful for specimens younger than 50,000 years old. That's a blink of an eye in geologic time. But radiocarbon dating is very useful for more recent events. One important use of radiocarbon is early human sites. Carbon-14 dating is also limited to the remains of once-living things. To date rocks, scientists use other radioactive isotopes.

Other Radioactive Isotopes

The isotopes listed below (**Table** below) are used to date igneous rocks. These isotopes have much longer half-lives than carbon-14. Because they decay more slowly, they can be used to date much older specimens. Which of these isotopes could be used to date a rock that formed half a million years ago? How about half a billion years ago?

Unstable Isotope	Decays to	At a Half-Life of (years)	Dates Rocks Aged (years old)
Potassium-40	Argon-40	1.3 billion	100 thousand – 1 billion
Uranium-235	Lead-207	700 million	1 million – 4.5 billion
Uranium-238	Lead-206	4.5 billion	1 million – 4.5 billion

Limitations of Radiometric Dating

Radiometric dating is a very useful tool, but it does have limits:

1. The material being dated must have measurable amounts of the parent and/or the daughter isotopes.
2. Radiometric dating can be done on only some materials. It is not useful for determining the age of sedimentary rocks. For this, geologists date a nearby igneous rock. Then they use relative dating techniques to figure out the age of the sedimentary rock. They may not get it exactly, but there will be some idea.

Summary

- Radiocarbon is useful for relatively young, carbon-based materials. Other longer-lived isotopes are good for older rocks and minerals.
- Different isotope pairs are useful for certain materials of certain ages.
- Radiometric dating cannot be used if parent or daughter are not measurable.

Review

1. How would you determine which isotope pair to use to date a certain rock?
2. How does radiocarbon dating work? What materials does it work best on?
3. Which types of rocks are best for radiometric dating? Which are not good?
4. If you dated a mineral from inside an igneous rock, what would that date indicate? How about from a sedimentary rock?

Explore More

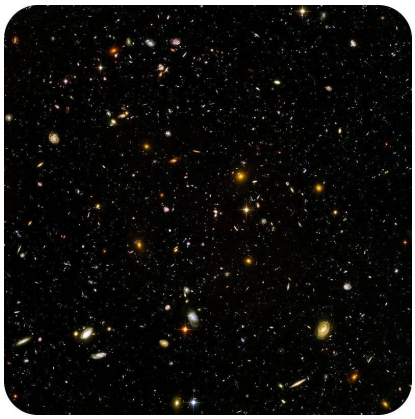
Use the resource below to answer the questions that follow.



1. What do scientists hope to answer with radiometric dating?
2. Is the whole rock, in this case graywacke, dated?
3. How is the rock crushed? How is it powdered?
4. Who explained radioactivity? What was his explanation?
5. What is a mass spectrometer? How does it work?
6. What is the spectrometer separating in this rock?
7. How will scientists use this information to date the rock? What else do they need to know before they can get a date?
8. Why is the dating of rocks important?

This page titled 15.12: Radiometric Dating is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

15.13: Age of Earth



What is deep time?

We can look so far out into space that it's hard to imagine the distances. We also have trouble imagining the extend of geologic time. This section might help.

Age of Earth

Earth scientists use radiometric dating, index fossils, and other clues. They have determined that Earth is 4.6 billion years old. The planet is the same age as the rest of the solar system.

Geologic Time Condensed to One Year

It's always fun to think about geologic time in a framework that we can more readily understand. Here are when some major events in Earth history would have occurred if all of Earth history was condensed down to one calendar year.

January 1, 12:00 am: Earth forms from the planetary nebula – 4600 million years ago

February 25, 12:30 pm: The origin of life; the first cells – 3900 million years ago

March 4, 3:39 pm: Oldest dated rocks – 3800 million years ago

March 20, 1:33 pm: First stromatolite fossils – 3600 million years ago

July 17, 9:54 pm: First fossil evidence of cells with nuclei – 2100 million years ago

November 18, 5:11 pm: Cambrian Explosion – 544 million years ago

December 1, 8:49 am: First insects – 385 million years ago

December 2, 3:54 am: First land animals, amphibians – 375 million years ago

December 5, 5:50 pm: First reptiles – 330 million years ago

December 12, 12:09 pm: Permo-Triassic Extinction – 245 million years ago

December 13, 8:37 pm: First dinosaurs – 228 million years ago

December 14, 9:59 am: First mammals – 220 million years ago

December 22, 8:24 pm: First flowering plants – 115 million years ago

December 26, 7:52 pm: Cretaceous-Tertiary Extinction – 66 million years ago

December 26, 9:47 pm: First ancestors of dogs – 64 million years ago

December 27, 5:25 am: Widespread grasses – 60 million years ago

December 27, 11:09 am: First ancestors of pigs and deer – 57 million years ago

December 28, 9:31 pm: First monkeys – 39 million years ago

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

December 31, 5:18 pm: Oldest hominid – 4 million years ago

December 31, 11:02 pm: Oldest direct human ancestor – 1 million years ago

December 31, 11:48 pm: First modern human – 200,000 years ago

December 31, 11:59 pm: Revolutionary War – 235 years ago

Source: http://www.timetoast.com/timelines/63215

Watch the following video for another analogy of geologic time.



Summary

- Earth is 4.6 billion years old. It is also 4,600 million years old.
- If Earth history is equal to a year, all of human history has taken place in the last 12 minutes.
- The Cambrian Explosion took place on November 18. Life is very recent.

Review

1. How old is Earth?
2. What was the longest major stage in the history of life and what was it?
3. When did modern humans arise in Earth history?
4. When did the cell nucleus evolve?

Explore More

Use the resource below to answer the questions that follow.



1. When did Earth form in years ago and on the one year calendar?
2. When did the first life appear in years ago and on the one year calendar?
3. When did multicellular life evolve in years ago and on the one year calendar?
4. When did the first plants evolve in years ago and on the one year calendar?
5. When did the dinosaurs go extinct in years ago and on the one year calendar?
6. When were the Himalayas formed in years ago and on the one year calendar?
7. When did the first humans appear in years ago and on the one year calendar?
8. When was the end of the last ice age in years ago and on the one year calendar?

This page titled 15.13: Age of Earth is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

15.14: Understanding Earth's History- Challenge 3

1. The distinctive patterns of tree rings, ice cores, and ___ can be used to determine the time they were formed.

varves

2. The counting of ___ layers is one of the methods of ice core dating.

dust-snow

3. ___ analysis yields clues about how changes in the concentration of atmospheric gases have influenced Earth's climate over time.

Ice core

4. If two half-lives have passed, ___ percent of the parent isotope remains.

25

5. Radioactive decay of an isotope leads to the formation of a ___ product.

stable daughter

6. ___ discovered the spontaneous emission of particles that they called "radioactivity."

Pierre and Marie Curie

7. When an organism dies, carbon-14 decays to stable nitrogen-14 by releasing a ___.

beta particle

8. Carbon dating measures when an organism died because only then does ___.

carbon-14 decay into nitrogen-14

9. Carbon-14 dating is used for dating human remains and artifacts because ___.

carbon-14 has a relatively short half-life and early human fossils and materials often contain carbon

10. ___ is the most useful technique for dating Earth's matter and coming up with a quantitative age for the planet.

Radiometric dating

11. ___ determines the age of an object based on the concentration of a particular radioactive isotope contained within the object.

Radiometric dating

12. Earth is ___ years old.

4.6 billion

This page titled 15.14: Understanding Earth's History- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

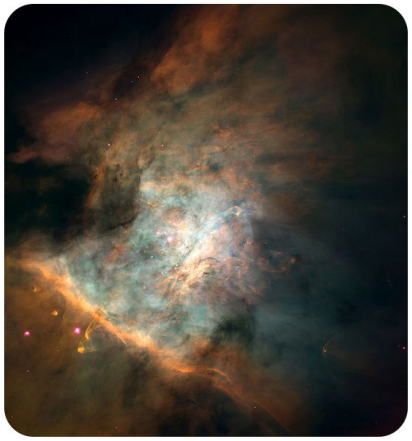
CHAPTER OVERVIEW

16: Earth's History

16.1: Formation of the Sun and Planets
16.2: Formation of Earth
16.3: Formation of the Moon
16.4: Early Atmosphere and Oceans
16.5: Earth's History- Challenge 1
16.6: Precambrian Continents
16.7: Paleozoic Plate Tectonics
16.8: Paleozoic and Mesozoic Seas
16.9: Mesozoic Plate Tectonics
16.10: Cenozoic Plate Tectonics
16.11: Earth's History- Challenge 2

This page titled 16: Earth's History is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

16.1: Formation of the Sun and Planets



Where are stars born? Are stars being born right now?

Stars are born in clouds like the one in the picture. Gravity pulls material together. When it is extremely dense, it begins nuclear fusion. That is, it becomes a star. We can see places where stars are being born right now. Of course, it takes light a long time to travel to us. So what we see right now may have happened many millions or even billions of years ago.

Formation of the Solar System

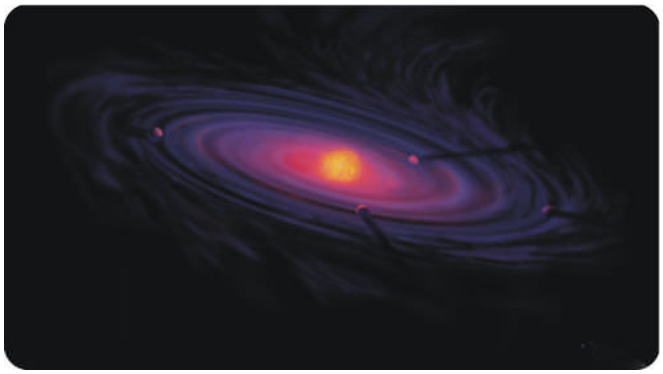
Our solar system began about 5 billion years ago. The Sun, planets, and other solar system objects all formed at about the same time. The leading hypothesis for how they formed is called the **nebular hypothesis**.

The Solar Nebula

The Sun and planets formed from a giant cloud of gas and dust. This was the **solar nebula**. The cloud contracted and began to spin. As it contracted, its temperature and pressure increased. The cloud spun faster and formed into a disk. Scientists think the solar system at that time looked like these disk-shaped objects in the Orion Nebula. New stars are forming in the Orion Nebula today.

Solar System Bodies Form

Gravity pulled a lot of material to the center of the cloud. Temperatures and pressures at the center of the cloud were extreme. It was so hot that **nuclear fusion** reactions began. A star was born—the Sun. In these reactions, hydrogen fuses to make helium. Extreme amounts of energy are released.



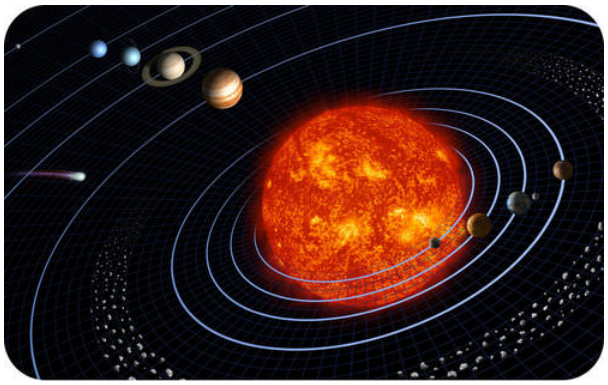
An artist's painting of a protoplanetary disk.

Meanwhile, the outer parts of the disk were cooling off. Matter condensed from the cloud. Small pieces of dust started clumping together. These clumps collided and combined with other clumps. Gravity brought more clumps together to make larger bodies.

Gravity at the center of the disk attracted rock and metal. Lighter material remained farther out in the disk. Eventually, these small bodies grew to become the planets and moons that we find in our solar system today.

The Planets

Since gravity pulled the more dense material inward, the inner planets—Mercury, Venus, Earth, and Mars—are made of rock and metal. The outer planets—Jupiter, Saturn, Uranus, and Neptune—condensed farther from the Sun (**Figure** below). They are made from lighter materials, such as hydrogen, helium, water, ammonia, and methane. Out by Jupiter and beyond, where it's very cold, these materials form solid particles. Dwarf plants, comets, and asteroids formed too.



The Sun and planets (note that this image is old enough to include Pluto, which is no longer considered one of the planets).

The nebular hypothesis explains the basic features of the solar system:

- The orbits of the planets lie in nearly the same plane. The Sun is at the center.
- The planets revolve in the same direction.
- The planets mostly rotate in the same direction.
- The axes of rotation of the planets are mostly nearly perpendicular to the orbital plane.
- The oldest Moon rocks are 4.5 billion years old.

The center of the nebula became a star, our Sun!

Summary

- A giant cloud of dust and gas is called a nebula. A nebula collapsed to form the solar system. This is the nebular hypothesis.
- When hydrogen began to fuse into helium, the Sun became a star.
- Planets nearer the Sun are formed of denser metal and rocks. Planets farther out are lighter and gaseous.

Review

1. What is the nebular hypothesis?
2. What was the solar nebula?
3. How did the material at the center of the solar system become a star?
4. What are the categories of bodies in the solar system? In general, where can they be found?
5. What is the evidence that supports the nebular hypothesis?

Explore More

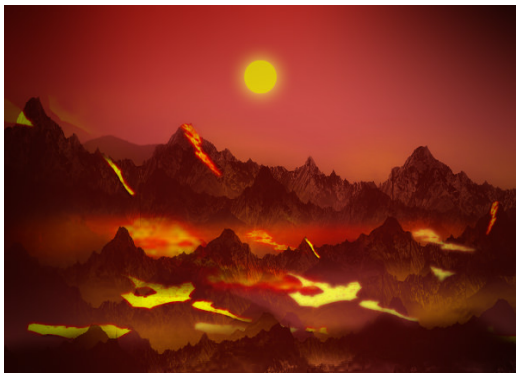
Use the resource below to answer the questions that follow.



1. What is a protostar?
2. At what temperature did nuclear fusion begin?
3. When was our star born? How much longer will it last?
4. How does the Sun produce its light?
5. What does recent research suggest about the birth of our Sun?
6. What was the Big Bang?

This page titled 16.1: Formation of the Sun and Planets is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

16.2: Formation of Earth



What was early Earth like?

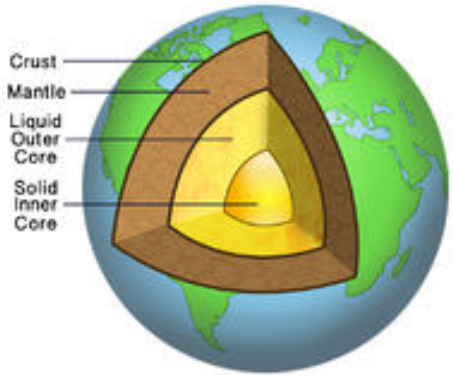
Earth was not always the planet it is today. In its earliest days, Earth was scorching hot. It did not have an atmosphere or water. If life originated early on, it was wiped out by the terrible conditions.

Formation of Earth and Moon

Material at similar distances from the Sun collided together to form each of the planets. Earth grew from material in its part of space. The Moon's origin is completely different from Earth's.

Earth Forms

Earth formed like the other planets. Different materials in its region of space collided. Eventually, the material made a planet. All of the collisions caused Earth to heat up. Rock and metal melted. The molten material separated into layers. Gravity pulled the denser material into the center. The lighter elements rose to the surface (**Figure** below). Because the material separated, Earth's core is made mostly of iron. Earth's crust is made mostly of lighter materials. In between the crust and the core is Earth's mantle, made of solid rock.



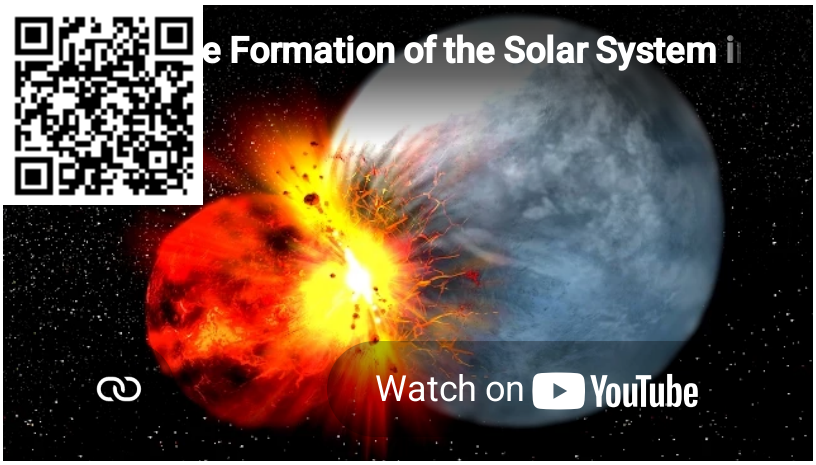
Earth's layers.

Moon Forms

This model for how the Moon formed is the best fit of all of the data scientists have about the Moon.

In the early solar system, there was a lot of space debris. Asteroids flew around, sometimes striking the planets. An asteroid the size of Mars smashed into Earth. The huge amount of energy from the impact melted most of Earth. The asteroid melted too. Material from both Earth and the asteroid was thrown out into orbit. Over time, this material smashed together to form our Moon. The lunar surface of the Moon is about 4.5 billion years old. This means that the collision happened about 70 million years after Earth formed.

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



Summary

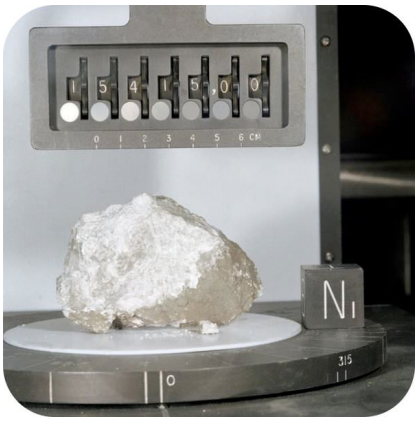
- Earth grew from material that collided in its part of space.
- The material melted and gravity separated it into layers.
- An enormous asteroid struck Earth. The material flew into orbit and came together to form the Moon.

Review

1. How did Earth form?
2. How did Earth material separate into layers?
3. How did the Moon form?

This page titled 16.2: Formation of Earth is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

16.3: Formation of the Moon



Why is this called the Genesis Rock?

The Genesis Rock was brought from the Moon to Earth by Apollo 15 astronauts. The rock is only 100 million years younger than the solar system and comes from the Moon's original crust.

How the Moon Formed

One of the most unique features of planet Earth is its large Moon. Unlike the only other natural satellites orbiting an inner planet, those of Mars, the Moon is not a captured asteroid. Understanding the Moon's birth and early history reveals a great deal about Earth's early days.

Features of the Moon

To determine how the Moon formed, scientists had to account for several lines of evidence:

- The Moon is large; not much smaller than the smallest planet, Mercury.
- Earth and Moon are very similar in composition.
- Moon's surface is 4.5 billion years old, about the same as the age of the solar system.
- For a body its size and distance from the Sun, the Moon has a very little core; Earth has a fairly large core.
- The oxygen isotope ratios of Earth and Moon indicate that they originated in the same part of the solar system.
- Earth has a faster spin than it should have for a planet of its size and distance from the Sun.

Can you devise a "birth story" for the Moon that takes all of these bits of data into account?

Moon's Birth Story

Astronomers have carried out computer simulations that are consistent with these facts and have detailed a birth story for the Moon. A little more than 4.5 billion years ago, roughly 70 million years after Earth formed, planetary bodies were being pummeled by asteroids and planetoids of all kinds. Earth was struck by a Mars-sized asteroid (**Figure** below).

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



An artist’s depiction of the impact that produced the Moon.

The tremendous energy from the impact melted both bodies. The molten material mixed up. The dense metals remained on Earth, but some of the molten, rocky material was flung into an orbit around Earth. It eventually accreted into a single body, the Moon. Since both planetary bodies were molten, material could differentiate out of the magma ocean into core, mantle, and crust as they cooled. Earth’s fast spin is from energy imparted to it by the impact.

Moon Rocks

Lunar rocks reveal an enormous amount about Earth’s early days. The Genesis Rock, with a date of 4.5 billion years, is only about 100 million years younger than the solar system (see opening image). The rock is a piece of the Moon’s anorthosite crust, which was the original crust. Why do you think Moon rocks contain information that is not available from Earth’s own materials?

Can you find how all of the evidence presented in the bullet points above is present in the Moon’s birth story?

Summary

- The scientific explanation for how the Moon formed must take into account its features, such as its large size, internal structure, chemical composition, and spin.
- Earth was struck by a giant asteroid that melted the planet and asteroid and flung material into orbit where it coalesced and cooled to become the Moon.
- Moon's original crust is anorthosite, a feldspar-rich, light rock.

Review

1. Relay the story of how the Moon formed. Integrate as many of the Moon's features into the story as possible.
2. Why are Earth and Moon roughly the same age as the rest of the solar system?
3. Why do scientists learn a lot about the early Earth from their studies of the Moon?

This page titled 16.3: Formation of the Moon is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

16.4: Early Atmosphere and Oceans



What did Earth look like at first?

The earliest Earth did not have an atmosphere or free water. The planet was far too hot for gases and water to collect. The atmosphere and oceans that we see today evolved over time. The gases came from volcanic eruptions and from comets.

Formation of the Atmosphere and Oceans

An atmosphere is the gases that surround a planet. The early Earth had no atmosphere. Conditions were so hot that gases were not stable.

Earth's First Atmosphere

Earth’s first atmosphere was different from the current one. The gases came from two sources. Volcanoes spewed gases into the air. Comets carried in ices from outer space. These ices warmed and became gases. Nitrogen, carbon dioxide, hydrogen, and water vapor were in the first atmosphere (**Figure** below). Take a look at the list of gases. What's missing? The early atmosphere had almost no oxygen.



Gases from Earth’s interior came through volcanoes and into the atmosphere.

The Early Oceans

Earth’s atmosphere slowly cooled. Once it was cooler, water vapor could condense. It changed back to its liquid form. Liquid water fell to Earth’s surface as rain. Over millions of years water collected to form the oceans. Water began to cycle on Earth as water evaporated from the oceans and returned again as rainfall.

Streams carry dissolved minerals. These ions make the oceans salty. Four billion-year-old marine sedimentary rocks have been found. The first oceans could have formed as early as 4.2 to 4.4 billion years ago!

The Later Atmosphere

Eventually life evolved. Single-celled organisms were the first life forms to appear, and some of them produced oxygen as a byproduct of photosynthesis. Oxygen spread around the planet about 2.5 billion years ago (though photosynthesis evolved around this time, plants wouldn't appear until much later). Many organisms died off because they could not handle the oxygen. But this

development was extremely important for other life. Animals need oxygen to breathe. If photosynthesis had not evolved, there would be no animals.

Oxygen is needed to make ozone. Ozone is a molecule made of three oxygen ions. Ozone in the upper atmosphere blocks harmful solar radiation from reaching the surface. Without oxygen, life on Earth would have been very simple.



Summary

- Earth's first atmosphere came from the planet's interior. Gases also came from asteroids and comets from elsewhere in the solar system.
- There was very little oxygen in the atmosphere until plants evolved. Oxygen allowed animals to evolve and ozone to form.
- The first oceans formed when water rained out of the atmosphere into basins.

Review

1. What were the sources of gases in Earth's early atmosphere?
2. Where did oxygen come from? Why is oxygen so important for life on Earth?
3. How did the first oceans form?

This page titled 16.4: Early Atmosphere and Oceans is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

16.5: Earth's History- Challenge 1

1. The inner planets are made primarily of ___.

dense rock and metal

2. ___ brings gas and dust together to form new stars.

Gravity

3. The planets formed because ___.

clumps of material orbiting what would become the Sun continued to collide with each other due to gravity

4. Earth formed ___ as the other planets.

at about the same time

5. Earth's early crust probably ___.

recycled into the mantle because of vigorous convection

6. Earth's interior separated into layers based on density through the process of ___.

differentiation

7. The ___ ratios of the Moon and Earth indicate that they originated in the same part of the solar system.

oxygen isotope

8. The Moon formed when ___.

a Mars-sized asteroid hit Earth

9. The material that came together to form the Moon was flung into space from ___.

Earth

10. Earth's first atmosphere was made up of ___.

carbon dioxide, ammonia, hydrogen, and water vapor

11. Oxygen appeared in Earth's atmosphere though ___.

photosynthesis

12. The ozone layer protects Earth's surface from ___.

ultraviolet rays

This page titled 16.5: Earth's History- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

16.6: Precambrian Continents



When did Earth become a dynamic planet?

Earth was always dynamic! Earth has changed many times over billions of years. Huge mountains have formed, been destroyed, and been replaced with new mountains. Continents have moved, split apart, and collided with each other. Ocean basins have opened up. Life on Earth evolved slowly for billions of years.

Early Continents

The earliest crust was probably basalt. It may have resembled the current seafloor. This crust formed before there were any oceans. More than four billion years ago, continental crust appeared. The first continents were very small compared with those today.

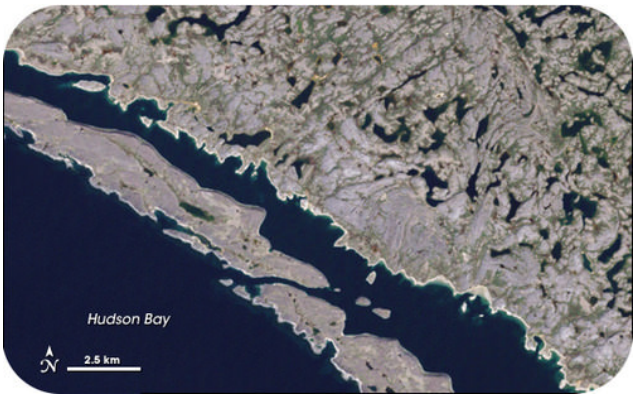
Continents Grow

Continents grow when **microcontinents**, or small continents, collide with each other or with a larger continent. Oceanic island arcs also collide with continents to make them grow.

Cratons

The earliest continental crust is now found in the ancient cores of continents, called **cratons**. Geologists can learn many things about the Precambrian by studying the rocks of the cratons.

- Cratons contain felsic igneous rocks, which are remnants of the first continents.
- Cratonic rocks contain rounded sedimentary grains. Rounded grains indicate that the minerals eroded from an earlier rock. It also means that rivers or seas existed.
- One common rock type in the cratons is **greenstone**, a metamorphosed volcanic rock (**Figure** below). Since greenstones are found today in oceanic trenches, what does the presence of greenstones mean? These ancient greenstones indicate the presence of subduction zones.



Ice age glaciers scraped the Canadian Shield down to the 4.28 billion year old greenstone in Northwestern Quebec.

Supercontinents

There are times in Earth history when all of the continents come together to form a **supercontinent**. Supercontinents come together and then break apart. Pangaea was the last supercontinent on Earth, but it was not the first. The supercontinent before Pangaea is called Rodinia. Rodinia contained about 75% of the continental landmass that is present today. The supercontinent came together about 1.1 billion years ago. Rodinia was not the first supercontinent either. Scientists think that three supercontinents came before Rodina, making five so far in Earth history.

Early Plate Tectonics

Since the early Earth was very hot, mantle convection was very rapid. Plate tectonics likely moved quickly. The early Earth was an active place with abundant volcanic eruptions and earthquakes. The remnants of these early rocks are now seen in the ancient cores of the continents.

Further Reading

Paleozoic Plate Tectonics

Paleozoic and Mesozoic Seas

Mesozoic Plate Tectonics

Cenozoic Plate Tectonics

Summary

- The first crust was basalt. It resembled the modern seafloor.
- Microcontinents come together to create continents and supercontinents.
- Convection on early Earth was faster and so plate tectonics was faster. Since then, Earth has been cooling.

Review

1. What were the first continents like?
2. Where do we find the oldest crust we can find? Is this what is left of the first crust? How do we know?
3. What are supercontinents? How do we know of their existence (think back to the concepts in the *Plate Tectonics* chapter)?
4. Why was plate tectonics faster in the early Earth?

Explore More



1. What did the early Earth look like?

2. Why do some scientists think that life may have originated more than once?
3. What landmasses existed 2.5 billion years ago?
4. When did Arctica take shape?
5. What was Rodinia?
6. What came together to form Pangaea and when did this happen?
7. What is driving the movement of the plates?
8. What is convective flow?
9. Where does the energy come from to drive plate movements?
10. What material is found in the core that makes it hot?

This page titled 16.6: Precambrian Continents is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

16.7: Paleozoic Plate Tectonics



Could these mountains have existed in the Paleozoic?

Sure! There have been lots of huge mountain ranges in Earth history. When continents collide, big mountains grow. The formation of Pangaea created long large mountain ranges. The mountains that formed then probably looked a lot like the Himalayas do today.

The Paleozoic Era

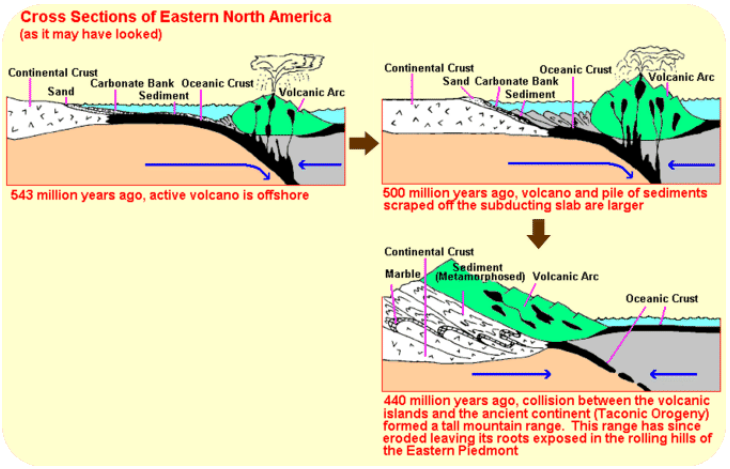
The Paleozoic is the earliest era of the Phanerozoic. The Paleozoic was also the longest era of the Phanerozoic. But the Paleozoic was relatively recent. It began only 570 million years ago. At the start of the Paleozoic, there was a supercontinent called Rodinia. The supercontinent broke apart during the early part of the Paleozoic.

The Phanerozoic is recent history compared with the Precambrian. This is one reason that the Paleozoic is much better known than the Precambrian. Another reason is that Paleozoic organisms had hard parts, and they fossilized better.

Formation of Pangaea

A mountain-building event is called an **orogeny**. Orogenies take place over tens or hundreds of millions of years. Continents smash into each other. Microcontinents and island arcs smash into continents. All of these events cause mountains to rise.

When Pangaea came together, there were orogenies all along the collision zones. Geologists find much evidence of these orogenies. For example, Laurentia collided with the Taconic Island Arc during the Taconic Orogeny (**Figure** below). The remnants of this mountain range make up the Taconic Mountains in New York.



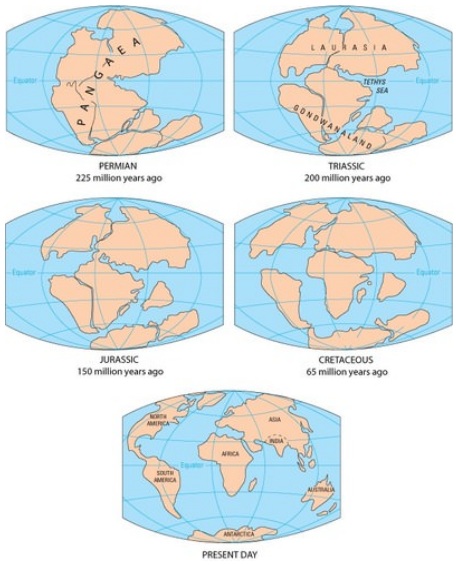
The Taconic Orogeny is an example of a collision between a continent and a volcanic island arc.

Laurentia experienced other orogenies as it collided with the northern continents. The southern continents came together to form Gondwana. When Laurentia and Gondwana collided to create Pangaea, the Appalachians rose. Geologists think the Appalachians were once higher than the Himalayas are now.

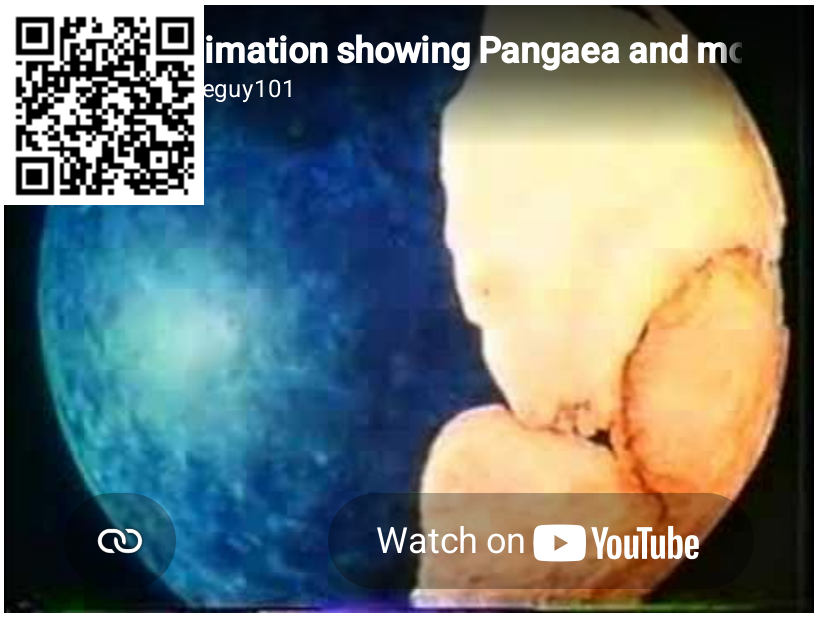
Pangaea

Pangaea was the most recent supercontinent on Earth. Evidence for the existence of Pangaea was what Alfred Wegener used to create his continental drift hypothesis. Continental drift is described in the chapter Plate Tectonics.

As the continents move, the shape of the oceans changes too. At the time of Pangaea, most of Earth's water was collected in a huge ocean. This ocean was called Panthalassa (**Figure** below).



Pangaea was the sole landform 250 million years ago. The rest of the planet was a huge ocean called Panthalassa, along with a few smaller seas.



Summary

- The Paleozoic began with the supercontinent Rodinia. The era ended with the supercontinent Pangaea.
- As continents come together, orogenies build up mountain ranges.
- Pangaea was a giant landmass made of all of the continents around 250 million years ago.

Review

1. How do plate tectonics processes result in orogenies?
2. How did Pangaea come together?
3. How is the creation of Pangaea related to events like the Taconic orogeny?

https://k12.libretexts.org/@go/page/5935

This page titled 16.7: Paleozoic Plate Tectonics is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

16.8: Paleozoic and Mesozoic Seas

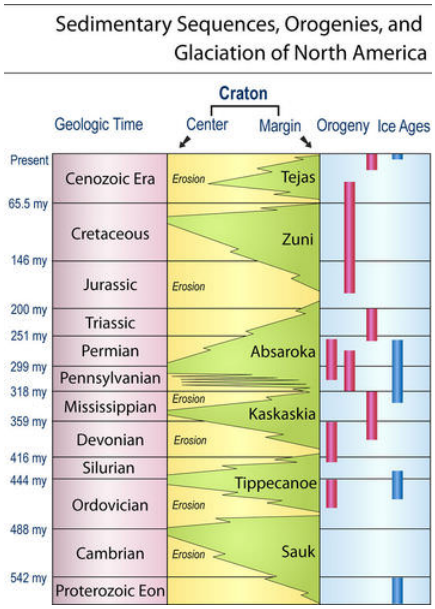


Do you like the beach? If so, the Paleozoic may be for you!

If we were living right now at the time of a marine transgression, there would be a lot more beach. Surf's up!

Marine Transgressions and Regressions

Sea level rises and falls. During the Paleozoic and Mesozoic, the seas rose over the continents. This is called a **marine transgression**. During a **marine regression**, the sea level retreats. The Paleozoic had four complete cycles of marine transgressions and regressions. The Mesozoic had two (**Figure** below).



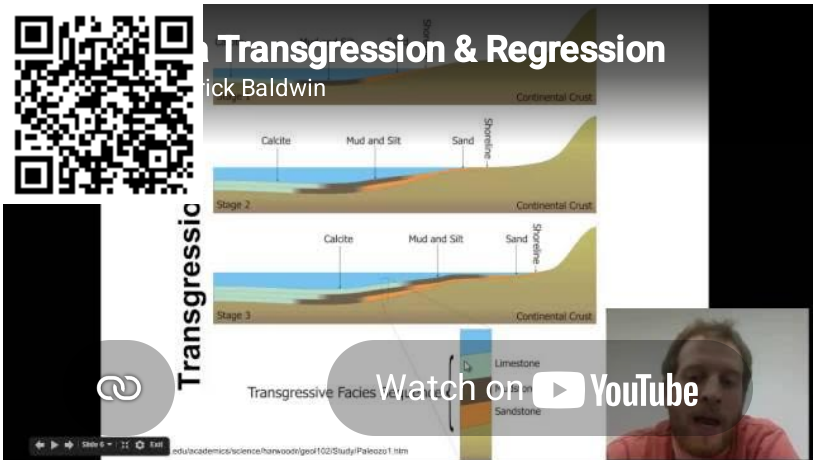
Six marine transgressions and regressions have occurred during the Phanerozoic.

What makes sea level rise? There are two possibilities: either the land sinks or the water level rises. Tectonic processes can cause the land to sink. Melting glaciers can cause the water level to rise. Sea level rises if seafloor spreading goes faster. The hotter crust is buoyed up and displaces the water. This causes the ocean basin to become smaller. What could cause sea level to fall in a marine regression? Land rises up. Glaciers grow. Seafloor spreading slows down. Just the opposite of what makes sea level rise!

Geologists think that the Paleozoic marine transgressions and regressions were the result of the decrease and increase in the size of glaciers covering the lands.

Rock Facies

Geologists know about marine transgressions and regressions from sedimentary rocks. These events leave characteristic rock layers known as sedimentary **facies**. Sand and other coarse grained rock fragments are deposited on the beach where the wave energy is high. Offshore in lower energy environments, fine-grained silt is deposited. Farther offshore in lower energy waters, carbonate mud that later hardens is deposited. The rocks that result are sandstone, shale, and limestone. As the sea moves on or offshore, one rock layer is on top of the other.



Summary

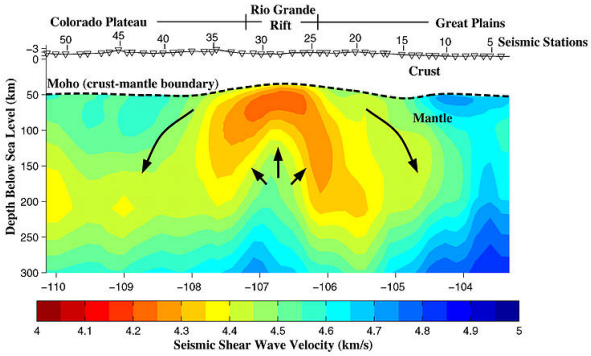
- Sea level depends on the relationship of the water level to the land.
- Sea level will rise when glaciers melt. Sea level will fall when glaciers grow.
- Facies are characteristic rock layers, such as sandstone, shale, limestone for a marine transgression. The reverse indicates a marine regression.

Review

1. How do scientists use sedimentary facies to recognize a marine transgression?
2. How do scientists use sedimentary facies to recognize a marine regression?
3. What are the possible causes of a marine transgression?
4. What are the possible causes of a marine regression?
5. How do geologists know that there were two transgressions and regressions in the Mesozoic?

This page titled 16.8: Paleozoic and Mesozoic Seas is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

16.9: Mesozoic Plate Tectonics

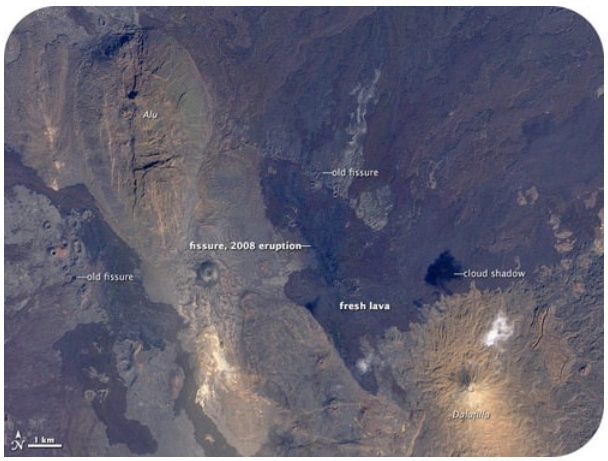


Why would a supercontinent break up?

A continent is like a giant blanket that traps heat. Heat from the mantle comes up but cannot escape through the continent. This image shows hot material beneath New Mexico. The heat is trapped beneath the North American plate. The hot material is causing rifting to begin. This is known as the Rio Grande Rift.

Supercontinent Breakup

Why would a supercontinent break up? Remember that Earth's interior is hot. Heat builds up beneath the supercontinent. This causes the continent to buoy upward. Continental rifting begins. Basalt lava fills in the rift. This could lead to seafloor spreading and the formation of a new ocean basin. This basalt province is where Africa is splitting apart and generating basalt lava. (**Figure** below)



In the Afar Region of Ethiopia, Africa is splitting apart. Three plates are pulling away from a central point.

The Breakup of Pangaea

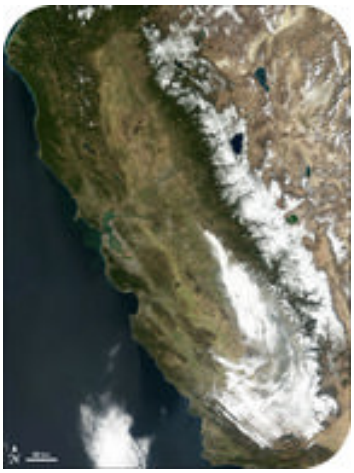
At the end of the Paleozoic, there was one continent and one ocean. Then Pangaea began to break apart about 180 million years ago. The Panthalassa Ocean separated into the individual but interconnected oceans that we see today on Earth.

Continental rifting and then seafloor spreading separated Africa and South America. The Atlantic Ocean basin formed in between the continents. Seafloor spreading continues to enlarge the Atlantic Ocean (**Figure** above).

Growth of Continents

The moving continents collided with island arcs and **microcontinents**. Mountain ranges grew near the continents' edges. The oceanic Farallon plate subducted beneath western North America during the late Jurassic and early Cretaceous. This activity

produced igneous intrusions and other structures. The intrusions have since been uplifted. They are exposed in the Sierra Nevada Mountains (**Figure** below).



The snow-covered Sierra Nevada is seen striking SE to NW across the eastern third of the image. The mountain range is a line of uplifted batholiths from Mesozoic subduction.



Summary

- Continents keep mantle heat from escaping. This may eventually lead to continental rifting.
- Continents grow as microcontinents or igneous activity add continental crust to an existing continent.
- When a supercontinent breaks apart, new seafloor forms between the new continental masses.

Review

1. Is Pangaea still breaking up? Why or why not?
2. How do continents grow?
3. How did the Sierra Nevada mountains form?

This page titled 16.9: Mesozoic Plate Tectonics is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

16.10: Cenozoic Plate Tectonics



How does the Cenozoic end?

We don't know how the Cenozoic ends. We're still in it! The Cenozoic has been going on for 65 million years. Toward the very end of this time, humans evolved. We are now witness to the geology of the Cenozoic. What came earlier in this era looks a lot like what is going on now.

Cenozoic

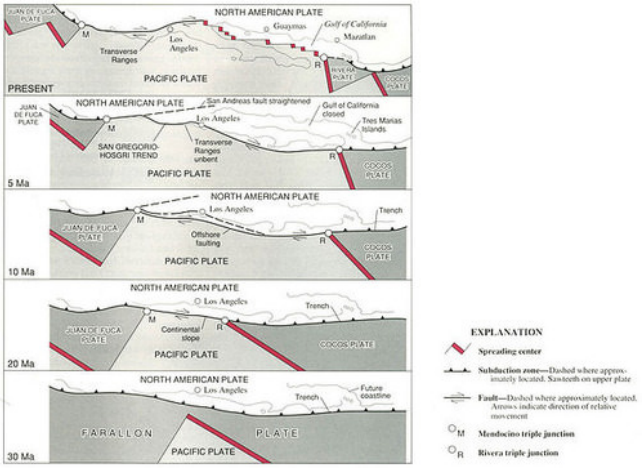
The Cenozoic began around 65.5 million years ago. We say that it begins after the Cretaceous extinction. We are still in the Cenozoic today. The Cenozoic accounts for only about 1.5% of Earth's total history. But since it's the the most recent era, it is the one we know the most about. Much of what has been discussed elsewhere in this text describes the geology of the Cenozoic. A few highlights are mentioned here.

Plate Tectonics

The plate tectonics of the Cenozoic are still going on today. Early in the Cenozoic, blocks of crust uplifted to form the Rocky Mountains. Subduction off of the Pacific Northwest formed the Cascades volcanic arc. Crust is being pulled apart to form the Basin and Range province that centers on Nevada.

Evolution of the San Andreas Fault

The San Andreas Fault is where the Pacific and North American plates meet (**Figure** below). How did the San Andreas Fault form? The Farallon Plate was subducting beneath the North American Plate. This began about 30 million years ago. By 20 million years ago, the Pacific Plate and East Pacific Rise spreading center had started to subduct. This split the Farallon Plate into two smaller plates. The plates started a transform motion where the Pacific and North American plates meet. This formed the San Andreas Fault. The fault moved inland.



This figure shows the evolution of the San Andreas Fault zone from 30 million years ago (bottom) to present (top).

Most Cenozoic plate tectonic activity involves continents moving apart. But smaller regions are coming together. Africa collided with Eurasia to create the Alps. India crashed into Asia to form the Himalayas.

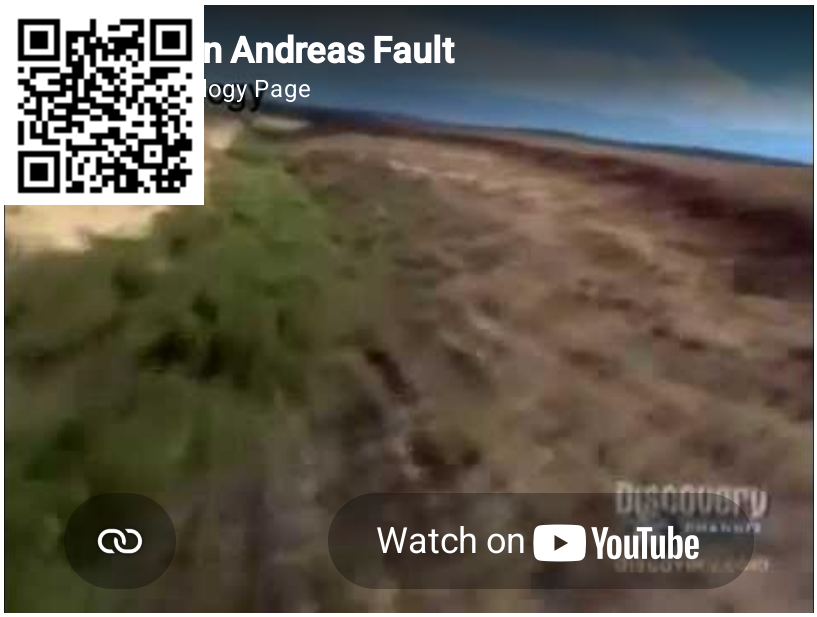
Ice Ages

The Pleistocene ice ages began 2.6 million years ago. Glaciers advanced and retreated four times (**Figure** below). During the retreats, the climate was often warmer than it is today.



Glacial ice at its maximum during the Pleistocene.

These continental ice sheets were extremely thick, like the Antarctic ice cap is today. The Pleistocene ice ages guided the evolution of life in the Cenozoic, including the evolution of humans.



Summary

- During the Cenozoic, Pangaea began to split up.
- Subduction of the Farallon plate has resulted in the formation of the Rocky Mountains and the San Andreas Fault.
- The Pleistocene was marked by four advances of ice. The remnants of the last advance of glaciers are found today.

Review

1. Why do we know so much more about the Cenozoic than the other eras of geologic time?
2. How do plate tectonics processes explain the Rocky Mountains? The San Andreas Fault? The Himalayas?
3. What were the Pleistocene ice ages? What did the ice ages do to the evolution of life?

This page titled 16.10: Cenozoic Plate Tectonics is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

16.11: Earth's History- Challenge 2

1. Earth's earliest crust was made up of ___.

basalt

2. The presence of ancient greenstones in cratons indicates the presence of ___.

subduction zones

3. The continental collisions that create supercontinents also create mountain ranges through the process of ___.

orogeny

4. The Paleozoic began with the supercontinent ___ and ended with the supercontinent ___.

Rodinia; Pangaea

5. At the end of the Paleozoic, there existed ___ and ___.

one supercontinent called Pangaea; one super-ocean called Panthalassa

6. Sea levels fall and land is gained from the sea during ___.

marine regressions

7. A rise in sea level is a marine ___.

transgression

8. Marine transgressions and regressions leave characteristic rock layers known as sedimentary ___.

facies

9. The subduction of the oceanic Farallon plate beneath western North America during the late Jurassic and early Cretaceous produced ___ intrusions.

igneous

10. The subduction of the Farallon plate created the ___ mountains.

Sierra Nevada

11. If vigorous seafloor spreading can cause marine transgressions, slow seafloor spreading can cause ___.

marine regressions

12. Africa collided with ___ to create the Alps.

Eurasia

13. When Antarctica drifted over the South Pole region, ___.

the continent began to grow an ice cap

14. The Quaternary and Holocene are part of the ___ era.

Cenozoic

This page titled 16.11: Earth's History- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

17: Evolution and Populations

17.1: Modern Biodiversity
17.2: Characteristics and Origins of Life
17.3: Metabolism and Replication
17.4: Adaptation and Evolution of Populations
17.5: Theory of Evolution by Natural Selection
17.6: Population Size
17.7: Extinction and Radiation of Life
17.8: Evolution and Populations- Challenge 1
17.9: Growth of Human Populations
17.10: Agriculture and Human Population Growth
17.11: Revolutions in Human Population
17.12: Overpopulation and Over-Consumption
17.13: Future Human Population Growth
17.14: Sustainable Development
17.15: Evolution and Populations- Challenge 2

This page titled 17: Evolution and Populations is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

17.1: Modern Biodiversity



Do you know life on Earth?

It's likely that there are many places on Earth that you would not recognize as being on your home planet. There are also many creatures that you would not realize that you share a planet with. That's because of the incredible diversity of species. Wouldn't it be fun to see some of these unusual creatures?

Biological Diversity

More than 1.3 million species of organisms have been cataloged. Many millions of species have not been discovered yet. Scientists estimate that there may be about 8.7 million species in all. Why does the planet have so much biological diversity? (Biological diversity is shortened to **biodiversity**.) The tremendous variety of organisms is due to the tremendous numbers of habitats that they have evolved to fill.

Ways to Live in the Environment

Each organism has the ability to survive in a specific environment. Dry desert environments are difficult to live in. Desert plants have special stems and leaves to conserve water (**Figure** below). Animals have other ways to live in the desert. The Namib Desert receives only 1.5 inches of rainfall each year. The Namib Desert beetle lives there. How do the beetles get enough water to survive? Early morning fog deposits water droplets. The droplets collect on a beetle's wings and back (**Figure** below). The beetle tilts its rear end up. When the droplet is heavy enough, it slides forward. It lands in the beetle’s mouth. There are many other environments that need unique approaches for survival (**Figure** below and below).



Aloe vera plants like these ones have fat, waxy leaves that allow them to conserve water.



The Namib Desert Beetle has bumps on its back for collecting water.



Stoats change color in the winter, from brown to white, so that they can hide in the snow.



Crowned cranes have plumage that helps them attract a mate.

Getting Food and Being Food (Or Not)

Organisms must be able to get food and avoid being food. Hummingbirds have long, thin beaks that help them drink nectar from flowers. Some flowers are tubular. Different species of flowers have tubes of different lengths. Different species of hummingbirds have different lengths of beaks. A particular hummingbird species has evolved to feed from one or a few species of flowers.

The battle between needing food and being food plays out in the drama between lions and zebras. When a herd of zebras senses a lion, the animals run away. The zebras' dark stripes confuse the lions. It becomes hard for them to focus on just one zebra. The zebras may get away. But lions are swift and agile. A lion may be able to get a zebra, maybe one that's old or sick.

Summary

- There are 1.3 million known species, but many more have not been discovered.
- The enormous number of species is due to the tremendous variety of environments in which they can live.
- Organisms have features that help them to find food or avoid being eaten.

Review

1. Study the organisms in the photos above. For the aloe vera plant and the beetles, list the features that each has for successful living.
2. Study the organisms in the photos above. For the stoats and the crowned crane, list the features that each has for successful living.
3. How does being well suited for a particular environment lead to biodiversity?

Explore More

Use the resource below to answer the questions that follow.



1. What is biodiversity?
2. How did so much biodiversity come about?
3. How does biodiversity help people?
4. Why is biodiversity important?
5. Why are so many species disappearing now?
6. How many species are disappearing from tropical rainforests each year? Why?

This page titled 17.1: Modern Biodiversity is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

17.2: Characteristics and Origins of Life



What is *life*?

How can you tell a blob of organic material from a living creature? What characteristics does something need to be considered alive? Does this photo resemble early Earth? Erupting geysers? Mats of bacteria? Maybe so! Of course, you have to ignore the trees in the distance.

The Origin Of Life

No one knows how or when life first began on the turbulent early Earth. There is little hard evidence from so long ago. Scientists think that it is extremely likely that life began and was wiped out. Possibly even more than once! If there was life, it would have been wiped out by the impact that created the moon.

This issue of what's living and what's not is important. It helps us to think about the origin of life. When does a blob of organic material become life? As you can see, we need to have a definition of life.

Characteristics of Life

To be considered alive, a molecule must:

- be organic. The organic molecules needed are amino acids.
- have a metabolism.
- be capable of replication (be able to reproduce).

Amino acids are molecules of carbon, hydrogen, oxygen and nitrogen. These molecules are some of the building blocks of life because they create proteins. **Proteins** are complex organic molecules that make up cells. They are the most abundant class of biological molecules.

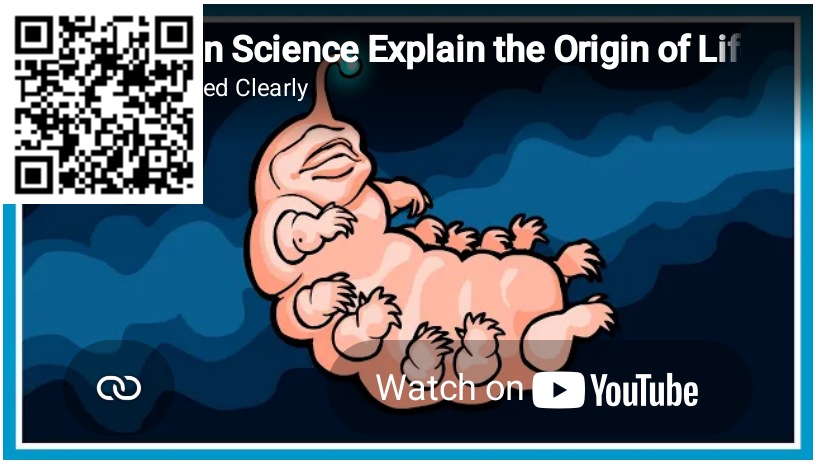
Learning About the Origin of Life

To look for information regarding the origin of life, scientists:

- perform experiments to recreate the environmental conditions found at that time.
- study the living creatures that make their homes in extreme environments. These environments are most like Earth’s early days.
- seek traces of life left by ancient microorganisms, also called **microbes** (**Figure** below). These include microscopic features or chemistry left by life. It is very difficult to distinguish these from non-biological features.



How can we tell where these microbes have been?



Summary

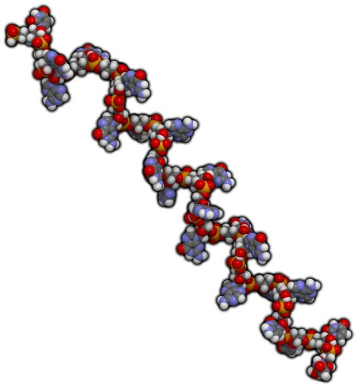
- For something to be alive it must be organic, have a metabolism, and be capable of replication.
- Amino acids create proteins. They are the building blocks of life.
- To learn about the origins of life, scientists perform experiments. They study creatures that live in extreme environments. They look for traces of life that were left by ancient microbes.

Review

1. What are the characteristics of life?
2. What are amino acids? Why are they important?
3. What are proteins? If something doesn't have proteins can it be alive?
4. How do scientists learn about the origins of life?

This page titled 17.2: Characteristics and Origins of Life is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

17.3: Metabolism and Replication



What is an RNA world?

DNA passes most genetic information today. But some scientists think that for the first life on Earth, genetic information was passed by RNA. They call this the RNA World hypothesis.

Metabolism

Organic molecules must carry out the chemical work of cells. This is their **metabolism**. Living organisms need chemical reactions to live, grow, and reproduce. The chemical reactions occur in sequences of steps. These sequences are known as metabolic pathways. The metabolic pathways are very similar for all life on Earth. That includes single-celled bacteria that have been around for billions of years. It includes the most complex life forms on Earth today. What does it mean that the metabolic pathways are so similar for all life? This means that the metabolic pathways evolved very early in Earth's history.

Replication

Living cells need organic molecules, known as **nucleic acids**. Nucleic acids are molecules that store genetic information. They pass that genetic information to the next generation. Deoxyribonucleic acid (DNA) is the nucleic acid that carries information for nearly all living cells today. DNA has done this for most of Earth's history. Ribonucleic acid (RNA) delivers genetic instructions to the location in a cell where protein is synthesized. RNA regulates protein synthesis. Some scientists think that RNA was the first replicating molecule.

A segment of DNA that is inheritable is a **gene**. Every organism has a collection of genes that code for the traits that organism could have. Not all genes are expressed; therefore, knowing all of your genes does not tell you exactly who you are.

Summary

- An organism's metabolism is the chemical reactions that allow it to live, grow, and reproduce.
- Nucleic acids pass genetic information to the next generation.
- DNA passes genetic information for living cells. RNA passes genetic information for protein synthesis.

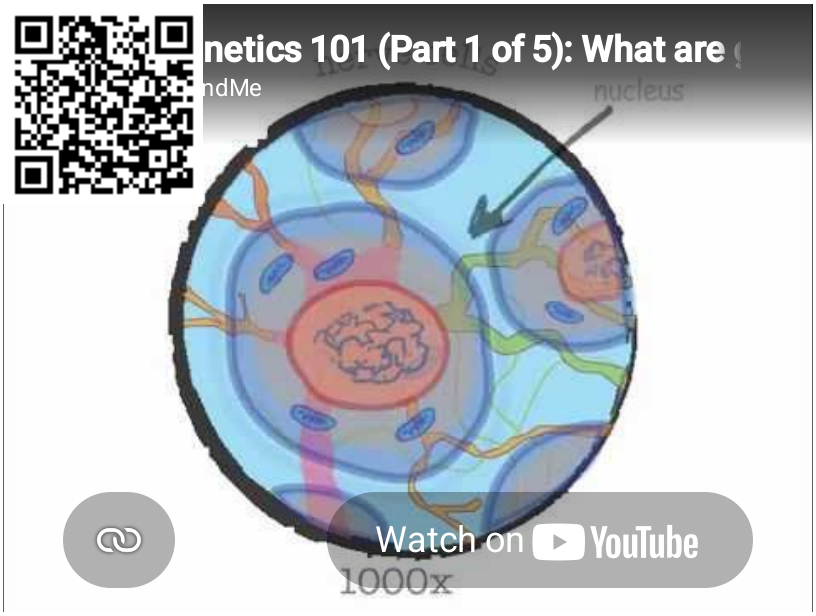
Review

1. What is the purpose of an organism's metabolism?
2. What are metabolic pathways?
3. Metabolic pathways are similar between very simple and very complex organisms. What do scientists think this means?
4. What do nucleic acids do?
5. What are the two nucleic acids and what does each do?
6. If you have a gene for a purple nose, but you don't in fact have a purple nose, what do scientist say about that gene?

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

Explore More

Use the resource below to answer the questions that follow.



1. Where are virtually all of your genes?
2. What are genes?
3. Describe the structure of a DNA molecule.
4. What do the four bases—adenine (A), thymine (T), cytosine (C), and guanine (G)—do?
5. What are chromosomes made of?
6. How many chromosomes do humans have?
7. How similar are we to chimps? How similar to other humans?

This page titled 17.3: Metabolism and Replication is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

17.4: Adaptation and Evolution of Populations



Why would an organism match its background? Wouldn't it be better to stand out?

An organism that blends in with its background is more likely to avoid predators. If it survives, it is more likely to have offspring. Those offspring are more likely to blend into their backgrounds. This butterfly appears to be well adapted to its environment. It is less likely to be eaten by a bird than a butterfly that stands out against the tree.

Variation and Adaptation

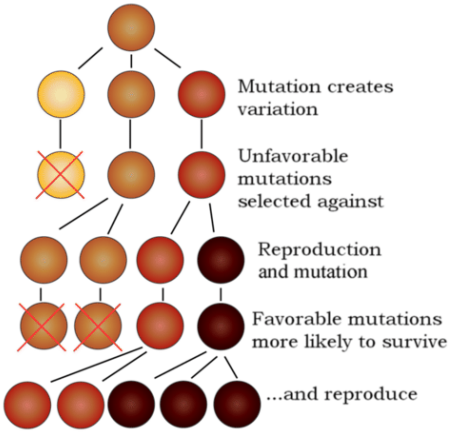
Every organism is different from every other organism. Every organism's genes are different, too.

Variations

There are **variations** in the traits of a population. For example, there are lots of variations in the color of human hair. Hair can be blonde, brown, black, or even red. Hair color is a trait determined by genes.

Mutations

At some time in the past, a variation probably came from a mutation. A **mutation** is a random change in an organism's genes (**Figure** below). Mutations are natural. Some are harmful, but many are neutral. If a mutation is harmful, the organism may not live to reproduce. If the mutation is beneficial, that organism may have a better chance to survive. An organism that survives is likely to have offspring. If it does, it may pass the mutation on to its offspring. The offspring may be more likely to survive.



Genetic mutation is central to the creation of biological diversity.

Adaptations

Some of the characteristics an organism has may help it survive. These characteristics are called **adaptations**. Some adaptations are better than others.

Many adaptations protect organisms from the external environment (**Figure** below).



Cacti have thick, water-retaining bodies that help them conserve water.

Other adaptations help an organism move or gather food. Reindeer have sponge-like hooves that help them walk on snowy ground without slipping and falling. Fish at the bottom of the ocean are tiny and use very little energy because there is very little food. Organisms have special features that help them avoid being eaten. Some plants have poisonous or foul-tasting substances in them that keep animals from eating them. Their brightly colored flowers serve as a warning. The same is true of some frogs, which can be poisonous (**Figure** below).



Poison dart frogs have toxins in their skin. Their bright colors warn potential predators not to take a bite!

How Adaptations Develop

Adaptations develop this way. Think about a population of oak trees. Imagine that a fungus has arrived from Asia to North America. Most of the North American oak trees are killed by the fungus. But a few oak trees have a mutation that allows them to survive the fungus. Those oak trees are better adapted to the new environment than the others. Those trees have a better chance of surviving. They will probably reproduce. The trees may pass on the favorable mutation to their offspring. The other trees will die. Eventually, the population of oak trees will change. Most of the trees will have the trait to survive the fungus. This is an adaptation. Over time, traits that help an organism survive become more common. Traits that hinder survival eventually disappear.

Thousands of northern elephant seals—some weighing up to 4,500 pounds—make an annual migration to breed each winter at Año Nuevo State Reserve in California. Marine biologists are using high-tech tools to explore the secrets of these amazing creatures.



Summary

- Different members of a population have different genes for the same trait.
- Some of these differences are due to mutations.
- Some traits allow an individual organism to be better adapted to its environment. That individual will be more likely to survive and to reproduce.

Review

1. How do adaptations develop?
2. What does it mean to say that an organism is well adapted to its environment?
3. What is a mutation?

This page titled 17.4: Adaptation and Evolution of Populations is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

17.5: Theory of Evolution by Natural Selection



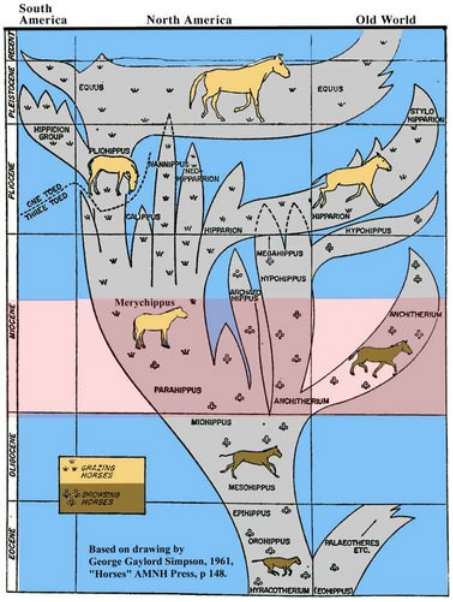
How did dark deer mice become lighter over time?

A species changes color over time if its environment changes. Many other types of changes can take place, too. The darker deer mice evolved into the lighter deer mice in some locations. What do you think changed about the environment?

Biological Evolution

Adaptations in a species add up over time. These adaptations will mean that many genes have changed. If the environment is stable, the species won't change. But if the environment is changing, the species will need to adapt. Many adaptations may be necessary. In time, the species may change a lot. The descendants will be very different from their ancestors. They may even become a new species. This process is called biological evolution but is usually referred to just as **evolution**.

Organisms alive today evolved from earlier life forms. We can learn about this from fossils. For example, horse fossils from 60 million years ago are very different from modern horses. Ancient horses were much smaller than they are today (**Figure** below). The horses' teeth and hooves have also changed. The horses evolved because of changes in their environment.



Ancient horses were quite different from present-day horses.

Although basic horse evolution appears to be linear, there were many more branches. Horse evolution is very well understood.

Natural Selection

Evolution happens because of **natural selection**. Good traits become more common in a population. Bad traits become less common. The deer mouse, species *Peromyscus maniculatus* gives an example of evolution by natural selection. In Nebraska, this mouse is typically brown. But in places where glaciers dropped lighter sand over the darker soil, the mice are light. Why? Because predators could more easily spot the dark mice on light sand. The lighter mice were more likely to survive and have offspring.

Natural selection favored the light mice. Over time, the population became light colored. Enough changes may take place over time that the two types of mice become different species.

Summary

- Changes in the genes of a species may result in a new species. This is biological evolution.
- Natural selection can change a species or even make a new species. Natural processes favor some traits over others in a population. This causes those traits to be more common in subsequent generations.
- Evolution just means change over time.

Review

1. Why are some deer mice brown and some lighter colored in Nebraska?
2. Using the example of the deer mice, how does natural selection explain the change with time of darker mice into lighter mice?
3. How does biological evolution work?

Explore More

Use the resource below to answer the questions that follow.



1. How do identical twins, who should have exactly the same sets of genes (genome) end up with differences?
2. How are genomes changed and passed on to offspring so that the offspring aren't genetically identical to one or the other parent?

This page titled 17.5: Theory of Evolution by Natural Selection is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

17.6: Population Size



How many geese are the right number for this area?

As many as can survive and have healthy offspring! The figure above shows a flock of snow geese at the Kenai National Wildlife Refuge. Their population will tend to grow as big as it can for the resources available. Once it is too large, some of its members will die off. This keeps the population size at the right number.

How Populations Grow

A population usually grows when it has what it needs. If there's plenty of food and other resources, the population will get bigger. Refer to the table below (**Table** below); it shows how a population of bacteria grew. A single bacteria cell was added to a container of nutrients. Conditions were ideal. The bacteria divided every 30 minutes. After just 10 hours, there were more than a million bacteria! Assume the bacteria population keeps growing at this rate. How many bacteria will there be at 10.5 hours? Or at 12 hours?

Time (hours)	Number of Bacteria
0	1
0.5	2
1.0	4
1.5	8
2.0	16
2.5	32
3.0	64
3.5	128
4.0	256
4.5	512
5.0	1,024
5.5	2,048
6.0	4,096
6.5	8,192
7.0	16,384
7.5	32,768
8.0	65,536
8.5	131,072
9.0	262,144
9.5	524,288
10	1,048,576

Population Growth Rate

The **population growth rate** is how fast a population is growing. The letter *r* stands for the growth rate. The growth rate equals the number of new members added to the population in a year for each 100 members already in the population. The growth rate includes new members added to the population and old members removed from the population. Births add new members to the population. Deaths remove members from the population. The formula for population growth rate is:

$r = b - d$, where

b = birth rate (number of births in 1 year per 100 population members)

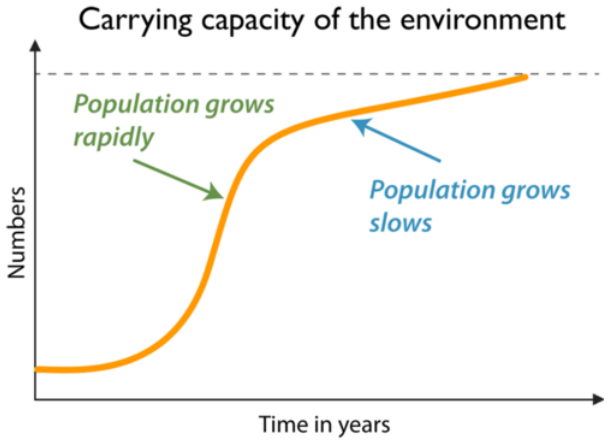
d = death rate (number of deaths in 1 year per 100 population members)

If the birth rate is greater than the death rate, r is positive. This means that the population is growing bigger. For example, if $b = 10$ and $d = 8$, $r = 2$. This means that the population is growing by 2 individuals per year for every 100 members of the population. This may not sound like much, but it's a fairly high rate of growth. A population growing at this rate would double in size in just 35 years!

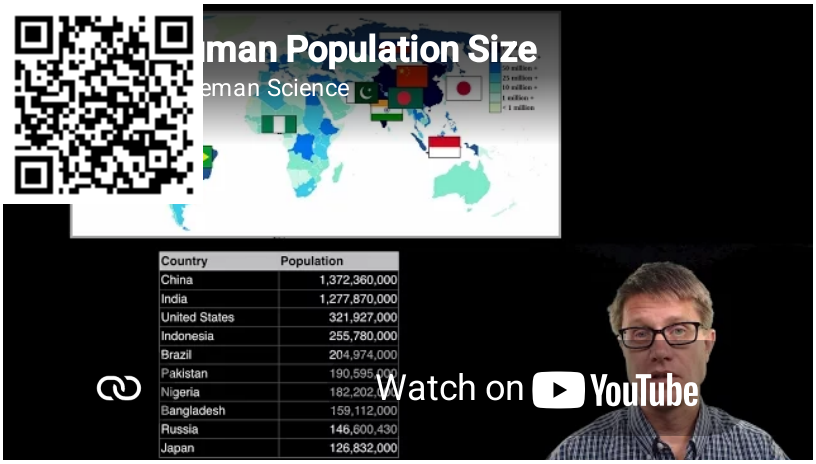
If the birth rate is less than the death rate, *r* is negative. This means that the population is becoming smaller. What do you think might cause this to happen?

Carrying Capacity

A population can't keep growing bigger and bigger forever. Sooner or later, it will run out of things it needs. For a given species, there is a maximum population that can be supported by the environment. This maximum is called the **carrying capacity**. When a population gets close to the carrying capacity, it usually grows more slowly (**Figure** below). When the population reaches the carrying capacity, it stops growing.



A population can't get much larger than the carrying capacity. What might happen if it did?



Summary

- A population will grow as long as it has what it needs.
- The carrying capacity of an environment is reached when the number of births equal the number of deaths.
- A limiting factor determines the carrying capacity for a species.

Review

1. What happens if a population exceeds its carrying capacity?
2. Explain how a single bacterium can grow to a population of more than a million 10 hours later.
3. What happens if the birth rate in a population is more than the death rate? What happens if it is less?

This page titled 17.6: Population Size is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

17.7: Extinction and Radiation of Life



What is next for life on Earth?

Life is dynamic! Species begin, populations grow, species die out, new species are born. Extinction is an important part of this. If organisms never went extinct, there wouldn't be any habitats available for new ones to arise. What could be next?

Extinction

Most of the species that have lived have also gone extinct. There are two ways to go extinct. The most obvious way is to die out completely. The other way a species goes extinct is if it evolves into a different species. Extinction is a normal part of Earth's history. Most of the organisms that have lived have gone extinct.

Sometimes large numbers of species go extinct in a short amount of time. This is a **mass extinction**. The causes of different mass extinctions are different: collisions with comets or asteroids, massive volcanic eruptions, or rapidly changing climate are all possible causes of some of these disasters (**Figure** below).



An extinct *Tyrannosaurus rex*. This fossil resembles a living organism.

Adaptive Radiation

After a mass extinction, many habitats are no longer inhabited by organisms because they have gone extinct. With new habitats available, some species will adapt to the new environments. Evolutionary processes act rapidly during these times. Many new species evolve to fill those available habitats. The process in which many new species evolve in a short period of time to fill available niches is called **adaptive radiation**. At the end of this period of rapid evolution, the life forms do not look much like the ones that were around before the mass extinction. One example came after the extinction of the dinosaurs. Mammals underwent adaptive radiation and became the dominant life form. Although they lived in the habitats the dinosaurs had lived in, they didn't look much like the dinosaurs.

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



- Species go extinct when all of the individuals die out or evolve into a different species.
- Many species go extinct at roughly the same time during a mass extinction.
- New habitats become available and species evolve to fill them so that biodiversity increases during adaptive radiation.

Review

1. Why is extinction considered a normal part of Earth's history?
2. What are some of the possible causes of mass extinctions?
3. Why do many new species evolve after a mass extinction?

This page titled 17.7: Extinction and Radiation of Life is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

17.8: Evolution and Populations- Challenge 1

1. ___ are random changes in an organism's genes.

Mutations

2. In Nebraska, natural selection favors deer mice that ___.

match the color of the soil where they live

3. A harmful mutation may become beneficial if ___.

the environment changes

4. Scientists learn about natural selection by looking at older organisms preserved as ___.

fossils

5. Adaptations are ___.

small genetic changes that build up over time and allow organisms to survive in changing environments

6. When glaciers dropped light sand over Nebraska, the deer mouse population became lighter in color on average because ___.

darker mice couldn't hide from predators as well as light mice, so the environment selected against darker coats

7. If a population uses vital resources faster than those resources are being replenished, the population has ___.

exceeded its carrying capacity

8. The formula to calculate the growth rate of a population is ___.

birth rate - death rate

9. ___ is an important abiotic factor affecting population growth.

Space

10. Three characteristics of all life include ___.

metabolism, being organic, and being capable of replication/reproduction

11. To learn about the origin of life, scientists examine ancient microorganisms, study organisms living in extreme environments, and ___.

perform experiments that recreate the environmental conditions found at that time

This page titled 17.8: Evolution and Populations- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

17.9: Growth of Human Populations



How fast is human population growing?

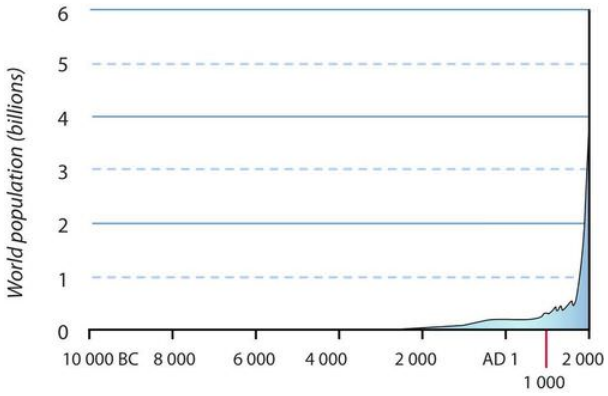
There are more than 7 billion people in the world. As you read this sentence, at least three more people will be added. Think about that for second or so, and there's another three. Why is the human population growing so fast? Has it always grown this fast? What causes populations to grow?

Human Population Numbers

Bacteria in a dish with ample nutrients double in population until there is no more space. Every population eventually reaches its maximum size. The population of bacteria in the dish reaches its carrying capacity. The **carrying capacity** is the number of an organisms that can live with the resources that are available. The **limiting factor** for the bacteria in the dish is space. That's the factor that limits the population of the bacteria in the dish. If there were unlimited space then maybe nutrients would be the limiting factor. Some resource will always run out to limit a population. Let's now apply these concepts to the human population.

Human population growth over the past 10,000 years has been tremendous (**Figure** below). The entire human population was estimated to be:

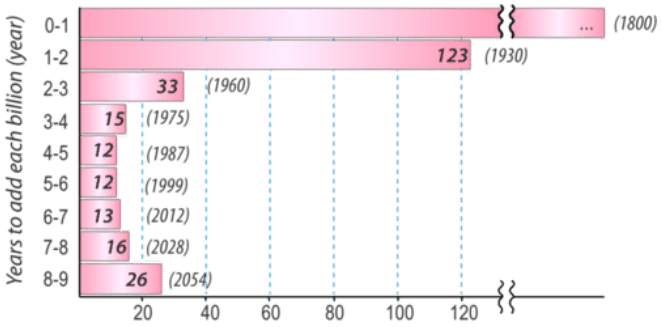
- 5 million in 8000 BC
- 300 million in 1 AD
- 1 billion in 1802
- 3 billion in 1961
- 7 billion in 2011



Human population from 10,000 BC through 2000 AD. This shows the exponential increase in human population that has occurred in the last few centuries.

The Rate of Growth

Not only has the population increased, but the rate of population growth has increased (**Figure** below). The population was estimated to reach 7 billion in 2012, but it did so in 2011. This was just 12 years after reaching 6 billion.



The amount of time between the addition of each one billion people to the planet's population, including speculation about the future. Already, the population reached 7 billion one year earlier than projected.

As the human population continues to grow, different factors limit population in different parts of the world. Space, clean air, clean water, and food to feed everyone are limiting in some locations. Worldwide though, human ingenuity has not placed a limit on the population. Not only does the population increase, the rate of population growth increases.

There is a sign that population growth is slowing. Although population continues to grow rapidly, the rate that the growth rate is increasing has declined. Still, a recent estimate by the United Nations claims that 10.1 billion people will be sharing this planet by the end of the century. The total added will be about 3 billion people. That number is more than were even in existence as recently as 1960. Yet that is much less than the number we would expect if 1 billion people were being added every 12 years.

Summary

- The human population is growing more than exponentially.
- The rate of human population growth is still increasing. However, the rate at which the rate of growth is increasing has declined.
- The United Nations estimates a population of 10.1 billion by the end of the century.

Review

1. What does it mean that the human population growth rate is increasing?
2. What does it mean that the rate that the growth rate is increasing has declined?
3. Looking at the graph above: When did the human population start to really grow? When did it really take off?

Explore More

Use the resource below to answer the questions that follow.



1. What was the population in 1800?
2. What was the population in 1930?
3. What number did the population reach in 2011?

https://k12.libretexts.org/@go/page/5967

4. What could the population be in 2045?
5. What is the average lifespan of people today?
6. What was the average lifespan of people in 1960?
7. What is a megacity?
8. How many megacities were there in 1975?
9. How many megacities are there now?
10. Explain what the world needs. What does that mean?
11. How much of the population lacks adequate sanitation?

This page titled 17.9: Growth of Human Populations is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

17.10: Agriculture and Human Population Growth



What's your vision of a chicken farm?

In many nations, farming today is industrial, growing the maximum amount of food for the minimum price, often without much thought as to the long-term social or environmental consequences. These industrial food production plants are a long way from the farms of the past.

Advances in Agriculture and Population

Every major advance in agriculture has allowed global population to increase. Early farmers could settle down to a steady food supply. Irrigation, the ability to clear large swaths of land for farming efficiently, and the development of farm machines powered by fossil fuels allowed people to grow more food and transport it to where it was needed.

Hunters and Gatherers

What is Earth's carrying capacity for humans? Are humans now exceeding Earth's carrying capacity for our species? Many anthropologists say that the carrying capacity of humans on the planet without agriculture is about 10 million (**Figure** below). This population was reached about 10,000 years ago. At the time, people lived together in small bands of hunters and gatherers. Typically men hunted and fished; women gathered nuts and vegetables.



In a hunter-gatherer society, people relied on the resources they could find where they lived.

Obviously, human populations have blown past this hypothetical carrying capacity. By using our brains, our erect posture, and our hands, we have been able to manipulate our environment in ways that no other species has ever done. What have been the important developments that have allowed population to grow?

Farming

About 10,000 years ago, we developed the ability to grow our own food. Farming increased the yield of food plants and allowed people to have food available year round. Animals were domesticated to provide meat. With agriculture, people could settle down, so that they no longer needed to carry all their possessions (**Figure** below). They could develop better farming practices and store food for when it was difficult to grow. Agriculture allowed people to settle in towns and cities.



More advanced farming practices allowed a single farmer to grow food for many more people.

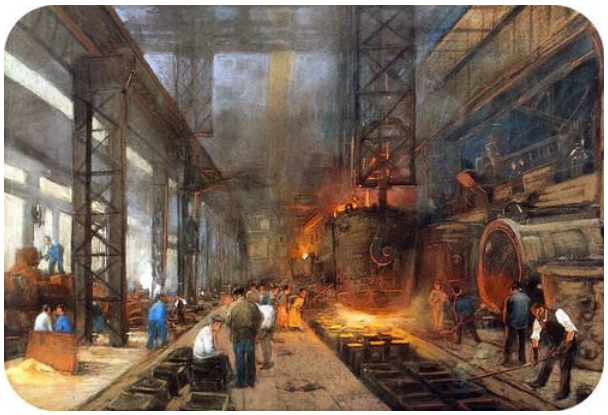
When advanced farming practices allowed farmers to grow more food than they needed for their families (**Figure** below), some people were then able to do other types of work, such as crafts or shop keeping.



Farming has increasingly depended on machines. Such advanced farming practices allow one farmer to feed many more people than in the past.

The Industrial Revolution

The next major stage in the growth of the human population was the **Industrial Revolution**, which started in the late 1700s (**Figure** below). This major historical event marks when products were first mass-produced and when fossil fuels were first widely used for power.



Early in the Industrial Revolution, large numbers of people who had been displaced from food production began working in factories.

The Green Revolution

The **Green Revolution** has allowed the addition of billions of people to the population in the past few decades. The Green Revolution has improved agricultural productivity by:

- Improving crops by selecting for traits that promote productivity; recently, genetically engineered crops have been introduced.
- Increasing the use of artificial fertilizers and chemical **pesticides**. About 23 times more fertilizer and 50 times more pesticides are used around the world than were used just 50 years ago (**Figure** below).
- Agricultural machinery: plowing, tilling, fertilizing, picking, and transporting are all done by machines. About 17% of the energy used each year in the United States is for agriculture.
- Increasing access to water. Many farming regions depend on groundwater, which is not a renewable resource. Some regions will eventually run out of this water source. Currently about 70% of the world's fresh water is used for agriculture.



Rows of a single crop and heavy machinery are normal sights for modern day farms.

The Green Revolution has increased the productivity of farms immensely. A century ago, a single farmer produced enough food for 2.5 people, but now a farmer can feed more than 130 people. The Green Revolution is credited for feeding 1 billion people that would not otherwise have been able to live.

The Future

The flip side to this is that for the population to continue to grow, more advances in agriculture and an ever increasing supply of water will be needed. We've increased the carrying capacity for humans by innovation: growing crops, trading for needed materials, and designing ways to exploit resources that are difficult to get at, such as groundwater. However, most of these resources are limited. Our population growth is not sustainable.

The question is, even though we have increased the carrying capacity of the planet, have we now exceeded it (**Figure** below)? Are humans on Earth experiencing **overpopulation**?



Manhattan is one of the most heavily populated regions in the world.

There is not yet an answer to that question, but there are many different opinions. In the eighteenth century, Thomas Malthus predicted that human population would continue to grow until we had exhausted our resources. At that point, humans would become victims of famine, disease, or war. This has not happened, at least not yet. Some scientists think that the carrying capacity of the planet is about 1 billion people, not the 7 billion people we have today. The limiting factors have changed as our intelligence has allowed us to expand our population. Can we continue to do this indefinitely into the future?

Summary

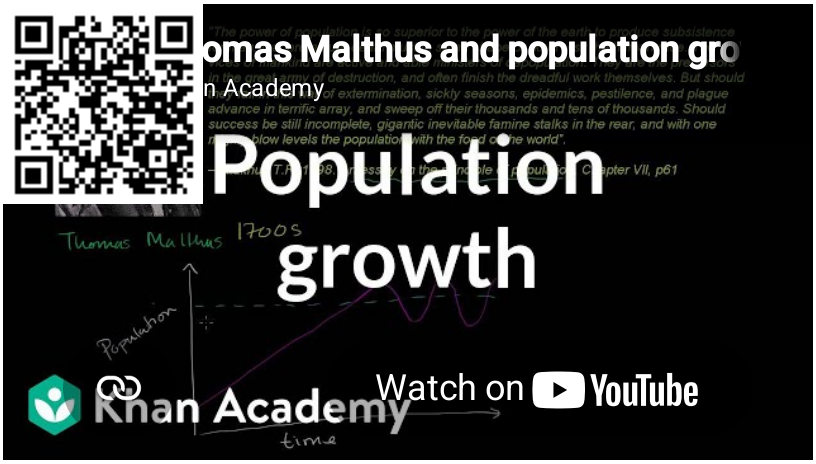
- Hunters and gatherers lived off the land, with no agriculture, and reached a total population of no more than around 10 million.
- Farming allowed people to settle down and allowed populations to grow.
- The Green Revolution and the Industrial Revolution are heavily dependent on fossil fuels.

Review

1. Link major advances in agriculture and industry with changes in the human population.
2. What is carrying capacity? Has the human population exceeded Earth's carrying capacity for humans? If so, how could this have happened?
3. What is the Green Revolution? How has it affected human population?
4. What do you think of Thomas Malthus' prediction? Have we proven Malthus wrong or have we just not gotten to that point yet?

Explore More

Use this resource to answer the questions that follow.



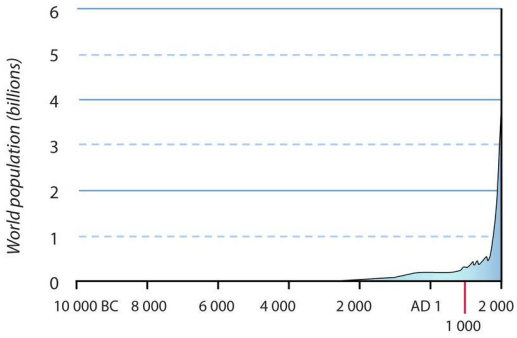
1. Who was Thomas Malthus?
2. What did Malthus think would happen as population increased?

https://k12.libretexts.org/@go/page/5969

3. What did Malthus think would limit population?
4. What is the Malthusian limit?
5. What is happening to population growth in some developed countries today?
6. Malthus didn't account for what in his theory?
7. What country is close to the Malthusian limit today?

This page titled 17.10: Agriculture and Human Population Growth is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

17.11: Revolutions in Human Population



Where on the graph are the major population changes?

Let's look at this graph again. It shows human population from 10,000 BC through 2000 AD. Where are the big changes in slope of the line? Can you identify them? In this concept, we'll learn what causes them.

What Causes Human Populations to Grow?

Look at the graph above. Human population increased dramatically at certain times. The graph begins 10,000 BC, although you can't really see the line. Population starts to rise perceptibly at around 1800 BC. The numbers begin to rise dramatically about 200 years ago. What causes these changes?

Agricultural Revolution

Farming was developed about 10,000 years ago. Farming meant a steady supply of food. People could settle in villages. The rise at around 1800 BC is due to increased farming and the rise of cities and towns. After 1800 AD, population shoots up dramatically. Really dramatically. What happened?

Industrial Revolution

The **Industrial Revolution** is what happened. The Industrial Revolution began in the late 1700s in Europe, North America, and a few other places. Before the Industrial Revolution, most labor was done by people. The Industrial Revolution changed the source of power from humans to fossil fuels. This allowed more work to be done and more food to be grown. People began to move into cities.

Where the Industrial Revolution was taking place, the human population started to grow really fast. The birth rate was always high. What changed was the death rate. The population grew because more people stayed alive. The death rate fell for several reasons:

1. New farm machines were invented. They increased the amount of food that could be produced. With more food, people were healthier and could live longer.
2. Steam engines and railroads were built. These machines could quickly carry food long distances. This made food shortages less likely.
3. Sanitation was improved. Sewers were dug to carry away human wastes (**Figure** below). This helped reduce the spread of disease.

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



Digging a London sewer (1840s). Before 1800, human wastes were thrown into the streets of cities such as London. In the early 1800s, sewers were dug to carry away the wastes.

With better food and less chance of disease, the death rate fell. More children lived long enough to reach adulthood and have children of their own. As the death rate fell, the birth rate stayed high for awhile. This caused rapid population growth.

The Green Revolution

The most recent increase in the slope of the population line is because of another advance in agriculture. The **Green Revolution** began in the mid-1900s. The Green Revolution has allowed billions of people to be added to the population in the past few decades. New methods and products increased how much food could be grown. These advances include:

- Improving crops by selecting for certain genetic traits. The desired traits promote productivity. Recently, genetically engineered crops have been introduced.
- Increasing the use of artificial fertilizers and chemical **pesticides**.
- Increasing the use of agricultural machinery: plowing, tilling, fertilizing, picking, and transporting. These machines are powered by fossil fuels, rather than humans.
- Increasing access to water. Many rivers have been dammed. Wells tap into many groundwater aquifers.

The Green Revolution has increased the productivity of farms immensely. A century ago, a single farmer produced enough food for 2.5 people, but now a farmer can feed more than 130 people. The Green Revolution is credited for feeding 1 billion people that would not otherwise have been able to live.

The Health Revolution

Health care has been improving over the most recent centuries. **Vaccines** were developed that could prevent many diseases (**Figure** below). **Antibiotics** were discovered that could cure most infections caused by bacteria. Together, these two advances saved countless lives.



This child is getting a polio vaccine. She will never get sick with polio, which could save her life or keep her from becoming crippled.

Summary

- Farming allowed people to have a steady food source and settle down. The Green Revolution has dramatically increased agricultural productivity.
- The Industrial Revolution brought new machinery, increased the food supply, and improved sanitation.
- Vaccinations and antibiotics have greatly improved human health.
- With a dramatically lower death rate, human populations have grown.

Review

1. What caused the first rise in human population?
2. Why has the Industrial Revolution altered human population numbers?
3. How has the Green Revolution increased agricultural productivity?
4. If the birth rate doesn't change but the death rate goes down, what happens to population?

Explore More

Use the resources below to answer the questions that follow.



1. Where did most people work in the late 1700s? Who did they work for?
2. What did the new machines do?
3. What became more affordable?
4. Why did families move? Where did they move from and to?
5. Who were the workers? Who did they work for?
6. What problems did industrialization cause?
7. Where were the worst conditions?
8. Why were unions formed?

This page titled 17.11: Revolutions in Human Population is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

17.12: Overpopulation and Over-Consumption



Is life the same for all 7 billion of us?

No. A minority of people use most of the world's energy and other resources. Not only are their needs met, but they have many luxuries. Many other people lack resources. Many don't have enough to eat or live, with the threat of hunger. Many also do not have safe, clean water. Some people live in crowded, run-down housing. Some people live in mansions.

Overpopulation?

Overpopulation takes place when the number of organisms exceeds the carrying capacity of the region. What is the carrying capacity of Earth for humans? Are seven billion people the human carrying capacity? Nine billion? We don't know yet.

It seems that we have increased the carrying capacity of the planet for humans. We have done this with agriculture and fossil fuels and improvements in health care. Have we now exceeded Earth's carrying capacity (**Figure** below)? Are humans on Earth experiencing overpopulation?



Manhattan, one part of New York City, is one of the most heavily populated regions in the world.

There is not yet an answer to that question. So far, many of us have skated along without much trouble. But since we depend on resources that are non-renewable, the answer could well be yes. Either way, we face very serious problems, like climate change, that could devastate the human population and the world.

Human Population and the Environment

There is evidence that there are too many of us; that the large population is becoming too high. That's because we are harming the environment. Some of the harmful effects of a high human population are:

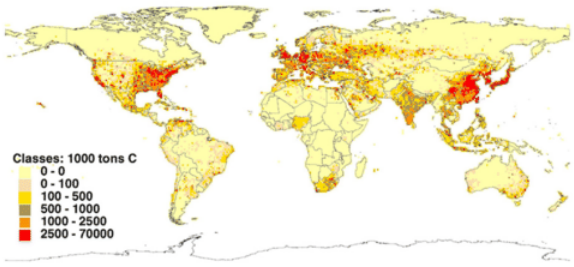
- Supplying all those people with energy creates a lot of pollution. For example, huge oil spills have killed millions of living things.
- Burning fossil fuels pollutes the air. This also causes global warming.
- Fossil fuels and other resources are being used up. We may run out of oil by the mid-2000s. Many other resources will run out sooner or later.

- People are killing too many animals for food. For example, some of the best fishing grounds in the oceans have almost no fish left.
- People have destroyed many habitats. For example, they've drained millions of acres of wetlands. Wetlands have a great diversity of species. As wetlands shrink, species go extinct.
- People have introduced **invasive species** - species originally from a different area—to invade new habitats. The introduction can be intentional or accidental. Often, the aliens have no natural predators in their new home. They may drive native species extinct. In the mid-1900s, Australian tree snakes invaded Guam and other islands in the Pacific. The snakes stowed away on boats and planes. Tree snakes had no natural predators on the islands so their population exploded. The snakes have caused the extinction of nine of the eleven native bird species on Guam (**Figure** below).



A brown tree snake.

- People themselves are also affected by the large size of the human population. Some people have a lot; some have very little. Many people refer to the abundance of luxury items in some people's lives as **over-consumption**. People in developed nations use 32 times more resources than people in the developing countries of the world. The symbol of this is CO_2 emissions, which are a waste product from fossil fuel burning. Populations that burn the most fossil fuels have a high standard of living.



CO_2 emissions tell which countries are using the most fossil fuels.

Summary

- Supporting 7 billion people is taking an environmental toll on the planet.
- Pollution, habitat destruction, and invasive species are a few of the problems caused by the high population.
- Over-consumption means that some people use a much larger amount of the resources than others.

Review

1. What are some of the ways that the large human population is harming the environment?
2. What are invasive species? Why are they able to do so much damage?
3. What is over-consumption?

Explore More

Use the resource below to answer the questions that follow.



1. What was the prediction made about world population in SciShow's early episode on Overpopulation?
2. What will happen to the size of the human population by 2100?
3. What is Total Fertility Rate? What has been happening to this number since the 1960s and why?
4. What is happening to Total Fertility Rate in Africa? Why does that affect the future prediction of population?
5. How could the average woman give birth to 0.8 children in her lifetime in Singapore? (What is 0.8 child?)
6. Why is Africa's total fertility rate relatively high?
7. How many people are predicted to live in sub-Saharan Africa by 2100?

This page titled 17.12: Overpopulation and Over-Consumption is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

17.13: Future Human Population Growth

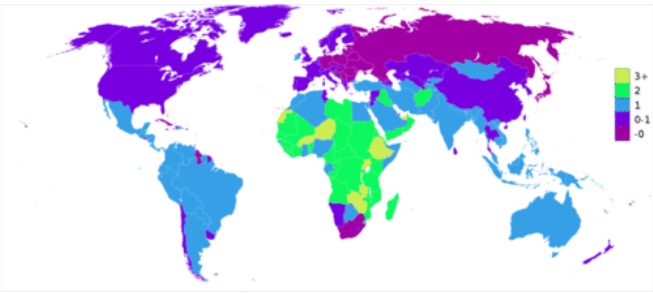


Does the world seem crowded?

In some places, there seem to be people everywhere. Times Square in New York City is definitely one of those places. In other places, there are hardly any people at all. Does that mean that the world is not overpopulated? Is space all that people need?

Growth Rates Around the World

With ample food, better health, and easier work, people live longer. Children are much more likely to reach adulthood and have their own children. In many countries, death rates have gone down dramatically, but birth rates remain high. This means that the population is growing. Pictured below is the growth rates of human populations all over the world (**Figure** below).



World population growth rates. Is the population growing faster in the wealthiest countries or the poorest countries?

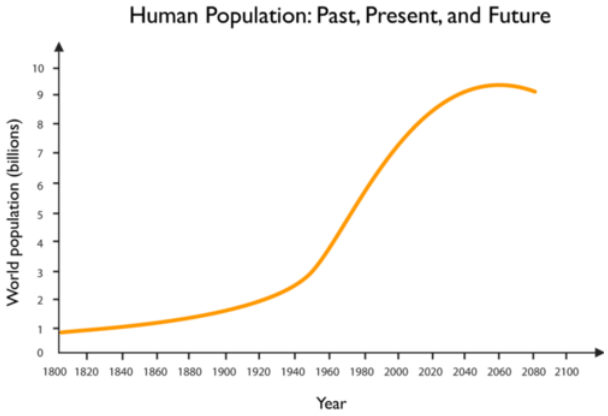
The Future

Human ingenuity has allowed the population to continue to grow. We've increased Earth's **carrying capacity** for humans by our ingenuity. We grow crops, trade for needed materials, and design ways to exploit resources that are difficult to get at, such as groundwater. We use long-buried ancient organisms for fuel. We have broken the rules for biological populations. In our effort to escape the confines of the earth's carrying capacity, we may have brought about our own demise.

Of course, there's a flip side to this. For the population to continue to grow, more advances in agriculture will be needed. The best lands are already in use. Most rivers that can be dammed, have been dammed. In many aquifers, groundwater is not replenished on the time frame needed. Fossil fuels too are limited. Obtaining fossil fuels or developing new power sources will be more costly.

Future Population Growth

The rate of increase of the growth rate of the human population is decreasing (**Figure** below). The population may stop growing by the mid 2000s. Some scientists think that the human population will peak at about 9 billion people. What will need to change for the population to stop growing then?



Try to locate on this graph Earth's carrying capacity for humans. Do you think this projection is very accurate or just a guess?

Summary

- Humans have exceeded the carrying capacity of Earth for humans by their ingenuity.
- The rate of population increase is starting to decline. The population is still exploding though.
- The growth rate is higher in less developed nations.

Review

1. How does the human population exceed the natural carrying capacity of a region for humans?
2. Are we exceeding the carrying capacity of the entire planet?
3. Where is the human population growing the most? Where is it growing the least or not growing?
4. Why does the population graph level out and then decline a bit? Is that pattern certain? What is it based on?
5. What other population growth patterns are possible?

Explore More

Use the resource below to answer the questions that follow.



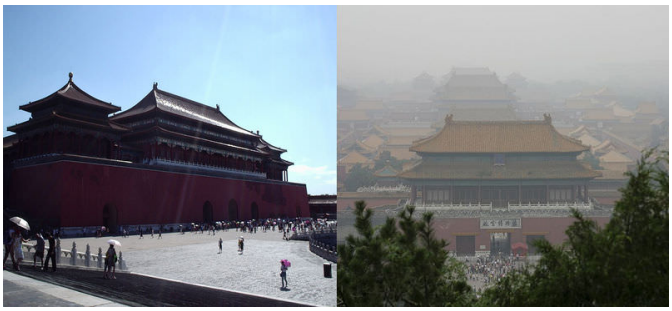
1. How many people will Earth need to support by 2050?
2. How come there will be so many?
3. Where will most of the population growth occur?
4. Which country's population will shrink?

https://k12.libretexts.org/@go/page/5975

5. What country's population will triple?
6. In terms of economic stability, where will most of the population growth be?
7. What kept our population in check in the past?

This page titled 17.13: Future Human Population Growth is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

17.14: Sustainable Development



Is there another way?

Visibility in Beijing is sometimes so bad that the airport must be closed due to smog. In their rush to develop, many nations are making the same mistakes that the developed nations have already made. Is there a more sustainable path?

Sustainable Development

Is it possible for all the world's people to live well and still protect the planet? That's the aim of **sustainable development**. Its goals are to:

1. help people out of poverty.
2. protect the environment.
3. use resources no faster than the rate at which they are regenerated.

A smaller human population is part of the solution. Studies show that educated women have fewer and healthier children. Educating women (and men) is a long-term goal of population control.

Developing new technologies can help. For example, fish farming can feed people good healthy protein. The farming must be done in an environmentally sound way.

Better use of resources is another part. For example, when forests are logged, new trees should be planted.

Citizens can change their behavior to reduce the impact they have on the planet. They can demand that products are produced sustainably. People can consume less. They can think about the impact they have when they do consume.

Everyone can help in the effort. What will you do?

Summary

- Sustainable development tries to bring people up to certain minimum living conditions. This must be done without doing further damage to the environment.
- To develop sustainably, the human population must stabilize or decrease.
- Resources must be developed and used consciously and in environmentally sound ways.

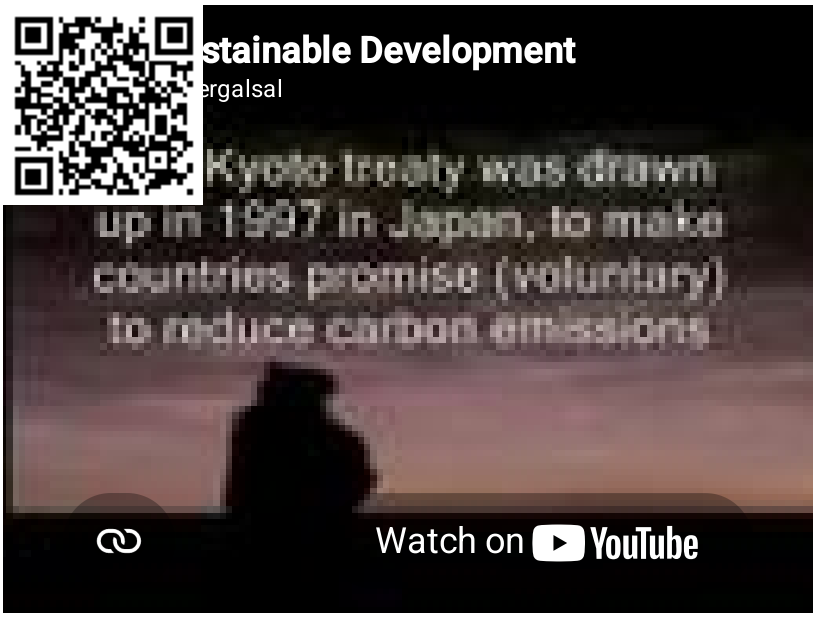
Review

1. How can population growth be decreased?
2. What are the goals of sustainable development?
3. What are some ways that you and your family can live more sustainably?

Explore More

Use the resource below to answer the questions that follow.

cK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



1. Explain sustainable development.
2. What are renewable energy sources?
3. Why aren't fossil fuels sustainable sources of energy?
4. Why didn't the United States sign the Kyoto treaty?
5. List examples of renewable energy sources.
6. What can we do to reduce our carbon footprint?
7. How can we reduce the demand for fossil fuels?

This page titled 17.14: Sustainable Development is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

17.15: Evolution and Populations- Challenge 2

1. The time period marked by a significant increase in mass production and fossil fuel consumption is the ___.

Industrial Revolution

2. ___ kill insects and other pests that eat or harm crops.

Pesticides

3. About 17% of the energy used in the U.S. is used for ___.

agriculture

4. The abundance of luxuries in some people's lives and the resources required to produce them is referred to as ___.

overconsumption

5. ___ is experiencing an increase in abject poverty.

Sub-Saharan Africa

6. On average, population is growing ___ in industrialized countries than in developing countries.

more slowly

7. The number of individuals of a species that an environment can support is its ___.

carrying capacity

8. Human population is growing most rapidly in ___.

Africa

This page titled 17.15: Evolution and Populations- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

18: Ecosystems

18.1: Biological Communities
18.2: Roles in an Ecosystem
18.3: Flow of Energy in Ecosystems
18.4: Flow of Matter in Ecosystems
18.5: Nitrogen Cycle in Ecosystems
18.6: Ecosystems- Challenge 1
18.7: Fresh Water Ecosystems
18.8: Types of Marine Organisms
18.9: Marine Food Chains
18.10: Ocean Ecosystems
18.11: Ecosystems- Challenge 2

This page titled 18: Ecosystems is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

18.1: Biological Communities



Where can you find an ecosystem?

Just about everywhere you could go in nature, you would be taking a field trip to an ecosystem. There are underwater ecosystems and coastal ecosystems. There are small scale ecosystems and large ones. There are even ecosystems inside your body!

What Is An Ecosystem?

An **ecosystem** is a group of living things and their environment. The word ecosystem is short for "ecological system." Like any system, an ecosystem is a group of parts that work together. You can see examples of ecosystems in **Figure** below. The forest pictured is a big ecosystem. Besides trees, what living things do you think are part of the forest ecosystem? The dead tree stump in the same forest is a small ecosystem. It includes plants, mosses, and fungi. It also includes insects and worms.



This forest is a big ecosystem. Besides trees, what living things do you think are part of the forest ecosystem?

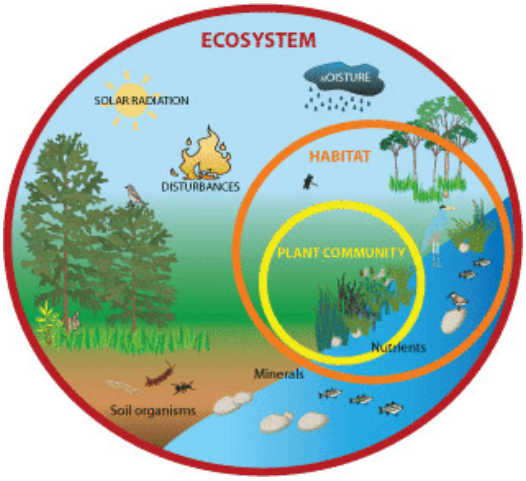


A dead tree stump in the same forest is a small ecosystem. It includes plants, mosses, and fungi. It also includes insects and worms.

An ecosystem can be big or small. A small ecosystem can be part of a larger ecosystem.

Abiotic Factors

Abiotic factors are the nonliving parts of ecosystems. They include air, sunlight, soil, water, and minerals. These are all things that are needed for life. They determine which living things—and how many of them—an ecosystem can support. Pictured below is an ecosystem and its abiotic factors (**Figure** below).



Which abiotic factors do you see here?

Biotic Factors

Biotic factors are the living parts of ecosystems. They are the species of living things that reside together.

Species, Niche, and Habitat

A **species** is a unique type of organism. Members of a species can interbreed and produce offspring that can breed (they are fertile). Organisms that are not in the same species cannot do this. Examples of species include humans, lions, and redwood trees. Can you name other examples?

Each species has a particular way of making a living. This is called its **niche**. You can see the niche of a lion below (**Figure** below). A lion makes its living by hunting and eating other animals. Each species also has a certain place where it is best suited to live. This is called its **habitat**. The lion's habitat is a grassland. Why is a lion better off in a grassland than in a forest?

How a Lion "Makes a Living"



A lion hunts a zebra. What is the lion's niche?

Living Together

All the members of a species that live in the same area form a **population**. Many different species live together in an ecosystem. All their populations make up a **community**. What populations live together in the grassland pictured above (**Figure** above)?

Summary

- All of the individuals of a species that exist together at a given place and time make up a population. A community is made up of all of the populations in an area.
- The living and nonliving factors that living organisms need plus the communities of organisms themselves make up an ecosystem.

- A habitat is where an organism lives, and a niche is what it does to make a living.

Review

1. Define species, population, community, niche, habitat, biotic factor, and abiotic factor.
2. Compare a lion and a deer. Which biotic and abiotic factors that each of these animals needs to live are the same?
3. Which biotic and abiotic factors are different between a lion and a deer?

Explore More

Use the resource below to answer the questions that follow.



1. What are the biotic components of an ecosystem?
2. What is a species?
3. What is a population?
4. List two examples of populations.
5. What is a community?
6. What is different between the size of an ecosystem and the size of a natural community?

This page titled 18.1: Biological Communities is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

18.2: Roles in an Ecosystem



Can you pick out the organisms at the bottom and at the top of this food chain?

What's at the bottom of this food chain? Plankton. These tiny creatures incorporate energy from the Sun through photosynthesis. The energy is then passed between the various levels of the food chain. After plankton, corals are next. Coral are animals that live with tiny zooxanthellae that also photosynthesize. This means that all of the energy in the food chain originates from the Sun! Of course, you know what's at the top of this food chain!

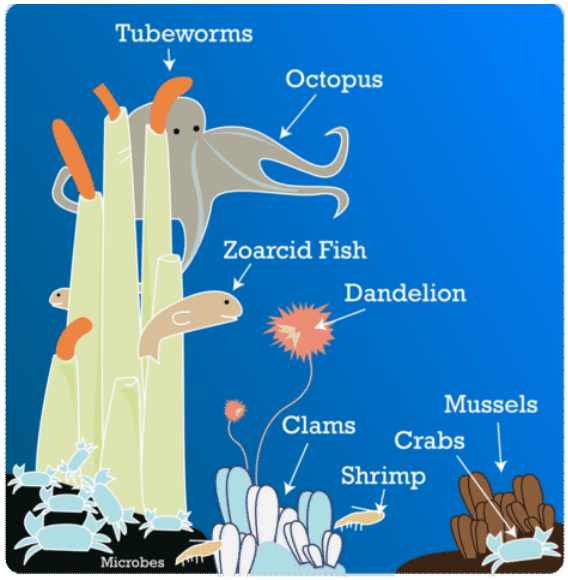
Roles in Ecosystems

All ecosystems have living things that play the same basic roles. Some organisms must be producers. Others must be consumers. Decomposers are also important.

Producers

Producers are living things that use energy to make food. Producers make food for themselves and other living things. There are two types of producers:

- By far the most common producers use the energy in sunlight to make food. This is called **photosynthesis**. Producers that photosynthesize include plants and algae. These organisms must live where there is plenty of sunlight.
- Other producers use the energy in chemicals to make food. This is called **chemosynthesis**. Only a very few producers are of this type, and all of them are microbes. These producers live deep under the ocean where there is no sunlight. An example is pictured below (**Figure** below).

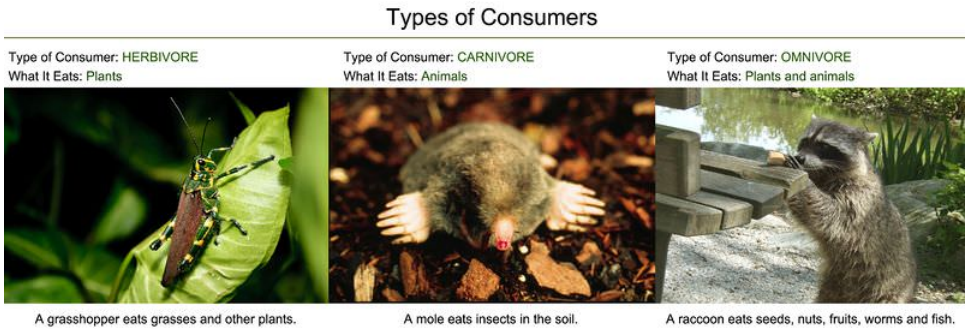


https://k12.libretexts.org/@go/page/5597

Microbes use chemicals to make food. The chemicals pour out of a crack on the ocean floor at a mid-ocean ridge. What consumers live in this ecosystem?

Consumers

Consumers can't make their own food. Consumers must eat producers or other consumers. Listed below are the three main types of consumers (**Figure** below): **herbivores**, **carnivores**, and **omnivores**. Which type are you?



Examples of the main types of consumers. Can you name other consumers of each type?

Consumers get their food in different ways (**Figure** below). **Grazers** feed on living organisms without killing them. A rabbit nibbles on leaves, and a mosquito sucks a drop of blood. **Predators**, like lions, capture and kill animals for food. The animals they eat are called **prey**. Even some plants are consumers. Pitcher plants trap insects in their sticky fluid in their "pitchers." The insects are their prey. **Scavengers** eat animals that are already dead. This hyena is eating the remains of a lion's prey. **Decomposers** break down dead organisms and the wastes of living things (**Figure** below). This dung beetle is rolling a ball of dung (animal waste) back to its nest. The beetle will use the dung to feed its young. The mushrooms pictured are growing on a dead log. They will slowly break it down. This releases its nutrients to the soil.



Ways consumers get food. Do you know how earthworms get food?

https://k12.libretexts.org/@go/page/5597

Summary

- Herbivores eat plants, carnivores eat meat, and omnivores eat both.
- Predators are animals that eat a prey animal. Scavengers eat organisms that are already dead. Decomposers break down dead plants and animals into component parts, including nutrients.
- Producers create food energy. They are the base of all life on Earth. Most producers use photosynthesis but a very small number use chemosynthesis.

Review

1. What are consumers? What are the three types of consumers and what do they eat?
2. Compare and contrast photosynthesis and chemosynthesis.
3. What role do decomposers play in an ecosystem? What would happen if there were no decomposers?

Explore More

Use the resource below to answer the questions that follow.



1. What is competition?
2. What is predation?
3. What is symbiosis?
4. How do stable communities develop?
5. What is succession?
6. What is a niche? What does a niche include?
7. What causes competition?

This page titled 18.2: Roles in an Ecosystem is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

18.3: Flow of Energy in Ecosystems



What is the source of energy for almost all ecosystems?

The Sun supports most of Earth's ecosystems. Plants create chemical energy from abiotic factors that include solar energy. The food energy created by producers is passed through the food chain.

How Energy Flows Through Ecosystems

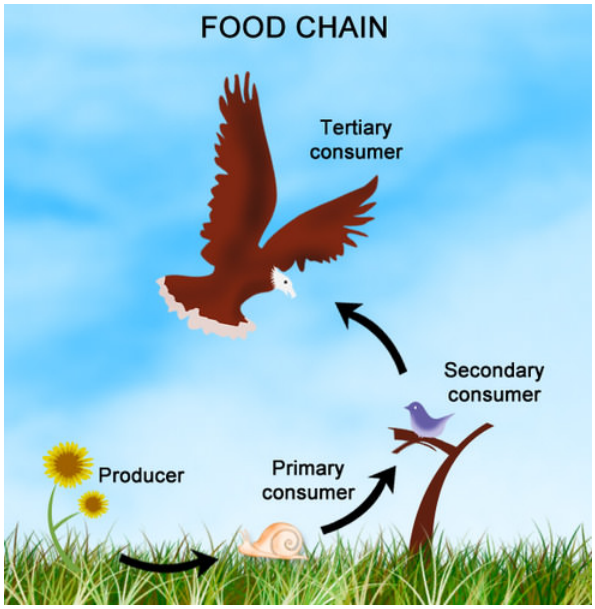
All living things need energy. They need it to power the processes of life. For example, it takes energy to grow. It also takes energy to produce offspring. In fact, it takes energy just to stay alive. Remember that energy can’t be created or destroyed. It can only change form. Energy changes form as it moves through ecosystems.

The Flow of Energy

Most ecosystems get their energy from the Sun. Only producers can use sunlight to make usable energy. Producers convert the sunlight into chemical energy or food. Consumers get some of that energy when they eat producers. They also pass some of the energy on to other consumers when they are eaten. In this way, energy flows from one living thing to another.

Food Chains

A **food chain** is a simple diagram that shows one way energy flows through an ecosystem. Pictured below is an example of a food chain (**Figure** below). Producers form the base of all food chains. The consumers that eat producers are called primary consumers. The consumers that eat primary consumers are secondary consumers. This chain can continue to multiple levels.

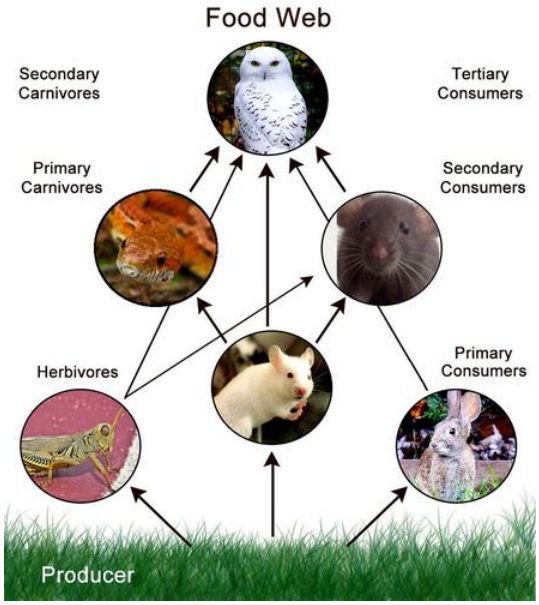


What do the arrows stand for in a food chain?

At each level of a food chain, a lot of energy is lost. Only about ten percent of the energy passes to the next level. Where does that energy go? Some energy is given off as heat. Some energy goes into animal wastes. Energy also goes into growing things that another consumer can't eat, like fur. It's because so much energy is lost that most food chains have just a few levels. There's not enough energy left for higher levels.

Food Webs

Food chains are too simple to represent the real world. They don't show all the ways that energy flows through an ecosystem. A more complex diagram is called a **food web** (**Figure** below). A food web consists of many overlapping food chains. Can you identify the food chains in the figure? How many food chains include the mouse?



The owl in this food web consumes at two different levels. What are they?

Food webs also overlap. For example, an eagle is part of a land food web. But it might go to the sea to grab a fish. That fish is part of a marine food web.

Summary

- A food chain describes the passage of energy.
- A food web is a set of interconnected and overlapping food chains.
- Food webs are interconnected.

Review

1. What does a food chain depict?
2. Why do scientists usually use a food web instead of a food chain?
3. Start with the Sun. Describe what happens to energy as it moves through ecosystems.

Explore More

Use the resource below to answer the questions that follow.



1. What do all organisms require?
2. What provides the energy required by the ecosystem?
3. How is energy transferred from one organism to another?
4. How is some of the energy lost?
5. How do nutrients move through an ecosystem?
6. How does the movement of energy and nutrients differ in ecosystems?

This page titled 18.3: Flow of Energy in Ecosystems is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

18.4: Flow of Matter in Ecosystems



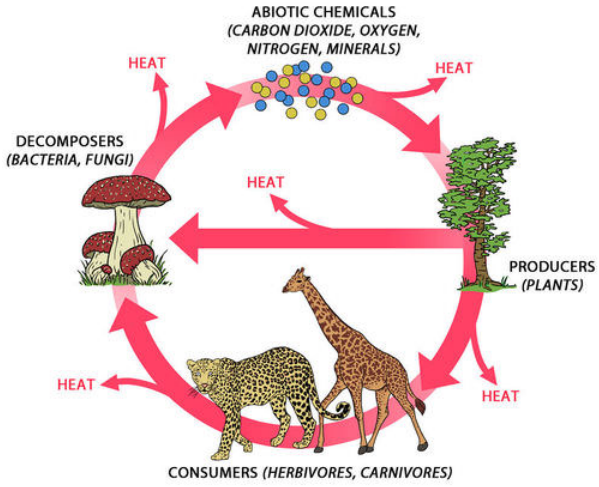
What happens when you don't get enough of a nutrient?

Millions of sailors in the 15th through 18th centuries died mysteriously. They developed a disease called scurvy. The scurvy, it turns out, was due to the lack of vitamin C in their diets. It wasn't until 1932 that the link between scurvy and vitamin C was made. Without the right nutrients in the right amounts, you can't live. Other animals and plants also need the right nutrients to live.

How Matter Moves Through Ecosystems

Living things need nonliving matter as well as energy. What do you think matter is used for? It's used to build bodies. It's also needed to carry out the processes of life. Any nonliving matter that living things need is called a **nutrient**. Carbon and nitrogen are examples of nutrients. Matter is recycled in ecosystems. In the figure below, you can see how (**Figure** below).

- Decomposers release nutrients when they break down dead organisms.
- The nutrients are taken up by plants through their roots.
- The nutrients pass to primary consumers when they eat the plants.
- The nutrients pass to higher level consumers when they eat lower level consumers.
- When living things die, the cycle repeats.



This diagram shows two cycles. One is the cycle of energy, the other is the cycle of matter. Compare the two cycles. Do you see how the Sun keeps adding energy? That’s because energy is lost at each step of the cycle. Matter doesn’t have to be added. Can you explain why?

Summary

- Nutrients are crucial to the growth of organisms.
- Decomposers break down dead organisms into nutrients and gases so that they can be used by other organisms.
- Nutrients can enter or exit an ecosystem at any point and can cycle around the planet.

Review

1. How does the flow of matter differ from the flow of energy through an ecosystem?
2. How do nutrients move through an ecosystem?
3. What would happen to life on Earth if there were no decomposers? Why?

Explore More

Use the resource below to answer the questions that follow.



1. What form does carbon take in the atmosphere?
2. What do producers do with carbon?
3. What happens to the carbon in stored in leaves?
4. Once the carbon is on the ground, where can it be stored?
5. Where is the carbon in a temperate, deciduous forest?
6. Where is the carbon in a rainforest?
7. Where is the carbon in the frigid Arctic? How much is in biomass?
8. How does methane form in a peat bog?

This page titled 18.4: Flow of Matter in Ecosystems is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

18.5: Nitrogen Cycle in Ecosystems

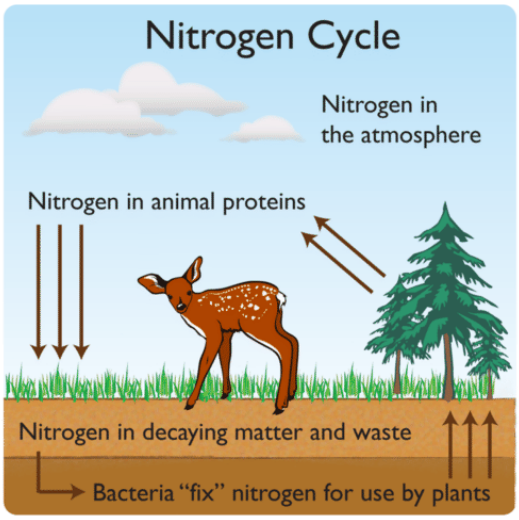


Why are these fish dead?

In a dead zone, there is so little oxygen that fish can't live. What causes the oxygen to disappear? Indirectly, it's nitrogen.

The Nitrogen Cycle

Living things need nitrogen. Nitrogen is a key element in proteins. Like carbon, nitrogen cycles through ecosystems. The **nitrogen cycle** is pictured below (**Figure** below).



The nitrogen cycle includes air, soil, and living things.

Fixing Nitrogen

Air is about 78 percent nitrogen. Decomposers release nitrogen into the air from dead organisms and their wastes. However, producers such as plants can't use these forms of nitrogen. Nitrogen must combine with other elements before producers can use it. This is done by certain bacteria in the soil. It's called "fixing" nitrogen.

Human Actions and the Nitrogen Cycle

Nitrogen is one of the most important nutrients needed by plants. That's why most plant fertilizers contain nitrogen. Adding fertilizer to soil allows more plants to grow. As a result, a given amount of land can produce more food. So far, so good. But what happens next?

Rain dissolves fertilizer in the soil. Runoff carries it away. The fertilizer ends up in bodies of water, from ponds to oceans. Nitrogen is a fertilizer in the water. Since there is a lot of nitrogen, it causes algae to grow out of control. Pictured below is a pond covered with algae (**Figure** below). Algae use up carbon dioxide in the water. After the algae die, decomposers break down the dead tissue.

The decomposers use up all the oxygen in the water. This creates a dead zone. A **dead zone** is an area in a body of water where nothing grows because there is too little oxygen. There is a large dead zone in the Gulf of Mexico (**Figure** below). The U.S. states outlined on the map have rivers that drain into the Gulf of Mexico. The rivers drain vast agricultural lands. The water carries fertilizer from these areas into the Gulf.



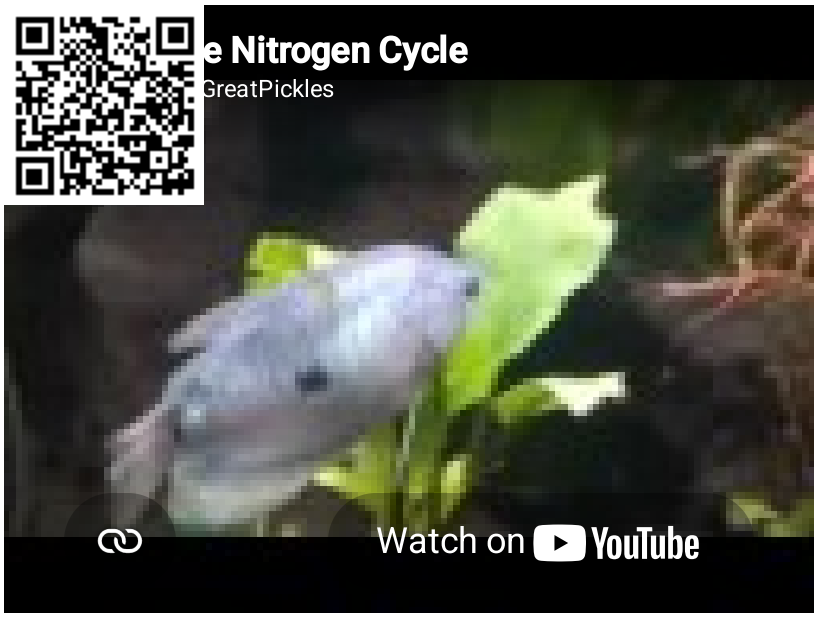
Pond coverd with algae



Dead zone in the Gulf of Mexico

The pond on the left is covered with algae because there is too much nitrogen in the water. The red-shaded area in the map on the right is a dead zone in the Gulf of Mexico. It's called the hypoxic ("low oxygen") zone in the figure.

This very thorough video on the nitrogen cycle with an aquatic perspective was created by high school students.



Summary

- Nitrogen is an essential part of many molecules needed by living organisms.
- Nitrogen is fixed when it is changed into a form that organisms can use.
- Dead zones come about when excess nitrogen in the water causes algae to grow out of control. Decomposers use oxygen to decompose the algae when they die. The lack of oxygen makes it impossible for other organisms to live in that zone.

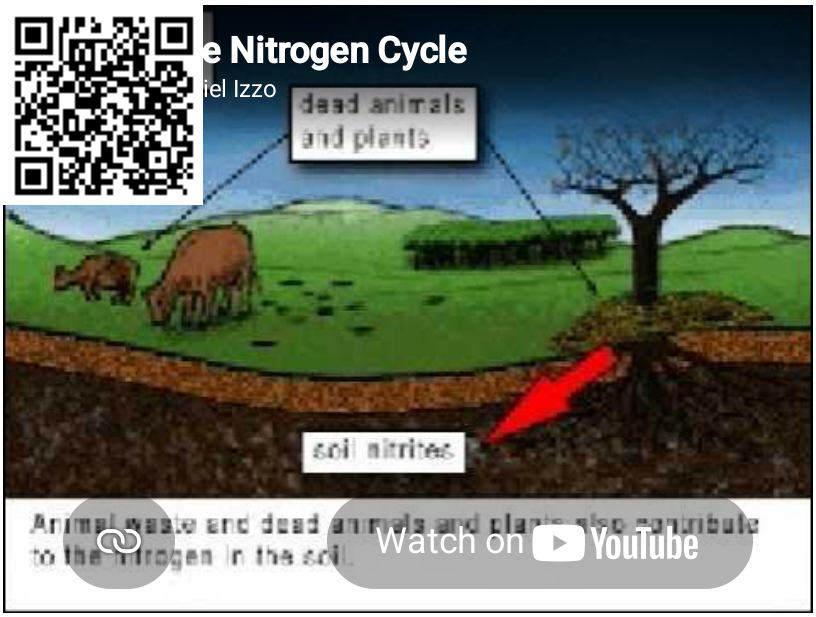
Review

1. What is nitrogen fixing?
2. Why is nitrogen fixing important?

3. How do dead zones come about?
4. Why does the Gulf of Mexico contain such a large dead zone?

Explore More

Use the resource below to answer the questions that follow.



1. What percentage of the air is nitrogen?
2. How is nitrogen removed from the air?
3. What contributes nitrogen to the soil?
4. What happens to soil nitrites?
5. How is nitrogen released from the soil?
6. Why is this called the nitrogen cycle?

This page titled 18.5: Nitrogen Cycle in Ecosystems is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

18.6: Ecosystems- Challenge 1

1. Abiotic factors in an ecosystem include ___.

living space, water, and temperature (this list isn't exhaustive)

2. An organism's "job" within its community is its ___.

niche

3. What is the relationship between population, community, and ecosystem?

A population is all the individuals of a particular species living in a given area. A community includes all the different populations of an area. An ecosystem is the biotic and abiotic factors in which the community lives.

4. A tapeworm living in the stomach of a human is an example of ___.

parasitism

5. A plant-pollinator relationship is a ___ relationship.

mutualistic

6. Lichen is a fungus and an algae living together. The algae provides food through photosynthesis, while the fungi retains the moisture that they both need to live. This relationship is an example of ___.

mutualism

7. Food webs are more accurate than food chains because ___.

many organisms eat at multiple trophic levels

8. There is a large number of producers in an ecosystem, but there are much fewer ___ at the highest trophic level.

consumers

9. A ___ depicts the feeding connections in an ecosystem.

food web

10. Broken down rocks and minerals provide ___ in ecosystems.

nutrients

11. Plant cell growth depends on the nutrients ___.

nitrogen and phosphorus

12. Substances that enter a food chain at the bottom and leave at the top are ___.

nutrients

13. ___ cannot use atmospheric nitrogen, so they depend on bacteria in their root nodules to "fix" nitrogen for them.

Legumes and other plants

14. Nitrogen-fixing bacteria convert nitrogen to ___.

ammonia

15. Nitrifying bacteria convert ___ to ___.

ammonium to nitrites

This page titled 18.6: Ecosystems- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

18.7: Fresh Water Ecosystems



What do the swamps of Florida look like?

Orlando, Florida is home to many amusement parks. On the left is a swamp with swamp wildlife. On the right is the village of Hogsmeade, or at least a replica. The Wizarding World of Harry Potter is one of the many amusement parks in and around Orlando. These amusement parks are built on land that was mostly lakes and swamps.

Freshwater Ecosystems

Lakes, ponds, streams, springs, and wetlands are fresh water bodies. The organisms that live in them are part of freshwater ecosystems. These ecosystems vary by temperature, pressure (in lakes), and the amount of light that penetrates. The type of plants that grow in these ecosystems varies.

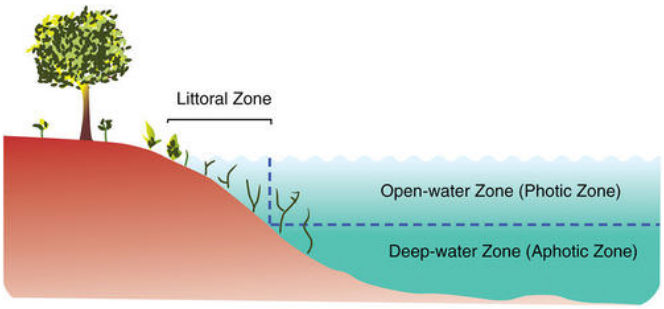
Lake Ecosystems

Limnology is the study of the plants and animals that live in fresh water bodies. A lake has zones just like the ocean. The ecosystem of a lake is divided into three distinct zones (**Figure** below):

1. The surface (littoral) zone is the sloped area closest to the edge of the water.
2. The open-water zone (also called the **photic zone**) has sunlight.
3. The deep-water zone (also called the **aphotic zone**) has little or no sunlight.

There are several life zones found within a lake:

- In the **littoral zone**, sunlight allows plants to grow. Plants provide food and shelter to animals such as snails, insects, and fish.
- Other plants and fish live in the open-water zone. These include bass and trout.
- The deep-water zone is dark so there is no photosynthesis. Most deep-water organisms are scavengers. They feed on dead organisms that fall to the bottom of the lake. Crabs and catfish are two of these types of organisms. Fungi and bacteria are decomposers that live in the deep zone.



The three primary zones of a lake are the littoral, open-water, and deep-water zones.

Wetlands

Some of Earth's freshwater is found in wetlands. A **wetland** is an area that is covered with water, or at least has very soggy soil, during all or part of the year. Certain species of plants thrive in wetlands, and they are rich ecosystems. Freshwater wetlands are usually found at the edges of streams, rivers, ponds, or lakes. Wetlands can also be found at the edges of seas.

Types of Freshwater Wetlands

Not all wetlands are alike, as you can see below (**Figure** below). Wetlands vary in how wet they are and how much of the year they are soaked. Wetlands also vary in the kinds of plants that live in them. This depends mostly on the climate where the wetland is found. Types of wetlands include marshes, swamps, and bogs.

- A **marsh** is a wetland that is usually under water. It has grassy plants, such as cattails.
- A **swamp** is a wetland that may or may not be covered with water but is always soggy. It has shrubs or trees.
- A **bog** is a wetland that has soggy soil. It is generally covered with mosses.



These are just three of many types of wetlands.

Importance of Wetlands

People used to think that wetlands were useless. Many wetlands were filled in with rocks and soil to create solid land. This land was then developed with roads, golf courses, and buildings. Now we know that wetlands are very important. Laws have been passed to help protect them. Why are wetlands so important?

- Wetlands have great biodiversity. They provide homes or breeding sites to a huge variety of species. Because so much wetland area has been lost, many of these species are endangered.
- Wetlands purify water. They filter sediments and toxins from runoff before it enters rivers, lakes, and oceans.
- Wetlands slow rushing water. During hurricanes and other extreme weather, wetlands reduce the risk of floods.

Although the rate of loss has slowed, wetlands are still being destroyed today.



Summary

- The conditions that affect lake ecosystems are similar to those that affect ocean ecosystems. These include light penetration, temperature, and water depth.
- Wetlands are lands that are wet for a significant portion of the year.

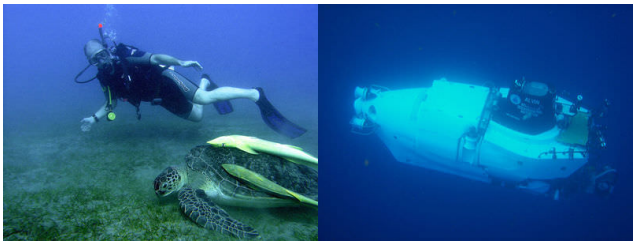
- Wetlands are extremely important as an ecosystem and as a filter for pollutants.

Review

1. Compare and contrast the zones found in lakes.
2. For many decades, people drained wetlands. Was this a good idea or a bad idea? Why?
3. Compare and contrast the three main types of wetlands.

This page titled 18.7: Fresh Water Ecosystems is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

18.8: Types of Marine Organisms



How can you visit marine life?

It's easiest to get to the relatively shallow seafloor just offshore. Experienced divers can descend to 130 feet (43 meters), which gives them access to most marine life. Manned submersibles can descend to the bottom of the deep ocean. Where would you like to go? A coral reef or a hydrothermal vent?

Living Things in the Ocean

Marine organisms range in size from tiny bacteria to the largest known animal, the blue whale. All are adapted for life in salt water. Most are adapted for extreme pressures.

When you think of life in the ocean, do you think of fish? Actually, fish are not the most common life forms in the ocean. Plankton are the most common. Plankton make up one of three major groups of marine life. The other two groups are nekton and benthos (**Figure** below).



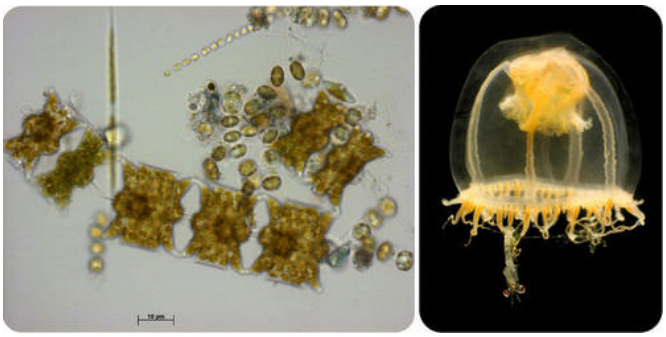
Living things in the oceans are placed in these three groups.

Plankton

Plankton are living things that float in the water. Most plankton are too small to see with the unaided eye (**Figure** below). Plankton are unable to move on their own. Ocean motions carry them along.

There are two main types of plankton:

1. **Phytoplankton** are “plant-like” plankton. Since they make food by photosynthesis, they live in the photic zone. Most are algae.
2. **Zooplankton** are “animal-like” plankton that include tiny animals and fish larvae. They feed on phytoplankton.



The phytoplankton (left) and zooplankton (right) shown here have been magnified. Otherwise, they would be too small for you to see.

Nekton

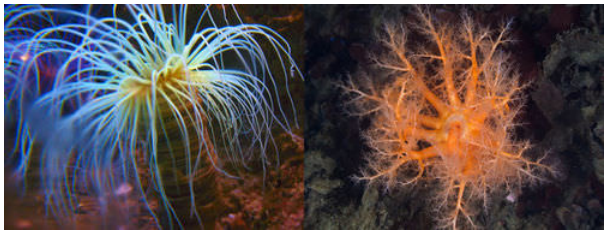
Nekton are living things that swim through the water (**Figure** below). They may live at any depth, in the photic or aphotic zone. Most nekton are fish, although some are mammals. Fish have fins and streamlined bodies to help them swim. Fish also have gills to take in oxygen from the water.



Nekton swim through ocean water.

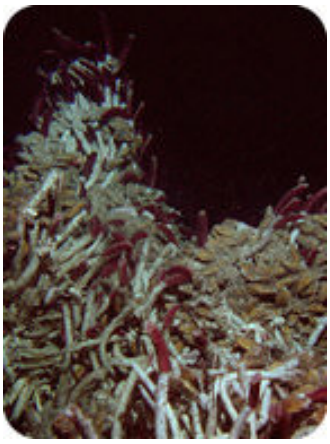
Benthos

Benthos are living organisms on the ocean floor. Many benthic organisms attach themselves to rocks and stay in one place. This protects them from crashing waves and other water movements. Some benthic organisms burrow into sediments for food or protection. Benthic animals may crawl over the ocean floor. Examples of benthos include clams and worms. Pictured below are two other examples (**Figure** below).



These animals live on the ocean floor.

Some benthos live near vents on the deep ocean floor. Tubeworms are an example (**Figure** below). Scalding hot water pours out of the vents. The hot water contains chemicals that some specialized bacteria can use to make food. Tubeworms have the bacteria living inside them. The bacteria get protection and the tubeworms get some of the food.



Tubeworms live near hot water vents on the deep ocean floor.



Summary

- Plankton are tiny organisms that are swept along on currents. Phytoplankton are tiny plant-like organisms. Zooplankton are tiny animals.
- Nekton are organisms that go through the water under their own power. Fish and marine mammals are nekton.
- Benthos bury in the sediment, attach to rocks, or crawl over the seafloor.

Review

1. Compare and contrast phytoplankton and zooplankton.
2. How are nekton adapted to life in the sea?
3. How are benthos adapted to life in the sea?

This page titled 18.8: Types of Marine Organisms is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

18.9: Marine Food Chains

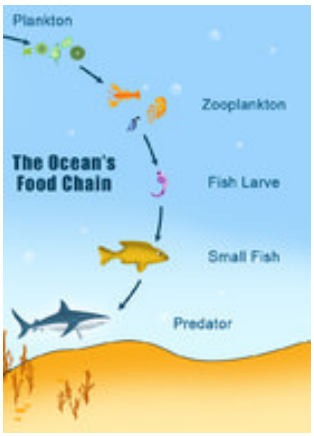


What's the most unusual life form you could see on Earth?

Some people might disagree. But the most unusual life on Earth could be the strange organisms that live at hydrothermal vents at mid-ocean ridges. These organisms break down chemicals to make food energy. They engage in chemosynthesis. Would you like to see an ecosystem with chemosynthesis at its base?

Marine Food Chains

Pictured below is a marine food chain (**Figure** below). Phytoplankton form the base of the food chain. Phytoplankton are the most important primary producers in the ocean. They use sunlight and nutrients to make food by **photosynthesis**. Small zooplankton consume phytoplankton. Larger organisms eat the small zooplankton. Larger predators eat these consumers. In an unusual relationship, some enormous whales depend on plankton for their food. They filter tremendous amounts of these tiny creatures out of the water.



Many marine food chains look like this example.

The bacteria that make food from chemicals are also primary producers. These organisms do not do photosynthesis since there is no light at the vents. They do something called **chemosynthesis**. They break down chemicals to make food.

When marine organisms die, decomposers break them down. This returns their nutrients to the water. The nutrients can be used again to make food. Decomposers in the oceans include bacteria and worms. Many live on the ocean floor. Do you know why?

Summary

- Photosynthesis is the base of nearly all food chains on Earth. This is true of marine food chains, too.
- In chemosynthesis, organisms break down chemicals to make food.
- As on land, marine decomposers break down dead organisms. They release nutrients.

Review

1. Compare and contrast the two types of primary production discussed here.
2. What is a typical marine food chain like?

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

3. What is the role of decomposers in a marine food chain?

Explore More

Use the resource below to answer the questions that follow.



1. Why are fish valuable?
2. What are primary producers?
3. What is chemosynthesis?
4. What is photosynthesis?
5. What are the primary producers of the ocean? Which gas do they use and which do they release into the atmosphere?
6. Why are the primary producers of the ocean important?

This page titled 18.9: Marine Food Chains is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

18.10: Ocean Ecosystems



What would a field trip into the ocean reveal?

There are all sorts of incredible life forms in the seas! Most live near the surface or come up to the surface. Some live very far below the surface and never come up. All are well adapted to their watery environment.

The Intertidal

Have you been to a rocky shore and seen the **intertidal**? It's the zone at the beach that is covered when the tide is up and uncovered when the tide is out. An abundance of life is found there, but it's a difficult place to live. Conditions change rapidly. Waves pound and the tide goes in and out (**Figure** below).



Organisms in a tide pool include a sea star and a sea urchin.

Many animals in the intertidal live in tide pools. What specific adaptations do they have to that zone? The mussels on the top left have hard shells. These protect them from waves and from drying out. The sea anemones in the lower right are more often submerged. They can close up during low tides. Both types of organisms have strong attachments so they don't wash out to sea.

Many young organisms get their start in estuaries and so they must be adapted to rapid shifts in salinity.

Reefs

Corals and other animals create limestone rock **reefs** near the shore. Coral reefs are the “rainforests of the oceans.” They have a tremendous amount of species diversity (**Figure** below).



Coral reefs are very beautiful and very diverse.

Reefs can form interesting shapes in the oceans. Remember that there are many volcanoes in the ocean. Coral reefs can form on volcanoes in tropical water. Since the volcanoes are cones, the reef forms in a circle around the volcano. Eventually the volcano becomes inactive. The mountain subsides and erodes so that it is below sea level. This leaves a circular coral reef (**Figure** below).



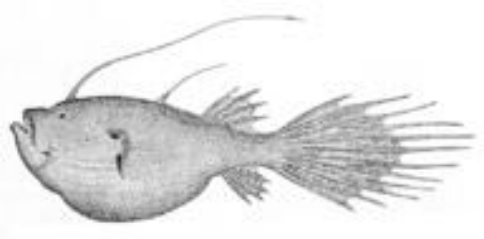
In this image of Maupiti Island in the South Pacific, the remnants of the volcano are surrounded by the circular reef.

Eventually, all that is left is a reef island called an **atoll**. A lagoon is found inside the reef.

Oceanic Zone

The open ocean is a vast area. Food washes down from the land. Food is also created by photosynthesizing plankton. Zooplankton and larger animals feed on the phytoplankton and on each other. Larger animals such as whales and giant groupers may live their entire lives in the open water.

In the deepest ocean, survival is almost impossible (**Figure** below). It's very rare to find a meal, so the fish there use very little energy. They are very small. The fish move very little and breathe slowly. Missing a meal could be deadly, so the fish have interesting ways of getting and keeping food. Some species have jaws that unhinge to accept a larger fish. Some have backward-folding teeth to keep prey from escaping.



An 1896 drawing of a deep sea angler fish with a bioluminescent "lure" to attract prey.

Hydrothermal Vents

Hydrothermal vents are among the most unusual ecosystems on Earth. They are located at mid-ocean ridges where water is extremely hot. The food source for these ecosystems is chemosynthesis (**Figure** below). This ecosystem is entirely separate from the photosynthesis at the surface. Shrimp, clams, fish, and giant tube worms have been found in these extreme places.



Tubeworms

Giant tube worms are found at hydrothermal vents. They get food from the chemosynthetic bacteria that live within them. The bacteria provide food; the worms provide shelter.

Summary

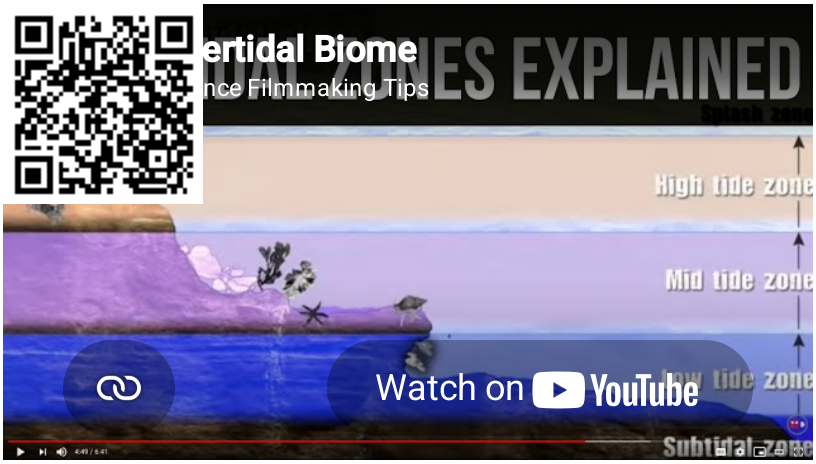
- Life in the intertidal is difficult, but there are many types of organisms there.
- There are few organisms that live in the deepest ocean. The ones that do have amazing adaptations to the exceptionally harsh conditions.
- A hydrothermal vent ecosystem has chemosynthesis as its food source. The ecosystem is independent of photosynthesis at the surface.

Review

1. Why is there so much biodiversity in the intertidal zone?
2. Why is survival in the deep ocean difficult? To do this, what adaptations do organisms have?
3. What is different about the hydrothermal vent ecosystem from a surface ocean ecosystem?

Explore More

Use the resources below to answer the questions that follow.



1. What is the intertidal zone?
2. What do organisms in an intertidal zone have to deal with each day?
3. What is zonation?
4. What adaptation to the algae of the mid-tidal zone have to being exposed to air about half the day?
5. How have some of the organisms in the intertidal zone adapted to life there?



6. Why is the deep sea not well explored?
7. What is the epipelagic zone? Which organisms live there?
8. What is the mesopelagic zone? Which organisms live there?
9. What color are most of the animals in this zone and why?
10. What is bioluminescence?
11. What is the deep scattering layer?

This page titled 18.10: Ocean Ecosystems is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

18.11: Ecosystems- Challenge 2

1. Marine invertebrates ___.

account for a lot of the ocean's biodiversity

2. Most marine invertebrates live ___.

close to shore

3. Zooplankton are found ___.

near the surface where phytoplankton live and nutrients are abundant

4. Marine decomposers typically live ___.

on the ocean floor

5. Organisms that engage in chemosynthesis get their energy from ___.

chemicals

6. Zooplankton consume ___.

phytoplankton

7. The breakdown of chemicals to produce energy is called ___.

chemosynthesis

8. A coral reef that surrounds a volcano is an ___.

atoll

9. Hydrothermal vents are located in ___.

the deep ocean

10. Marshes have a lot of ___.

reeds and grasses

11. ___ is the study of bodies of freshwater and the organisms that live there.

Limnology

12. The sloped side of a lake where sunlight penetrates is the ___.

littoral zone

This page titled 18.11: Ecosystems- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

19: History of Life on Earth

19.1: Evolution of Simple Cells
19.2: Evolution of Eukaryotes to Multicellular Life
19.3: Life of the Phanerozoic Eon
19.4: History of Paleozoic Life
19.5: History of Mesozoic Life
19.6: History of Cenozoic Life
19.7: Human Evolution
19.8: Life and the Geologic Time Scale
19.9: History of Life on Earth- Challenge

This page titled 19: History of Life on Earth is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

19.1: Evolution of Simple Cells



What would you see if you could go back 4.5 billion years?

If you took a field trip back in time to the earliest Earth, things would be very different. Everything would be very hot. What company would you have? Maybe some simple microbes. Maybe not.

Ancient Life

For the first 4 billion years of Earth history there is only a little evidence of life. Organisms were tiny and soft and did not fossilize well. But scientists use a variety of ways to figure out what this early life was like. Note that the period from Earth's origin to the beginning of the Phanerozoic is called the Precambrian.

Life Begins

Life probably began in the oceans. No one knows exactly how or when. Life may have originated more than once. If life began before the Moon formed, that impact would have wiped it out. Then life would have had to originate again. Eventually conditions on Earth became less violent. The planet could support life.

The first organisms were made of only one cell (**Figure** below). The earliest cells were **prokaryotes**. Prokaryotic cells are surrounded by a cell membrane. They do not have a nucleus. Their organelles are free in the cell. The cells get their nutrients directly from the water they live in. The cells need to use these nutrients to live and grow.



E. coli (Escherichia coli) is a primitive prokaryote that may resemble the earliest cells.

The cells also needed to be able to make copies of themselves. To do this they stored genetic information in **nucleic acids**. The two nucleic acids are **DNA** (deoxyribonucleic acid) and **RNA** (ribonucleic acid). Nucleic acids pass genetic instructions to the next generation.

Oxygen Enters the Atmosphere

Early cells took nutrients from the water. Eventually the nutrients would have become less abundant.

Around 3 billion years ago, photosynthesis began. Organisms could make their own food from sunlight and inorganic molecules. From these ingredients they made chemical energy that they used. Oxygen is a waste product of photosynthesis. That first oxygen combined with iron to create iron oxide. As more oxygen was produced, the gas entered the atmosphere.

Some of the oxygen in the atmosphere became ozone. The ozone layer formed to protect Earth from harmful ultraviolet radiation. This made the environment habitable for more complex life forms.

Early Organisms

The first organisms to photosynthesize were **cyanobacteria**. These organisms may have been around as far back as 3.5 billion years. Cyanobacteria are still alive today (**Figure** below). Now they are called blue-green algae. They are common in lakes and seas, and they account for 20% to 30% of photosynthesis today.



These rocks in Glacier National Park, Montana may contain some of the oldest fossil microbes on Earth.

Summary

- A prokaryote has a cell membrane, but otherwise organelles are loose within the cell.
- Photosynthesis allows organisms to produce food energy with oxygen as a by-product. After photosynthesis evolved, iron oxidized and then oxygen entered the atmosphere. Ozone was created in the upper atmosphere.
- Cyanobacteria, which are still around today, were the earliest known photosynthesizing organisms.

Review

1. Describe the features of prokaryotes.
2. Why was the development of photosynthesis so important to the evolution of life?
3. What do we know about the first life forms?

Explore More

Use the resource below to answer the questions that follow.



1. What are cyanobacteria?
2. When did cyanobacteria dominate Earth?
3. How are the features of a prokaryotic cell?
4. What are cyanobacteria responsible for?
5. Where are cyanobacteria found?
6. What are stromatolites?
7. How do we know that stromatolites flourished early in Earth history?
8. What is a heterocyst? What does it do?
9. What is an akinete? What is its function?

This page titled 19.1: Evolution of Simple Cells is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

19.2: Evolution of Eukaryotes to Multicellular Life

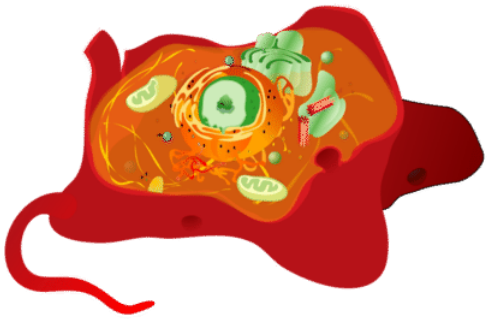


If you could go back to the late Precambrian, would you recognize these as ancestors of modern life?

This is a depiction of *Dickinsonia costata*, a member of the Ediacara fauna. No one knows quite how to categorize these organisms. Some scientists think that they are the ancestors of modern life. But most scientists believe that the Ediacara fauna died out and that other organisms were the ancestors of modern life. If you could go back in time maybe you could figure it out. But since that isn't possible, is there any way to really know?

Life Gets More Complex

Eukaryotes evolved about 2 billion years ago. Unlike prokaryotes, **eukaryotes** have a cell nucleus. They have more structures and are better organized. Organelles within a eukaryote can perform certain functions. Some supply energy; some break down wastes. You can see an example of a eukaryotic cell below (**Figure** below).



A eukaryotic cell. This one is from an animal.

Multicellular Life Originates

For life to become even more complex, multicellular organisms needed to evolve. Prokaryotes and eukaryotes can be multicellular.

Toward the end of the Precambrian, the Ediacara fauna evolved (**Figure** below). The Ediacara fauna was extremely diverse. The organisms appeared after Earth defrosted from a worldwide glaciation. The Ediacara fauna seems to have died out without leaving descendants. Other multicellular organisms appeared in the Phanerozoic.



A fossil of an Ediacara organism.

Summary

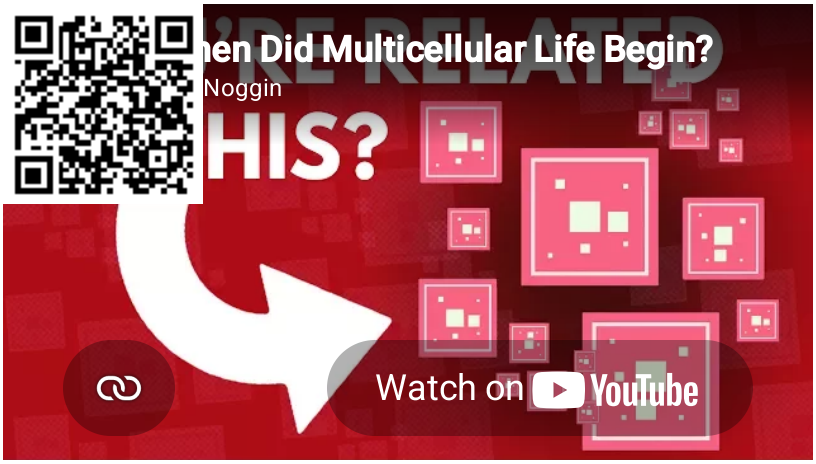
- Eukaryotic cells have a nucleus. They also have well-developed structures.
- Eukaryotes did not evolve until 2 billion years ago.
- Ediacara organisms probably went extinct. Other organisms were the ancestors to modern life.

Review

1. Describe eukaryotic cells.
2. Why are organelles important to cells?
3. Describe the Ediacara fauna.

Explore More

Use the resource below to answer the questions that follow.



1. What were the first life forms on Earth?
2. What is the origin of multicellular organisms?
3. What three traits are needed for a group of cells to be considered a multicellular life form?
4. How many branches of complex organisms are there projected to be?
5. What is the oldest multicellular life fossil found?
6. What is necessary for all life that we know of?
7. What do scientists look for when looking for life on Earth?
8. What needed to happen for cells living in colonies to become multicellular organisms?

This page titled 19.2: Evolution of Eukaryotes to Multicellular Life is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

19.3: Life of the Phanerozoic Eon



Does this look like a creature from Earth you know?

It's not hard to take a field trip to see some ancient life. Horseshoe crabs live along the east coast of the United States and elsewhere. These ancient creatures have been more-or-less unchanged for the past 450 million years. This is indicated by fossils. That doesn't get them quite back to the beginning of the Paleozoic but close. So hundreds of millions of generations of horseshoe crabs have seen most of the Phanerozoic go by.

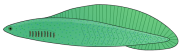
Phanerozoic Eon

The **Phanerozoic Eon** is divided into three eras—the **Paleozoic**, the **Mesozoic**, and the **Cenozoic** (**Figure** (below). They span from about 540 million years ago to the present. We live now in the Cenozoic Era.

Earth’s climate changed numerous times during the Phanerozoic Eon. At the end of the Precambrian, much of the planet was covered with glaciers. At the start of the Phanerozoic Eon, the climate became warm and humid. Since then Earth’s climate has gone through four cycles of frigid glaciers and warm tropical seas. Some organisms survive changes in the climate. Others go extinct when the climate changes too much.

Phanerozoic Time Line

Table below shows some of the life forms that developed during the Phanerozoic Eon. Life gradually became more diverse and new species appeared. Most modern organisms evolved from species that are now extinct.

Era	Millions of Years Ago	Major Forms of Life
Cenozoic	0.2 (200,000 years ago)	First humans
	35	First grasses; grasslands begin to dominate the land
Mesozoic	130	First plants with flowers
	150	First birds on Earth
	200	First mammals on Earth
	251	Age of dinosaurs begins 
Paleozoic	300	First reptiles on Earth
	360	First amphibians on Earth
	400	First insects on Earth
	475	First plants and fungi begin growing on land
	500	First fish on Earth 

Summary

- The Phanerozoic has spanned from 540 million years ago to present.
- The Phanerozoic Eon is made up of the Paleozoic, Mesozoic, and Cenozoic Eras.
- The quantity and diversity of life has exploded since the beginning of the Phanerozoic.

Review

1. When did the Phanerozoic begin? When did it end?
2. What are some of the major events that have occurred in the Phanerozoic?
3. What eras make up the Phanerozoic?

This page titled 19.3: Life of the Phanerozoic Eon is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

19.4: History of Paleozoic Life



Okay, so you may not recognize the Precambrian. How about the Paleozoic?

Probably not. You'd see things like these bizarre animals. The creature on the left is much like a large arthropod. The creature on the right had five eyes, and a long nose like a vacuum cleaner hose. These creatures were found as fossils in the Burgess shale.

Paleozoic Era

The first period of the Paleozoic Era was the Cambrian. By the beginning of the Paleozoic, organisms evolved shells. Shells could hold their soft tissues together. Shells could protect them from predators and from drying out. Some organisms evolved external skeletons. These are called **exoskeletons**. Organisms with hard parts also make good fossils. Fossils from the Cambrian are much more abundant than fossils from the Precambrian.

The Cambrian Explosion

The warm, humid climate of the early Cambrian was good for life. There was a tremendous increase in diversity. There was also an amazing increase in the number of living things. For these two reasons, this time period is called the Cambrian Explosion.

With so much diversity, complex ecosystems could develop. All of this life was in the seas.

The Paleozoic Continues

Paleozoic seas were full of worms, snails, clams, trilobites, sponges, and brachiopods. Organisms with shells were common.

The first fish were simple, armored, jawless fish. Fish have internal skeletons. Some, like sharks, skates, and rays, have skeletons of cartilage. More advanced fish have skeletons of bones. Fish evolved jaws and many other adaptations for ocean life. Pictured below is some of the diversity of Earth's oceans (**Figure** below).



Mudskippers are fish that are able to walk short distances.

Moving Onto Land

An organism that lives in water is supported by the water. It does not need strong support structures. It also does not need to be protected against drying out. This is not true of land. Moving from the seas to land required many adaptations.

Algae had covered moist land areas for millions of years. By about 450 million years ago, plants began to appear on land. Once there were land plants, animals had a source of food and shelter. To move to land, animals needed strong skeletons. They needed protection from drying out. They needed to be able to breathe air. Eventually they developed skeletons, lungs, and the other the adaptations they needed moved onto the land.



Halkieria, or scale worms, are an example of a fossil life from the Cambrian.

One group of fish evolved into amphibians. Insects and spiders were already land dwellers by the time amphibians appeared.

Mass Extinctions

The eras of the Phanerozoic Eon are separated by **mass extinctions**. During these events, large numbers of organisms became extinct very rapidly. There have been several extinctions in the Phanerozoic. Two mass extinctions stand out more than the others. One took place at the end of the Paleozoic. The other took place at the end of the Mesozoic.

Permian Extinction

Between the Paleozoic Era and the Mesozoic Era was the largest mass extinction known. At the end of the Permian, nearly 95% of all marine species died off. In addition, 70% of land species became extinct. No one knows the cause of this extinction. Some scientists blame an asteroid impact. Other scientists think it was a gigantic volcanic eruption. It is possible that multiple things went wrong for life at the same time. The environment was changing, an asteroid impacted, and a giant volcanic eruption took place.

Summary

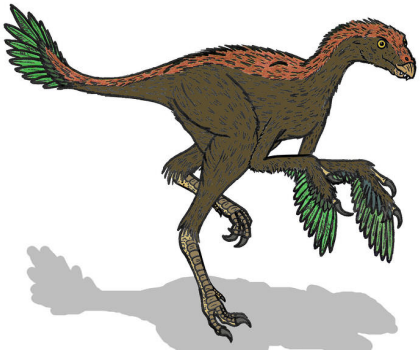
- In the Cambrian there was an explosion of life. This explosion was in number and in diversity.
- At the beginning of the Paleozoic, all life was in the seas. Later in the Paleozoic, life colonized the land.
- To colonize land, animals need to be able to keep themselves together. They need to keep from drying out. They need to be able to breathe air.
- At the end of the Permian was the largest known extinction in Earth history.

Review

1. What evolved during the Cambrian that was important for the evolution of life and what is its purpose?
2. What does a sea creature need to have if it's going to colonize the land?
3. What brought about the Permian extinction?

This page titled 19.4: History of Paleozoic Life is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

19.5: History of Mesozoic Life



Would Mesozoic Earth look familiar?

The Precambrian and Paleozoic Earth would probably not be recognizable. How about if you visited the Mesozoic? The planet would look a lot more like it does today. Animals would fill the niches you're used to seeing animals fill. But the animals would be mostly reptiles. So things wouldn't be so familiar after all.

The Mesozoic Era

The Paleozoic ended with a mass extinction. This left lots of habitats available for new organisms. Adaptive radiation by reptiles filled these habitats. The Mesozoic Era was the age of reptiles. The planet was generally warmer than it is now. This climate was very good for reptiles.

Reptiles developed adaptations for living away from water. Their thick skin keeps them from drying out. The evolution of the amniote egg allowed them to lay their eggs on dry land. The **amniote egg** has a shell and contains all the nutrients and water required for the developing embryo (**Figure** below).



Amniotic egg containing an alligator hatchling.

Dinosaurs

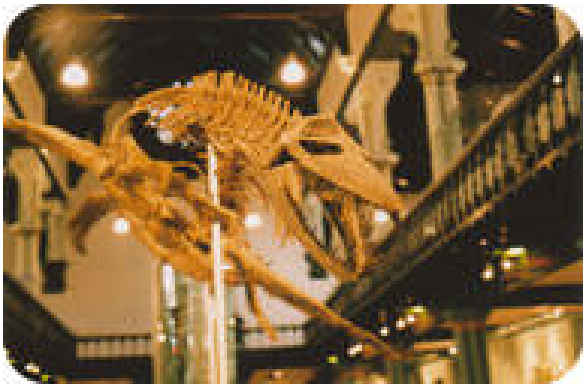
Earth in the Mesozoic was populated by an enormous diversity of reptiles. Most of the reptiles were dinosaurs. Dinosaurs reigned the planet for 160 million years. They had tremendous numbers and diversity. Some were small, and some were very large (**Figure** below). Some were peaceful plant eaters. Some were extremely frightening meat eaters. Some dinosaurs developed protection, such as horns, spikes, tail clubs, and shielding plates. These adaptations were defense against active predators.

Species of dinosaurs filled all the niches that are currently filled by mammals. Most dinosaurs lived on land. Still, pterosaurs flew the skies. Plesiosaurs and ichthyosaurs swam in the oceans (**Figure** below). Feathered dinosaurs gave rise to birds.



Some examples of Mesozoic dinosaurs include this Tyrannosaurus rex, pictured with two Gallimimus.

Scientists now think that some dinosaurs were endotherms (warm-blooded). There is a lot of evidence for this hypothesis. Some dinosaurs lived in very cold regions. Many dinosaurs grew fast and were very active. Dinosaur bones had canals, like birds. Some dinosaurs stood upright and had big brains. These features are more typical of endotherms.



Plesiosaurs were swimming dinosaurs.

Plants also did well in the Mesozoic. Lush forests covered the land. Flowering plants evolved later in the Mesozoic.

Rise of the Mammals

Mammals appeared near the end of the Triassic.

Cretaceous Extinction

The most famous mass extinction was 65 million years ago. Between the Mesozoic Era and the Cenozoic Era, about 50% of all animal species died off. This mass extinction is when the dinosaurs became extinct. Most scientists think that the extinction was caused by a giant meteorite that struck Earth. The impact heated the atmosphere until it became as hot as a kitchen oven. Animals roasted. Dust flew into the atmosphere and blocked sunlight for a year or more. This caused a deep freeze and inhibited photosynthesis. Sulfur from the impact mixed with water in the atmosphere. The result was acid rain. The rain dissolved the shells of the tiny marine plankton that form the base of the food chain. With little food being produced, animals starved.

Summary

- The amniote egg allowed reptiles to move away from water.
- In the Mesozoic, dinosaurs filled the niches that mammals fill today.
- About half of the life forms of the Mesozoic appear to have gone extinct due to a giant asteroid impact.

Review

1. How did life in the Mesozoic resemble life today? How did it differ from life today?
2. What was the importance of the amniote egg for Mesozoic life?
3. How are dinosaurs and modern birds related?

This page titled 19.5: History of Mesozoic Life is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

19.6: History of Cenozoic Life



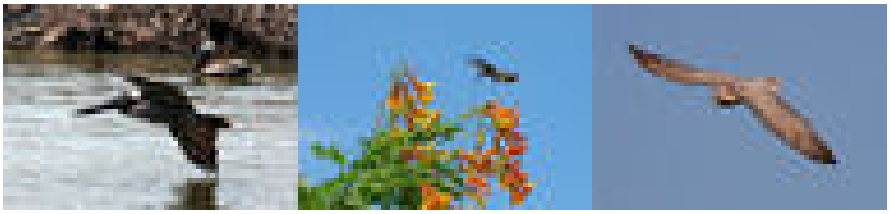
Do these animals look familiar?

The ice ages were very recent as Earth history goes. The animals are familiar, but they're still very different from modern ones. For one thing, most of them were huge. A small surface area-to-volume ratio is better for keeping warm (less surface area to lose thermal energy). Although the dominant animals were mammals, the Pleistocene Earth still does not look quite modern.

The Cenozoic Era

The Cenozoic Era is going on right now! It is the age of mammals. The Cenozoic began with the extinction of every land creature larger than a dog. This left many niches open. Organisms evolved to fill them.

There was a huge radiation of mammals. But birds, like the few seen in the pictures (**Figure** below), are more common and even more diverse. Both mammals and birds have the ability to regulate their own body temperature. They are endotherms (warm blooded). This was an advantage since Earth's climate went through sudden and dramatic changes.



Left: A pelican, catching a fish. Center: A hummingbird, taking a sip from a flower. Right: A falcon, ready to catch its prey.

Diversification of the Mammals

Mammals have adapted to all sorts of different environments. They were able to spread to even more environments than the reptiles. Mammals are endothermic and have fur, hair, or blubber for warmth. Mammals can walk, swim, or fly. They can live in nearly all terrestrial environments. Mammals initially filled the forests that covered many early Cenozoic lands. When grasslands arose, mammals evolved to fill those niches too. You can see pictures of many different mammals below (**Figure** below).



(top left) This bat lives in a cave, emerging at night to find food. (top right) Although you might not guess it, these humpback whales are gigantic, ocean-dwelling mammals. (bottom right) This Eurasian pygmy shrew has found a home on the forest floor. It is only a few inches long. (bottom left) These African elephants are native to central Africa.

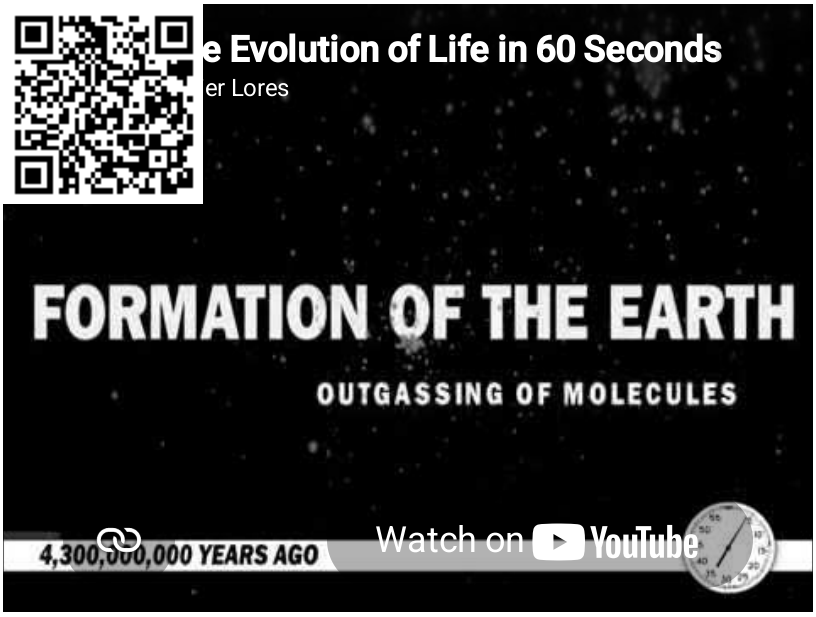
Pleistocene Megafauna

As climate cooled during the ice ages, large mammals evolved. These are called the Pleistocene megafauna. Mastodons, giant sloths, wooly mammoths, giant condors, and saber tooth cats all evolved (**Figure** below).



The saber-toothed cat lived during the Pleistocene.

"The Evolution of Life in 60 Seconds" video scales all 4.6 billion years of Earth history into one minute. Don’t blink at the end!



Many of the organisms that made up the Pleistocene megafauna went extinct as conditions warmed. Some may have been driven to extinction by human activities.

Other Cenozoic animals include hooved mammals, whales, primates, and eventually humans.

Imagine a vast grassy plain covered with herds of elephants, bison, and camels stretching as far as the eye can see. Lions, tigers, wolves, and, later, humans, hunt the herds on their summer migration.This was the San Francisco Bay Area at the close of the last ice age.



Summary

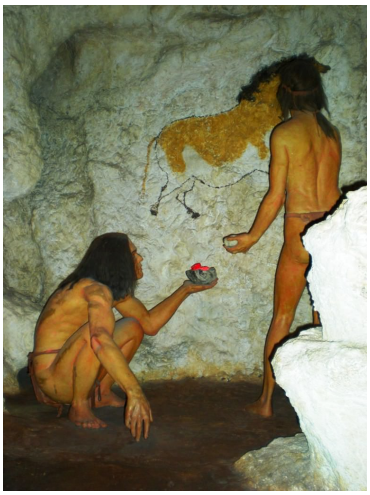
- With the extinction of the dinosaurs, niches were open for birds and mammals to fill.
- Birds and mammals are endotherms. Both are diverse and abundant.
- Many of the organisms of the Pleistocene ice ages were enormous. Animals with a low surface area to body ratio are better able to keep warm.
- Many of the Pleistocene megafauna have gone extinct.

Review

1. What are the Pleistocene megafauna, and why were they so large?
2. What characteristics do mammals have that allow them to fill so many niches and what do each of those things do?
3. List some of the types of mammals and state how they live.

This page titled 19.6: History of Cenozoic Life is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

19.7: Human Evolution



What is a "cave man"?

What if you were to wake up with a group of Neanderthals? They were close relatives to modern humans. Still, you might find them to be a bit different from your usual friends.

Human Evolution

Humans evolved during the later Cenozoic. New fossil discoveries continue to alter the details of what we know about human evolution. The major evolutionary events are well understood though.

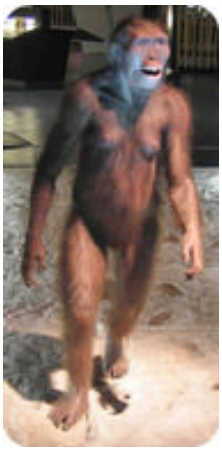
Primate Ancestors

Humans evolved from **primates**, a group of mammals that includes lemurs, monkeys and apes. Humans are part of the apes, but we did not evolve from **apes**, which also include chimpanzees and gorillas. Apes and humans have a primate common ancestor. About 5 to 7 million years ago, chimpanzees (our closest living relatives) and humans shared their last common ancestor.

Hominids

Animals of the genus, *Ardipithecus* lived roughly 4 to 6 million years ago. These animals had brains roughly the size of a female chimp. Although they lived in trees, they were bipedal. That is, they could stand on two feet. What are the advantages to being bipedal? An organism that can stand up can see farther. This is important if you live in a grassland. A bipedal organism uses its hands and arms for hunting.

Another human ancestor, *Australopithecus afarensis* lived between 3.9 and 2.9 million years ago (**Figure** below). These animals were completely bipedal. Their brains grew rapidly across the generations.



Australopithecus afarensis is a human ancestor that lived about 3 million years ago.

Homo

The genus ***Homo***, in which modern humans are the only living species, appeared about 2.5 million years ago. These human-like primates developed the first stone tools. *Homo erectus* evolved in Africa about 1.8 million years ago. Fossils of these animals show a much more human-like body structure. This allowed them to travel long distances to hunt. Cultures began and evolved.

Homo sapiens

Homo sapiens is our species. We originated about 200,000 years ago in Africa. Evidence of a spiritual life appears about 32,000 years ago. The evidence includes stone figurines that probably have religious significance (**Figure** below).



Stone figurines likely indicate a spiritual life.

The ice ages allowed humans to migrate. During the ice ages, water was frozen in glaciers. Land bridges such as the Bering Strait allowed humans to walk from Asia to North America.

Summary

- *Australopithecus afarensis* was completely bipedal and had a growing brain.
- *Homo erectus* evolved 1.8 million years ago. These organisms left behind signs of an early culture.
- Our species is *Homo sapiens*. We evolved 200,000 years ago in Africa, and spread.

Review

1. Why is being bipedal a good thing?
2. What is the evidence that humans evolved from apes?
3. Why are the ice ages important for the spread of modern humans?

Explore More

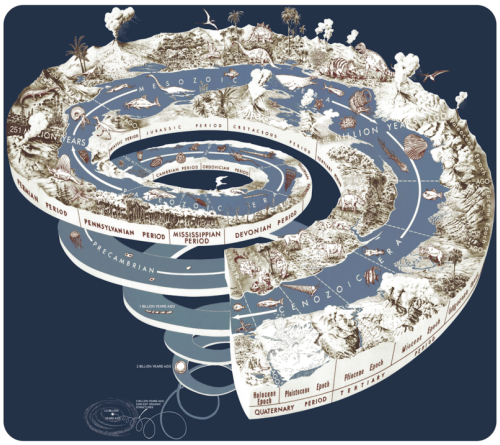
Use the resource below to answer the questions that follow.



1. What was Darwin's little heresy?
2. What was "the missing link" thought to be?
3. Why weren't the Neanderthal and Homo erectus fossils that were found thought to be the missing link?
4. What was the problem with the fossil evidence from Africa? What was found to be incorrect and why?
5. Why is it difficult to identify whether an apelike fossil is a direct human ancestor or not?
6. List the traits that separate humans from apes.
7. Why did the DNA of humans and apes seem as if they did not share a common evolutionary ancestor? How was that resolved?
8. When was the last common ancestor between chimps and humans? When was the last between Neanderthal and humans?
9. What is the scientific evidence for the creation of humans by a deity?

This page titled 19.7: Human Evolution is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

19.8: Life and the Geologic Time Scale



Does this look more like geologic time?

This image gives some sense of what life forms appeared when. Take a good look. It's pretty amazing!

Life and the Geologic Time Scale

The geologic time scale may include illustrations of how life on Earth has changed. Major events on Earth may also be shown. These include the formation of the major mountains or the extinction of the dinosaurs. The figure above is a different kind of the geologic time scale. It shows how Earth's environment and life forms have changed.

Your Place in Geologic Time

We now live in the Phanerozoic Eon, the Cenozoic Era, the Quarternary Period, and the Holocene Epoch. **Phanerozoic** means visible life. During this eon, rocks contain visible fossils. Before the Phanerozoic, life was microscopic. The Cenozoic Era means new life. It encompasses the most recent forms of life on Earth. The Cenozoic is sometimes called the Age of Mammals. Before the Cenozoic came the Mesozoic and Paleozoic. The Mesozoic means middle life. This is the age of reptiles, when dinosaurs were abundant. The Paleozoic is old life. Organisms like invertebrates and fish were the most common lifeforms.

The Quaternary Period is the time since the beginning of the ice ages. The climate has been cooler than it was earlier in the Cenozoic. Since the end of the Pleistocene ice ages, which are probably not entirely over, we have been in the Holocene Epoch. The Holocene is also called the Recent.

Summary

- Complex life forms evolved relatively late in geologic time.
- The Holocene is a teeny part of Earth history. Humans evolved very recently.
- The last 540 million years has seen an incredible amount of biodiversity.

Review

1. Why do we not know exactly when life first evolved on Earth?
2. When did life become abundant?
3. Where do humans appear in this graphic? Is that where you would expect them to be?

This page titled 19.8: Life and the Geologic Time Scale is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

19.9: History of Life on Earth- Challenge

1. Prokaryotes do not have ___.

membrane-bound organelles or a nucleus

2. Photosynthesis allowed for the proliferation of life because ___.

organisms no longer had to rely on nutrients floating by for food

3. ___ are reef-like structures in which colonies of cyanobacteria lived.

Stromatolites

4. The first humans evolved ___ years ago.

0.2 million

5. We are currently living in the ___ era.

Cenozoic

6. The dinosaurs lived in the ___ era.

Mesozoic

7. Most of the fossil fuels we burn today originated from ___swamps, dominated by ___ plants.

Carboniferous; seed-bearing

8. The largest increase in the number and diversity of living things on Earth was the ___ at the beginning of the ___ era.

Cambrian Explosion; Paleozoic

9. Simple plants lacking vascular tissue, like mosses, began to colonize land during the ___ period.

Ordovician

10. Homo erectus developed the first ___.

cultures

11. Cultures with control of fire, use of tools, and hunting strategies began to evolve with the appearance of the species ___.

Homo erectus

12. Species of the genus Ardipithecus lived in ___.

trees

13. Phanerozoic means ___.

visible life

14. The Quaternary Period marks the time since ___.

the beginning of the ice ages

15. "The Recent" is another name for the ___.

Holocene

This page titled 19.9: History of Life on Earth- Challenge is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

20: Earth's Energy

20.1: Energy Resources
20.2: Obtaining Energy Resources
20.3: Energy Conservation
20.4: Renewable vs. Nonrenewable Energy Resources
20.5: Earth's Energy- Challenge 1
20.6: Fossil Fuel Formation
20.7: Coal Power
20.8: Petroleum Power
20.9: Natural Gas Power
20.10: Fossil Fuel Reserves
20.11: Nuclear Power
20.12: Earth's Energy- Challenge 2
20.13: Solar Energy
20.14: Hydroelectric Power
20.15: Wind Energy
20.16: Geothermal Energy
20.17: Biomass Energy
20.18: Earth's Energy- Challenge 3

This page titled 20: Earth's Energy is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.1: Energy Resources



How can a trip to an amusement park be a learning experience?

Amusement parks use the laws of physics to generate fun! Gravity, energy, and centrifugal forces are all harnessed on various rides. Which is your favorite?

Energy

Energy is the capacity to do work. Work is the transfer of energy, so moving an object or changing the state of matter (for example, from solid to liquid) can be considered work. These activities require energy. Every living thing needs energy to live and grow.

What makes energy available whenever you need it? If you unplug a lamp, the light goes off. The lamp does not have a supply of energy to keep itself lit. The lamp uses electricity that comes through the outlet as its source of energy. The electricity comes from a power plant. The power plant has a source of energy to produce this electricity.

Fuel

The energy to make the electricity comes from fuel. Fuel stores the energy and releases it when it is needed. **Fuel** is any material that can release energy in a chemical change. The food you eat acts as a fuel for your body. Gasoline and diesel fuel are fuels that provide the energy for most cars, trucks, and buses. But there are many different kinds of fuel.

For fuel to be useful, its energy must be released in a way that can be controlled.

Heat

When fuel is burned, most of the energy is released as **thermal energy**. Heat is the transfer of thermal energy. Heat can be used to do work. Heat cooks food or warms your house. Sometimes the heat is just waste heat. It still heats the environment, though.

Thermal energy from a wood fire can boil a pot of water. If you put an egg in the pot, you can eat a hard boiled egg in 15 minutes (cool it down first!). The energy to cook the egg was stored in the wood. The wood got that energy from the Sun when it was part of a tree. The Sun generated the energy by nuclear fusion. You started the fire with a match. The head of the match stores energy as chemical energy. That energy lights the wood on fire. The fire burns as long as there is energy in the wood. Once the wood has burned up, there is no energy left in it. The fire goes out.

Using Energy

Your body gets its energy from food, but that is only a small part of the energy you use every day. Cooking your food takes energy, and so does keeping it cold in the refrigerator or the freezer. The same is true for heating or cooling your home. Whether you are turning on a light in the kitchen or riding in a car to school, you are using energy. Billions of people all around the world use energy, so there is a huge demand for resources to provide all of this energy. Not everyone uses energy equally, however. People in industrialized countries, especially the U.S., use a lot more energy than people in developing countries. Why do we need so much energy? The main reason is that almost everything that happens on Earth involves energy.



This lantern festival uses hundreds of candles for light.

The Sources of Earth's Energy

Almost all energy comes from the Sun. Plants make food energy from sunlight. Fossil fuels are made of the remains of plants and animals that stored the Sun's energy millions of years ago.

The Sun heats some areas more than others, which causes wind. The Sun's energy also drives the water cycle, which moves water over the surface of Earth. Both wind and water power can be used as renewable resources.

Earth's internal heat does not depend on the Sun for energy. This heat comes from remnant heat when the planet formed. It also comes from the decay of radioactive elements. Radioactivity is an important source of energy.



Summary

- Energy is the ability to do work or change matter.
- Energy from the Sun drives atmospheric processes on Earth, which leads to wind.
- Ancient energy from the Sun is stored in fossil fuels.

Review

1. What is energy?
2. What does it mean to say that energy changes matter from one state to another?
3. What are fuel and heat?
4. Where does the lamp in the room you're in now get its energy?

Explore More

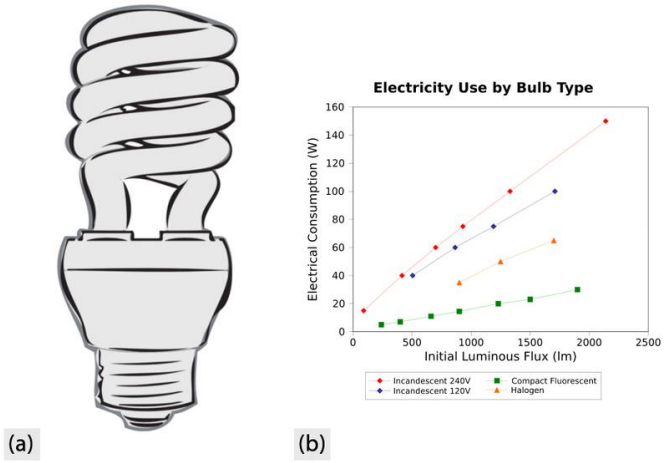
Use this resource to answer the questions that follow.



1. What is energy? Where is energy? Where is energy in the universe?
2. Define energy. What do you apply?
3. Where do you get your energy? What type of energy is that?
4. What type of energy does a log have? What happens if you add heat to the log?
5. What is nuclear energy? What would happen if you could release the nuclear energy in a log?
6. What is the same thing as energy?
7. What does dark energy do?
8. Where does energy go? How is it created? What happens to energy? What is the universe in terms of energy?

This page titled 20.1: Energy Resources is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.2: Obtaining Energy Resources



Have you converted to compact fluorescent light bulbs at your house?

Compact fluorescent light bulbs are more efficient than incandescent light bulbs. Look at the chart and try to see how much more efficient. The answer is that they could be as much as six times more efficient. So why aren't all people using compact fluorescent bulbs all the time? Early ones were large and expensive, and many people don't like the color of the light. But they are much more environmentally friendly.

Net Energy

Net energy is the amount of useable energy available from a resource after subtracting the amount of energy needed to make the energy from that resource available. For example, every 5 barrels of oil that are made available for use require 1 barrel for extracting and refining the petroleum. What is the net energy from this process? About 4 barrels (5 barrels minus 1 barrel).

What happens if the energy needed to extract and refine oil increases? Why might that happen? The energy cost of an energy resource increases when the easy deposits of that resource have already been consumed. For example, if all the nearshore petroleum in a region has been extracted, more costly drilling must take place further offshore (**Figure** below). If the energy cost of obtaining energy increases, the resource will be used even faster.



Offshore drilling is taking place in deeper water than before. It takes a lot of energy to build a deep drilling platform and to run it.

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

Net-Energy Ratio

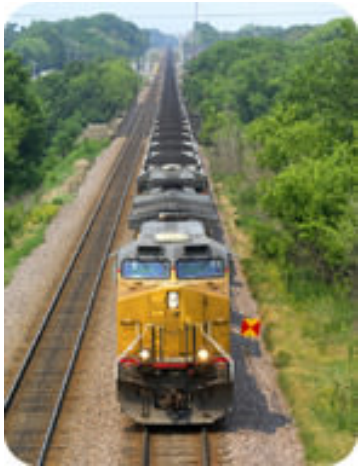
The **net-energy ratio** demonstrates the difference between the amount of energy available in a resource and the amount of energy used to get it. If it takes 8 units of energy to make available 10 units of energy, then the net-energy ratio is 10/8 or 1.25. What does a net-energy ratio larger than 1 mean? What if the net-energy ratio is less than 1? A net-energy ratio larger than 1 means that there is a net gain in usable energy; a net-energy ratio smaller than one means there is an overall energy loss.

Table below shows the net-energy ratios for some common energy sources.

Net-Energy Ratios for Common Energy Sources

Energy Source	Net-energy Ratio
Solar Energy	5.8
Natural Gas	4.9
Petroleum	4.5
Coal-fired Electricity	2.5-5.1

Notice from the table that solar energy yields much more net energy than other sources. This is because it takes very little energy to get usable solar energy. Sunshine is abundant and does not need to be found, extracted, or transported very far. The range for coal-fired electricity is because of the differing costs of transporting the coal. What does this suggest about using coal to generate electricity? The efficiency is greater in areas where the coal is locally mined and does not have to be transported great distances (**Figure** below).



Obtaining coal for energy takes a lot of energy. The coal must be located, extracted, refined, and transported.

This is not to say that solar energy is less expensive than other types of energy. The cost of energy is dependent on lots of different factors, such as the cost of the equipment needed to harness the energy. If solar power cost less to use, it would be more widespread.

Energy Efficiency

Energy efficiency describes how much useful work is extracted from one unit of energy. Remember that although energy is not created or destroyed, it's just transferred from one form to another, some energy is nearly always lost in the transfer as heat. By saying that the work must be useful, it is possible to account for the energy that is lost to non-useful work. For example, some energy may not be doing useful work if the equipment is not running well (maybe a piston is moving sideways a bit rather than just up and down).

Higher energy efficiency is desirable because:

- Less energy is being wasted.
- Non-renewable resources will last longer.

- The cost is kept lower.

Because so much of the energy we use is from fossil fuels, we need to be especially concerned about using them efficiently. Sometimes our choices affect energy efficiency. For example, transportation by cars and airplanes is less energy-efficient than transportation by boats and trains.

Summary

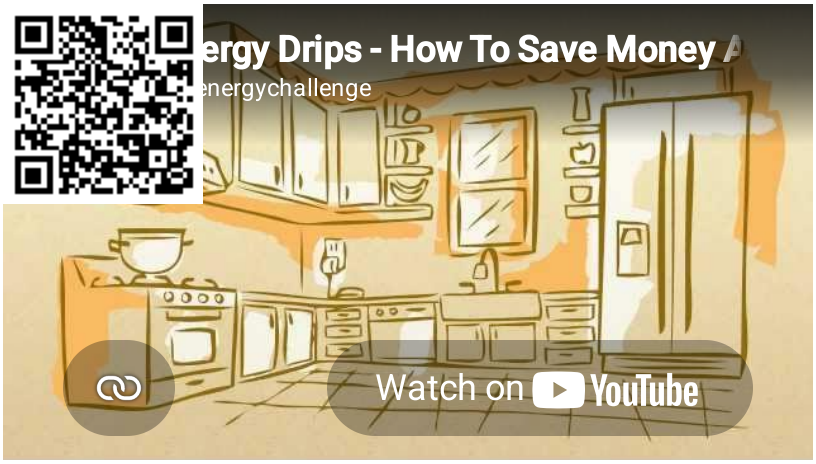
- Net energy is the amount of that is actually useable from an energy resource. Net-energy ratio is the ratio of the amount of useable energy from a resource and the amount it takes to make that energy useful.
- Many factors besides net-energy ratio go into determining if a type of energy will be used.
- An energy source with high energy efficiency provides a lot of work for the amount of energy used.

Review

1. Compare and contrast net energy, the net-energy ratio, and energy efficiency.
2. Since the net-energy ratio for solar energy is higher than other types of energy, why don't we use solar for electricity almost exclusively?
3. Why would the energy needed to make a type of energy useful increase or decrease? In other words, why would the net-energy ratio change?

Explore More

Use this resource to answer the questions that follow.



1. Besides energy, what is lost when energy drips away?
2. Why should you replace incandescent bulbs with CFLS?
3. Why is it good to plug electronics into a power strip?
4. Why should you use a programmable thermostat?
5. What is the purpose of insulation?
6. Why is an old appliance an energy sink?
7. If you did these things, how much money would you save in a decade on average (in Minnesota)?

This page titled 20.2: Obtaining Energy Resources is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.3: Energy Conservation



What can an amusement park ride tell us about energy?

This platform is about to change energy from potential to kinetic. The energy is not lost; it just changes forms. The ride has a lot of potential energy at the top. As the ride begins descending, this potential energy is converted to kinetic energy.

Conservation of Energy

In this section, we're not talking about saving energy. This section is about how energy cannot be created or destroyed. Energy can only change forms. So we say that energy is conserved. Energy changes form when something happens. But the total amount of energy always stays the same. The **Law of Conservation of Energy** says that energy cannot be created or destroyed. Scientists observed that energy could change from one form to another. They also observed that the overall amount of energy did not change.

Energy Changes

Here is an example of how energy changes form: kicking a soccer ball. Your body gets energy from food. Where does the food get its energy? If you're eating a plant, then the energy comes directly from the Sun. If you're eating an animal, then the energy comes from an animal that got its energy from a plant that got its energy from the Sun.

Your body breaks down the food. It converts the food to **chemical energy** and stores it. When you are about to kick the ball, the energy must be changed again. **Potential energy** has the potential to do work. When your leg is poised to kick the ball but is not yet moving, your leg has potential energy. A ball at the top of a hill has the potential energy of location.

Kinetic energy is the energy of anything in motion. Your muscles move your leg, your foot kicks the ball, and the ball gains kinetic energy (**Figure** below). The kinetic energy was converted from potential energy that was in your leg before the kick. The action of kicking the ball is energy changing forms. The same is true for anything that involves change.



Kicking a soccer ball takes energy from your food and gives it to the soccer ball.

Summary

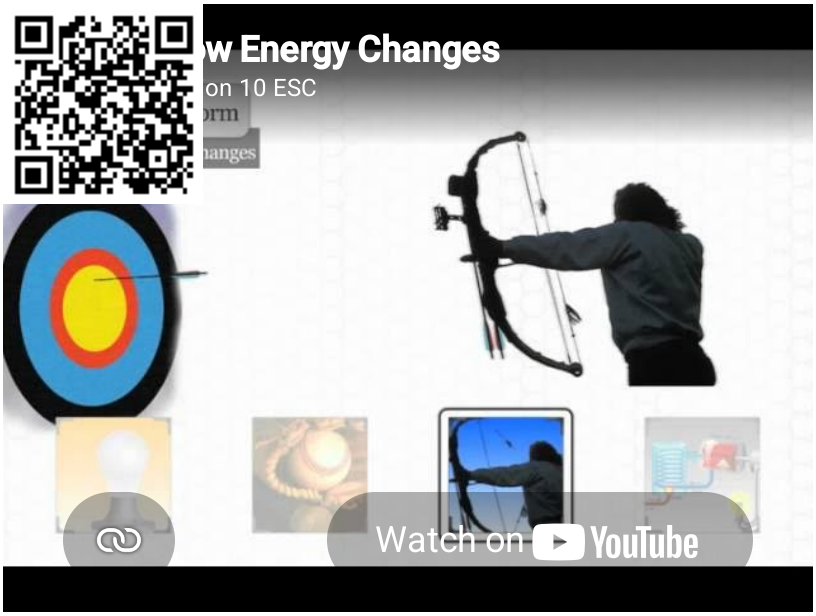
- Energy cannot be created or destroyed. This is the Law of Conservation of Energy.
- Energy changes from one form to another.
- Some types of energy are chemical, kinetic, and potential.

Review

1. Compare and contrast potential energy and kinetic energy.
2. What does it mean to say that energy cannot be created or destroyed.
3. Think about riding a bike up and down a hill. Where does energy change form in each step of the process and what type is each?

Explore More

Use the resource below to answer the questions that follow.



1. What types of energy is released when a light bulb is turned on?
2. What types of energy are involved in a baseball being hit by a bat?
3. What types of energy are involved in releasing an arrow from a bow?
4. What types of energy involved in making electricity?

This page titled 20.3: Energy Conservation is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.4: Renewable vs. Nonrenewable Energy Resources



Is your amusement park's energy source renewable?

Nearly all amusement parks use non-renewable energy. However, a few are now starting to use renewable energy. The Crealy Great Adventure Park in Devon, England, is going solar! Solar panels will be able to generate enough energy to power most of the park in the summer. When there is extra energy, it will supply the grid. Imagine what an amusement park could do if it were located in a sunny place!

Types of Energy Resources

Energy resources can be put into two categories—renewable or non-renewable. **Non-renewable resources** are used faster than they can be replaced. **Renewable resources** can be replaced as quickly as they are used. Renewable resources may also be so abundant that running out is impossible.

The difference between non-renewable and renewable resources is like the difference between ordinary batteries and rechargeable ones. If a flashlight with ordinary batteries goes dead, the batteries need to be replaced. But if the flashlight has rechargeable batteries, the batteries can be placed in a charger. The charger transfers energy from an outlet into the batteries. Once recharged, the batteries can be put back into the flashlight. Rechargeable batteries can be used again and again (**Figure** below). In this way, the energy in the rechargeable batteries is renewable.



Rechargeable batteries are renewable because they can be refilled with energy. Is the energy they are refilled with always renewable?

Types of Non-Renewable Resources

Fossil fuels include coal, oil, and natural gas. Modern society relies on fossil fuels for energy more than any other source. Millions of years ago, plants used energy from the Sun to form carbon compounds. These compounds were later transformed into coal, oil, or natural gas. Fossil fuels take millions of years to form. For this reason, they are non-renewable. We will use most fossil fuels up in a matter of decades. Burning fossil fuels releases large amounts of pollution. The most important of these may be the greenhouse gas, carbon dioxide.

Types of Renewable Resources

Renewable energy resources include solar, water, wind, biomass, and geothermal power. These resources are usually replaced at the same rate that we use them. Scientists know that the Sun will continue to shine for billions of years. So we can use the solar energy without it ever running out. Water flows from high places to lower ones. Wind blows from areas of high pressure to areas of low pressure. We can capture the kinetic energy of wind and water to generate power. We can count on wind and water to continue to flow! Burning wood (**Figure** below), is an example of biomass energy. Changing grains into biofuels is biomass energy. Biomass is renewable because we can plant new trees or crops to replace the ones we use. Geothermal energy uses water that was heated by the Earth's interior. Earth's internal heat isn't going anywhere anytime soon, so geothermal energy is considered renewable.



Wood is a renewable resource, but forest ecosystems need time to replenish. Burning wood also releases greenhouse gases.

Even renewable resources can be used unsustainably. We can cut down too many trees without replanting. We might need grains for food rather than biofuels. Some renewable resources are too expensive to be widely used. As the technology improves and more people use renewable energy, the prices will come down. The cost of renewable resources will go down relative to fossil fuels as we use fossil fuels up. In the long run, renewable resources will need to make up a large amount of what we use. If we don't switch soon, the worst effects of climate change will be upon us.

Important Things to Consider About Energy Resources

Before we put effort into increasing the use of an energy source, we should consider two things. Is there a practical way to turn the resource into useful form of energy? For example, it is not practical if we don't get much more energy from burning a fuel than we put into making it. For example, what if it took more energy to make solar panels than we could get from the solar panels once they were working? Then solar energy would not be worth pursuing until better solar panels were developed.

What happens when we turn the resource into energy? What happens when we use that resource? Mining the resource may cause a lot of health problems or environmental damage. Using the resource may create a large amount of pollution. In this case, that fuel may also not be the best choice for an energy resource.

KQED: Climate Watch: Unlocking the Grid

Today we rely on electricity more than ever, but the resources that currently supply our power are finite. The race is on to harness more renewable resources, but getting all that clean energy from production sites to homes and businesses is proving to be a major challenge.



Summary

- Non-renewable resources are used faster than they can be replaced. Once they're gone, they are, for all practical purposes, gone.
- Renewable resources are so abundant or are replaced so rapidly that, for all practical purposes, they can't run out.
- Fossil fuels are the most commonly used non-renewable resources. Renewable resources include solar, wind, hydro, and (possibly) biomass.
- Many factors must be considered when deciding whether or not to use a resource.

Review

1. What is a renewable resource? Give three examples.
2. What is a non-renewable resource? Give three examples.
3. Can a renewable resource become non-renewable?

This page titled 20.4: Renewable vs. Nonrenewable Energy Resources is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.5: Earth's Energy- Challenge 1

1. An idle ball on a hilltop, though not moving, contains ___.

potential energy

2. When we kick a soccer ball, potential energy gets converted into ___.

kinetic energy

3. Energy ___ describes how much useful work is extracted from one unit of energy.

efficiency

4. ___ is the amount of useable energy available in a resource after accounting for the amount of energy needed to make that energy available.

Net energy

5. To be energy efficient at home, ___.

make sure your home is well-insulated, replace incandescent bulbs with compact fluorescent bulbs, and turn off the heating/AC when not at home

6. Energy conservation can be achieved through ___ energy use.

efficient

7. Wind and moving water are sources of ___ energy.

renewable

8. ___ energy, while renewable, is not totally environmentally friendly.

Biomass

9. Renewable energy sources self-replenish ___ than they can be used up.

more quickly

This page titled 20.5: Earth's Energy- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.6: Fossil Fuel Formation



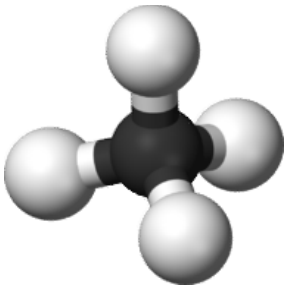
Where is the energy coming from to power this bumper car?

Bumper cars usually run on electricity. Much of the electricity we use comes from fossil fuels. Coal or other fuels are burned in a power plant. This powers a generator and creates electricity. So the car is probably running on fossil fuels!

Formation of Fossil Fuels

Fossil fuels are made from plants and animals that lived hundreds of millions of years ago. The plants used energy from the Sun to form energy-rich carbon compounds. As the plants and animals died, their remains settled onto the ground and at the bottom of the sea. Layer upon layer of organic material was laid down. Eventually, the layers were buried very deeply. They experienced intense heat and pressure. Over millions of years, the organic material turned into fossil fuels.

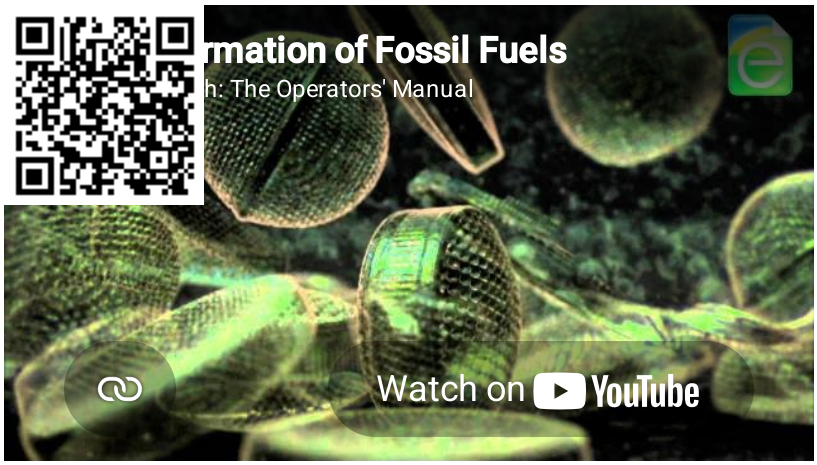
Fossil fuels are compounds of carbon and hydrogen, called **hydrocarbons** (**Figure** below).



Hydrocarbons are made of carbon and hydrogen atoms. This molecule with one carbon and four hydrogen atoms is methane.

Hydrocarbons can be solid, liquid, or gas. Coal is an example of a solid form. Petroleum, or crude oil, is a liquid hydrocarbon. Natural gas is a gaseous hydrocarbon.

The solar energy stored in fossil fuels is a rich source of energy. But because they take so long to form, they are nonrenewable. Fossil fuels also release a lot of greenhouse gases when they're burned.



Summary

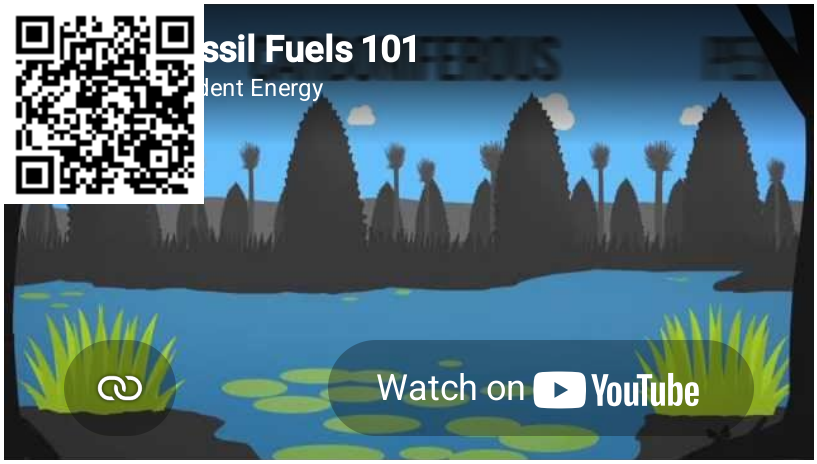
- Hydrocarbons are molecules made of one carbon and four hydrogen atoms.
- Ancient living organisms died and were buried quickly. Their remains were altered by intense heat and pressure. This formed fossil fuels.
- Fossil fuels include solid coal, liquid petroleum, and liquid natural gas.

Review

1. Why are coal, petroleum, and natural gas called fossil fuels?
2. How do fossil fuels form?
3. Where did the energy in a fossil fuel come from originally?

Explore More

Use this resource to answer the questions that follow.



1. What did fossil fuels form from? When did they form?
2. What was Earth like during this period of time?
3. What is the source of the fuel?
4. Which four factors affect which type of fossil fuel forms?
5. What leads to coal formation?
6. What leads to oil formation?
7. What is the difference in conditions that lead to the formation of natural gas rather than oil?
8. Why are fossil fuels used as energy sources?
9. What do we use fossil fuels for in terms of energy?
10. What else do we use fossil fuels for?

11. Why do geopolitical issues arise regarding fossil fuels? What does this really mean?
12. Why are fossil fuels considered non-renewable fuel sources?
13. Why is it harder to get at fossil fuels now?
14. What does burning fossil fuels do to the environment?

This page titled 20.6: Fossil Fuel Formation is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.7: Coal Power



Where does coal come from?

Would you go to a coal mine? It's not very attractive. We like the benefits of electricity, but coal must be mined. Coal mining can be done by tunneling into a mountain. But if the coal is near the surface, the whole mountaintop may be removed. That's what's been done in this photo.

Coal

Coal is a solid hydrocarbon. Coal is useful as a fuel, especially for generating electricity. Coal is relatively inexpensive and abundant. Many nations, like China and the U.S., rely heavily on coal. Around the world, coal is the largest source of energy for electricity.

How Coal Forms

Coal forms from dead plants that settled at the bottom of swamps millions of years ago (**Figure** below). Water and mud in the swamp kept oxygen away from the plant material. Sand and clay settled on top of the decaying plants. The weight of this material squeezed out the water and some other substances. Over time, the organic material became a carbon-rich rock. This rock is coal.



The plants in this tropical swamp could one day become coal.

Coal has different grades. Bituminous coal forms at lower temperatures. It contains a lot of sulfur. When it is burned, it causes a lot of pollution. Anthracite coal forms under higher temperatures. This drives off the sulfur, and the coal burns more cleanly.

What Is Coal?

Coal is a black or brownish-black rock that burns easily (**Figure** below). Most coal is sedimentary rock. The hardest type of coal, anthracite, is a metamorphic rock. That is because it is exposed to higher temperature and pressure as it forms. Coal is mostly carbon, but some other elements can be found in coal, including sulfur. The coal with the least sulfur is the cleanest coal. Anthracite has very little sulfur and thus is very desirable.



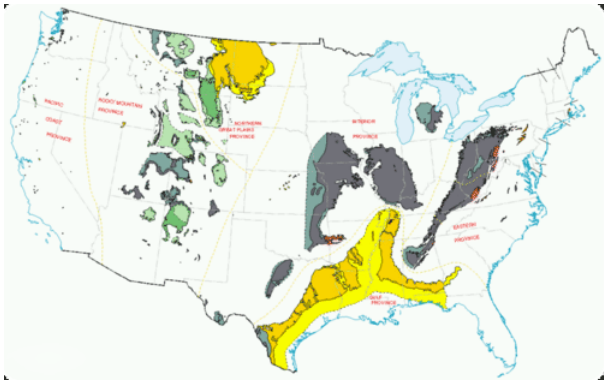
Coal is a solid hydrocarbon formed from decaying plant material over millions of years.

Using Coal

To prepare coal for use, the coal is first crushed into powder and burned in a furnace. Like other fuels, coal releases most of its energy as heat when it burns. The heat from the burning coal is used to boil water. This makes steam. The steam spins turbines, which creates electricity.

Coal in the USA

The United States is rich in coal (**Figure** below). Many regions of the country have significant coal deposits.



United States coal-producing regions in 1996. Orange is highest grade anthracite; red is low volatile bituminous; gray and gray-green is medium to high-volatile bituminous; green is subbituminous; and yellow is the lowest grade lignite.



https://k12.libretexts.org/@go/page/6075

Summary

- Coal is solid fossil fuels formed primarily from ancient swamp plants, especially during the Carboniferous.
- Coal is the source of most electricity.
- Coal that forms at higher temperatures burns more cleanly.

Review

1. How does coal form?
2. There are swamps today. Why is coal not considered a renewable resource?
3. Why are there different grades of coal? What is different about them?
4. How does burning coal make usable energy?

This page titled 20.7: Coal Power is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.8: Petroleum Power



What is this unusual sight?

There's oil beneath this land. These drill rigs are pumping it to the surface. Drill rigs can be small and closely spaced. They can be large and solitary. This is true, especially when they are in deep water offshore.

Oil

Oil is a thick, dark brown or black liquid. It is found in rock layers of Earth's crust. Oil is currently the most commonly used source of energy in the world.

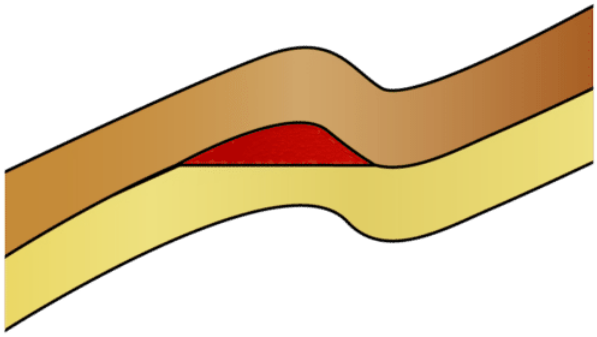
How Oil Forms

The way oil forms is similar, in many ways, to coal. Tiny organisms like plankton and algae die and settle to the bottom of the sea. Sediments settle over the organic material. Oxygen is kept away by the sediments. When the material is buried deep enough, it is exposed to high heat and pressure. Over millions of years, the organic material transforms into liquid oil.

Mining Oil

The United States produces only about one-quarter as much oil as it uses. The main oil producing regions in the U.S. are the Gulf of Mexico, Texas, Alaska, and California.

Geologists look for oil in folded layers of rock called anticlines (**Figure** below). Oil moves through permeable rock and is trapped by the impermeable cap rock.



Oil (red) is found in the porous rock layer (yellow) and trapped by the impermeable layer (brown). The folded structure has allowed the oil to pool so a well can be drilled into the reservoir.

Types of Oil

Oil comes out of the ground as **crude oil**. Crude oil is a mixture of many different hydrocarbons. Oil is separated into different compounds at an oil refinery. This is done by heating the oil. Each hydrocarbon compound in crude oil boils at a different temperature. We get gasoline, diesel, heating oil, waxes, plastics, and fertilizers from crude oil.

These fuels are rich sources of energy. Since they are mostly liquids, they can be easily transported. These fuels provide about 90% of the energy used for transportation around the world.

Gasoline

Gasoline is a concentrated resource. It contains a large amount of energy for its weight. This is important because the more something weighs, the more energy is needed to move it. If gasoline could provide only a little energy, a car would have to carry a lot of it to be able to travel very far, or the car would need to be filled up frequently. So a highly concentrated energy resource is a practical fuel to power cars and other forms of transportation.

Let's consider how gasoline powers a car. As gasoline burns, it releases most of its energy as heat. It also releases carbon dioxide gas and water vapor. The heat makes the gases expand. This forces the pistons inside the engine to move. The engine makes enough power to move the car.

Using Oil

Using gasoline to power automobiles affects the environment. The exhaust fumes from burning gasoline cause air pollution. These pollutants include smog and ground-level ozone. Air pollution is a big problem for cities where large numbers of people drive every day. Burning gasoline also produces carbon dioxide. This is a greenhouse gas and is a cause of global warming. Similar pollutants come from other forms of oil.

Summary

- Petroleum is a liquid fossil fuel. Petroleum is useful for vehicles because it is easily stored and transported.
- Petroleum is also used to make waxes, plastics, fertilizers, and other products.
- Using petroleum causes smog and global warming.

Review

1. What makes petroleum unique among fossil fuels? Why is this unique property extremely important?
2. Besides powering your car, what is petroleum used for?
3. How does crude oil form?

Explore More

Use the resource below to answer the questions that follow.



1. What produced the fossil fuels?
2. What role does sediment play in petroleum formation?

https://k12.libretexts.org/@go/page/6077

3. What is kerogen?
4. How does oil get trapped so that we can drill to it?
5. How do we find oil?
6. How do we get the oil out of the ground?
7. Why is drilling mud pumped down the pipe?
8. What are cuttings?
9. What does the pumping unit do?
10. What happens at the refinery? What does fractional distillation produce?
11. What are petrochemicals used for?
12. What other products are made from oil?

This page titled 20.8: Petroleum Power is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.9: Natural Gas Power



Why would oil drillers burn off fuel?

Natural gas is often found with petroleum. It is sometimes burned off by companies that are interested only in the petroleum. Burning natural gas off like this is wasting energy. These days, natural gas is becoming more popular as a fuel.

Natural Gas

Natural gas is mostly methane. Natural gas is usually found with petroleum. People prefer to burn natural gas when possible because it is relatively clean.

How Natural Gas Forms

Natural gas is often found along with coal or oil in underground deposits. This is because natural gas forms with these other fossil fuels. One difference between natural gas and oil is that natural gas forms at higher temperatures.

Natural Gas Use

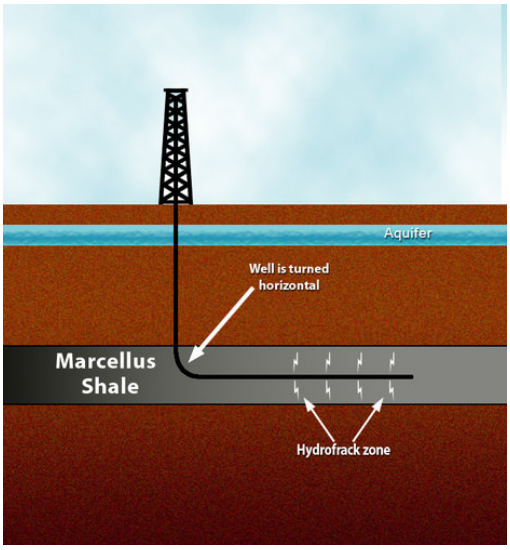
The largest natural gas reserves in the United States are located in the Rocky Mountain states, Texas, and the Gulf of Mexico region. California also has natural gas, mostly in the northern Sacramento Valley and the Sacramento Delta.

Natural gas must be processed before it can be used as a fuel. Poisonous chemicals and water must be removed.

Natural gas is delivered to homes, where it is used for cooking and heating. Natural gas is also a major energy source for powering turbines to make electricity. Natural gas releases most of its energy as heat when it burns. The power plant is able to use this heat, either in the form of hot gases or steam, to spin turbines. The spinning turbines turn generators, and the generators create electricity.

Extracting Natural Gas

Most natural gas comes from the wells that produce petroleum. An increasing amount comes from a new method. Hydraulic fracturing, called **fracking**, is very much in the news lately. Fracking makes it easier and quicker to get natural gas from the rock (**Figure** below).



Fracking delivers natural gas from rock that might not otherwise be obtainable.

With fracking, fluids are pumped through a borehole. The fluids create fractures in the rock that contains the natural gas. Chemicals in the fluid prevent the fractures from closing. The natural gas can then be pumped to the surface.

Consequences of Natural Gas Extraction and Use

Natural gas burns more cleanly than other fossil fuels. As a result, it causes less air pollution. It also produces less carbon dioxide than the other fossil fuels. Still, natural gas does emit pollutants.

Fracking is being found to be destructive in several ways. Some of the chemicals in the fracking fluids may be harmful. Some may cause cancer. Some may be endocrine disruptors. Endocrine disruptors interrupt the natural hormones in the bodies of humans and animals. These fluids can get into the groundwater. They may runoff into streams and other surface waters. There they can cause problems.

The liquid waste injected into the deep wells may cause earthquakes. Locations where seismic activity is unknown have begun to experience earthquakes. Is fracking related to earthquake activity? Many geologists think the link is undeniable.

Summary

- Natural gas forms with crude oil but at higher temperatures.
- Natural gas burns more cleanly than petroleum and produces fewer greenhouse gases.
- Hydraulic fracturing, known as fracking, is a relatively new method for extracting natural gas. Fracking may be linked to groundwater contamination and small earthquakes in non-seismic regions.

Review

1. What is fracking, and how does it work?
2. How is natural gas different from crude oil?
3. Why is natural gas considered more environmentally sound than other fossil fuels?
4. What are some problems with fracking fluids?

Explore More

Use the resource below to answer the questions that follow.



1. What is fracking?
2. Explain how natural gas is extracted.
3. What are the concerns with fracking?
4. How might the fluids get into the creeks and groundwater aquifer?
5. What are the advantages of the closed loop system?
6. Why do some of the local ranchers hope that the federal government gets involved in regulating fracking?

This page titled 20.9: Natural Gas Power is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.10: Fossil Fuel Reserves



Take a trip to Washington, D.C.?

People are always protesting in our nation's capital. That's part of liberty, part of democracy. The people in this photo are protesting the Keystone XL pipeline. Other people in other locations may be protesting for the pipeline. The Keystone Pipeline would bring crude oil from tar sands to the United States. People in favor say the oil from tar sands will bring down energy costs and provide jobs. People opposed say that the environmental consequences are not worth the benefits.

Alternative Fossil Fuels

Easy-to-reach fossil fuel sources are being used up. Technologies are being developed to get at harder-to-reach sources. Also, ways to tap into alternative sources of fossil fuels are increasingly being developed. These sources include oil shale and tar sands.

Oil Shale

Oil shale is rock with oil dispersed through it. The oil has not collected in reservoirs. Oil shale is mined in open pit mines. To extract the oil from the rock, the rock is first crushed and heated to very high temperatures. Water is washed over the rock, which converts the fuel to petroleum. The petroleum can then be extracted from the rock. You can see an example of an oil shale facility below (**Figure** below).

Most of the world's oil shale is spread out in large areas of Wyoming, Utah, and Colorado. In this region, water is scarce. Since the oil shale is spread over a large area, mining would be environmentally destructive.



An image of an oil shale facility in Colorado.

Tar Sands

Tar sands are rocky materials mixed with very thick oil. The tar is too thick to pump, and so tar sands are strip-mined. Hot water and caustic soda are used to separate the oil from the rock. This creates a slurry, which is shaken. The oil floats to the top and is skimmed off.

About 75% of the tar sands in the world are in Venezuela and Alberta, Canada (**Figure** below). Large areas of land are degraded when tar sands are mined. A tremendous amount of waste rock is produced from mining tar sands.



A satellite image of an oil-sands mine in Canada.

Consequences of Using Alternative Fossil Fuels

Surface mining causes environmental damage. A lot of water may be needed. The water may be degraded. For oil to be removed from shale, the water must be heated. This requires energy. Tar sands and oil shale fuels create more pollutants than other fossil fuels. Extracting usable energy from oil shale and tar sands produces more greenhouse gases.

Keystone XL Pipeline

The Keystone XL Pipeline would transport oil from the oil sands in Alberta, Canada. The oil would travel into the United States. In the U.S. it would be refined. The pipeline is controversial. A leak could cause damage to wildlife habitat. A leak could also release enough oil to contaminate the Ogallala Aquifer. The Aquifer is crucial to agriculture and urban development in the Midwestern U.S. When burned, the fuel from the oil sands would increase pollutants. Greenhouse gases into the atmosphere would increase. The future of the pipeline is currently on hold.

Summary

- Easy to get at fossil fuels are running out, but there are other sources that are harder to get at that are still available.
- Oil shales and tar sands are two of the alternative sources of fossil fuels that are much in the news.
- The need for fossil fuels continues to grow as people in the developed world use more, and more people in the developing world want them.

Review

1. What are oil shales? How is oil extracted from them?
2. What are tar sands? How is oil extracted from them?
3. What are the environmental hazards of using these two fuel sources?

Explore More

Use the resource below to answer the questions that follow.



1. How much oil from oil shale is there in the United States?
2. How much oil shale is there compared with the rest of the world?
3. How does the amount of oil in oil shale in the U.S. compare with proven oil reserves in the Middle East?
4. Where is the Green River Formation? Why are scientists interested in this formation?
5. What is oil shale? What form is the oil in?

This page titled 20.10: Fossil Fuel Reserves is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.11: Nuclear Power



Where could long-term nuclear waste go?

That's a very good question. For years, a waste facility was in development in Nevada. The site at Yucca Mountain was canceled due to public outcry. Now there is no facility for storing long-term nuclear waste from most sources. No facilities are currently being developed either.

Nuclear Energy

Nuclear energy is produced by splitting the nucleus of an atom. This releases a huge amount of energy.

How Nuclear Power Plants Work

Nuclear power plants use uranium that has been concentrated in fuel rods (**Figure** below). The uranium atoms are split apart when they are hit by other extremely tiny particles. These particles must be controlled or they would cause a dangerous explosion.



Nuclear power plants like this one provide France with almost 80% of its electricity.

Nuclear power plants use the energy they produce to heat water. The water turns into steam, which causes a turbine to spin. This, in turn, produces electricity.

Nuclear Power as a Resource

Many countries around the world use nuclear energy as a source of electricity. For example, France gets about 80% of its electricity from nuclear energy. In the United States, a little less than 20% of electricity comes from nuclear energy.

Nuclear energy does not pollute. If there are no accidents, a nuclear power plant releases nothing but steam into the air. But nuclear energy does create other environmental problems. Splitting atoms creates dangerous radioactive waste. These wastes can remain dangerous for hundreds of thousands of years. Scientists and engineers are still looking for ways to keep this waste safely away from people.

Consequences of Nuclear Power

Nuclear power is clean. It does not pollute the air. However, the use of nuclear energy does create other environmental problems. Uranium must be mined (**Figure** below). The process of splitting atoms creates radioactive waste. This waste may be dangerous for thousands or hundreds of thousands of years. As yet, there is no long-term solution for storing the radioactive waste.



Uranium mine in the Czech Republic.

For three decades new nuclear power plants were not built in the U.S. Accidents at Three Mile Island and Chernobyl, Ukraine made people nervous about harnessing nuclear power (**Figure** below).



Abandoned bunker near the site of the Chernobyl disaster.

Because nuclear energy is relatively clean, nuclear power made a comeback recently. But the 2011 disaster at the Fukushima Daiichi Nuclear Power Plant in Japan changed attitudes again. This accident seems to have resulted in a new fear of nuclear power. The disaster was caused by a 9.0 magnitude earthquake and tsunami. These events seriously damaged the plant.

Nuclear power is a controversial subject. Generating nuclear power does not release pollutants, but mining uranium and storing radioactive wastes damage the environment. Also, accidents do happen, and they can be devastating. The long-term disposal of wastes is a problem that has not yet been solved. The future of nuclear power is murky.

Summary

- Nuclear energy is released when the nucleus of an atom is split.
- Nuclear power plants use uranium in fuel rods. The fuel rods become nuclear waste. Nuclear waste can be dangerous for hundreds of thousands of years.
- Periodic accidents involving nuclear power plants scare people. These accidents slow down the development of nuclear power in many countries.

Review

1. How is nuclear energy generated?
2. Why is the waste from nuclear power plants dangerous for so long?
3. Why should nuclear power be developed?
4. Why should nuclear power not be developed?

Explore More

Use the resource below to answer the questions that follow.



1. How many countries use nuclear power?
2. How is electricity produced in these power plants?
3. What releases thermal energy in nuclear plants?
4. What is used as the fuel?
5. What are the two types of reactors?
6. What is the function of the control rods?

This page titled 20.11: Nuclear Power is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.12: Earth's Energy- Challenge 2

1. Coal is a solid ___.

hydrocarbon

2. Our dependence on fossil fuels is alarming because they are ___ and they emit ___.

non-renewable; greenhouse gases

3. Natural gas is a ___ hydrocarbon.

gaseous

4. Anthracite is a ___ rock.

metamorphic

5. ___ is the highest quality type of coal, used primarily for residential and commercial space heating.

Anthracite

6. Coal mining exposes the element ___, which reacts with air and water to form a highly corrosive chemical.

sulfur

7. Crude oil must be ___ to be useful.

refined

8. The Gulf of Mexico, Texas, and Alaska are major ___ in the U.S.

oil-producing regions

9. Crude oil is a mixture of many different ___.

hydrocarbons

10. ___ undergoes nuclear fission in a nuclear reactor.

Uranium

11. To generate power, nuclear power plants ___, causing them to ___ and release energy.

hit uranium atoms in fuel rods with tiny particles; split apart

12. Nuclear power is not completely clean because ___ and ___.

uranium must be mined from the earth; radioactive wastes created by power nuclear fission cannot be safely disposed.

This page titled 20.12: Earth's Energy- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.13: Solar Energy



Why don't we get our energy straight from the source?

The Sun produces far more energy than humans can use. The Sun is also the origin of most of the energy we use. Fossil fuels and wind energy, for example, originate with the Sun. So why don't we get all our energy from the Sun?

Solar Energy



Solar energy is clean and renewable. Solar panels are needed to collect the sunlight for use.

Solar energy is clean and renewable. Earth receives many times more solar energy than humans could ever imagine using.

Energy from the Sun

The Sun is Earth's main source of energy. The Sun gives us both light and heat. The Sun changes hydrogen into helium through nuclear fusion. This releases huge amounts of energy. The energy travels to Earth mostly as visible light. The energy is carried through the empty space by **radiation**. We can use sunlight as an energy resource, called solar energy.

Solar Energy as a Resource

Solar energy has been used on a small scale for hundreds of years. Today we are using solar energy for more of our power demands. Solar power plants are being built in many locations around the world. In the United States, the southwestern deserts are well suited for solar plants.

Solar Power Plants

Sunlight is turned into electricity at a solar power plant. A large group of mirrors focuses sunlight on one place. This place is called a receiver (**Figure** below). At the receiver, a liquid such as oil or water is heated to a high temperature. The liquid transfers its heat by **conduction**. In conduction, energy moves between two objects that are in contact. The warmer object transfers heat to the cooler object. At a solar power plant, the energy conducted by the heated liquid is used to make electricity. There are other methods that convert sunlight into electricity, as well.



A solar power tower is used to concentrate the solar energy collected by many solar panels.

Solar Energy Use

Solar energy is used to heat homes and water and to make electricity. Scientists and engineers have many ways to get energy from the Sun (**Figure** above). One is by using solar cells. Solar cells are devices that turn sunlight directly into electricity. Lots of solar cells make up an individual solar panel. You may have seen solar panels on roof tops. The Sun's heat can also be trapped in your home by using south facing windows and good insulation.

Consequences of Solar Energy Use

Solar energy has many benefits. It does not produce any pollution, and there is plenty of it available—much more than we could possibly use.

But solar energy has problems. The Sun doesn't shine at night. A special battery is needed to store extra energy during the day for use at night. The technology for most uses of solar energy is still expensive. Until solar technology becomes more affordable, most people will prefer to get their energy from other sources.



Summary

- Solar energy is the result of nuclear fusion in our nearest star.
- A liquid is heated and moves that energy by conduction.
- Solar power is expensive, but as demand increases, technology improves and costs decrease.

Review

1. How is solar power collected on a large scale?
2. What are some of the disadvantages of depending on solar energy?
3. What are some of the advantages of using solar energy?

This page titled 20.13: Solar Energy is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.14: Hydroelectric Power



What do dams do?

If you take a trip out of Las Vegas toward Phoenix, you can visit the Hoover Dam. Completed in 1935, the dam provides power to over a million homes. It also stores water for use by the residents of the desert southwest. Hoover Dam is one of the engineering marvels of the 20th century.

Water Power



Water flowing through a dam.

Moving water has energy (**Figure** above). That energy is used to make electricity. **Hydroelectric power**, or hydropower, harnesses the energy of water moving down a stream. Hydropower is the most widely used form of renewable energy in the world. This abundant energy source provides almost one fifth of the world's electricity. The energy of waves and tides can also be used to produce water power. At this time, wave and tidal power are rare.

Hydropower Plants

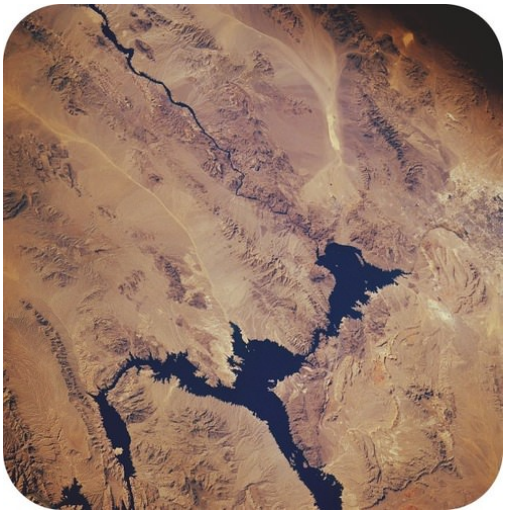
To harness water power, a stream must be dammed. Narrow valleys are the best for dams. While sitting in the reservoir behind the dam, the water has potential energy. Water is allowed to flow downhill into a large turbine. While flowing downhill, the water has kinetic energy. Kinetic energy makes the turbine spin. The turbine is connected to a generator, which makes electricity.

Hydropower as a Resource

Many of the suitable streams in the United States have been developed for hydroelectric power. Many streams worldwide also have hydroelectric plants. Hydropower is a major source of California's electricity. It accounts for about 14.5 percent of the total. Most of California's nearly 400 hydroelectric power plants are located in the Sierra Nevada mountains.

Benefits and Problems of Hydropower

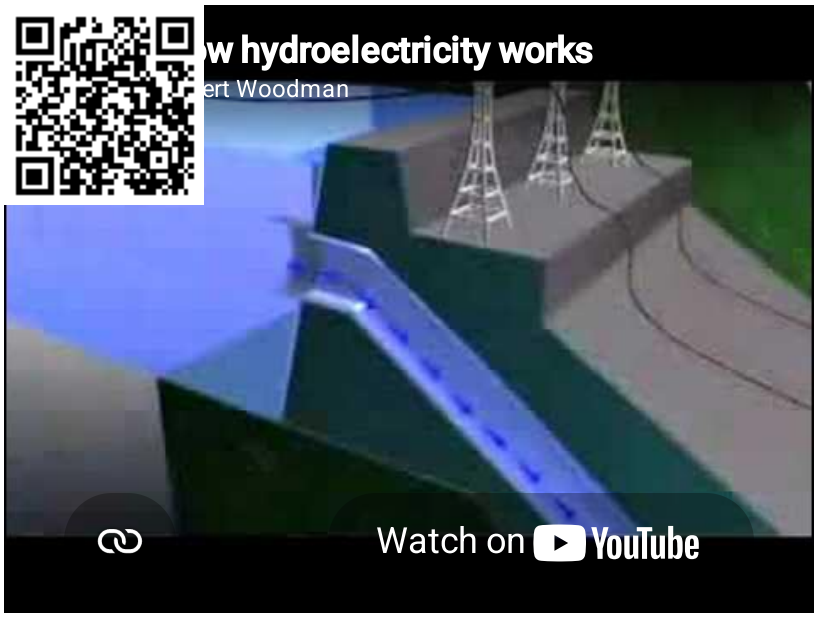
Water power does not burn a fuel. So it causes less pollution than many other kinds of energy. Water power is also a renewable resource. Water keeps flowing downhill. Although we use some of the energy from this movement, we are not using up the water.



The Colorado River backs up behind Hoover Dam. See the river coming in at the top of the photo.

Water power does have problems. A large dam stops a stream's flow, which floods the land upstream (**Figure** above). A beautiful location may be lost. People may be displaced. Ecosystems may be disrupted. The dams and turbines also change the downstream environment. Fish and other living things may not be able to survive. Dams slow the release of silt. Downstream deltas retreat and beaches may be starved of sand. Seaside cities may become exposed to storms and rising sea levels.

Tidal power stations may need to close off a narrow bay or estuary. Wave power plants must withstand coastal storms and the corrosion of seawater.



Summary

- Hydroelectric power is clean and is important in many regions of the world.
- Hydroelectric dams change the river's ecosystem.
- Hydropower utilizes the energy of falling water.

Review

1. How does energy change forms as it goes from behind a dam to downstream of a dam?
2. How is hydroelectric energy collected?
3. What are some of the downsides of using hydropower?

This page titled 20.14: Hydroelectric Power is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.15: Wind Energy



Is this what a wind farm looks like?

It's a strange sight. You're driving up the road in Southern California, and sprouting from the ground is a pack of windmills! Windmills are becoming more common on the eastern side of the mountains. This is because the wind comes off the Pacific Ocean and funnels through mountain passes. The wind is strong and California wants to take advantage of it.

Wind Power



Winds funnel through passes in mountain ranges. Altamont Pass in California is the site of many wind turbines.

The energy from the Sun creates wind (**Figure** above). Wind energy moves by **convection**. The Sun heats some locations more than others. Warm air rises, so other air rushes in to fill the hole left by the rising air. This horizontal movement of air is called wind.

Wind as a Resource

Wind power uses moving air as a source of energy. Some types of wind power have been around for a long time. People have used windmills to grind grain and pump water for hundreds of years. Sailing ships have depended on wind for millennia. Wind is now used to generate electricity. Moving air can make a **turbine** spin, just like moving water can. Moving air has kinetic energy. When wind hits the blades of the turbine, the kinetic energy makes the blades move. The turbine spins and creates electricity.

Wind Power Advantages and Disadvantages

Wind power has many advantages. It is clean: it does not release pollutants or carbon dioxide. It is plentiful almost everywhere. The technology to harness wind energy is being developed rapidly.

Wind power also has problems. Wind does not blow all of the time, so wind energy must be stored for later use. Alternatively, another energy source needs to be available when the wind is not blowing. Wind turbines are expensive. They can wear out quickly. Finally, windmills are not welcomed by residents of some locations. They say that they are unattractive. Yet even with these problems, wind turbines are a competitive form of renewable energy.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Many states are currently using wind power. Wind turbines are set up in mountain passes. This is common in California, where cool Pacific Ocean air is sucked across the passes and into the warmer inland valleys.



Summary

- Wind contains kinetic energy. The energy can move a turbine. This generates electricity.
- Wind power is clean. It does not release pollutants or greenhouse gases.
- Some people complain about the spread of windmills across certain locations, but, still, the use of wind energy is increasing.

Review

1. Describe how wind energy can be harnessed.
2. What are the upsides of using wind power?
3. What are some of the downsides of using wind power?
4. Why do you think that wind power use is increasing?

This page titled 20.15: Wind Energy is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.16: Geothermal Energy



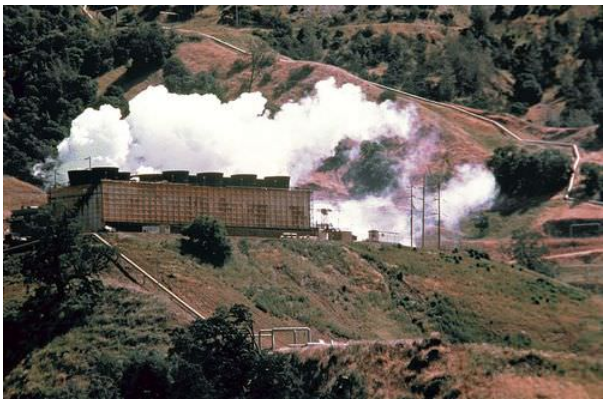
Why is there so much heat coming from below?

A visit to an active geothermal area is likely to be very interesting. Some of the most active ones in the U.S. are Yellowstone in Wyoming and Lassen Peak in California. These places are not available for energy production. But the Geysers Geothermal Resource Area in California is used for energy. A magma chamber deep below produces dry superheated steam. This steam can be harnessed.

Geothermal Energy

Geothermal energy stems from Earth's internal heat. Hot springs and geysers are produced by water that is heated by magma or hot rock below the surface.

At a geothermal power plant, engineers drill wells into the hot rocks. Hot water or steam may come up through the wells. Alternatively, water may be put down into the well to be heated. It then comes up. The hot water or steam makes a turbine spin. This makes electricity. Pictured below is an example of a geothermal power plant (**Figure** below).



A geothermal power plant in operation.

Geothermal Energy as a Resource

Because the hot water or steam can be used directly to make a turbine spin, geothermal energy can be used without processing. Geothermal energy is clean and safe. It is renewable. The earth's interior will be hot for the foreseeable future, and water can be pumped down into a well. There, the water can be heated again to make more steam.

Geothermal energy is an excellent resource in some parts of the world. Iceland gets about one fourth of its electricity from geothermal sources. In the United States, California leads all states in producing geothermal energy. Geothermal energy in California is concentrated in the northern part of the state. The largest plant is in the Geysers Geothermal Resource Area. Geothermal energy is not economical everywhere. Many parts of the world do not have underground sources of heat that are close enough to the surface for building geothermal power plants.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

KQED: Geothermal Heats Up

Where Earth's internal heat gets close to the surface, geothermal power is a clean source of energy. In California, the Geysers supplies energy for many nearby homes and businesses.



Summary

- Most geothermal energy being used now is in regions where hot material comes to the surface.
- Hot rocks are everywhere below Earth's surface. Geothermal energy could be used anywhere with drilling.
- Geothermal energy is clean and does not release greenhouse gases.

Review

1. How is geothermal energy harnessed?
2. What is the ultimate source of geothermal energy?
3. What is positive about geothermal energy?
4. What is not so good about geothermal energy?

This page titled 20.16: Geothermal Energy is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.17: Biomass Energy



Does this look like energy to you?

Algae is sometimes overlooked as a source of fuel. But algae are a potentially wonderful source of power. They convert energy from the Sun into food via photosynthesis. Algae can be grown in desert areas where other crops cannot grow. Nutrients for algae may be wastes from other processes. Algae can be processed to be made into a liquid. There is a lot of research going on to harness algae for biofuels.

Biomass

Biomass is the material that comes from plants and animals that were recently living. Biomass can be burned directly. This happens when you burn a log in your fireplace. For as long as humans have had fire, people have used biomass for heating and cooking.

To generate biomass energy, break down the cell walls of plants. This releases the sugars. The sugars are then fermented to create fuel.

Biofuel

More recently, people have learned to process biomass to make fuel. This is called **biofuel**. Biofuel is created from crops, such as corn or algae. Biofuel is unique among renewable energy sources. This is because it is liquid. Unlike solar energy, for example, biofuels can be used in a car (**Figure** below). Biofuels burn more cleanly than fossil fuels. They create less pollution and less carbon dioxide. Biofuels, such as ethanol, are added to gasoline. This cuts down the amount of fossil fuels that are used.



E85, a fuel that is 85% ethanol, being pumped into a vehicle.

Sources of Biomass Energy

Any organic material can be made into electricity. But some materials are better than others. Wastes can be used, like almond shells. Biomass power is a great use of wastes. It's hard to use wastes as a consistent large scale source of energy though.

Cow manure can have a second life as a source of methane gas, which can be converted to electricity. Food scraps can also be converted into green energy.

Consequences of Biomass Use

Some crops do not make good biofuels. Crops need energy, fertilizer, and land to grow. Sometimes the amount of resources that go into producing the crop is too high. The crop may produce less energy than it consumes. Corn is a very inefficient source of

biofuels. Also, the fertilizers and pesticides used to grow the crops enter the environment. These pollutants become runoff and end up in nearby bodies of water and eventually the oceans. Scientists are looking for much better sources of biomass energy.

Algae Biofuels

Research is being done into alternative crops for biofuels. A very promising alternative is algae. Algae appears to be a better biofuel than corn. Algae is much easier to convert to a usable fuel. Growing algae requires much less land and energy than crops. Algae can be grown in locations that are not used for other things. For example, they can be grown in desert areas where food crops are not often grown. Corn must be grown in fertile areas and requires a lot of water. This can reduce the land and water available for growing food. Algae can be fed agricultural and other waste, so valuable resources are not used. Much research is being done to bring these alternative fuels to market.

Summary

- Biofuels are useful because they are liquid. Biofuels can go into a gas tank unlike many other types of alternative energy.
- Algae is the focus of much research. Algae is a very promising alternative to traditional crops for biofuels.
- Biofuels have been used for as long as people have been burning wood for warmth or to cook their food.

Review

1. What are biofuels?
2. What does a source need to be a good biofuel? What makes a source a bad biofuel?
3. What makes algae appear to be a good source of biofuels?

This page titled 20.17: Biomass Energy is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

20.18: Earth's Energy- Challenge 3

1. In a concentrated solar power plant, sunlight is focused onto a receiver by a group of ___.

mirrors

2. The biggest advantage of solar energy over fossil fuels is that solar power is ___.

renewable

3. Solar energy travels through the empty space between the Sun and the earth via ___.

radiation

4. Water held behind a dam has ___ energy; when the water is released, that energy converts to ___ energy.

potential; kinetic

5. Hydroelectric power is generated when moving water ___.

makes a turbine spin

6. Hydroelectric power generation does not release ___.

pollution

7. Some people oppose the offshore Cape Wind project because they think that windmills are ___.

unattractive

8. One disadvantage of wind power is that ___.

windmills are expensive to build and maintain

9. Wind is always moving and has ___.

kinetic energy

10. Geothermal energy is ___.

pollution free and completely renewable

11. Geothermal power plants generate electricity when ___.

steam from a geothermal well or from water pumped down into the earth spins a turbine

12. Compared to other forms of renewable energy, biomass energy ___.

can be processed into a liquid and used by cars

13. When using a biofuel, the ___ and ___ required to grow that biofuel must be considered.

energy; water/fertilizer

14. Biofuels, such as ___, are added to gasoline to cut down the amount of fossil fuels that are used.

ethanol

This page titled 20.18: Earth's Energy- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

21: Earth's Materials

21.8: Preventing Hazardous Waste Problems
21.1: Materials Humans Use
21.2: Renewable vs. Nonrenewable Resources
21.3: Ore Deposits
21.4: Ore Mines
21.5: Ore Extraction
21.6: Earth's Materials- Challenge 1
21.7: Environmental Impacts of Mining
21.8: Hazardous Waste
21.10: Earth's Materials- Challenge 2
21.11: Availability of Natural Resources
21.12: Natural Resource Conservation
21.13: Earth's Materials- Challenge 3

This page titled 21: Earth's Materials is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

21.8: Preventing Hazardous Waste Problems



What should be done about hazardous waste sites?

Laws now protect lands from contamination. Many sites were damaged before those laws were passed. Cleaning up toxic wastes costs a lot of time and money. Sometimes the company that caused the damage no longer exists. Sometimes they cannot afford cleanup. Then it becomes the government's job to clean up the site. No other organization is big enough to be sure a cleanup happens.

The Superfund Act

Love Canal opened people's eyes to toxic waste burial. They realized there must be other "Love Canals" all over the country. Thousands of contaminated sites were found. The **Superfund Act** was passed in 1980. The law required that money be set aside for cleanup of toxic waste sites. The law also required safer disposal of hazardous waste in the future.

Love Canal became a **Superfund site** in 1983. As a result, several measures were taken to secure the toxic wastes. The land was capped so that water could not reach the waste. Toxic material was cleaned from the nearby area. Contaminated soils were removed.

Controlling Hazardous Waste

The greatest source of hazardous waste is industry. Agriculture is another major source. Even households produce a lot of hazardous waste.

Hazardous Waste From Industry and Agriculture

Thanks to the lessons of Love Canal, the U.S. now has laws requiring the safe disposal of hazardous waste. Companies must ensure that hazardous waste is not allowed to enter the environment in dangerous amounts. They must also protect their workers from hazardous materials. For example, they must provide employees with the proper safety gear and training (**Figure** below).



This agricultural worker is wearing the proper safety gear to handle a chemical pesticide.

Household Hazardous Waste

Cleaning products, lawn chemicals, paints, batteries, motor oil—these are just some of the many hazardous materials that may be found in households. You might think that a household doesn't produce enough hazardous waste to worry about. But all the waste

from all the households adds up. A city of just 50,000 people might produce more than 40 tons of hazardous waste each year! Clearly, how households deal with hazardous waste matters.

What can your family do? Reduce, reuse, recycle, or properly dispose of the wastes.

1. Reduce the amount of hazardous products you buy. For example, if you need only a quart of paint for a job, don't buy a gallon.
2. Use less hazardous products if you can. For example, clean windows with vinegar and water instead of toxic window cleaners.
3. Reuse products if it's safe to do so. For example, paint thinner that has been used to clean paint brushes can be strained and reused.
4. Recycle whenever possible. For example, some service stations allow you to drop off used motor oil, car batteries, or tires for recycling.
5. Always properly dispose of hazardous waste. For example, let liquid waste evaporate before placing the container in the trash.

Proper disposal depends on the waste. Many hazardous products have disposal guidelines on the label. That's one reason why you should keep the products in their original containers. The labels also explain how to use the products safely. Follow the instructions to protect yourself and the environment. Most communities have centers for disposing of household hazardous waste (**Figure** below). Do you know how to dispose of hazardous waste in your community?



Avoid putting hazardous waste in the household trash. Instead, take it to a hazardous waste collection center.



Summary

- Government regulations, like the Superfund Act, hold companies accountable for the hazardous materials they produce.
- Reduce, reuse, recycle to lessen your production of toxic waste.
- Dispose of toxic wastes properly.

Review

1. How do the Superfund Act and other government regulations prevent lands from being contaminated?
2. What can you do to prevent or lessen the generation of hazardous wastes?
3. How should you dispose of toxic wastes?

This page titled 21.8: Preventing Hazardous Waste Problems is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

21.1: Materials Humans Use



What resources are in those electronics?

When you pick up your personal electronics device or your mobile phone do you ever think about what's in it? A tremendous variety of elements are needed to make a single electronic device. Some are rare, some are common. All must somehow come from Earth or its environment.

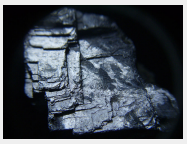
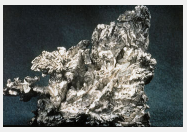
Natural Resources

A **natural resource** is anything in nature that humans need. Metals and fossil fuels are natural resources. So are water, sunlight, soil, and wind. Even living things are natural resources.

Using Natural Resources

We need natural resources for just about everything we do. We need them for food and clothing, for building materials, and energy. We even need them to have fun. Listed below are examples of how we use natural resources (**Table** below). Can you think of other ways we use natural resources?

https://k12.libretexts.org/@go/page/6101

Use	Resources	Example
Vehicles 	Rubber for tires from rubber trees Steel frames and other metal parts from minerals such as iron	Iron ore 
Electronics 	Plastic cases from petroleum products Glass screens from minerals such as lead	Lead ore 
Homes 	Nails from minerals such as iron Timber from trees	Spruce timber 
Jewelry 	Gemstones such as diamonds Minerals such as silver	Silver ore 
Food 	Sunlight, water, and soil Minerals such as phosphorus	Corn seeds in soil 
Clothing 	Wool from sheep Cotton from cotton plants	Cotton plants 
Recreation 	Water for boating and swimming Forests for hiking and camping	Pine forest 

Some natural resources are renewable. Others are non-renewable. It depends on what they are and how we use them.



Summary

- Many objects, such as a car, contain many types of resources.
- Resources may be renewable or non-renewable, and an object may contain some of each.
- Rare earth elements and other unusual materials are used in some electronic devices.

Review

1. What are natural resources?
2. Is clean air a natural resource? Why or why not?
3. What natural resources are important to you?

This page titled 21.1: Materials Humans Use is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

21.2: Renewable vs. Nonrenewable Resources



What is the difference between these two stands of trees?

Trees are **renewable resources**. Trees can be planted, grown up, and harvested for timber. Forests are a different thing, however. A forest is a mature ecosystem. It has trees of different sizes and ages, many other plants, and lots of animals. A forest is a renewable resource, but it takes much more time to grow a forest than to grow a stand of trees.

Renewable Resources

Renewable resources can be renewed as they are used. An example is **timber**, which comes from trees. New trees can be planted to replace those that are cut down. Sunlight is a renewable resource. It seems we will never run out of that! What are some other renewable resources?

Just because a resource is renewable doesn't mean we should use it carelessly. If we aren't careful, we can pollute resources. Then they may no longer be fit for use. Water is one example. If we pollute a water source, it may not be usable for drinking, bathing, or any other type of use. We can also overuse resources that should be renewable. In this case, the resources may not be able to recover. For example, fish are renewable resources. That's because they can reproduce and make more fish. But water pollution and overfishing can cause them to die out if their population becomes too low. Another example is pictured below (**Figure** below).



Forests should be renewable resources. The forest on the left is healthy and is used for recreation. The forest on the right was killed by acid rain. Human use: hiking and bird watching. Human misuse: destruction by acid rain.

Non-Renewable Resources

Some resources can't be renewed. At least, they can't be renewed fast enough to keep up with use. Fossil fuels are an example. It takes millions of years for them to form. We are using them up much more quickly than they are forming. Elements that are used to produce nuclear power are also non-renewable resources. Uranium, for example, which is rare. Sooner or later, it will run out.

Supplies of non-renewable resources are shrinking. This makes them harder to get. Oil is a good example. Oil reserves beneath land are running out. So oil companies have started to drill for oil far out in the ocean. This costs more money. It's also more dangerous. Pictured below is an oil rig that exploded in 2010 (**Figure** below). The explosion killed 11 people. Millions of barrels of oil spilled into the water, severely damaging marine ecosystems. It took months to plug the leak.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



This oil rig was pumping oil from below the ocean floor when it exploded.



Summary

- Resources may be renewable or non-renewable.
- Renewable resources should never run out. Non-renewable resources are available in limited supply.
- Some non-renewable resources are in shorter supply than before. It takes more effort to get to them.

Review

1. What is a renewable resource?
2. What is a non-renewable resource?
3. How might a resource go from being renewable to non-renewable?

Explore More

Use this resource to answer the questions that follow.



1. What are the down sides of fossil fuel use?
2. What are some of the sources of renewable energy that we could use? How much of our electricity do they account for now?
3. What is a space based solar panel farm? Why would it be useful?
4. Where do we use solar panels now? Where could we use them in the future?
5. What are the two good things that solar panels over water reservoirs do?
6. Explain what is expected to happen in the tallest water-solar tower that is being talked about for the Arizona desert.
7. What is fusion energy? What is the earliest that a fusion plant might come online?
8. How are fossil fuels related to nuclear fusion?

This page titled 21.2: Renewable vs. Nonrenewable Resources is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

21.3: Ore Deposits



How would you find ores?

There are many steps to finding an ore deposit. Find a place with likely geology. Test the soil and rock for the ore mineral or others that are often found with the ore mineral. Drill to test deeper rock and soil. Then make a map and do the calculations. If the deposit is found to be profitable, you can begin mining.

Using Minerals

When you use a roll of aluminum foil or some baby powder, you probably don't think about how the products were made. You may not even know that those products come from minerals! We use minerals in many everyday items. Minerals have to be located, removed from the ground, and refined before they can be made into the products.

Ore Deposits

A rock that contains important minerals is called an **ore**. The concentration of valuable minerals in an ore may be high or low.

Certain places on Earth are more likely to have certain ores. Geologists search for the places that might have ore deposits. For example, if you want copper, you need to look at regions with a particular geology. Copper is often found where hot fluids came off of a magma intrusion. Aluminum is found in intensely weathered soils in tropical areas. Some of the valuable deposits may be hidden underground. Some may be at the surface.

To find a mineral deposit, geologists study the geology of a lot of places. They then go to a spot where that type of mineral deposit could be found. They test the properties of the soil and rocks. They look at the chemistry and the physical properties. They determine if a mineral deposit is nearby.

After a mineral deposit is found, geologists determine how big it is. They may drill holes. They will test the chemistry of the rock from the holes. Using this information, they will outline the deposit on a map. This will allow them to determine the size and the concentration of ore minerals. The geologists then calculate the total amount of valuable minerals they think are in the deposit. The ore will be mined only if it is profitable. If so, a mineral deposit called an **ore deposit**.

The bauxite pictured below (**Figure** below) is a rock that contains minerals that are used to make aluminum.



Aluminum is made from the minerals in rocks known as bauxite.

If a mineral deposit is not profitable to mine, it is not considered an ore deposit. If conditions change, a deposit that wasn't profitable before may become profitable. An ore deposit may also become unprofitable to mine. What could occur to make these changes? The price of the ore could rise or fall. The price of extracting the ore could change. For example, if the ore is hard to get at and the price of fuel goes up. This may make the mineral deposit unprofitable to mine.

Summary

- An ore is a rock that contains important minerals.
- An ore deposit must be profitable to mine. If it is no longer profitable, it is no longer an ore deposit.
- Geologists find ore deposits by testing the chemistry of the rock and soil. They can also determine the size of the deposit.

Review

1. How can an ore deposit become unprofitable to mine?
2. How do geologists find an ore deposit?
3. How do geologists determine the size and concentration of ore?

This page titled 21.3: Ore Deposits is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

21.4: Ore Mines



Can you be a miner too?

Yes! You can go to certain rivers or streams to mine for gold placers. You dip a large metal pan into the stream, and get some gravel and a little water. You swish the mix around. The gold is the most dense material, and it will sink to the bottom of the pan. You can then extract it. The placers in the U.S with a lot of ore have already been mined out. But you might make a little money!

Mining Ores

If an ore is found to be profitable, it will probably be mined. There are two major types of mining: surface mining and underground mining. There are different types of each of those two.

Surface Mining

Surface mining allows extraction of ores that are close to Earth's surface. Overlying rock is blasted, and the rock that contains the valuable minerals is placed in a truck. The truck takes the rock to a refinery. **Figure** below shows a surface mining operation, including open-pit mining and mountaintop removal. As the name suggests, open-pit mining creates a big pit from which the ore is mined. The size of the pit grows as long as the miners can make a profit.

Other methods of surface mining include strip mining, placer mining, and dredging. Strip mining is like open pit mining but with material removed along a strip. A quarry is a type of open-pit mine that produces rocks and minerals that are used to make buildings and roads.



Open pit mining is a form of surface mining, extracting ores close to Earth's surface.

Placers are valuable minerals found in stream gravels. California's nickname, the Golden State, can be traced back to the discovery of placer deposits of gold in 1848. The gold weathered out of hard metamorphic rock in the western Sierra Nevada. The rock also contained deposits of copper, lead, zinc, silver, chromite, and other valuable minerals. The gold traveled down rivers and then settled in gravel deposits. Currently, California has active mines for gold and silver. Non-metal minerals such as sand and gravel, which are used for construction, are also mined in California and elsewhere.

Underground Mining

Underground mining is used to recover ores that are deeper into Earth's surface. Miners blast and tunnel into rock to gain access to the ores. An underground ore deposit can be approached from above, below, or sideways. The direction depends on the placement of the ore body, its depth, the concentration of ore, and the strength of the surrounding rock. An example of an underground mine can be seen below (**Figure** below).

Underground mining is very expensive and dangerous. Fresh air and lights must also be brought into the tunnels for the miners. Accidents are far too common.



An underground mine.

Summary

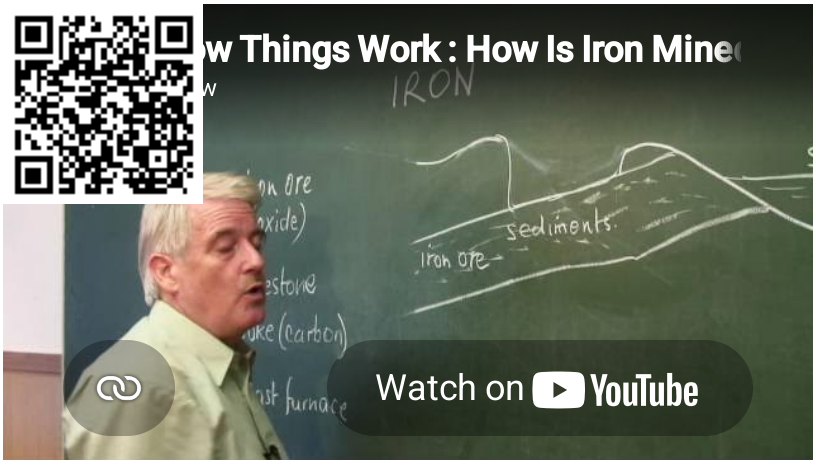
- Surface mines are created for mineral deposits that are near the surface.
- Underground mines are blasted into rock to get at deeper deposits.
- Underground mining is difficult; the safety and health of the miners is hard to maintain.

Review

1. What separates surface from underground mining? Which technique do you think is more expensive? More dangerous?
2. How is a placer deposit mined?
3. Why are some ore deposits mined by mountaintop removal?

Explore More

Use the resource below to answer the questions that follow.



1. Where is iron usually found?
2. What is iron ore?
3. How do we get to the ore?
4. What is overburden?

https://k12.libretexts.org/@go/page/6114

5. What happens to the ore after it is dug up?
6. What steps does it go through from the blast furnace to the steel that creates your refrigerator?

This page titled 21.4: Ore Mines is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

21.5: Ore Extraction



How can you save energy and materials?

Getting ore from rock takes a lot of energy. Getting ore from preexisting materials uses a lot less. It turns out that if you recycle just 40 aluminum cans, you will save the energy in one gallon of gasoline. You will save aluminum too!

Ore Extraction

When the ore leaves the mine, it is not yet a useful material (**Figure** below). Most ores are a combination of metal and other elements. The rocks are full of valuable minerals. They also contain rock that isn't valuable, which is called waste rock. The valuable minerals must be separated from the waste rock.



Enormous trucks haul rock containing ore from a mine site to where the rock is processed.

To separate the ore from the waste rock, first the rocks are crushed. Then the minerals are separated out of the ore. There are a few methods for doing this:

- **Heap Leaching**: the addition of chemicals, such as cyanide or acid, to remove ore. This is often done at very high temperatures.
- **Flotation**: the addition of a compound that attaches to the valuable mineral and floats.
- **Smelting**: roasting rock at a temperature greater than 900°C. This causes it to segregate into layers. The valuable minerals are then extracted. This requires a lot of energy.

Extracting metal from rock is so energy-intensive that it's much better to recycle. We use over 80 billion aluminum cans each year. If all of these cans were recycled, we would save the energy in 2 billion gallons of gasoline!



Summary

- To extract ore from rock, the rock is first crushed.
- Ore is extracted from rock by heap leaching, flotation, or smelting.
- Extracting ore from rock can take a lot of energy.

Review

1. Why does ore need to be extracted from rock?
2. How is ore extracted from rock?
3. Why does extracting ore from rock take a lot of energy?

This page titled 21.5: Ore Extraction is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

21.6: Earth's Materials- Challenge 1

1. Paper can be made mostly or entirely from ___.

renewable resources

2. Electronics need specific materials known as ___.

rare earth elements

3. A ___ resource is unlimited or replenished as quickly as it is used.

renewable

4. ___ resources cannot be replenished fast enough to keep up with human use.

Non-renewable

5. ___ form over millions of years from the remains of dead organisms and are mainly comprised of ___.

Fossil fuels; carbon

6. Regions where hot fluids came off a magma intrusion often have ___.

copper deposits

7. A mineral deposit that is profitable is called an ___.

ore deposit

8. Geologists determine the size of the deposit, test the concentration of ore in rock samples, and estimate the total amount of minerals in a ___.

mineral deposit

9. A ___ is a type of open-pit mine where rocks and minerals used to make buildings and roads are extracted.

quarry

10. Valuable minerals found in stream gravels are called ___.

placers

11. Panning for gold in streams works because ___.

gold sinks to the bottom of the pan

12. After ore is extracted from a mine, valuable minerals must be separated from ___.

waste rock

13. Around the world, humans use over ___ aluminum cans each year.

80 billion

14. To save ten gallons of gasoline that would otherwise be used to produce new aluminum cans, ___ used aluminum cans must be recycled.

400

This page titled 21.6: Earth's Materials- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

21.7: Environmental Impacts of Mining



Can you tell that this was a mine?

Mining can do a lot of damage to a region. Mining companies are now supposed to return the land to its natural state when they are done. Sometimes this works really well. It's hard to tell there was a mine here!

Mining and the Environment

Mining provides people with many resources they need. But mining can be hazardous to the environment. For surface mines, miners clear the land of soil and plants. Nearby lakes and streams may be inundated with sediment. The mined rock may include heavy metals. These also enter the sediment and water. Removing metals from rock may involve toxic chemicals. Acid flow from a mine site will change the chemistry of a nearby stream or lake.

Land Reclamation

U.S. law states that once mining is complete, the land must be restored to its natural state. This process is called **reclamation**. A pit may be refilled with dirt. It may be filled with water to create a lake. The pits may be turned into landfills. Underground mines may be sealed off or left open as homes for bats. The land is reshaped. Native plants are planted.

Mine Pollution

Mining can cause pollution. Chemicals released from mining can contaminate nearby water sources. Pictured below is water that is contaminated from a nearby mine (**Figure** below). The United States government has mining standards to protect water quality. Of course, more needs to be done.



This water has been polluted by a mountaintop removal mine.



Summary

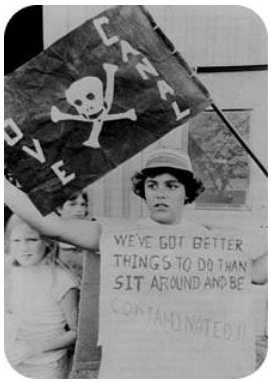
- Surface mining clears the land. Rock, dirt, and plants are all disturbed.
- Mining releases pollutants from rock or as metals are removed from rock.
- Reclamation occurs when people attempt to return the mined land to its original state.

Review

1. What damage may be caused by mining?
2. Why is sediment considered a problem in mined areas?
3. How is the region where there is a surface mine reclaimed?

This page titled 21.7: Environmental Impacts of Mining is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

21.8: Hazardous Waste



When do a few illnesses indicate a larger problem?

At Love Canal, New York, many children became sick. Many pregnancies never went to term. More than half of the babies born had a birth defect. Residents started to notice that things were not normal. When they investigated, they found out that their homes and school were built on a toxic waste dump. They called attention to the problem and asked for help.

The Story of Love Canal

Love Canal is a neighborhood in Niagara Falls. It is the site of one of the worst environmental disasters of all time. Love Canal gained worldwide attention in the late 1970s when the press started covering its story. The story is outlined and illustrated below (**Figure** below).



A company dumped barrels of chemical waste into an old canal. Then it covered the barrels with soil. An elementary school and many homes were built over the old canal, and children played in fields just a foot or two above the buried barrels.



Residents knew something was making them sick. Was it the old chemicals? Tests showed the ground was contaminated with poisonous chemicals. People had to leave, and efforts were made to clean up the chemicals, but even today, much of Love Canal remains off limits.



Learning from Love Canal: Love Canal opened people's eyes. They realized there must be other "Love Canals" all over the country. Thousands of contaminated sites were found, and money was set aside to clean them up. Laws were passed that required safer disposal of hazardous waste. The site shown above is the *Elizabeth Copper Mine Superfund Site* in Vermont.

What can we learn from the story of Love Canal?

Pollution by Hazardous Waste

Love Canal highlighted the problem of pollution by hazardous waste. **Hazardous waste** is any waste that is dangerous to the health of people or the environment. It may be dangerous because it is toxic, corrosive, flammable, or explosive. Hazardous waste can contaminate the land, soil, and water.

- Toxic waste is poisonous. Toxic waste may cause cancer or birth defects in people. It may also harm other living things.
- Corrosive waste is highly reactive with other substances. Corrosive waste may cause burns or destroy other materials that it touches.
- Flammable waste can burn easily. It may also give off harmful fumes when it burns.
- Explosive waste is likely to explode. The risk of explosion may be greater if the waste is mixed with other substances.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Hazardous Waste Around Your Home

Pictured below are some examples of hazardous waste (**Table** below). Look closely. Are any of these examples lurking around your home?

LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

Example	Description
	Cars contain toxic fluids such as brake fluid. The fluids may also be corrosive and flammable. This photo shows one way the fluids can end up in the ground.
	Cars use gasoline and oil. These materials are toxic and flammable. They pollute the land when they leak or spill.
	Batteries contain toxic and corrosive materials. People often toss them in the trash, but they should be disposed of properly.
	Electronics, such as old computers, contain toxic chemicals. They may be sent to landfills where the toxic materials end up in the ground.
	Medical waste can contain many hazards: Human body fluids may cause disease; old thermometers may contain toxic mercury; and pharmaceuticals may be toxic to people and other living things.
	Paints can be both toxic and flammable. Paints may spill on the ground or be thrown improperly in the trash.
	Chemicals are applied to farm fields and lawns. They include fertilizers, herbicides, and pesticides. Many of these chemicals are toxic to people and other animals.



Summary

- Hazardous waste is material that is toxic, chemically active, corrosive, or flammable.
- Hazardous wastes are damaging to the environment or human health.
- Hazardous materials are found in a variety of settings, including industry, agriculture, and people's homes.

Review

1. What is hazardous waste?
2. What are the types of hazardous waste?
3. Look around your home and garage, if you have one. Name some materials that are toxic.

This page titled 21.8: Hazardous Waste is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

21.10: Earth's Materials- Challenge 2

1. Dispose of household hazardous waste safely by ___.

following the rules listed on labels for each toxic material

2. Dry cleaners, automobile repair shops, hospitals, photo processing centers, and many other common facilities all generate ___.

hazardous waste

3. The automotive industry generates a lot of toxic ___, including gasoline, motor oil, battery acid, and brake fluid.

chemicals

4. The ___ oversees the cleanup of a Superfund site if the responsible party cannot.

federal government

5. The ___ regulates hazardous wastes in the U.S.

Resource Conservation and Recovery Act

6. Mining often produces ___ as a byproduct, which can change the composition of nearby lakes and streams.

acids

7. According to U.S. law, a mine region ___.

must be restored to its natural state

8. Reclamation of a mine may include ___.

filling pits with sediment, reshaping the land, and planting native vegetation

This page titled 21.10: Earth's Materials- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

21.11: Availability of Natural Resources



Which house owner uses more resources?

It's not hard to tell that the people on the right use more resources than those in the home on the left. Many natural resources were needed to create a home like this. Imagine a world in which everybody had equal access to resources. Some people would have fewer resources than they do now. But many people would have more.

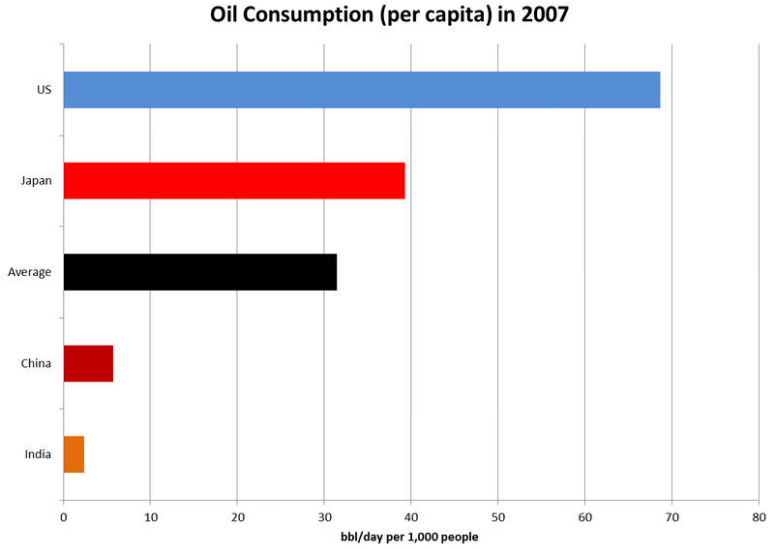
Resource Availability

Whether a resource is available for use depends on several factors.

- Supply: Some resources are very abundant. Some are rare. When a resource is close to running out, a replacement needs to be found. Some resources are very valuable because they are very rare.
- Price: The price of a resource depends on how much of it is available. It also depends on how easy it is to find and extract. A resource may not be used until its price goes up enough to cover the costs of finding and extracting it.
- Politics: Resources are not found equally around the world. Some nations may have a lot of certain vital resources. Some nations may have none. It is possible for a nation rich in a resource to control who gets it. They can also control the price.

Who Uses Natural Resources?

Rich nations use more natural resources than poor nations. In fact, the richest 20 percent of people use 85 percent of the world's resources. What about the poorest 20 percent of people? They use only 1 percent of the world's resources (**Figure** below).



The U.S. uses more than its share of oil. What if everyone used resources this way? We would need five times more space to produce what was used! (Note: Per capita means "per person.")

More People, More Resources

Every 20 minutes, the human population increases by 3,500 more people. More people need more resources. For example, we now use five times more fossil fuels than we did in 1970. The human population is expected to increase for at least 40 years. What will

happen to resource use?

Summary

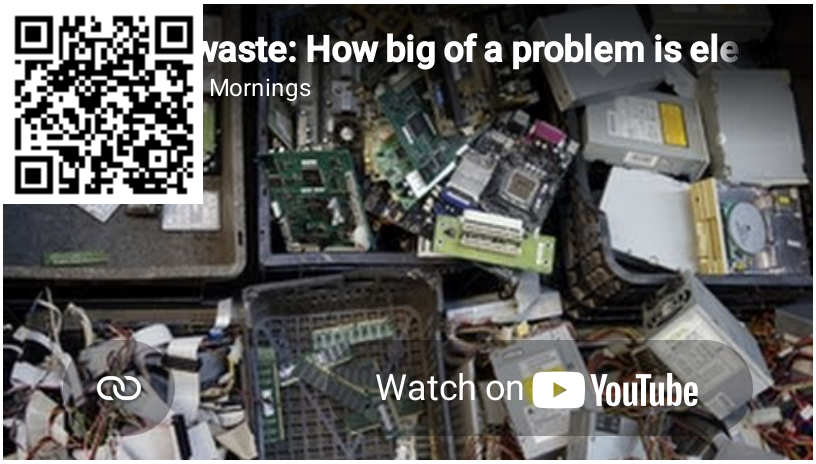
- The availability of a resource depends on how much of it there is, how much it costs to get, and where it is located.
- Politics plays an important role in resource availability.
- The world's wealthiest people use most of the resources. The world's poorest people use very few resources.

Review

1. What factors affect resource availability?
2. Why is politics important in the availability of resources?
3. Why do some nations consume more goods than others?

Explore More

Use this resource to answer the questions that follow.



1. What is e-waste?
2. What is happening to the amount of e-waste being produced?
3. Why is there so much e-waste now?
4. Where does the e-waste come from?
5. What needs to be done to improve the problem with e-waste?
6. What should you do if you want to recycle a piece of electronics?
7. How can you reduce your e-waste?
8. What is the positive trend? What is the negative trend from that?

This page titled 21.11: Availability of Natural Resources is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

21.12: Natural Resource Conservation



Can you make a difference?

Yes! You can conserve natural resources every day with every decision you make. Should you recycle that can? Yes! Should you buy a bottle of water or drink from the water fountain? Fountain! Should you walk or ride your bike to school or ask for a ride? Walk or ride your bike—it's good exercise too!

Conserving Natural Resources

How can we protect Earth's natural resources? One answer is **conservation**. This means saving resources. We need to save resources so some will be left for the future. We also need to protect resources from pollution and overuse.

When we conserve resources, we also cut down on the trash we produce. Americans throw out 340 million tons of trash each year. We throw out 2.5 million plastic bottles alone—every hour! Most of what we throw out ends up in landfills (**Figure** below). In a landfill, all those plastic bottles take hundreds of years to break down. What are the problems caused by producing so much trash? Natural resources must be used to produce the materials. Land must be given over to dump the materials. If the materials are toxic, they may cause pollution.



A bulldozer crushes a mountain of trash.

The Three "R"s

You probably already know about the three "R"s. They stand for reduce, reuse, and recycle. The third "R"—recycle—has caught on in a big way. That's because it's easy. There are thousands of places to drop off items such as aluminum cans for recycling. Many cities allow you to just put your **recycling** in a special can and put it at the curb. However, the first two "R"s are even more important.

We haven't done as well with the first two "R"s—reducing and reusing. But they aren't always as easy as recycling. Recycling is better than making things from brand new materials. But it still takes some resources to turn recycled items into new ones. It takes no resources at all to reuse items or not buy them in the first place.

Reduce

Reducing resource use means just what it says—using fewer resources. There are lots of ways to reduce our use of resources.

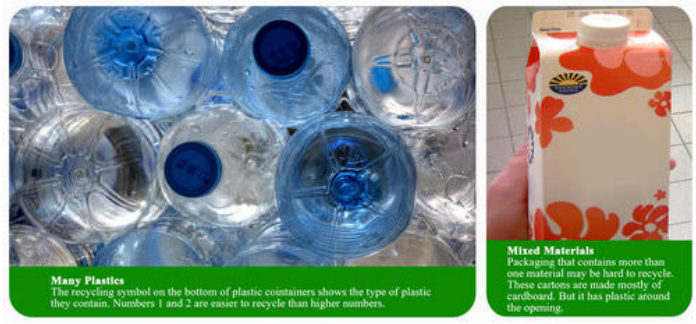
- Buy durable goods. Choose items that are well made so they will last longer. You'll buy fewer items in the long run, so you'll save money as well as resources. That's a win-win!
- Repair rather than replace. Fix your bike rather than buying a new one. Sew on a button instead of buying a new shirt. You'll use fewer resources and save money.
- Buy only what you need. Don't buy a gallon of milk if you can drink only half of it before it spoils. Instead, buy a half gallon and drink all of it. You won't be wasting resources (or money!).
- Buy local. For example, buy local produce at a farmer's market, like the one pictured below (**Figure** below). A lot of resources are saved by not shipping goods long distances. Products bought at farmer's markets use less packaging, too!



Buying locally grown produce at a farmer's market saves resources.

About a third of what we throw out is packaging. Try to buy items with the least amount of packaging. For example, buy bulk items instead of those that are individually wrapped. Also, try to select items with packaging that can be reused or recycled. This is called **precycling**. Pop cans and plastic water bottles, for example, are fairly easy to recycle. Some types of packaging are harder to recycle (**Figure** below). If it can't be reused or recycled, it's a waste of resources.

- Many plastics: The recycling symbol on the bottom of plastic containers shows the type of plastic they contain. Numbers 1 and 2 are easier to recycle than higher numbers.
- Mixed materials: Packaging that contains more than one material may be hard to recycle. This carton is made mostly of cardboard. But it has plastic around the opening.



These types of packaging are hard to recycle. Could you reuse any of them?

Reuse

Reusing resources means using items again instead of throwing them away. A reused item can be used in the same way by someone else. Or it can be used in a new way. For example, Shana has a pair of jeans she has outgrown. She might give them to her younger sister to wear. Or she might use them to make something different for herself, say, a denim shoulder bag. Some other ideas for reusing resources are pictured below (**Figure** below).



Do you reuse products, like these? Can you think of other ways to reuse resources?

Recycle

Many things can be recycled. The materials in them can be reused in new products. For example, plastic water bottles can be recycled. The recycled material can be made into t-shirts! Old phone books can also be recycled and made into textbooks. When you shop for new products, look for those that are made of recycled materials (**Figure** below). Even food scraps and lawn waste can be recycled. They can be composted and turned into humus for the garden.



This label shows that the product was made from recycled materials.

At most recycling centers, you can drop off metal cans, cardboard and paper products, glass containers, and plastic bottles. Recycling stations, like the one pictured below (**Figure** below), are common. Curbside recycling usually takes these items too. Do you know how to recycle in your community? Contact your local solid waste authority to find out. If you don't already recycle, start today. It's a big way you can help the planet!



Are there recycling stations like this one where you live?

Though recycling is a good way to start conserving resources, it still takes energy and other resources to recycle many materials. Reducing and reusing resources are the best ways to make a difference.

Summary

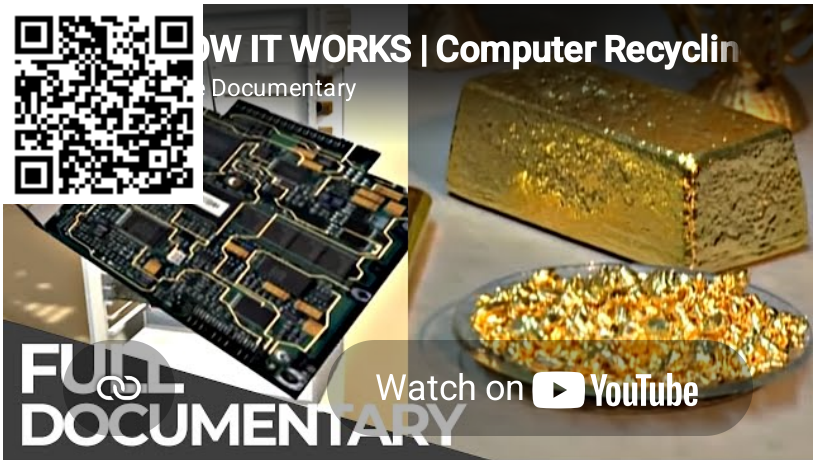
- Conservation is a very effective way to help us to have useful materials in the future.
- To conserve, follow the three R's: reduce, reuse, recycle.
- Reduce means to just use less.
- Reuse means to use something again, pass it on to someone who will, or change it so that it can be used in another way.
- Recycle means to have it recycled in your community. This is great; although, it does take energy.

Review

1. Why is conservation a good thing?
2. What are the three R's? What do they mean?
3. Give an example of each of the three R's that you could do in your own life.

Explore More

Use this resource to answer the questions that follow.



1. In a computer, where is silver and copper? Where is gold?
2. What do these precious metals do in a computer?
3. How are precious metals retrieved from an old computer?
4. How is the gold separated from a microprocessor?
5. What does this gold become?
6. Why is the metal in other computer parts harder to recycle?
7. How do positive and negative charges help to recycle the metal?
8. How are gold salts created?
9. Are all of the metals used again in computers? What else could these metals be used for?
10. What do satellites and the space shuttle use gold for?

This page titled 21.12: Natural Resource Conservation is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

21.13: Earth's Materials- Challenge 3

1. Non-renewable resources ___.

cannot be replenished as quickly as humans use them

2. Electronic waste generated in industrialized nations ___.

exposes people in those countries to hazardous compounds

3. A nation with a lot of neodymium may ___ that resource to countries that ___ it.

export; import

4. The best way to reduce consumption is to ___.

buy fewer things

5. What type of grocery bag is best for the environment?

Reusable cloth bags

6. To reduce plastic consumption, avoid drinking from ___ and instead drink from ___.

disposable plastic bottles; the tap or fountains

This page titled 21.13: Earth's Materials- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

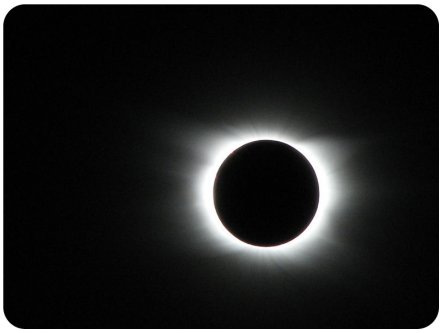
CHAPTER OVERVIEW

22: The Solar System

22.3: Outer Layers of the Sun
The Solar System: Challenge 1
22.1: Sun
22.2: Interior of the Sun
22.4: Surface Features of the Sun
22.6: Planets of the Solar System
22.7: Planet Orbits in the Solar System
22.8: Gravity in the Solar System
22.9: The Solar System- Challenge 2
22.10: Inner vs. Outer Planets
22.11: Mercury
22.12: Venus
22.13: Moon
22.14: Mars
22.15: The Solar System- Challenge 3
22.16: Jupiter
22.17: Saturn
22.18: Uranus
22.19: Neptune
22.20: The Solar System- Challenge 4
22.21: Exoplanets
22.22: Asteroids
22.23: Comets
22.24: Meteors
22.25: Dwarf Planets
22.26: The Solar System- Challenge 5

This page titled 22: The Solar System is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.3: Outer Layers of the Sun



What can you see during a solar eclipse?

A solar eclipse is kind of like a field trip to the Sun from Earth. You can see something (with special tinted glasses) that you don't usually see. The Sun has a remarkable ring of light around it. This is the corona. If you have a chance to see a solar eclipse, you should do it.

The Outer Layers

The three outer layers of the Sun are its atmosphere. The layers are, from inside to outside, the photosphere, the chromosphere, and the corona.

The Photosphere

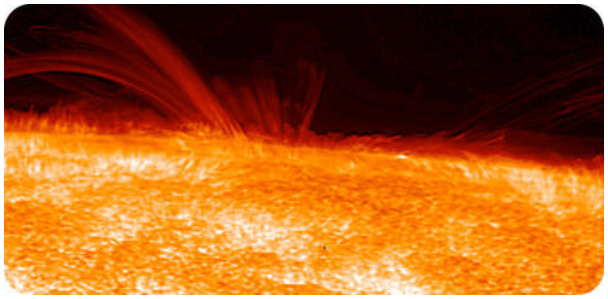
The **photosphere** is the visible surface of the Sun (**Figure** below). It's the part that we see shining. Surprisingly, the photosphere is also one of the coolest layers of the Sun. It is only about 6,000°C.



The Sun's atmosphere contains the photosphere, the chromosphere, and the corona. This image was taken by NASA's Spacelab 2 instruments.

The Chromosphere

The **chromosphere** (**Figure** below) lies above the photosphere. It is about 2,000 km thick. The thin chromosphere is heated by energy from the photosphere. Temperatures range from about 4,000°C to about 10,000°C. The chromosphere is not as hot as other parts of the Sun, and it glows red. Jets of gas sometimes fly up through the chromosphere. With speeds up to 72,000 km per hour, the jets can fly as high as 10,000 km.



The chromosphere.

The Corona

The **corona** (**Figure** below) is the outermost part of the Sun's atmosphere. It is the Sun's halo, or "crown." With a temperature of 1 to 3 million K, the corona is much hotter than the photosphere. The corona extends millions of kilometers into space. Sometime you should try to see a total solar eclipse. If you do, you will see the Sun's corona shining out into space.



During a total solar eclipse, the Sun's corona becomes visible, peeking out from behind the Moon.

Summary

- The photosphere is the part of the Sun that we see shining.
- The chromosphere is an active layer that glows red.
- The corona is the halo around the Sun.

Review

1. What layer of the Sun do you see during a total solar eclipse?
2. What are the distinctive characteristics of the photosphere?
3. What are the distinctive characteristics of the chromosphere?
4. What is the corona?

This page titled 22.3: Outer Layers of the Sun is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

The Solar System: Challenge 1

1. The SOHO spacecraft ___.

has been in orbit around the Sun since 1996 and sends solar data and images back to Earth

2. The Sun makes up about ___ percent of all the mass in the solar system.

99.8

3. If the Sun was the size of an official league basketball, Earth would be about ___ in diameter.

2 millimeters

4. The region of the Sun that emits sunlight is the ___.

photosphere

5. The inner layers of the Sun, from inside out, are ___.

the core, the radiative zone, and the convection zone

6. The chromosphere, the layer between the corona and the photosphere, is the ___ layer of the Sun.

coolest

7. Jets of gas sometimes fly up through the ___.

chromoosphere

8. The photosphere is about ___ degrees Celsius.

6,000

9. The temperature of the chromosphere ranges from about ___ degrees Celsius to ___ degrees Celsius.

4,000; 10,000

10. A strong solar flare can lead to ___.

coronal mass ejections

11. Sunspots are ___.

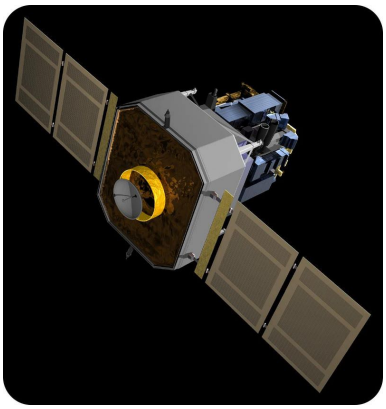
cooler, darker areas of the Sun

12. ___ are plasma loops that connect two sunspots.

Solar prominences

This page titled The Solar System: Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.1: Sun



How can we learn about something as hot as the Sun?

Humans have sent spacecraft up to study our star. The SOHO spacecraft has been in operation since 1996. The craft orbits the Sun in step with Earth but closer to it. SOHO has sent back amazing images. Onboard instruments have also sent back mountains of data. The data is mostly about the Sun's outer layers.

The Sun

Our Sun is a **star**, a sphere of plasma held together by gravity. It is an ordinary star that is extraordinarily important. The Sun provides light and heat to our planet. This star supports almost all life on Earth.

The Sun is the center of the **solar system**, which includes all of the planets and other bodies that orbit it. It is by far the largest part of the solar system (**Figure** below). Added together, all of the planets make up just 0.2 percent of the solar system's mass. The Sun makes up the remaining 99.8 percent of all the mass in the solar system!



The sizes of the planets relative to the Sun, if the Sun were the size of a basketball.

Summary

- The Sun is an ordinary star. It supports nearly all life on Earth.
- The Sun is at the center of the solar system.
- The Sun makes up almost all of the mass of the solar system.

Review

1. What are the major properties of the Sun?
2. Where is the Sun located?
3. Why is the Sun important to life on Earth?

Explore More

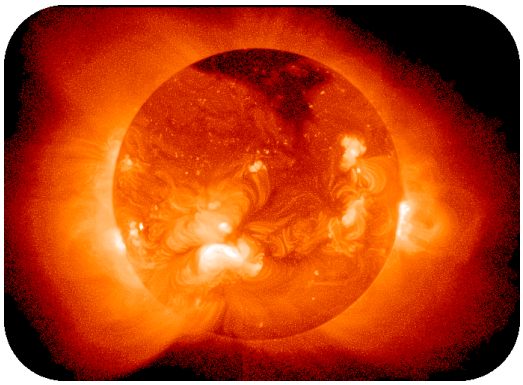
Use the resource below to answer the questions that follow.



1. Why is it that you can't see the star closest to Earth in the night sky?
2. Where is the Sun located?
3. Why is our Sun special? Is it a special type of star?
4. What is the structure of the solar system from the center to the farthest reaches?
5. Which type of solar system bodies come from the farthest part of the solar system?

This page titled 22.1: Sun is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.2: Interior of the Sun



What does the Sun look like?

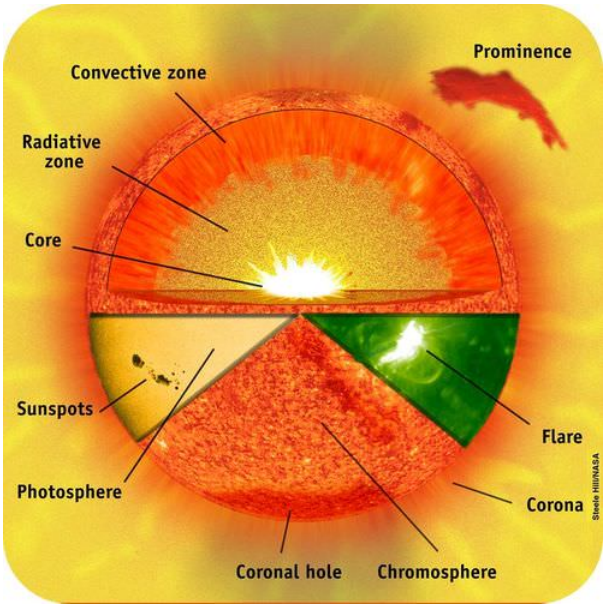
Different instruments pick up different features of the Sun. None can show us the Sun's interior. But studies from the SOHO spacecraft and other craft allow us to study the interior. We know a surprising amount about a body that is so hot and so far away.

Layers of the Sun

The Sun is made almost entirely of the elements hydrogen and helium. The Sun has no solid material. Most atoms in the Sun exist as **plasma**. Plasma is superheated gas with an electrical charge. Because the Sun is made of gases, it does not have a defined outer boundary. Like Earth, the Sun has an internal structure. The inner three layers make up what we would actually call “the Sun.”

Internal Structure

Because the Sun is not solid, it does not have a defined outer boundary. It does, however, have a definite internal structure with identifiable layers (**Figure** below). Since the layers are not solid, the boundaries are fuzzy and indistinct. From inward to outward, the layers are: the core, the radiative zone, and the convection zone.



The layers of the Sun.

The Core

The **core** is the Sun's innermost layer. The core is plasma. It has a temperature of around 15 million degrees Celsius (°C). Nuclear fusion reactions create the immense temperature. In these reactions, hydrogen atoms fuse to form helium. This releases vast

amounts of energy. The energy moves toward the outer layers of the Sun. Energy from the Sun's core powers most of the solar system.

Radiative Zone

The **radiative zone** is the next layer out. It has a temperature of about 4 million °C. Energy from the core travels through the radiative zone. The energy travels at an extremely slow rate. Light particles are called **photons**. In the radiative zone, photons can travel only a few millimeters before they hit another particle. The particles are absorbed and then released again. It may take 50 million years for a photon to travel all the way through the radiative zone.

The Convection Zone

The **convection zone** surrounds the radiative zone. In the convection zone, hot material from near the Sun's center rises. This material cools at the surface and then plunges back downward. The material then receives more thermal energy from the radiative zone.



Summary

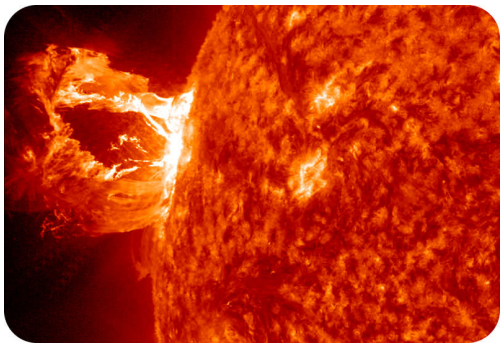
- The Sun is made mostly of plasma. Plasma is superheated gas with a positive electrical charge.
- Nuclear fusion takes place in the Sun's extremely hot core.
- The radiative zone is outside the core.
- The convection zone is where convection takes place. It is located outward from the radiative zone.

Review

1. What are the properties of the core?
2. What is plasma?
3. What powers the Sun?

This page titled 22.2: Interior of the Sun is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.4: Surface Features of the Sun



Is the Sun always the same?

For most of human history, people thought the Sun didn't change much. But technology has offered us a window into the Sun's life. SOHO and other technologies allow us to observe incredible sunspots, flares, and prominences. Some of these are featured in this concept.

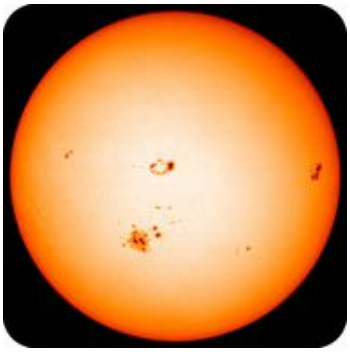
Surface Features of the Sun

The Sun has many incredible surface features. Don't try to look at them, though! Looking directly at the Sun can cause blindness. Find the appropriate filters for a pair of binoculars or a telescope and enjoy!

Sunspots

The most noticeable magnetic activity of the Sun is the appearance of sunspots. **Sunspots** are cooler, darker areas on the Sun's surface (**Figure** below). Sunspots occur in an 11-year cycle. The number of sunspots begins at a minimum. The number gradually increases to the maximum. Then the number returns to a minimum again.

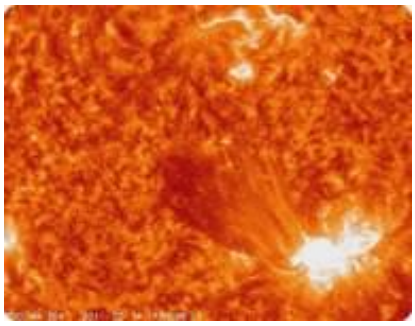
Sunspots form because loops of the Sun's magnetic field break through the surface. Sunspots usually occur in pairs. The loop breaks through the surface where it comes out of the Sun. It breaks through again where it goes back into the Sun. Sunspots disrupt the transfer of heat from the Sun's lower layers.



The darker regions in this image are sunspots.

Solar Flares

A loop of the Sun's magnetic field may break. This creates **solar flares**. Solar flares are violent explosions that release huge amounts of energy (**Figure** below). The streams of high energy particles they emit make up the **solar wind**. Solar wind is dangerous to spacecraft and astronauts. Solar flares can even cause damage on Earth. They have knocked out entire power grids and can disturb radio, satellite, and cell phone communications.



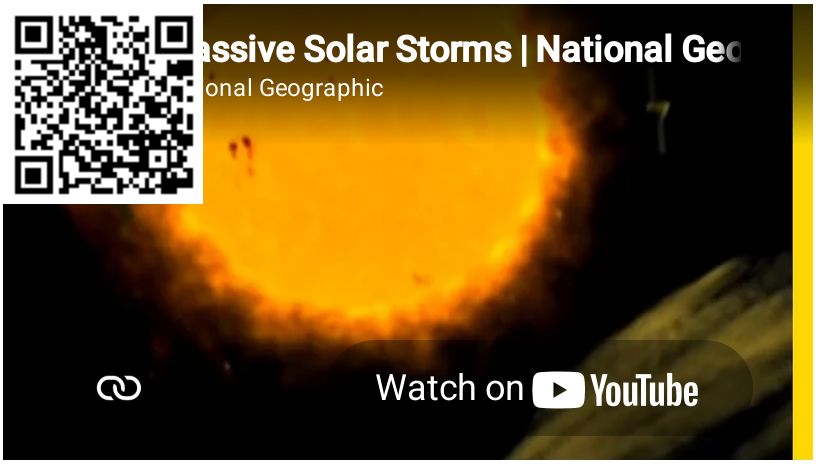
The solar flare is the bright area in the lower right.

Solar Prominences

Another amazing feature on the Sun is **solar prominences**. Plasma flows along the loop that connects sunspots. This plasma forms a glowing arch. The arch is a solar prominence. Solar prominences can reach thousands of kilometers into the Sun's atmosphere. Prominences can last for a day to several months. Prominences can be seen during a total solar eclipse.

Solar Dynamics Observatory

NASA's Solar Dynamics Observatory (SDO) was launched on February 11, 2010. SDO is studying the Sun's magnetic field. This includes how the Sun affects Earth's atmosphere and climate. SDO provides extremely high resolution images. The craft gathers data faster than anything that ever studied the Sun.



Summary

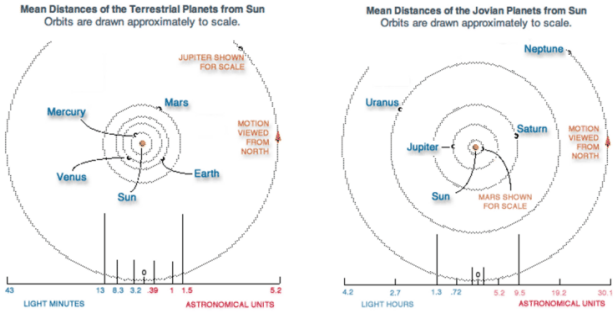
- Sunspots occur in pairs. Each is one side of a loop of the Sun's magnetic field on the Sun's surface. Sunspots come and go on an 11-year cycle.
- Sunspots are cooler and darker than the rest of the Sun's surface. They are marked by intense magnetic activity.
- Solar prominences are the plasma loops that connect two sunspots.
- Solar flares and coronal mass ejections are eruptions of highly energetic particles from the Sun's surface.

Review

1. What are sunspots? What is a sunspot cycle?
2. How are solar prominences related to sunspots?
3. What is being learned from the Solar Dynamics Observatory?

This page titled 22.4: Surface Features of the Sun is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.6: Planets of the Solar System

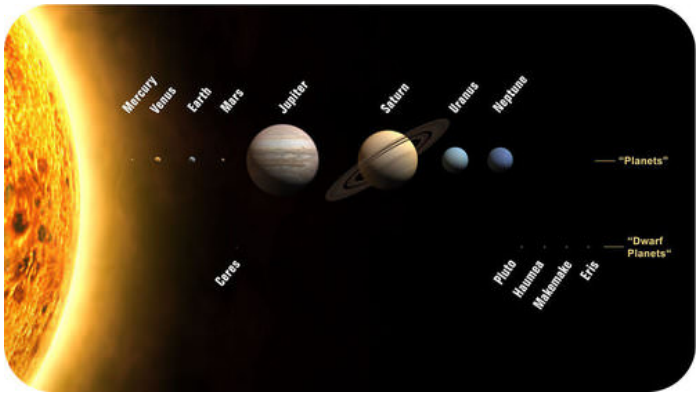


Can humans take a field trip through the solar system?

A field trip through the solar system would take a long time. It took 12 years for the Voyager spacecraft to get from Earth to Neptune. If a human was on board, he or she would probably want to come back! Fortunately, unmanned spacecraft can send back images of far distant places in the solar system.

Solar System Objects

Astronomers now recognize eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune), five dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris), more than 150 moons, and many, many asteroids and other small objects (**Figure** below). These objects move in regular and predictable paths around the Sun.



Relative sizes of the Sun, planets, and dwarf planets and their positions relative to each other are to scale. The relative distances are not to scale.

Planet Sizes

The Sun is just an average star compared to other stars. But it is by far the largest object in the solar system. The Sun is more than 500 times the mass of everything else in the solar system combined! Listed below is data on the sizes of the Sun and planets relative to Earth (**Table** below).

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

Object	Mass (relative to Earth)	Diameter (relative to Earth)
Sun	333,000	109.2
Mercury	0.06	0.39
Venus	0.82	0.95
Earth	1.00	1.00
Mars	0.11	0.53
Jupiter	317.8	11.21
Saturn	95.2	9.41
Uranus	14.6	3.98
Neptune	17.2	3.81

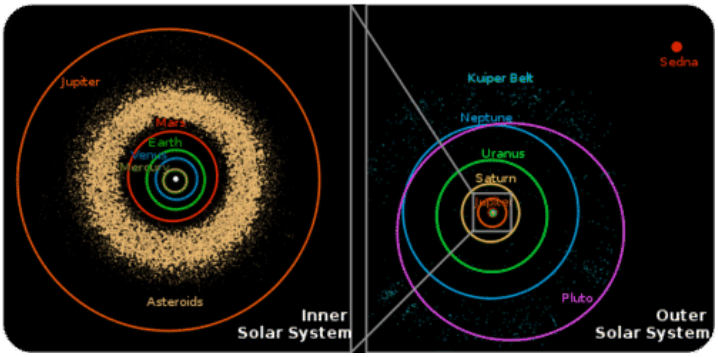
Distances in the Solar System

Distances in the solar system are often measured in **astronomical units** (AU). One astronomical unit is defined as the distance from Earth to the Sun. 1 AU equals about 150 million km (93 million miles). Listed below is the distance from the Sun to each planet in AU (**Table** below). The table shows how long it takes each planet to spin once on its axis. It also shows how long it takes each planet to complete an orbit. Notice how slowly Venus rotates! A day on Venus is actually longer than a year on Venus!

Planet	Average Distance from Sun (AU)	Length of Day (in Earth days)	Length of Year (in Earth years)
Mercury	0.39	56.84	0.24
Venus	0.72	243.02	0.62
Earth	1.00	1.00	1.00
Mars	1.52	1.03	1.88
Jupiter	5.20	0.41	11.86
Saturn	9.54	0.43	29.46
Uranus	19.22	0.72	84.01
Neptune	30.06	0.67	164.8

The Size and Shape of Orbits

Figure below shows the relative sizes of the orbits of the planets, asteroid belt, and Kuiper belt. In general, the farther away from the Sun, the greater the distance from one planet's orbit to the next. The orbits of the planets are not circular but slightly elliptical (**Figure** below).



The relative sizes of the orbits of planets in the solar system. The inner solar system and asteroid belt is on the upper left. The upper right shows the outer planets and the Kuiper belt.

Summary

- The solar system has eight planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. There are also five known dwarf planets: Ceres, Pluto, Makemake, Haumea, and Eris.
- Solar system distances are measured as multiples of the distance between Earth and Sun. This is one astronomical unit (AU).
- All planets and dwarf planets orbit the Sun. All planets and dwarf planets rotate on their axes.
- The planets make slightly elliptical orbits around the Sun.

Review

1. What are the names of the planets and dwarf planets?
2. Where are the most massive planets? Where are the least massive planets?
3. What is an astronomical unit? Why is this unit used to measure distances in the solar system?

Explore More

Use the resource below to answer the questions that follow.

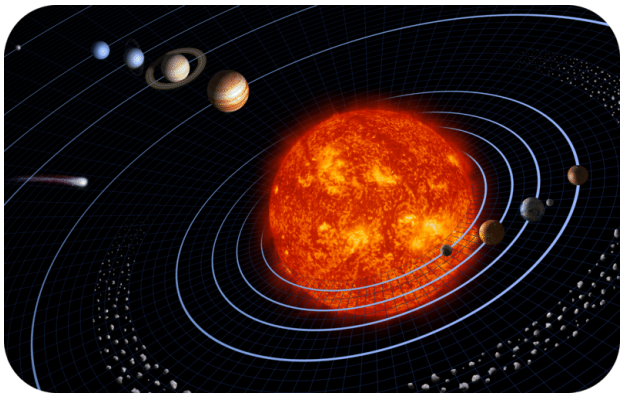


1. What did early astronomers believe about planet Earth?
2. How many planets did early astronomers know about?
3. What did Kepler discover?
4. How did our solar system form?
5. How many planets are in the solar system?
6. What is the Kuiper belt?
7. What is the Oort cloud?
8. What is found in the Oort cloud?
9. What is the outer boundary of the solar system?

10. Why are scientists interested in the other planets?

This page titled 22.6: Planets of the Solar System is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.7: Planet Orbits in the Solar System

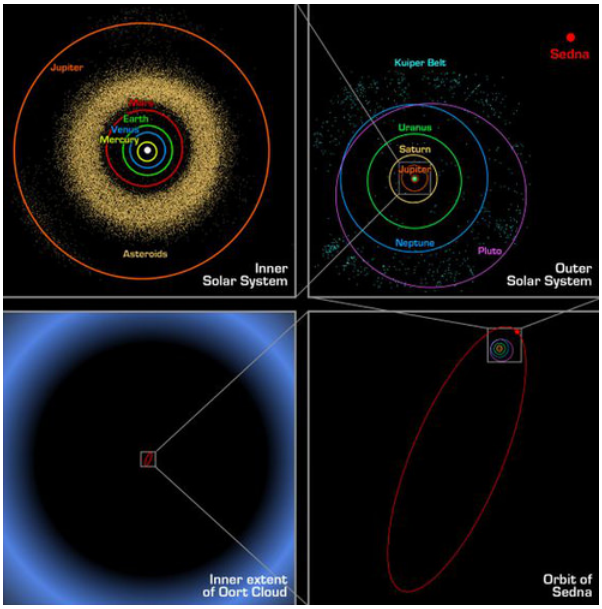


"Accordingly, since nothing prevents the earth from moving...

...I suggest that we should now consider also whether several motions suit it, so that it can be regarded as one of the planets. For, it is not the center of all the revolutions." - Nicolaus Copernicus

The Size and Shape of Orbits

Figure below shows the relative sizes of the orbits of the planets, asteroid belt, and Kuiper belt. In general, the farther away from the Sun, the greater the distance from one planet's orbit to the next. The orbits of the planets are not circular but slightly elliptical, with the Sun located at one of the foci (see opening image).



The relative sizes of the orbits of planets in the solar system. The inner solar system and asteroid belt is on the upper left. The upper right shows the outer planets and the Kuiper belt.

While studying the solar system, Johannes Kepler discovered the relationship between the time it takes a planet to make one complete orbit around the Sun, or its "orbital period," and the distance from the Sun to the planet. If the orbital period of a planet is known, then it is possible to determine the planet's distance from the Sun. This is how astronomers without modern telescopes could determine the distances to other planets within the solar system.

How old are you on Earth? How old would you be if you lived on Jupiter? How many days is it until your birthday on Earth? How many days until your birthday if you lived on Saturn?

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org



Summary

- The eight planets orbit the Sun along slightly elliptical paths, with Sun located at one of the foci.
- Kepler discovered that by using a planet's orbital period, it is possible to determine its distance from the Sun.
- The farther the planets are from the Sun, the greater their distance from each other.

Review

1. When you look at the diagram of planet orbits, which planetoid (planet-like object) doesn't fit the criteria of a planet?
2. How did Johannes Kepler determine a planet's distance from the Sun?
3. Why would your age - the number of orbits you have made around the Sun - be different on a different planet? Would you be younger or older?

This page titled 22.7: Planet Orbits in the Solar System is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.8: Gravity in the Solar System

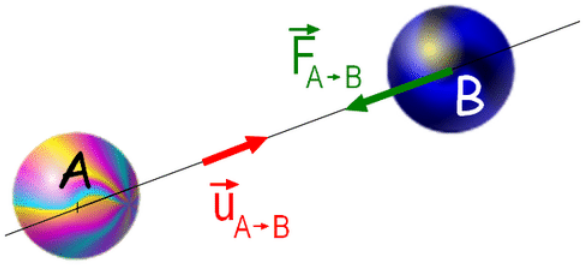


Have you ever heard the old adage, "What goes up must come down"?

Every moment of every day is a field trip to gravity. Gravity is everywhere! You have a gravitational attraction to your dog. You have one to your pencil. You even have one to your school principal! These gravitational attractions are very small compared with the most important one you have. This is your gravitational attraction to Earth. It's what keeps you from floating off into space. Gravity holds our planet together. Gravity keeps Earth orbiting the Sun. We wouldn't be here without gravity.

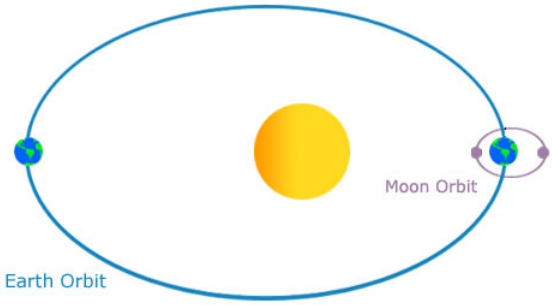
The Role of Gravity

All objects in the universe have an attraction to each other. This attraction is known as **gravity** (**Figure** below). The strength of the force of gravity depends on two things. One is the mass of the objects. The other is the distance between the objects. As an object's mass increases, the attraction increases. As the distance between the objects increases, the attraction decreases.



The strength of the force of gravity between objects A and B depends on the mass of the objects and the distance (u) between them.

Isaac Newton first described gravity as the force that causes objects to fall to the ground. Gravity is also the force that keeps the Moon circling Earth. Gravity keeps Earth circling the Sun. Without gravity, these objects would fly off into space (**Figure** below).



The Moon orbits the Earth, and the Earth-Moon system orbits the Sun.

Earth's gravity pulls any object on or near Earth toward the planet's center.

Summary

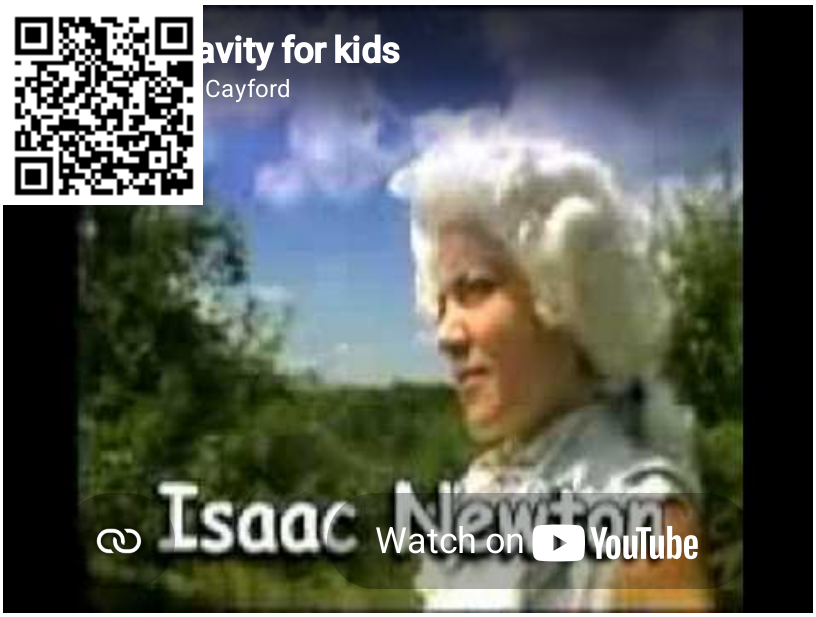
- All objects have a gravitational attraction to each other. This is called gravity.
- The attraction is proportional to the mass of the objects. The attraction is inversely proportional to the distance between the objects.
- Gravity keeps the Moon orbiting Earth. Gravity keeps the planets orbiting the Sun.

Review

1. For which object is the force of gravity greatest: Earth, Moon, or Sun? Why?
2. Imagine that the Moon and the Sun are the same distance from Earth. Which one would Earth be gravitationally attracted to?
3. What is gravity?

Explore More

Use the resource below to answer the questions that follow.



1. Who was Isaac Newton?
2. What did Newton discover?

3. How did Newton make his discovery?

This page titled 22.8: Gravity in the Solar System is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.9: The Solar System- Challenge 2

1. ___ is the planet most similar to Earth in terms of size and overall mass.

Venus

2. Mercury makes about ___ revolutions around the Sun in the time Earth makes 10 revolutions.

40

3. On which planet would a person's weight be closest to their weight on Earth?

Venus

4. The time it takes a planet to make one complete orbit around the Sun is known as its ___.

orbital period

5. The planets' orbits are ___ in shape.

slightly elliptical

6. ___ discovered the relationship between a planet's orbital period and its distance from the Sun.

Johannes Kepler

7. ___ experiences the strongest gravitational attraction to the Sun.

Mercury

8. Order the following in terms of decreasing gravitational force: Earth, Moon, Sun

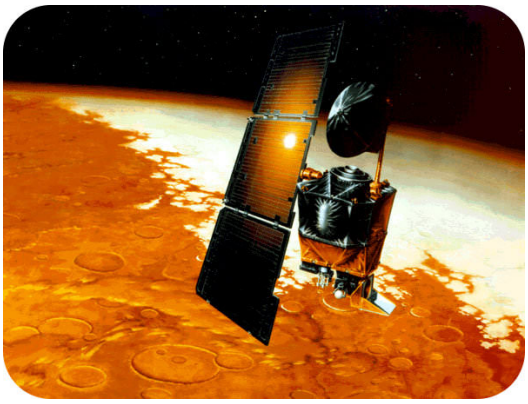
Sun, Earth, Moon

9. ___ is the planet that experiences the weakest gravitational attraction to the Sun.

Neptune

This page titled 22.9: The Solar System- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.10: Inner vs. Outer Planets



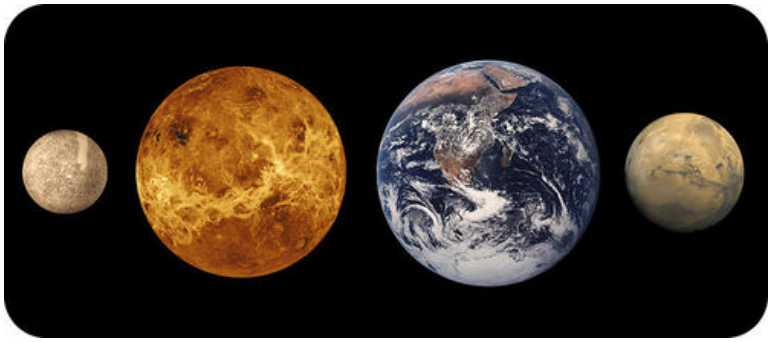
What's better than a field trip?

All of the inner planets are orbited by man-made satellites. Jupiter and Saturn have man-made satellites too. We can see what the planets look like from the photos they take. The satellites also carry instruments that collect a lot of important data. This is better than taking a field trip to such hostile places. You can learn a lot while sitting on your own, very comfortable planet!

The Inner Planets

The four planets closest to the Sun—Mercury, Venus, Earth, and Mars—are the **inner planets** or **terrestrial planets** (**Figure** below). They are similar to Earth. All are solid, dense, and rocky. None of the inner planets has rings. Compared to the outer planets, the inner planets are small. They have shorter orbits around the Sun and they spin more slowly. Venus spins backward and spins the slowest of all the planets.

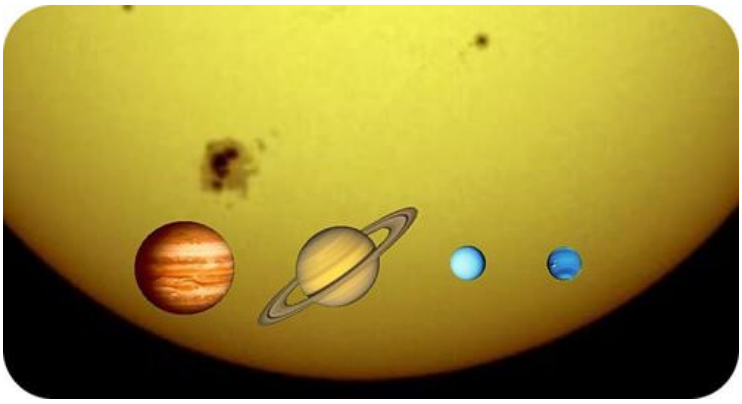
All of the inner planets were geologically active at one time. They are all made of cooled igneous rock with inner iron cores. Earth has one big, round moon, while Mars has two very small, irregular moons. Mercury and Venus do not have moons.



This composite shows the relative sizes of the four inner planets. From left to right, they are Mercury, Venus, Earth, and Mars.

The Outer Planets

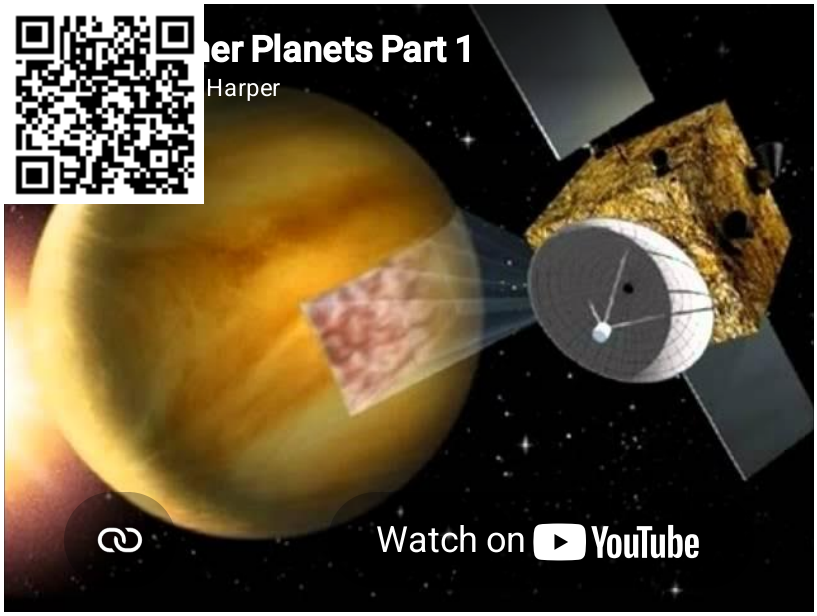
Jupiter, Saturn, Uranus, and Neptune are the **outer planets** of our solar system. These are the four planets farthest from the Sun. The outer planets are much larger than the inner planets. Since they are made mostly of gases, they are also called **gas giants**. Pictured below are the relative sizes of the outer planets and the Sun (**Figure** below).



This image shows the four outer planets and the Sun, with sizes to scale. From left to right, the outer planets are Jupiter, Saturn, Uranus, and Neptune.

The gas giants are made mostly of hydrogen and helium. These are the same elements that make up most of the Sun. Astronomers think that most of the nebula that formed the solar system was hydrogen and helium. The inner planets lost these very light gases. Their gravity was too low to keep them, and they floated away into space. The Sun and the outer planets had enough gravity to keep the hydrogen and helium.

All of the outer planets have numerous moons. They also have **planetary rings** made of dust and other small particles. Only the rings of Saturn can be easily seen from Earth.



Summary

- The four inner planets have slower orbits, slower spin, no rings, and they are made of rock and metal.
- The four outer planets have faster orbits and spins, a composition of gases and liquids, numerous moons, and rings.
- The outer planets are made of hydrogen and helium, so they are called gas giants.

Review

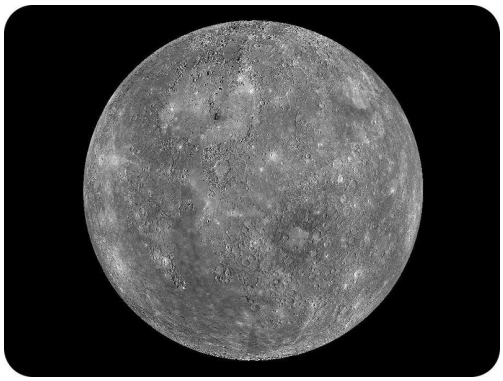
1. Describe the characteristics of the four inner planets.
2. Describe the characteristics of the four outer planets.
3. Why are the inner and outer planets so different from each other?

This page titled 22.10: Inner vs. Outer Planets is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

LibreTexts™

cK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

22.11: Mercury



What does this planet look like?

Mercury looks a lot like Earth's Moon. Why do you think it does? Both have been struck by a lot of asteroids. Both have no atmosphere, so there is little weathering and erosion. If they had an atmosphere, many of the craters would have been eroded away. Both have no plate tectonics to transform the landscape. This would also remove a lot of craters.

Mercury

Mercury is the smallest planet. It has no moon. It is also the planet closest to the Sun. Pictured below is the surface of Mercury covered with craters (**Figure** below), like Earth's Moon. Many of the impact craters are billions of years old. This means that Mercury hasn't changed much geologically for billions of years. It has no plate tectonics. With only a trace of an atmosphere, it has no weather to wear down the ancient craters.



The surface of Mercury is covered with craters, like Earth's Moon.

Exploring Mercury

Because Mercury is so close to the Sun, it is difficult to observe from Earth, even with a telescope. The Mariner 10 spacecraft did a flyby of Mercury in 1974–1975. In 2004, the MESSENGER mission left Earth. On its way to Mercury, it did one flyby of Earth, two of Venus, and three of Mercury. In March 2011, MESSENGER became the first spacecraft to enter an orbit around Mercury. To date, MESSENGER has taken over 100,000 images and has revealed many interesting features of the planet's interior.

Short Year, Long Days

Mercury is named for the Roman messenger god. Mercury was a messenger because he could run extremely fast. The Greeks gave the planet this name because Mercury moves very quickly in its orbit around the Sun. Mercury orbits the Sun in just 88 Earth days. Mercury has a very short year, but it also has very long days. Mercury rotates slowly on its axis, turning exactly three times for every two times it orbits the Sun. Therefore, each day on Mercury is 58 Earth days long.

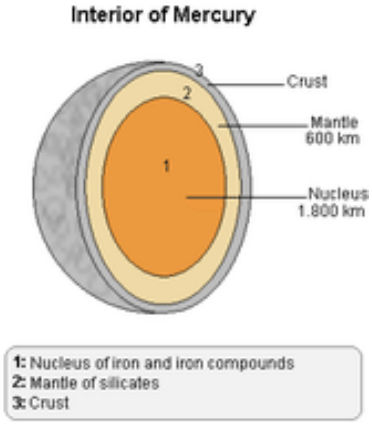
CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Extreme Temperatures

Mercury is very close to the Sun, so it can get very hot. Mercury also has virtually no atmosphere. Since the planet rotates very slowly, the temperature varies tremendously. In direct sunlight, the surface can be as hot as 427°C (801°F). On the dark side, the surface can be as cold as –183°C (–297°F)! The coldest temperatures may be on the insides of craters. Most of Mercury is extremely dry. Scientists think that there may be a small amount of water, in the form of ice, at the planet's poles. The poles never receive direct sunlight.

A Liquid Metal Core

Pictured below is a diagram of Mercury's interior (**Figure** below). Mercury is one of the densest planets. Scientists think that the interior contains a large core made mostly of melted iron. The inner core may be solid, however. Mercury's core takes up about 85% of the planet's radius.



Mercury is one of the most dense planets, with a very large core.

Summary

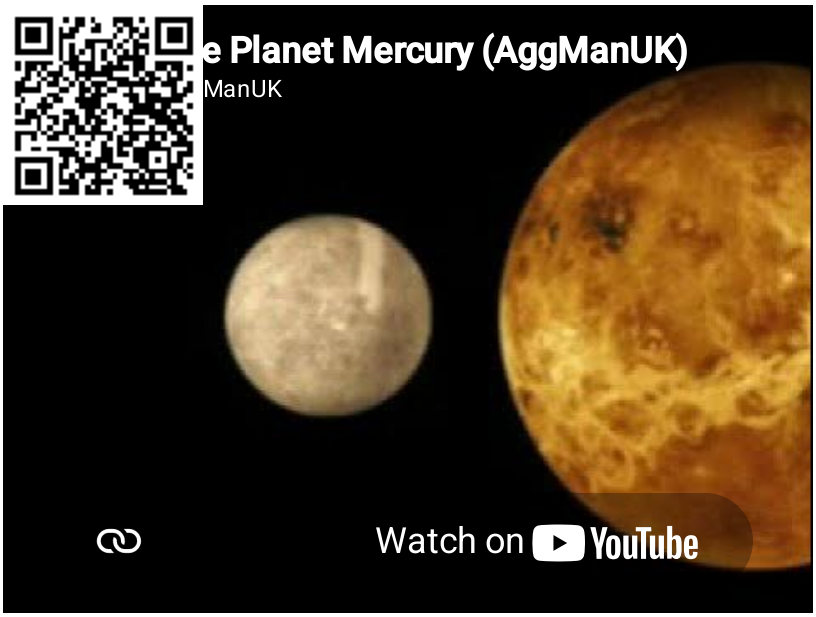
- Mercury appears to be moving rapidly because it's so close to the Sun.
- Mercury has short years, just 88 Earth days. Mercury has long days, about 57 Earth days.
- Mercury is extremely hot and has a liquid metal core.

Review

1. Why is a year on Mercury only 88 days long?
2. Why is Mercury mostly really hot?
3. Why does Mercury have so many craters?

Explore More

Use the resource below to answer the questions that follow.



1. What probe was sent to Mercury?
2. How does Mercury compare in size to the other planets?
3. What is the composition of Mercury?
4. What is the possible explanation for why Mercury has such a large core?
5. Describe the temperature variations on Mercury.
6. How long does a day last on Mercury, measured in Earth days?
7. What is the evidence of volcanic activity on Mercury? What was the origin of that activity?
8. Why do scientists think there may be ice on Mercury?
9. Why can't the Hubble Space Telescope be used to view Mercury?

This page titled 22.11: Mercury is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.12: Venus



What's beneath Venus's clouds?

This image was produced by the Magellan probe on a flyby. Radar waves sent by the spacecraft reveal mountains, valleys, vast lava plains, and canyons. The colors are not real. They enhance the features so we can better see them.

Venus

Named after the Roman goddess of love, Venus is the only planet named after a female. **Venus** is sometimes called Earth's "sister planet." Venus is our nearest neighbor and is most like Earth in size. But Venus is a lot different from Earth. Earth's life would not find the planet very hospitable at all.

A Harsh Environment

Viewed through a telescope, Venus looks smooth and featureless. The planet is covered by a thick layer of clouds. You can see the clouds in pictures of Venus (**Figure** below).



Venus in real color. The planet is covered by a thick layer of clouds.

We make maps of the surface using radar because the thick clouds won't allow us to take photographs of the surface of Venus. This is shown in the first image at the top.

Atmosphere

Clouds on Earth are made of water vapor. Venus's clouds are a lot less pleasant. They are made of carbon dioxide, sulfur dioxide, and large amounts of corrosive sulfuric acid! Scientists think the color of sunlight on Venus is reddish-brown.

The atmosphere of Venus is so thick that the pressure on the surface of Venus is very high. In fact, it is 90 times greater than the pressure at Earth's surface! The thick atmosphere causes a strong greenhouse effect. As a result, Venus is the hottest planet. Even

though it is farther from the Sun, Venus is even much hotter than Mercury. Temperatures at the surface reach 465°C (860°F). That's hot enough to melt lead!

Surface

The surface of Venus is shrouded by thick clouds. Radar images show a complex surface. There are volcanoes and craters like those found on other planets and moons. The surface is not nearly as complex as the surface of Earth.

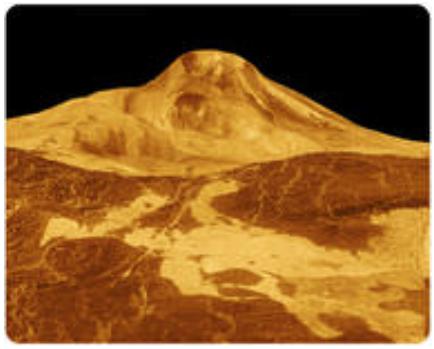
Craters

There are a large number of craters on Venus. However, there are not nearly as many as on Mercury or the Moon. So the planet's surface must be fairly young. This suggests that the planet experiences volcanism and has a hot interior.

Volcanoes

Venus has more volcanoes than any other planet. There are between 100,000 and one million volcanoes on Venus! Most of the volcanoes are now inactive.

Pictured below is an image made using radar data (**Figure** below). The volcano is Maat Mons. Lava beds are in the foreground.



Radar image of the Maat Mons volcano on Venus with lava beds in the foreground.

Motion and Appearance

Venus is the only planet that rotates clockwise as viewed from its North Pole. All of the other planets rotate counterclockwise. Venus turns slowly, making only one turn every 243 days. This is longer than a year on Venus! It takes Venus only 225 days to orbit the Sun.

Because the orbit of Venus is inside Earth's orbit, Venus always appears close to the Sun. You can see Venus rising early in the morning, just before the Sun rises (**Figure** below). For this reason, Venus is sometimes called "the morning star." When it sets in the evening, just after the Sun sets, it may be called "the evening star." Since planets only reflect the Sun's light, Venus should not be called a star at all! Venus is very bright because its clouds reflect sunlight very well. Venus is the brightest object in the sky besides the Sun and the Moon.



Venus (right) and the Moon (left) just before sunrise.

Like Mercury, but unlike Earth, Venus does not have a moon.

Summary

- Venus has a very thick, toxic atmosphere.
- Venus has lot of carbon dioxide in the atmosphere. The atmosphere has a very strong greenhouse effect and therefore traps a lot of heat.
- Venus has fewer impact craters than Mercury or the Moon. Venus has a lot of volcanoes, including some very large ones.

Review

1. Why does Venus have such a large greenhouse effect?
2. There are fewer impact craters on Venus than on nearby Mercury. What does this tell scientists about the differences between these two planets?
3. Why is Venus called the morning or evening star?

Explore More

Use the resource below to answer the questions that follow.



1. How long is a day on Venus in Earth days? How many Earth days make a Venusian year?
2. How is Venus similar to Earth?
3. Does Venus have plate tectonics? Why or why not?
4. Describe Venus' atmospheric composition.
5. What is the average temperature of Venus? Why is this the case?
6. What is the composition of the rain on Venus?
7. Why does Venus appear so bright to us?
8. Describe the conditions on Venus' surface.
9. What is Sif Mons? Is this something that currently happens all over Venus?
10. How long would a probe last on Venus?
11. What country successfully landed probes on Venus? (Amazingly, this probe lasted about 2 hours.)

This page titled 22.12: Venus is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.13: Moon



Would you like to go on this field trip?

The most amazing "field trips" in human history took place in the Apollo program. Between 1969 and 1972, six manned spaceships landed on the Moon. Human astronauts walked on the Moon. They brought back soil and rock samples. No human has visited Earth's satellite since 1972. There is talk of someday returning, but there are no concrete plans.

Earth's Moon

The Moon is Earth's only natural satellite. The Moon is about one-fourth the size of Earth, 3,476 kilometers in diameter. Gravity on the Moon is only one-sixth as strong as it is on Earth. If you weigh 120 pounds on Earth, you would weigh only 20 pounds on the Moon. You can jump six times as high on the Moon as you can on Earth. The Moon makes no light of its own. Like every other body in the solar system, it only reflects light from the Sun.

Orbit

The Moon rotates on its axis once for every orbit it makes around Earth. What does this mean? This means that the same side of the Moon always faces Earth. The side of the Moon that always faces Earth is called the near side. The side of the Moon that always faces away from Earth is called the far side. From Earth, people have seen only the Moon's near side. The far side has been seen only by spacecraft and Apollo astronauts.

Atmosphere

The Moon has no atmosphere. With no atmosphere, the Moon is not protected from extreme temperatures. The average surface temperature during the day is approximately 107°C (225°F). Daytime temperatures can reach as high as 123°C (253°F). At night, the average temperature drops to -153°C (-243°F). The lowest temperatures measured are as low as -233°C (-397°F).

Lunar Surface

We all know what the Moon looks like. It's always looked the same during our lifetime. In fact, the Moon has looked the same to every person who has looked up at it for all time. Even the dinosaurs, trilobites, or cyanobacteria, should they have looked up at it, would have seen more-or-less the same thing. This is not true of Earth. Natural processes continually alter Earth's surface. Without these processes, would Earth's surface resemble the Moon's? The Moon does have more craters than it did in the long distant past, of course.

Even though we can't see it from Earth, the Moon has changed recently too. Astronauts' footprints are now on the Moon. They will remain unchanged for thousands of years, because there is no wind, rain, or living thing to disturb them. A falling meteorite could destroy them. Tiny micrometeorites bombard the Moon's surface and smooth it over time too.

Craters

The surface of the Moon is very different from Earth. The lunar landscape is covered by **craters** caused by meteoroid impacts (**Figure** below). (**Lunar** means relating to the Moon.) The craters are bowl-shaped basins on the Moon's surface. Because the

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Moon has no water, wind, or weather, the craters remain unchanged.

The Moon's coldest temperatures are found deep in the craters. The coldest craters are at the south pole on the Moon's far side. The Sun never shines on the bottoms of the deepest craters. These temperatures are amongst the coldest in our entire solar system.



Craters, like the one shown in this image, are found on the surface of the Moon.

Maria

When you look at the Moon from Earth, you notice dark and light areas. The **maria** are dark, solid, flat areas of lava (mostly basalt). Maria cover around 16% of the Moon's surface, mostly on the near side. The maria formed about 3.0 to 4.0 billion years ago, when the Moon was continually bombarded by meteoroids (**Figure** below). Large meteorites broke through the Moon's newly formed surface. This eventually caused magma to flow out and fill the craters. Scientists estimate volcanic activity on the Moon ended about 1.2 billion years ago.

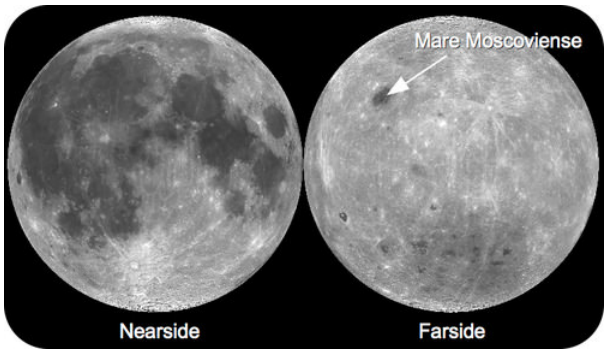


Maria (the dark areas) and terrae (the light areas) cover the Moon.

Terrae

The lighter parts on the Moon are called **terrae**, or highlands (**Figure** above). They are higher than the maria and include several high mountain ranges. The rock that makes up the highlands is composed mostly of feldspar, which is lighter in color and crystallized more slowly than the maria. The rock looks light because it reflects more of the Sun's light.

The figure below shows the near and far sides of the Moon (**Figure** below). They are different!



The Mare Moscoviense is one of the few maria, or dark, flat areas, on the far side.

The rocks of the terrae formed while the lunar magma ocean cooled just after the Moon formed. The maria formed later.

Water

There are no lakes, rivers, or even small puddles anywhere to be found on the Moon's surface. There is no running water and no atmosphere. This means that there is no erosion. Natural processes continually alter Earth's surface. Without these processes, our planet's surface would be covered with meteorite craters just like the Moon. Many moons in our solar system have cratered surfaces.

NASA scientists have discovered a large number of water molecules mixed in with lunar dirt. There is also surface water ice in some of the frigid places that are always in shadow. Even though there is a very small amount of water, there is no atmosphere. Temperatures are extreme. So it comes as no surprise that there has not been evidence of life on the Moon.

Lunar Interior

Like Earth, the Moon has a distinct crust, mantle, and core. The crust is composed of igneous rock. This rock is rich in the elements oxygen, silicon, magnesium, and aluminum. On the near side, the Moon's crust is about 30 kilometers thick. On the far side, the crust is about 100 kilometers thick. The mantle is made of rock like Earth's upper mantle. The Moon has a small metallic core, perhaps 300 to 500 kilometers in diameter. The composition of the core is probably mostly iron with some sulfur and nickel. We learned this both from the rock samples gathered by astronauts and from spacecraft sent to the Moon.

Exploration

Humans have walked on only two planetary bodies: Earth and the Moon. The footprints the men left behind are the first signs of life ever on the Moon. Scientists learned a great deal about the Moon from the Apollo missions. The samples that were brought back have been studied in laboratories. We know an incredible amount about the Moon because of these samples. Having these rocks radically changed our thinking about the Moon.

The Moon is easily seen from Earth. Early astronomers used telescopes to study and map its surface. The Moon has also seen a great number of satellites, rovers, and orbiters. After all, it is now relatively easy to get spacecraft to the satellite. Also, before humans could be safely sent to the Moon, many studies and experiments had to be completed.

Summary

- The Moon revolves around Earth as they orbit the Sun. The same side of Moon always faces Earth.
- The lunar surface has dark basalt maria. The light highlands are called terrae.
- The Moon has a crust, mantle, and core.
- The Moon has no atmosphere and only a very tiny amount of water.

Review

1. Why do we only see one side of the Moon from Earth?
2. What are the Moon's terrae like in structure and rock type?
3. How did the maria form?
4. In what form is water found on the Moon? In what form is it not found on the Moon?

Explore More

Use the resource below to answer the questions that follow.



1. What is the Moon?
2. How far is the Moon from Earth? Where will it be relative to its current location 100 years from now?
3. What did Galileo prove about the Moon? How did he do that?
4. Where did the Moon come from?
5. What is the Moon like relative to Earth?
6. Why do we always see the same side of the Moon?
7. Describe the Moon's structure.
8. What are maria?
9. What are terrae?
10. What created the craters on the Moon?
11. If a small meteor went toward the Moon's surface and one the same size went toward Earth's surface, which would actually reach the surface and why?
12. If there is water on the Moon, how did it get there and where is it?
13. What is an eclipse?
14. What is a lunar eclipse?
15. What is a total solar eclipse?
16. Why is the Moon unique?
17. Who was the first person on the Moon?

This page titled 22.13: Moon is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.14: Mars



How do we get such incredible views of other planets?

Mars is close, and it's not obscured by its atmosphere like Venus is. The Hubble Space Telescope took this incredible photo of Mars. This is a true color photo; the red is soil, the white is the polar ice cap, the dark is basalt. Mars has many features like Earth's, but Mars is missing one very important feature: an ocean.

Mars

Mars is the fourth planet from the Sun. The Red Planet is the first planet beyond Earth's orbit.

Mars' atmosphere is thin compared to Earth's. This means that there is much lower pressure at the surface. Mars's greenhouse effect is also weak, so temperatures are only slightly higher than they would be if the planet did not have an atmosphere. The Martian climate is most like Earth's of any planet in the solar system.

Exploration

Mars is the easiest planet to observe. As a result, it has been studied more than any other planet besides Earth. People can stand on Earth and observe the planet through a telescope. We have also sent many space probes to Mars. A car-sized robotic rover, Curiosity, arrived on the Red Planet in August 2012. Curiosity joins Opportunity, which has been active since 2004.

No humans have ever set foot on Mars. NASA and the European Space Agency have plans to send people to Mars. The goal is to do it sometime between 2030 and 2040. The expense and danger of these missions are phenomenal.



Surface Features

Mars has mountains, canyons, and other features similar to Earth. But it doesn't have as much geological activity as Earth. There is no evidence of plate tectonics on Mars. There are also more craters on Mars than on Earth. But there are fewer craters than on the

Moon. What does this suggest to you regarding Mars' tectonic history? Pictured below is an image of the Martian surface (**Figure** below).



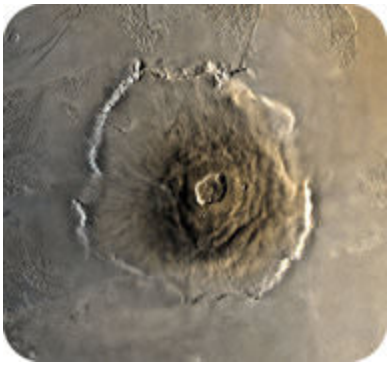
Mars is Earth's second nearest neighbor planet.

A Red Planet

Viewed from Earth, Mars is red. This is due to large amounts of iron in the soil. The ancient Greeks and Romans named the planet Mars after the god of war because the planet's red color reminded them of blood. Mars has only a very thin atmosphere made up mostly of carbon dioxide.

Volcanoes

Mars is home to the largest volcano in the solar system: Olympus Mons (**Figure** below). Olympus Mons is a shield volcano. The volcano is similar to the volcanoes of the Hawaiian Islands. But Olympus Mons is a giant, about 27 km (16.8 miles; 88,580 ft) tall. That's three times taller than Mount Everest! At its base, Olympus Mons is about the size of the entire state of Arizona, about 624 km (374 miles) across.



The largest volcano in the solar system, Olympus Mons.

Canyons

Mars also has the largest canyon in the solar system, Valles Marineris (**Figure** below). This canyon is 4,000 km (2,500 miles) long. That's as long as Europe is wide! One-fifth of the circumference of Mars is covered by the canyon. Valles Marineris is 7 km (4.3 miles) deep. How about Earth's Grand Canyon? Earth's most famous canyon is only 446 km (277 miles) long and about 2 km (1.2 miles) deep. Valles Marineris is thought to be a tectonic crack in the Martian crust.



The largest canyon in the solar system, Valles Marineris

Is There Water on Mars?

Water on Mars has been a fascinating topic in recent years. Scientists had thought that Mars could not have liquid water because the pressure of the atmosphere is too low. By searching images from orbiters, they have discovered hydrated salts, which indicate the presence of liquid water. They also found dark streaks going down hills that lengthen during summer and fade in winter. The streaks are caused by water that flows downhill in summer and freezes in winter.

The planet has much more solid water than liquid water. The south pole of Mars has a very visible ice cap. Scientists also have evidence that there is also a lot of ice just under the Martian surface. The ice melts when volcanoes erupt. At these times liquid water flows across the surface.

The rover has found evidence of a flowing stream on Mars. Layers of smooth, water-polished pebbles have been photographed. This is exactly what you would see in a stream on Earth. There are many surface features that look like water-eroded canyons. Since there is and was liquid water on Mars, scientists think that life might have existed there in the past. It is possible for very simple lifeforms to exist there now! One of Curiosity's tasks is to sample the soil to search for carbon and other evidence of life.

Two Martian Moons

Mars has two very small, irregular moons, Phobos (**Figure** below) and Deimos. These moons were discovered in 1877. They are named after the two sons of Ares, who followed their father into war. The moons were probably asteroids that were captured by Martian gravity.



Phobos is Mars' larger moon. It has a radius of 11.1 km (6.9 miles).

Summary

- Mars is the easiest planet to study because it doesn't have thick clouds obscuring its surface. It is also close to Earth.
- The surface of Mars has volcanoes and canyons. There is a polar ice cap and channels that were once filled with water. Curiosity has found evidence of a flowing stream.
- Mars has two moons that are thought to be captured asteroids.

Review

1. Why is Mars red?
2. What is the evidence that Mars once had flowing liquid water? Why is this important?
3. Describe the major surface features of Mars.
4. What is the likely origin of the two moons orbiting Mars?

Explore More

Use the resource below to answer the questions that follow.



1. What is the diameter of Mars? How does it compare relative to Earth's diameter?
2. If you weigh 100 pounds on Earth, what will you weigh on Mars?
3. What is primary component of Mars' atmosphere?
4. Why is Mars red?
5. What does the absence of plate tectonics on Mars mean?
6. What type of volcano is Olympus Mons? Why is it so big?
7. What is Valles Marineris? How do you think the valley might have formed?
8. If snow can form in the Martian atmosphere, why isn't snow seen on the surface of Mars?
9. Why aren't the Dust Devils dangerous on Mars?

This page titled 22.14: Mars is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.15: The Solar System- Challenge 3

1. The outer planets are ___.

Jupiter, Saturn, Uranus, and Neptune

2. The inner planets are ___.

Mercury, Venus, Earth, and Mars

3. Compared to Earth, Mercury has ___ years and ___ days.

short; long

4. Mercury's large core is mostly liquid ___.

iron

5. Mercury is ___ because it has such a large core.

dense

6. Venus is sometimes referred to as the ___.

Morning Star

7. Surface temperatures on Venus reach up to ___.

465 degrees Celsius

8. The atmospheric pressure on Venus is ___ times greater than the atmospheric pressure on Earth.

90

9. The dark areas of the Moon are called ___.

maria

10. The footprints of astronauts on the Moon cannot be erased by weathering and erosion, but a ___ could destroy them.

meteorite impact

11. Maria cover about ___ percent of the Moon's surface.

16

12. Mars is nicknamed the Red Planet because of the ___ in its soil.

iron oxide

13. Water cannot stay in liquid form for long on Mars because ___.

the atmospheric pressure is too low

14. Mars has ___ moons, named ___ and ___.

two; Phobos; Deimos

This page titled 22.15: The Solar System- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.16: Jupiter



What are Jupiter's most distinctive features?

Jupiter has been studied well for being so far away. Many flybys, one orbiter, and a probe have all visited the planet. While the possibility exists for humans to reach Mars, a manned trip to Jupiter seems a long ways away. The round trip would take at least 10 years. Who would want to spend more than a decade on a spaceship? At least they could see the Great Red Spot and other features in person!

Jupiter

Jupiter is the largest planet in our solar system. Jupiter is named for the king of the gods in Roman mythology. The Romans named the largest planet for their most important god. They followed the tradition of the Greeks, who had similarly named the planet Zeus. The Romans built a temple to Jupiter on a hill.

Jupiter is truly a giant! The planet has 318 times the mass of Earth, and over 1,300 times Earth’s volume. So Jupiter is much less dense than Earth. Because Jupiter is so large, it reflects a lot of sunlight. When it is visible, it is the brightest object in the night sky besides the Moon and Venus. Jupiter is quite far from Earth. The planet is more than five times as far from Earth as the Sun. It takes Jupiter about 12 Earth years to orbit once around the Sun.

A Ball of Gas and Liquid

Since Jupiter is a gas giant, could a spacecraft land on its surface? The answer is no. There is no solid surface at all! Jupiter is made mostly of hydrogen, with some helium, and small amounts of other elements. The outer layers of the planet are gas. Deeper within the planet, the intense pressure condenses the gases into a liquid. Jupiter may have a small rocky core at its center.

A Stormy Atmosphere

Jupiter's atmosphere is unlike any other in the solar system! The upper layer contains clouds of ammonia. The ammonia is different colored bands. These bands rotate around the planet. The ammonia also swirls around in tremendous storms. The **Great Red Spot** (**Figure** below) is Jupiter's most noticeable feature. The spot is an enormous, oval-shaped storm. It is more than three times as wide as Earth! Clouds in the storm rotate counterclockwise. They make one complete turn every six days or so. The Great Red Spot has been on Jupiter for at least 300 years. It may have been observed as early as 1664. It is possible that this storm is a permanent feature on Jupiter. No one knows for sure.



The Great Red Spot has been on Jupiter since we've had telescopes powerful enough to see it.

Moons and Rings

Jupiter has lots of moons. As of 2012, we have discovered over 66 natural satellites of Jupiter. Four are big enough and bright enough to be seen from Earth using a pair of binoculars. These four moons were first discovered by Galileo in 1610. They are called the **Galilean moons**. The figure below shows the four Galilean moons and their sizes relative to each other (**Figure** below). These moons are named Io, Europa, Ganymede, and Callisto. The Galilean moons are larger than even the biggest dwarf planets, Pluto and Eris. Ganymede is the biggest moon in the solar system. It is even larger than the planet Mercury!



The Galilean moons are as large as small planets.

Scientists think that Europa is a good place to look for extraterrestrial life. Europa is the smallest of the Galilean moons. The moon's surface is a smooth layer of ice. Scientists think that the ice may sit on top of an ocean of liquid water. How could Europa have liquid water when it is so far from the Sun? Europa is heated by Jupiter. Jupiter's tidal forces are so great that they stretch and squash its moon. This could produce enough heat for there to be liquid water. Numerous missions have been planned to explore Europa, including plans to drill through the ice and send a probe into the ocean. However, no such mission has yet been attempted.

Photos from the Voyager missions showed that Jupiter has a ring system. This ring system is very faint, so it is very difficult to observe from Earth.

Exploration

Jupiter has fascinated scientists at least since Galileo turned his first telescope on the planet. In 1979, two spacecrafts, Voyager 1 and Voyager 2, visited Jupiter and its moons. The Galileo orbiter orbited the planet for seven years and flew by all of the Galilean moons plus one other moon. The orbiter released a probe to study the planet's atmosphere. Missions to Jupiter are presently underway. Juno arrived in late 2016.

Summary

- Jupiter is mostly hydrogen with some helium, and may contain a small rocky core.
- Jupiter has a thick atmosphere. The Great Red Spot is a storm that has been going for at least 300 years.
- One of Jupiter's moons, Europa, appears to have a liquid ocean beneath the surface. This ocean could be a place for life.

Review

1. Why is the Great Red Spot thought to be a storm? How could scientists know that it's been going on for at least 300 years?
2. What is Jupiter made of? Why couldn't a spacecraft land on its surface?
3. Why does Europa have a liquid ocean? Why do scientists think that Europa could have life?

Explore More

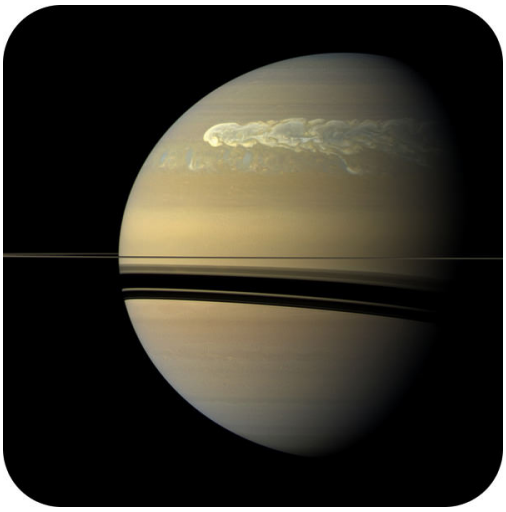
Use the resource below to answer the questions that follow.



1. How long does Jupiter take to orbit the Sun? Why so long?
2. How does the mass of Jupiter compare to Earth's?
3. How long is one day on Jupiter?
4. What makes the different bands on the planet?
5. Why is the Giant Red Spot red?
6. What is happening to the Giant Red Spot?
7. What two elements make up the majority of Jupiter? Why is this important?
8. What happened to the Comet Shoemaker-Levy 9?
9. How many moons does Jupiter have?
10. Describe Jupiter's ring system. How did it form?
11. What causes the auroras on Jupiter?

This page titled 22.16: Jupiter is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.17: Saturn



If you could take a trip to Saturn, what would you see?

This storm was captured by the Cassini spacecraft. It was the most intense storm seen on Saturn since Cassini began orbiting Saturn eight years ago. The storm went on for several weeks. Of course, a human orbiting Saturn might be most fascinated by the planet's beautiful rings.

Saturn

Saturn is the second largest planet in the solar system (**Figure** below). Saturn's mass is about 95 times Earth's mass. The gas giant is 755 times Earth's volume. Despite its large size, Saturn is the least dense planet in our solar system. Saturn is actually less dense than water. This means that if there were a bathtub big enough, Saturn would float! In Roman mythology, Saturn was the father of Jupiter. Saturn orbits the Sun once about every 30 Earth years.



Saturn is the least dense planet in our solar system.

Composition

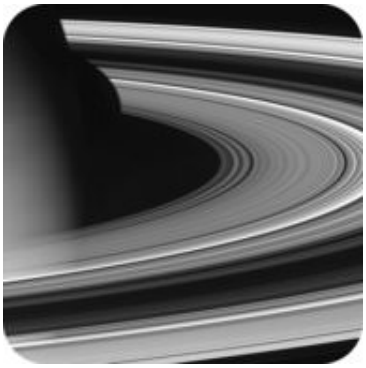
Saturn's composition is similar to Jupiter's. The planet is made mostly of hydrogen and helium. These elements are gases in the outer layers and liquids in the deeper layers. Saturn may also have a small solid core. Saturn's upper atmosphere has clouds in bands of different colors. These clouds rotate rapidly around the planet. But Saturn has fewer storms than Jupiter. Thunder and lightning have been seen in the storms on Saturn.

Rings

Saturn's rings were first observed by Galileo in 1610. Remember that his telescope was not very good. He didn't know they were rings and thought that they were two large moons. One moon was on either side of the planet. In 1659, the Dutch astronomer

Christiaan Huygens realized that they were rings circling Saturn's equator. The rings appear tilted. This is because Saturn is tilted about 27 degrees to its side.

The Voyager 1 spacecraft visited Saturn in 1980. Voyager 2 followed in 1981. These probes sent back detailed pictures of Saturn, its rings, and some of its moons (**Figure** below). From the Voyager data, we learned what Saturn's rings are made of. They are particles of water and ice with a little bit of dust. There are several gaps in the rings. These gaps were cleared out by moons within the rings. Gravity attracts dust and gas to the moon from the ring. This leaves a gap in the rings. Other gaps in the rings are caused by the competing forces of Saturn and its moons outside the rings.



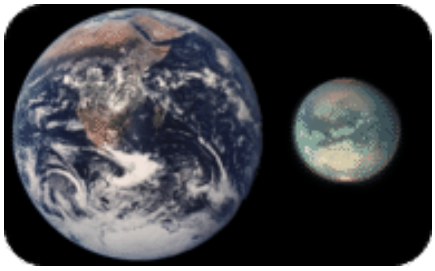
The rings of Saturn.

Scientists think that there are two possibilities for how Saturn's rings formed. One possibility is by the breakup of one of Saturn's moons. The other possibility is from material that never made it into the planet when Saturn originally formed.

Moons

As of 2012, 62 natural moons have been identified around Saturn. Only seven of Saturn's moons are spherical. All but one is smaller than Earth's moon. Some of the very small moons are found within the rings. All the particles in the rings are like little moons, because they orbit around Saturn. Someone must decide which ones are large enough to call moons.

Saturn's largest moon, Titan, is about one and a half times the size of Earth's moon. Titan is even larger than the planet Mercury. The picture below compares the size of Titan to Earth (**Figure** below). Scientists are very interested in Titan. The moon has an atmosphere that is thought to be like Earth's first atmosphere with nitrogen and methane. This atmosphere was around before life developed on Earth. Like Jupiter's moon, Europa, Titan may have a layer of liquid water under a layer of ice. Scientists now think that there are lakes on Titan's surface. Don't take a dip, though. These lakes contain liquid methane and ethane instead of water! Methane and ethane are compounds found in natural gas.



This composite image compares Saturn's largest moon, Titan (right), to Earth (left).

Summary

- Like Jupiter, Saturn is made of hydrogen and helium.
- Saturn's rings are composed of water and ice, with some dust and rock.
- Saturn's moon Titan is interesting to scientists because of its composition and liquid ocean.

Review

1. Describe Saturn's rings. How did they form?
2. Why could Saturn float in a giant bathtub?
3. What features exist on Titan that suggest that there could be life?

Explore More

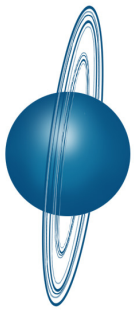
Use the resource below to answer the questions that follow.



1. What is the density of Saturn? Why is this unique?
2. What is interesting about Saturn's temperature, and what does this mean?
3. What did Cassini discover about Saturn?
4. Explain the two ideas about how Saturn got its rings.
5. What are shepherds?
6. What is the Hexagon storm?

This page titled 22.17: Saturn is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.18: Uranus



What is this blue ball?

Uranus is so far away that there has been relatively little exploration of the planet. The closest approach was a flyby by Voyager 2 in 1986. Great images have also been taken by the Hubble Space Telescope.

Uranus

Uranus is named for the Greek god of the sky, the father of Saturn. Astronomers pronounce the name "YOOR-uh-nuhs." Uranus was not known to ancient observers. The planet was first discovered with a telescope by the astronomer William Herschel in 1781.

Uranus is faint because it is very far away. Its distance from the Sun is 2.8 billion kilometers (1.8 billion miles). A photon from the Sun takes about 2 hours and 40 minutes to reach Uranus. Uranus orbits the Sun once about every 84 Earth years.

An Icy Blue-Green Ball

Uranus is a lot like Jupiter and Saturn. The planet is composed in part of hydrogen and helium. There is a thick layer of gas on the outside. Farther on the inside is liquid. But Uranus has a higher percentage of icy materials than Jupiter and Saturn. These materials include water, ammonia, and methane. Uranus is also different because of its blue-green color. Clouds of methane filter out red light. This leaves a blue-green color. The atmosphere of Uranus has bands of clouds. These clouds are hard to see in normal light. The result is that the planet looks like a plain blue ball.

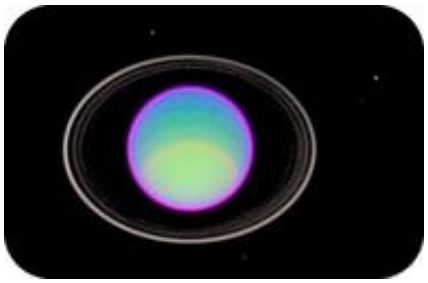
Uranus is the least massive outer planet. Its mass is only about 14 times the mass of Earth. Like all of the outer planets, Uranus is much less dense than Earth. Gravity is actually weaker than on Earth's surface. If you were at the top of the clouds on Uranus, you would weigh about 10 percent less than what you weigh on Earth.

The Sideways Planet

All of the planets rotate on their axes in the same direction that they move around the Sun. Except for Uranus. Uranus is tilted on its side. Its axis is almost parallel to its orbit. So Uranus rolls along like a bowling ball as it revolves around the Sun. How did Uranus get this way? Scientists think that the planet was struck and knocked over by another planet-sized object. This collision probably took place billions of years ago.

Rings and Moons of Uranus

Uranus has a faint system of rings (**Figure** below). The rings circle the planet's equator. However, Uranus is tilted on its side. So the rings are almost perpendicular to the planet's orbit.



This image from the Hubble Space Telescope uses infrared light filters to show the faint rings of Uranus.

We have discovered 27 moons around Uranus. All but a few are named for characters from the plays of William Shakespeare. The five largest moons of Uranus, Miranda, Ariel, Umbriel, Titania, and Oberon, are pictured below (**Figure** below).



The five biggest moons of Uranus: Miranda, Ariel, Umbriel, Titania, and Oberon.

Summary

- Uranus is composed of hydrogen and helium. Methane clouds filter red light and give the planet a blue-green color.
- The rotational axis of Uranus is tilted almost parallel to its orbit.
- Uranus has rings that are nearly perpendicular to the planet's orbit.

Review

1. Why is Uranus an icy blue color?
2. How did Uranus come to be tilted on its side?
3. How are the rings of Uranus oriented?

Explore More

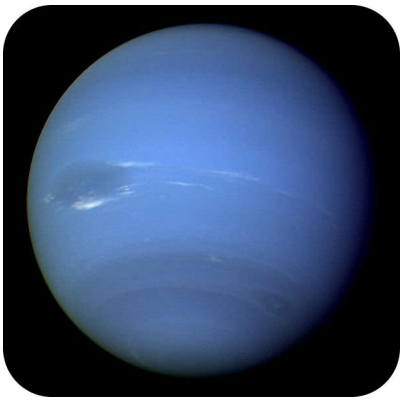
Use the resource below to answer the questions that follow.



1. When and by whom was Uranus discovered?
2. How long does it take Uranus to orbit the Sun?
3. How does Uranus differ from the other large planets?
4. Why does Uranus appear blue-green?
5. How does Uranus' composition differ from the composition of Jupiter and Saturn?
6. Describe the axis of Uranus.
7. How were Uranus' rings discovered?
8. How many rings does Uranus have?

This page titled 22.18: Uranus is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.19: Neptune

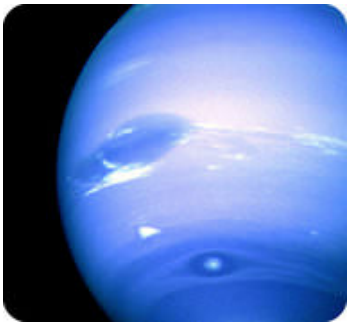


Does this photo give you an idea of how Neptune got its name?

Because of its blue color, Neptune was named for the Roman god of the sea. The blue is not a planetary ocean though!

Neptune

Neptune (**Figure** below) is the eighth planet from the Sun. Neptune is so far away you need a telescope to see it from Earth. Neptune is the most distant planet in our solar system. It is nearly 4.5 billion kilometers (2.8 billion miles) from the Sun. One orbit around the Sun takes Neptune 165 Earth years.



Neptune has a great dark spot at the center left and a small dark spot at the bottom center.

Discovery

Scientists guessed Neptune's existence before it was discovered. Uranus did not always appear exactly where it should. They said this was because a planet beyond Uranus was pulling on it. This gravitational pull was affecting its orbit. Neptune was discovered in 1846. It was just where scientists predicted it would be!

Uranus and Neptune are often considered “sister planets.” They are very similar to each other. Neptune has slightly more mass than Uranus, but it is slightly smaller in size.

Extremes of Cold and Wind

Like Uranus, Neptune is blue. The blue color is caused by gases in its atmosphere, including methane. Neptune is not a smooth looking ball like Uranus. The planet has a few darker and lighter spots. When Voyager 2 visited Neptune in 1986, there was a large dark-blue spot south of the equator. This spot was called the Great Dark Spot. When the Hubble Space Telescope photographed Neptune in 1994, the Great Dark Spot had disappeared. Another dark spot had appeared north of the equator. Astronomers believe that both of these spots represent gaps in the methane clouds on Neptune.

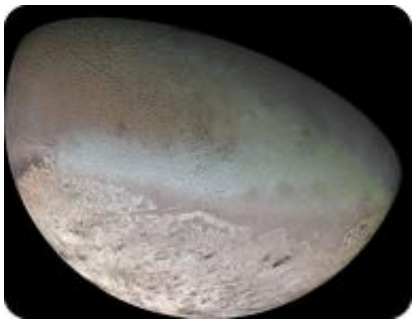
Neptune's appearance changes due to its turbulent atmosphere. Winds are stronger there than on any other planet in the solar system. Wind speeds can reach 1,100 km/h (700 mph). This is close to the speed of sound! The rapid winds surprised astronomers.

This is because Neptune receives little energy from the Sun to power weather systems. It is not surprising that Neptune is one of the coldest places in the solar system. Temperatures at the top of the clouds are about –218°C (–360°F).

Neptune's Rings and Moons

Like the other outer planets, Neptune has rings of ice and dust. These rings are much thinner and fainter than Saturn's. Neptune's rings may be unstable. They may change or disappear in a relatively short time.

Neptune has 13 known moons. Only Triton (**Figure** below) has enough mass to be round. Triton orbits in the direction opposite Neptune's orbit. Scientists think Triton did not form around Neptune. The satellite was captured by Neptune's gravity as it passed by.



Neptune's moon, Triton.

Summary

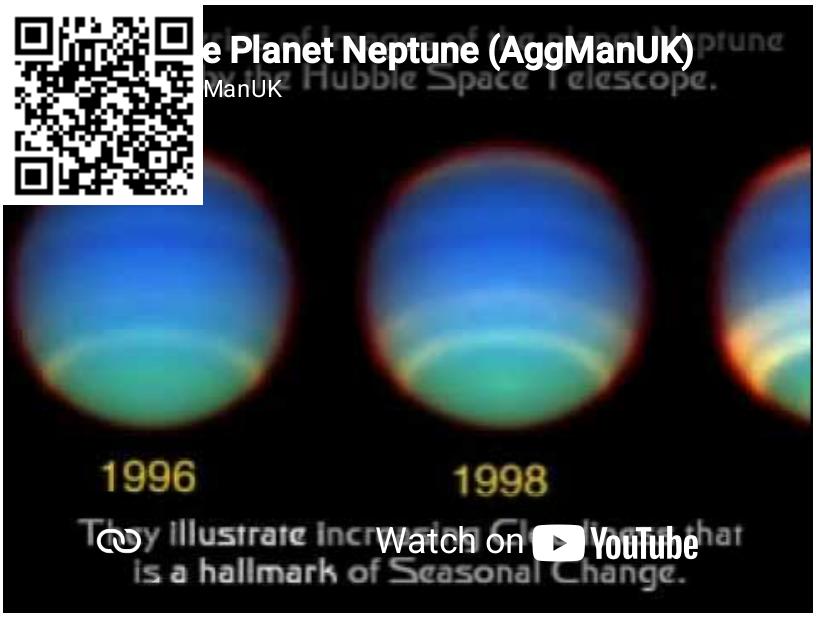
- Neptune is so far from Earth that it can't be seen without a telescope.
- Neptune has a turbulent atmosphere. The turbulence changes the planet's appearance. The blue color is due to frozen methane.
- Neptune has 13 moons, including Triton. Triton orbits in the opposite direction from Neptune.

Review

1. How was Neptune discovered?
2. Why is the wind so fast? Why are the tops of the clouds so cold?
3. What is the origin of Neptune's moon Triton?

Explore More

Use the resource below to answer the questions that follow.



1. Explain how Neptune was discovered.
2. How many moons does Neptune have?
3. Why is Triton unique?
4. How cold is Neptune at the surface of its clouds?
5. Explain why Neptune is blue in color.
6. How long does each season last on Neptune?
7. What is the Great Dark Spot?
8. What causes the wind storms on Neptune?
9. What happened to the Great Dark Spot?
10. How many rings does Neptune have?

This page titled 22.19: Neptune is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.20: The Solar System- Challenge 4

1. Jupiter's atmosphere contains ___.

ammonia clouds in different colored bands

2. Jupiter is ___ astronomical units (AU) away from the earth.

5.2

3. The giant, oval-shaped storm on Jupiter is called ___.

the Great Red Spot

4. In Roman mythology, Saturn is the ___ of Jupiter.

father

5. ___ sent back detailed pictures of Saturn, its rings, and some of its moons in 1980.

Voyager 1

6. Saturn's mass is about ___ times greater than Earth's.

95

7. ___ first discovered Uranus.

William Herschel

8. Light from the Sun takes about ___ hours and ___ minutes to reach Uranus.

2; 40

9. The five largest moons of Uranus are ___.

Titania, Ariel, Miranda, Oberon, and Umbriel

10. The Great Dark Spot on Neptune ___.

disappears and reappears in different locations

11. Neptune's appearance changes because ___.

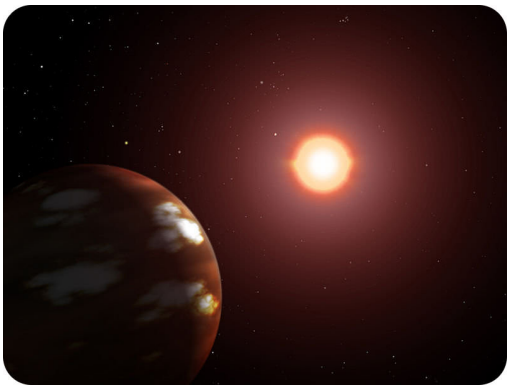
it has a turbulent atmosphere

12. ___ is Neptune's only moon with enough mass to be spherical.

Triton

This page titled 22.20: The Solar System- Challenge 4 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.21: Exoplanets



Are you surprised by exoplanets?

Scientists have always thought there had to be planets outside our solar system. They just couldn't see them. Now that there are ways to find exoplanets, it turns out that there are many of them. In this artist's depiction, the star Gliese 436 is a dwarf star and is reddish because it is cool. The planet has recently been discovered. It is the size of Neptune and orbits its star every 2.6 days.

Extrasolar Planets

Since the early 1990s, astronomers have discovered other solar systems. A solar system has one or more planets orbiting one or more stars. We call these planets “extrasolar planets,” or **exoplanets**. They are called exoplanets because they orbit a star other than the Sun. As of April 2014, more than 4,600 exoplanets have been found, with 1706 confirmed. The rate of discovery is increasing rapidly!



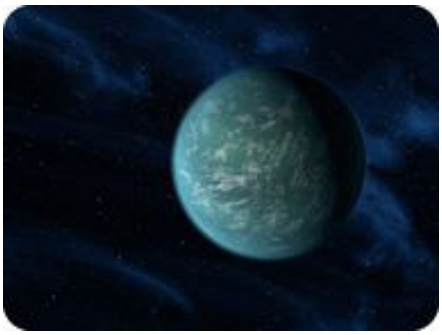
This protoplanetary disk in the Orion nebula will condense to form planets.

Exoplanets are very far away, and they are relatively tiny. So we have been able to take pictures of only a few exoplanets. Most are discovered because of some tell-tale signs. One sign is a very slight motion of a star that must be caused by the pull of a planet.

Another sign is the partial dimming of a star’s light as the planet passes in front of it.

Life

If life exists elsewhere in the Universe, it is almost certainly on an exoplanet. Which exoplanets could have life? Probably those that are most like Earth. Kepler-22b is in the Earth-zone of a Sun-like star. This means that the planet is the right distance from its star for life. The planet could have liquid water, which is necessary for life on Earth. Scientists do not know if there is life on Kepler-22b and won't for a long time. It's fun to think about though! An artist's depiction of Kepler-22b is pictured below (**Figure** below).



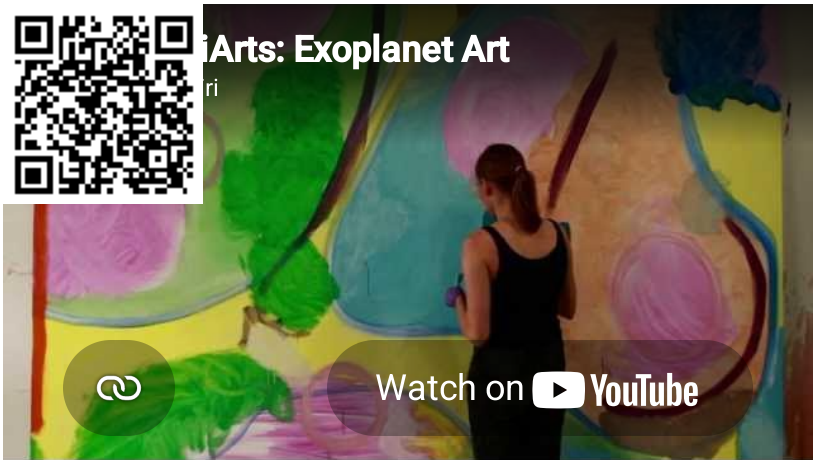
Keppler-22b. Could there be life here?



According to NASA, a statistical analysis shows that the Milky Way galaxy contains 100 million planets. That's a lot of exoplanets!

Science Friday: SciArts: Exoplanet Art

What would the sky look like from another planet? In this video by Science Friday, artist Helena Kauppila explains how she makes drawings of the night sky as seen by other planets.



Summary

- Now that scientists know how to identify extrasolar planets, the numbers of confirmed examples are increasing rapidly.
- If there is life elsewhere in the Universe, it is most likely on an Earth-like exoplanet.
- The gravitational pull of a planet may be detected in the slight motion of a star.

Review

1. What is an exoplanet?
2. Where are exoplanets located?
3. Why are exoplanets interesting to scientists? What are they looking for?

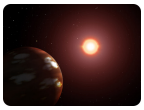
Explore More

Use the resource below to answer the questions that follow.



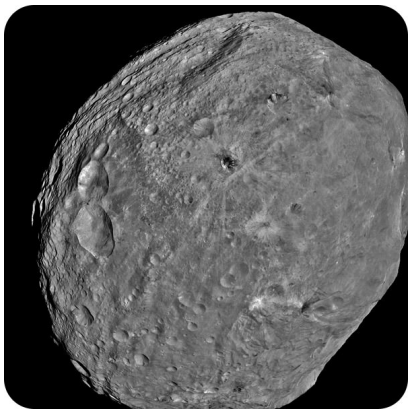
1. What are exoplanets?
2. When was the first exoplanet discovered?
3. When this video was made, there were 250 known exoplanets. Now, more than a thousand have been discovered. What does that tell you about exoplanet research?
4. Why is finding exoplanets difficult?
5. What is used to find exoplanets?
6. Which type of planets are the easiest to find?
7. What is a transit? What does it look like when an exoplanet transits its star far from us?
8. What can scientists learn from a transit?
9. What type of planets do scientists most want to find?
10. Explain the habitable zone.
11. Kepler has completed its mission and it has gathered years worth of data for analysis. What was Kepler's mission?
12. How long would it take to visit the nearest exoplanet?

References

Image	Reference	Attributions
	**[Figure 1]**	**License:** CC BY-NC
	**[Figure 2]**	**Credit:** Courtesy of NASA/ESA/L. Ricci (ESO) **Source:** commons.wikimedia.org/wiki/File:Proplyd_473-245_in_the_Orion_Nebula_(captured_by_the_Hubble_Space_Telescope).jpg **License:** CC BY 3.0
	**[Figure 3]**	**Credit:** Courtesy of NASA/Ames/JPL-Caltech 2012 **Source:** commons.wikimedia.org/wiki/File:Kepler22b-artwork.jpg **License:** Public Domain

This page titled 22.21: Exoplanets is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.22: Asteroids



Is this rock an asteroid?

This rock is somewhat round. It is called asteroid Vesta, but it may actually be a protoplanet: too round to be an asteroid, not round enough to be a dwarf planet. This image of Vesta was taken as a spacecraft orbited around it for a year. Scientists are interested in asteroids for many reasons. They are remnants from the early solar system. Asteroids have caused mass extinctions.

Asteroids

After the Sun and planets formed, there was some material left over. These small chunks didn't get close enough to a large body to be pulled in by its gravity. They now inhabit the solar system as asteroids and comets.

Asteroids (**Figure** below) are very small, irregularly shaped, rocky bodies. Asteroids orbit the Sun, but they are more like giant rocks than planets. Since they are small, they have features that are different from planets. Asteroids do not have enough gravity to become round. They are too small to have an atmosphere. With no internal heat, they are not geologically active.

An asteroid can only change due to a collision. A collision may cause the asteroid to break up. It may create craters on the asteroid’s surface. An asteroid may strike a planet if it comes near enough to be pulled in by its gravity.



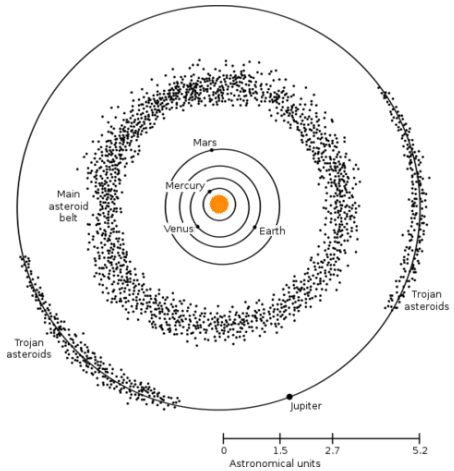
Asteroid Ida with its tiny moon Dactyl. The asteroid’s mean radius is 15.7 km.

The Asteroid Belt

Hundreds of thousands of asteroids have been found in our solar system. They are still being discovered at a rate of about 5,000 new asteroids per month! The majority are located in between the orbits of Mars and Jupiter. This region is called the **asteroid belt** (**Figure** below). There are many thousands of asteroids in the asteroid belt. Still, their total mass adds up to only about four percent of Earth’s Moon.

Asteroids formed at the same time as the rest of the solar system. Although there are many in the asteroid belt, they were never able to form into a planet. Jupiter's gravity kept them apart.

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org



The asteroid belt is between Mars and Jupiter.

Near-Earth Asteroids

Near-Earth asteroids have orbits that cross Earth's orbit. This means that they can collide with Earth. There are over 4,500 known near-Earth asteroids. Small asteroids do sometimes collide with Earth. An asteroid about 5–10 m in diameter hits about once per year. Five hundred to a thousand of the known near-Earth asteroids are much bigger. They are over 1 kilometer in diameter. When large asteroids hit Earth in the past, many organisms died. At times, many species became extinct in a mass extinction. Astronomers keep looking for near-Earth asteroids. They hope to predict a possible collision early so they can to try to stop it.

Asteroid Missions

Scientists are very interested in asteroids. Most are composed of material that has not changed since early in the solar system. Scientists can learn a lot from them about how the solar system formed. Asteroids may be important for space travel. They could be mined for rare minerals or for construction projects in space.

Scientists have sent spacecrafts to study asteroids. In 1997, the NEAR Shoemaker probe orbited the asteroid 433 Eros. The craft finally landed on its surface in 2001. The Japanese Hayabusa probe returned to Earth with samples of a small near-Earth asteroid in 2010. The U.S. Dawn mission spent a year in orbit around Vesta ending in August 2012.

KQED: Asteroid Hunters

Thousands of objects, including comets and asteroids, are zooming around our solar system; some could be on a collision course with Earth. QUEST explores how these Near Earth Objects are being tracked and what scientists are saying should be done to prevent a deadly impact.



https://k12.libretexts.org/@go/page/6200

Summary

- Asteroids are small rocky bodies that orbit the Sun.
- Most asteroids reside in the asteroid belt, between Mars and Jupiter.
- Near-Earth asteroids are the ones most likely to strike Earth.

Review

1. What is the reason there is a belt of asteroids between Mars and Jupiter?
2. Why do scientists look for asteroids that might strike our planet?
3. What do scientists learn from missions to asteroids?

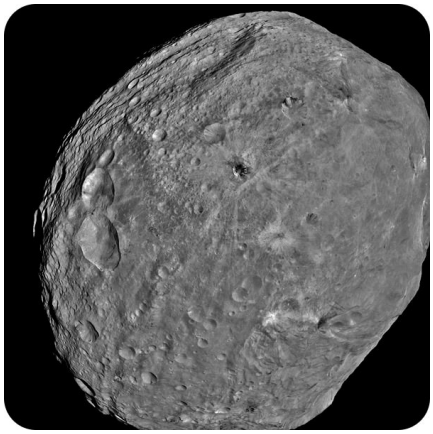
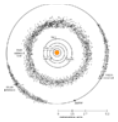
Explore More

Use the resource below to answer the questions that follow.



1. What caused the dinosaurs to go extinct?
2. What are asteroids?
3. What are small asteroids called?
4. What steps are taken by NASA to detect asteroids?

References

Image	Reference	Attributions
	**[Figure 1]**	**Credit:** User:Mizusumashi/Wikimedia Commons and User:Autiwa/Wikimedia Commons **Source:** http://commons.wikimedia.org/wiki/File:Asteroid_Belt.svg **License:** Public Domain
	**[Figure 2]**	**Credit:** Courtesy of NASA/JPL, modified by Chzz;Courtesy of H Weaver (JHU/APL), A Stern (SwRI), and the HST Pluto Companion Search Team **Source:** http://commons.wikimedia.org/wiki/File:243_ida_crop.jpg ; http://commons.wikimedia.org/wiki/File:Pluto_and_its_satellites_%282005%29.jpg **License:** Public Domain
	**[Figure 3]**	**Credit:** User:Mizusumashi/Wikimedia Commons and User:Autiwa/Wikimedia Commons;Courtesy of H Weaver (JHU/APL), A Stern (SwRI), and the HST Pluto Companion Search Team **Source:** http://commons.wikimedia.org/wiki/File:Asteroid_Belt.svg ; http://commons.wikimedia.org/wiki/File:Pluto_and_its_satellites_%282005%29.jpg **License:** Public Domain

This page titled 22.22: Asteroids is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.23: Comets



Is this comet going to hit?

Astronauts on board the International Space Station witness incredible things. This photo of Comet Lovejoy was taken in December 2011. Although it looks like its going to strike Earth, it was not even visible from our planet by the naked eye. The comet is now traveling far out into space.

Comets

Comets are small, icy objects that have very elliptical orbits around the Sun. Their orbits carry them from the outer solar system to the inner solar system, close to the Sun. Early in Earth's history, comets may have brought water and other substances to Earth during collisions.

Comet tails form as the comet flies close to the Sun and the outer layers of ice melt and form a glowing coma. Particles streaming from the Sun push this gas and dust into a long tail. The tail always points away from the Sun. The coma is bright because it reflects light from the Sun (**Figure** below). Comets appear for only a short time when they are near the Sun. They seem to disappear as they move back to the outer solar system.



Comet Hale-Bopp, also called the Great Comet of 1997. The comet has two visible tails: a bright, curved dust tail and a fainter, straight tail of ions (charged atoms) pointing directly away from the Sun.

The time between one appearance of a comet and the next is called the comet's period. Halley's comet, with a period of 75 years, will be seen next in 2061. The first mention of the comet in historical records may go back as much as two millennia.

Where Comets Come From

Short-period comets have periods of about 200 years or less. These comets come from a region beyond the orbit of Neptune called the **Kuiper belt** (pronounced “KI-per”). The Kuiper belt also contains asteroids and at least two dwarf planets.

Comets with periods as long as thousands or even millions of years come from a very distant region of the solar system. This region is called the Oort cloud. It is about 50,000-100,000 AU from the Sun (50,000–100,000 times the distance from the Sun to Earth).



Summary

- Comets are icy objects that have very elliptical orbits around the Sun.
- Comet tails form as ice vaporizes and glows in the Sun's light.
- Short-period comets come from the Kuiper belt beyond Neptune, and long-period comets come from the Oort cloud far out away from the Sun.

Review

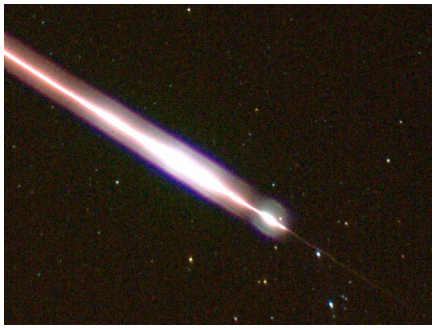
1. Why do comets only have tails when they are near the Sun?
2. Where is the Kuiper belt, and what is found in it?
3. Why do most comets appear in regular, predictable time periods?

References

Image	Reference	Attributions
	**[Figure 1]**	**Credit:** User:Mizusumashi/Wikimedia Commons and User:Autiwa/Wikimedia Commons **Source:** commons.wikimedia.org/wiki/File:Asteroid_Belt.svg **License:** Public Domain
	**[Figure 2]**	**Credit:** Flickr:sungod17;User:Mizusumashi/Wikimedia Commons and User:Autiwa/Wikimedia Commons;Courtesy of H Weaver (JHU/APL), A Stern (SwRI), and the HST Pluto Companion Search Team **Source:** www.flickr.com/photos/43437384@N07/8675567467/ ; commons.wikimedia.org/wiki/File:Asteroid_Belt.svg ; commons.wikimedia.org/wiki/File:Pluto_and_its_satellites_%282005%29.jpg **License:** CC BY 2.0; Public Domain

This page titled 22.23: Comets is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.24: Meteors



Is this a comet?

When a meteor shoots through the atmosphere, it burns and glows. When we look up and see one, we call it a shooting star. In this image, the meteor looks like a comet. No need to go anywhere to see this. Just try to catch one of these meteor showers: the Perseids in mid-August or the Geminids in mid-December. Look for information on the dates and whether the Moon will not be lighting up the sky.

Meteors

If you look at the sky on a dark night, you may see a **meteor** (**Figure** below). A meteor forms a streak of light across the sky. People call them shooting stars because that's what they look like. But meteors are not stars at all. The light you see comes from a small piece of matter burning up as it flies through Earth's atmosphere.



Meteors burning up as they fall through Earth's atmosphere.

Meteoroids

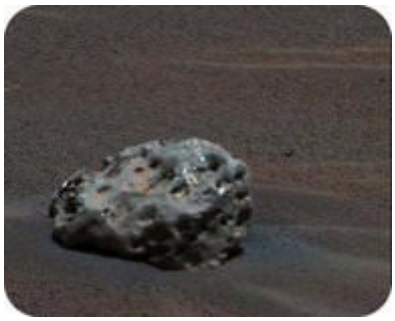
Before these small pieces of matter enter Earth’s atmosphere, they are called **meteoroids**. Meteoroids are as large as boulders or as small as tiny sand grains. Larger objects are called asteroids; smaller objects are interplanetary dust. Meteoroids sometimes cluster together in long trails. They are the debris left behind by comets. When Earth passes through a comet trail, there is a **meteor shower**. During a meteor shower, there are many more meteors than normal for a night or two.



Meteorites

A meteoroid is dragged toward Earth by gravity and enters the atmosphere. Friction with the atmosphere heats the object quickly, so it starts to vaporize. As it flies through the atmosphere, it leaves a trail of glowing gases. The object is now a meteor. Most meteors vaporize in the atmosphere. They never reach Earth's surface. Large meteoroids may not burn up entirely in the atmosphere. A small core may remain and hit Earth's surface. This is called a **meteorite**.

Meteorites provide clues about our solar system. Many were formed in the early solar system (**Figure** below). Some are from asteroids that have split apart. A few are rocks from nearby bodies like Mars. For this to happen, an asteroid would have to have smashed into Mars and sent up debris. A bit of the debris would have to then enter Earth's atmosphere as a meteor.



The Mars Rover, Opportunity, found a metal meteorite on the Red Planet.

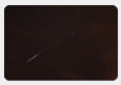
Summary

- A meteor that strikes Earth's surface is a meteorite.
- Many meteorites are remnants of the earliest material that formed in the solar system.
- Shooting stars are meteors that burn up in Earth's atmosphere.

Review

1. Compare and contrast meteoroid, meteor, and meteorite.
2. What are meteorites important to scientists?
3. Why are meteors known as shooting stars?

References

Image	Reference	Attributions
	**[Figure 1]**	**Credit:** User:Mizusumashi/Wikimedia Commons and User:Autiwa/Wikimedia Commons **Source:** commons.wikimedia.org/wiki/File:Asteroid_Belt.svg **License:** Public Domain
	**[Figure 2]**	**Credit:** Jared Tennant;User:Mizusumashi/Wikimedia Commons and User:Autiwa/Wikimedia Commons;Courtesy of H Weaver (JHU/APL), A Stern (SwRI), and the HST Pluto Companion Search Team **Source:** commons.wikimedia.org/wiki/File:Perseid_meteor_shower.jpg ; commons.wikimedia.org/wiki/File:Asteroid_Belt.svg ; commons.wikimedia.org/wiki/File:Pluto_and_its_satellites_%282005%29.jpg **License:** CC BY 2.0; Public Domain
	**[Figure 3]**	**Credit:** Courtesy of NASA/JPL/Cornell;User:Mizusumashi/Wikimedia Commons and User:Autiwa/Wikimedia Commons;Courtesy of H Weaver (JHU/APL), A Stern (SwRI), and the HST Pluto Companion Search Team **Source:** http://photojournal.jpl.nasa.gov/catalog/PIA07269 ; commons.wikimedia.org/wiki/File:Asteroid_Belt.svg ; commons.wikimedia.org/wiki/File:Pluto_and_its_satellites_%282005%29.jpg **License:** Public Domain

This page titled 22.24: Meteors is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.25: Dwarf Planets



What is, and what is not, a planet?

Pluto just didn't fit the criteria for a planet, so it was placed in a new category with others of its kind, dwarf planets. So what is a planet, and what is Pluto?

What is a Planet?

In 2006, the International Astronomical Union decided that there were too many questions surrounding what could be called a planet and so refined the definition of a planet.

According to the new definition, a planet must:

- Orbit a star.
- Be big enough that its own gravity causes it to be shaped as a sphere.
- Be small enough that it isn't a star itself.
- Have cleared the area of its orbit of smaller objects.

Dwarf Planets

The **dwarf planets** of our solar system are exciting proof of how much we are learning about our solar system. With the discovery of many new objects in our solar system, astronomers were able to refine the definition of a dwarf planet in 2006.

So dwarf planets are like planets except for one thing. They have not cleared their orbits of smaller objects. They do not have enough gravity to do this. There are five recognized dwarf planets in the solar system: Ceres, Pluto, Makemake, Haumea, and Eris.

Pluto

The reclassification of Pluto to the new category dwarf planet stirred up a great deal of controversy. How the classification of Pluto has evolved is an interesting story in science.

From the time it was discovered in 1930 until the early 2000s, Pluto was considered the ninth planet. When astronomers first located Pluto, the telescopes were not as good. Pluto and its moon, Charon, were seen as one much larger object (**Figure** below). With better telescopes, astronomers realized that Pluto was much smaller than they had thought.



Pluto and its moon, Charon, are actually two objects.

Better technology also allowed astronomers to discover many smaller objects like Pluto that orbit the Sun. One of them, Eris, discovered in 2005, is even larger than Pluto.

Pluto is different in other ways. The outer planets are all gas giants. Pluto is small, icy, and rocky. Pluto has a diameter of about 2,400 km. It has only about one-fifth the mass of Earth's Moon. Pluto's orbit is tilted relative to the other planets. It's orbit is shaped like a long, narrow ellipse. Pluto's orbit sometimes even passes inside Neptune's orbit.

Pluto's orbit is in the Kuiper belt. With more than 200 million Kuiper belt objects in its path, Pluto has failed the test of clearing other bodies out of its orbit.

From what you've read above, do you think Pluto should be called a planet? Why are people hesitant to take away Pluto's planetary status? Is Pluto a dwarf planet?

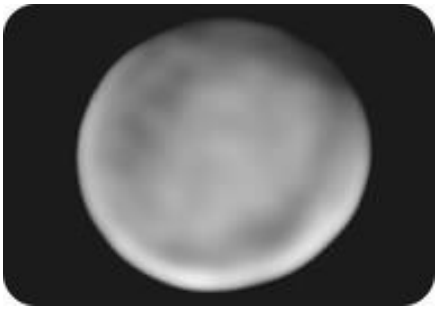
Pluto has three moons of its own. The largest, Charon, is big compared to Pluto. The Pluto-Charon system is sometimes called a double dwarf planet (**Figure** above). Two smaller moons, Nix and Hydra, were discovered in 2005.

Pluto and the other dwarf planets, besides Ceres, are found orbiting out beyond Neptune.

Ceres

Ceres (**Figure** below) is a rocky body that orbits the Sun. It could be an asteroid or a planet. Before 2006, Ceres was thought to be the largest asteroid. Is it an asteroid? Ceres is in the asteroid belt. But it is by far the largest object in the belt. Ceres has such high gravity that it is spherical.

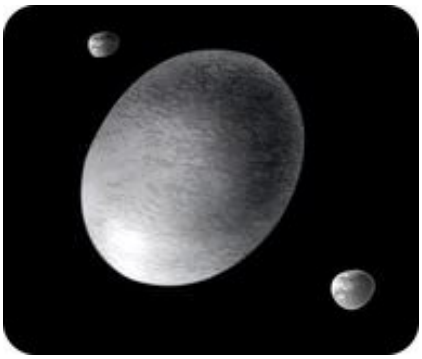
Is Ceres a planet? Ceres has only about 1.3% of the mass of the Earth's Moon. Its orbit is full of other smaller bodies. Its gravity was not high enough to clear its orbit. Ceres fails the fourth criterion for being a planet. Ceres is now considered a dwarf planet, the closest to the Sun.



Ceres is a large spherical object in the asteroid belt.

Haumea

Haumea was named a dwarf planet in 2008. It is an unusual dwarf planet. The body is shaped like an oval! Haumea's longest axis is about the same as Pluto's diameter. Its shortest axis is about half as long. The body's orbit is tilted 28 degrees. Haumea is so far from the Sun that it takes 283 years to make one orbit (**Figure** below).



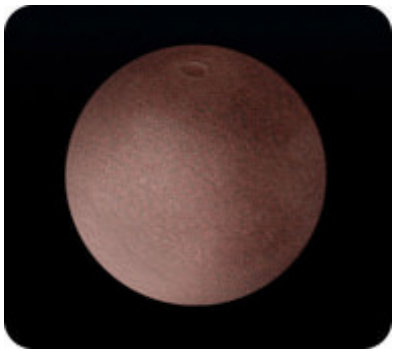
An artist’s drawing of what Haumea and its moons might look like. The moons are drawn closer to Haumea than their actual orbits.

Haumea is the third-brightest Kuiper belt object. Haumea has two moons. Haumea's odd oval shape is probably caused by its extremely rapid rotation. It rotates in just less than 4 hours! Like other Kuiper belt objects, Haumea is covered by ice. Its density is similar to Earth’s Moon, at 2.6 – 3.3 g/cm^3. This means that most of Haumea is rocky.

Haumea is part of a collisional family. This is a group of astronomical objects that formed from an impact. This family has Haumea, its two moons, and five more objects. All of these objects are thought to have formed from a collision very early in the formation of the solar system.

Makemake

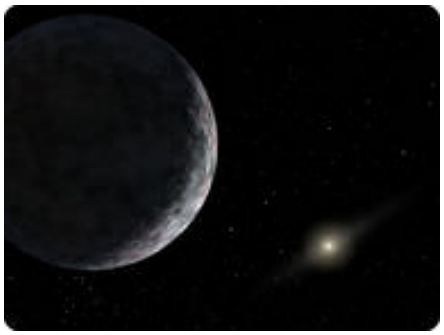
Makemake is the third-largest and second-brightest dwarf planet we have discovered so far (**Figure** below). Makemake is only 75 percent the size of Pluto. Its diameter is between 1300 and 1900 kilometers. The name comes from the mythology of the Easter Islanders. Makemake was the god that created humanity. At a distance between 38.5 to 53 AU, this dwarf planet orbits the Sun in 310 years. Makemake is made of methane, ethane, and nitrogen ices.



Makemake is a dwarf planet.

Eris

Eris is the largest known dwarf planet in the solar system. It is 27 percent larger than Pluto.



Eris is the largest known dwarf planet, but it's so far from the Sun that it wasn't discovered until 2005.

Like Pluto and Makemake, Eris is in the Kuiper belt. But Eris is about three times farther from the Sun than Pluto. Because of its distance, Eris was not discovered until 2005. Early on, it was thought that Eris might be the tenth planet. Its discovery helped astronomers realize that they needed a new definition of “planet.” Eris has a small moon that orbits Eris once about every 16 days.

Astronomers know there may be other dwarf planets far out in the solar system. Look for Quaoar, Varuna, and Orcus to possibly be added to the list of dwarf planets in the future. We still have a lot to discover and explore!

Summary

- There are currently five dwarf planets in our solar system: Pluto, Eris, Haumea, Makemake, and Ceres.
- Most dwarf planets are similar to planets, except that they haven't cleared their space of debris.
- Pluto was thought to be larger than it is because its large moon made the dwarf planet look bigger than it is.

Review

1. Why isn't Pluto still a planet? Why do some people still insist that it is?
2. Why did people think that Pluto was a planet in the decades after its discovery?
3. What are the characteristics of the other dwarf planets that have been recognized?

Explore More

Use the resource below to answer the questions that follow.



1. Who discovered Pluto? When?
2. When was Pluto demoted to a dwarf planet?
3. What is Pluto's diameter compared to Earth's?
4. Why don't scientists know much about Pluto?
5. What is odd about Pluto's orbit?
6. What are the names of some of Pluto's moons?
7. Why is the Pluto-Charon system different from the Earth-Moon system? (In other words, why is Earth a planet and Moon a satellite, but Pluto-Charon are more like a double planet or double dwarf planet?)
8. What spacecraft is on its way to Pluto? When will it get there?

References

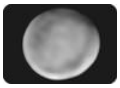
Image	Reference	Attributions
	**[Figure 1]**	**Credit:** User:Mizusumashi/Wikimedia Commons and User:Autiwa/Wikimedia Commons **Source:** commons.wikimedia.org/wiki/File:Asteroid_Belt.svg **License:** Public Domain
	**[Figure 2]**	**Credit:** Courtesy of H Weaver (JHU/APL), A Stern (SwRI), and the HST Pluto Companion Search Team;User:Mizusumashi/Wikimedia Commons and User:Autiwa/Wikimedia Commons **Source:** commons.wikimedia.org/wiki/File:Pluto_and_its_satellites_%282005%29.jpg ; commons.wikimedia.org/wiki/File:Asteroid_Belt.svg **License:** Public Domain
	**[Figure 3]**	**Credit:** Courtesy of Dumas C et. al, NASA/JPL;User:Mizusumashi/Wikimedia Commons and User:Autiwa/Wikimedia Commons **Source:** http://www.nasa.gov/mission_pages/dawn/ceresvesta/index.html ; commons.wikimedia.org/wiki/File:Asteroid_Belt.svg **License:** Public Domain
	**[Figure 4]**	**Credit:** Courtesy of Ann Feild (Space Telescope Science Institute), NASA;User:Mizusumashi/Wikimedia Commons and User:Autiwa/Wikimedia Commons **Source:** commons.wikimedia.org/wiki/File:2003EL61art.jpg ; commons.wikimedia.org/wiki/File:Asteroid_Belt.svg **License:** Public Domain

Image	Reference	Attributions
	**[Figure 5]**	**Credit:** Courtesy of Ann Feild (Space Telescope Science Institute), NASA;User:Mizusumashi/Wikimedia Commons and User:Autiwa/Wikimedia Commons **Source:** commons.wikimedia.org/wiki/File:2005FY9art.jpg ; commons.wikimedia.org/wiki/File:Asteroid_Belt.svg **License:** Public Domain
	**[Figure 6]**	**Credit:** Courtesy of NASA/JPL-Caltech;User:Mizusumashi/Wikimedia Commons and User:Autiwa/Wikimedia Commons **Source:** commons.wikimedia.org/wiki/File:2003_UB313_NASA_illustration.jpg ; commons.wikimedia.org/wiki/File:Asteroid_Belt.svg **License:** Public Domain

This page titled 22.25: Dwarf Planets is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

22.26: The Solar System- Challenge 5

1. ___ extrasolar planets have been discovered so far.

More than 1500

2. Scientists started discovering exoplanets in ___.

1990s

3. A planet is considered to be in a star's habitable zone when ___.

it has the right temperature to have liquid water

4. Scientists are interested in asteroids because ___.

many are representatives of the earliest solar system

5. ___ near-Earth asteroids cross Earth's orbit.

More than 4,500

6. Long-period comets come from the ___.

Oort Cloud

7. In the early solar system, comets that struck Earth may have brought ___.

water

8. Before reaching Earth's atmosphere, meteors are known as ___.

meteoroids

9. A meteor shower occurs when ___.

Earth passes through a comet's tail

10. ___ are meteors that make it to Earth's surface.

Meteorites

11. Eris has ___ known moon(s).

1

12. ___ is the largest known dwarf planet in the solar system.

Eris

13. ___ is the third-largest and second-brightest dwarf planet discovered so far.

Makemake

This page titled 22.26: The Solar System- Challenge 5 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

CHAPTER OVERVIEW

23: Beyond the Solar System

23.1: Star Constellations
23.2: Star Power
23.3: Star Classification
23.4: Star Formation
23.5: Beyond the Solar System- Challenge 1
23.6: Main Sequence Star Lives
23.7: Red Giants and White Dwarfs
23.8: Supergiants and Supernovas
23.9: Neutron Stars and Black Holes
23.10: Beyond the Solar System- Challenge 2
23.11: Star Clusters
23.12: Galaxies
23.13: The Milky Way
23.14: Universe
23.15: Expansion of the Universe
23.16: Big Bang
23.17: Dark Matter
23.18: Beyond the Solar System- Challenge 3

This page titled 23: Beyond the Solar System is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.1: Star Constellations



Why do the constellations appear in the same patterns all the time?

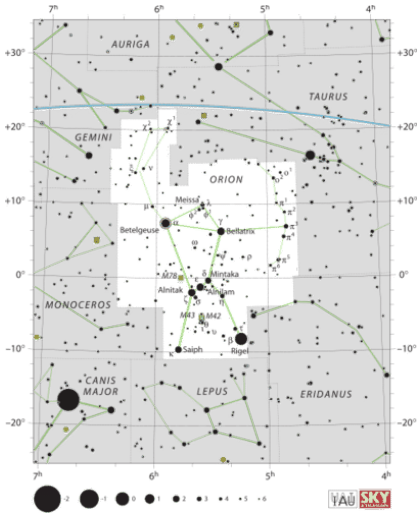
This is a constellation, a pattern of stars in the night sky. This constellation is called Orion. The features you can see best are his belt and sword. You can see Orion's belt in the sky from many locations. These stars are very bright. For many constellations, the stars are not near each other. They just happen to appear near each other in our sky.

Stars

When you look at the sky on a clear night, you can see hundreds of stars. A **star** is a giant ball of glowing gas that is very, very hot. A star generates energy through nuclear fusion reactions. Most of these stars are like our Sun. However, some stars are smaller than our Sun, and some are larger. Except for our own Sun, all stars are so far away that they only look like single points—even through a telescope.

Constellations

The stars that make up a **constellation** appear close to each other from Earth. In reality, they may be very distant from one another. Constellations were important to people, like the Ancient Greeks. People who spent a lot of time outdoors at night, like shepherds, named the constellations. They told stories about them. Pictured below is one of the most easily recognized constellations (**Figure** below). The ancient Greeks thought this group of stars looked like a hunter. They named it Orion, after a great hunter in Greek mythology.



Orion has three stars that make up his belt. Orion's belt is fairly easy to see in the night sky.

The constellations stay the same night after night. The patterns of the stars never change. However, each night the constellations move across the sky. They move because Earth is spinning on its axis. The constellations also move with the seasons. This is because Earth revolves around the Sun. The constellations in the winter are different from those in the summer. For example, Orion is high up in the winter sky. In the summer, it's up only in the early morning.

Constellations are useful. They help astronomers and other observers orient in the night sky. The star Betelgeuse, for example, is Orion's right shoulder. Betelgeuse is the eighth brightest star in the sky. The star is an excellent example of a red supergiant.

Apparent vs. Real Distances

The stars in a constellation appear close together in our night sky. But they are not close together at all out in space. In the constellation Orion, the stars visible to the naked eye are at distances ranging from just 26 light-years (which is relatively close to Earth) to several thousand light-years away.

What Is Astrology?

Ancient Babylonian astronomers created the Zodiac. The Zodiac is a circle that divides the ecliptic into twelve 30-degree zones. Each zone contains a constellation, many of them animals. Horoscopes based on these astrological signs first appeared in Ptolemaic Egypt in around 50 BC. These early people used astrology to explain things that are now much better explained by science. You can see an example of a Zodiac below (**Figure** below).



How did astrology come to be?

There is no reason to think that the alignment of the stars has anything to do with events that happen on Earth. The constellations are patterns made from stars in the sky. The patterns do not reflect any characteristics of the stars themselves. When scientific tests are done to provide evidence in support of astrological ideas, the tests fail. When a scientific idea fails, it is abandoned or modified. Astrologers do not change or abandon their ideas when they fail. So astrology is not science.

Summary

- The points of light in the night sky are stars that are balls of gas. They are lit by nuclear fusion.
- Constellations are patterns of stars seen from Earth. These stars are usually not near each other.
- Stars in a constellation may be fairly close together. More likely, though, they are extremely far apart.

Review

1. Why are constellations so important to people when they think about stars?
2. Are constellations useful?
3. Are stars in a constellation close to each other?
4. What is astrology? How is it different from astronomy?

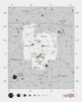
Explore More

Use the resource below to answer the questions that follow.



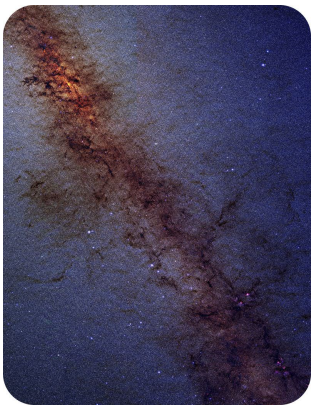
1. What does the word constellation mean?
2. What are the names of the constellations based on?
3. What was Orion? Why did the Greeks say the constellation disappeared for part of the year?
4. Why do constellations change position in the sky?
5. How many constellations are there?
6. How do zodiac constellations differ from other constellations?

References

Image	Reference	Attributions
	**[Figure 1]**	**Credit:** Courtesy of NASA **Source:** commons.wikimedia.org/wiki/File:Beit_Alpha.jpg **License:** Public Domain
	**[Figure 2]**	**Credit:** IAU and Sky & Telescope magazine (Roger Sinnott & Rick Fienberg) **Source:** commons.wikimedia.org/wiki/File:Orion_IAU.svg **License:** CC BY 3.0
	**[Figure 3]**	**Credit:** Courtesy of NASA **Source:** commons.wikimedia.org/wiki/File:Beit_Alpha.jpg **License:** Public Domain

This page titled 23.1: Star Constellations is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.2: Star Power



Did you know that the night sky is bright?

Starlight can be surprisingly bright in the night sky. Of course, daytime is all about starlight. The star is our Sun, and it shines so brightly because it is so close to us. Even the Moon is bright because of light from the Sun. Some stars produce much more energy than the Sun. They're just farther away, so the light is not as obvious. How do stars generate so much energy?

Nuclear Fusion

Stars shine because of **nuclear fusion**. Fusion reactions in the Sun's core keep our nearest star burning. Stars are made mostly of hydrogen and helium. Both are very light gases, but a star contains so much hydrogen and helium that its total mass is enormous. The pressure at the center of a star is great enough to heat the gases. This causes nuclear fusion reactions.

A nuclear fusion reaction is so named because the nuclei (center) of atoms fuse (join) together in the process. In stars like our Sun, hydrogen atoms join together to create a helium atom. Nuclear fusion reactions need a lot of energy to get started. Once they begin, they produce even more energy (**Figure** below).



A thermonuclear bomb is an uncontrolled fusion reaction in which enormous amounts of energy are released.

Particle Accelerators

Scientists have built machines called **particle accelerators**. These amazing tools smash particles that are smaller than atoms into each other head-on. This creates new particles. Scientists use particle accelerators to learn about nuclear fusion in stars. They can also learn about how atoms came together in the first few minutes of the Universe. Two well-known accelerators are SLAC, in California, and CERN, in Switzerland (**Figure** below).



The SLAC National Accelerator Lab in California can propel particles a straight 2 mi (3.2 km).

Summary

- In a nuclear fusion reaction, nuclei combine to form a larger nucleus.
- The energy from fusion reactions keeps the star shining.
- Particle accelerators simulate nuclear fusion in stars.

Review

1. How do stars get their power?
2. Why can this happen in stars and not elsewhere?
3. What do scientists learn from particle accelerators?

Explore More

Use the resource below to answer the questions that follow.



1. What happens during nuclear fusion?
2. What allows the positively charged hydrogen nuclei to collide, instead of repelling each other?
3. What is produced by the collision?
4. What kind of fusion powers the Sun?
5. What characteristics of stars make them good nuclear fusion reactors?
6. What did nuclear fusion contribute to the Universe billions of years ago?

References

Image	Reference	Attributions
	**[Figure 1]**	**Credit:** Courtesy of Peter Kaminski/US Geological Survey;Courtesy of NASA **Source:** commons.wikimedia.org/wiki/File:Stanford-linear-accelerator-usgs-ortho-kaminski-5900.jpg ; commons.wikimedia.org/wiki/File:Beit_Alpha.jpg **License:** Public Domain
	**[Figure 2]**	**Credit:** Courtesy of the US Department of Energy;Courtesy of NASA **Source:** http://commons.wikimedia.org/wiki/Fil...stle_Romeo.jpg ; commons.wikimedia.org/wiki/File:Beit_Alpha.jpg **License:** Public Domain
	**[Figure 3]**	**Credit:** Courtesy of Peter Kaminski/US Geological Survey;Courtesy of NASA **Source:** commons.wikimedia.org/wiki/File:Stanford-linear-accelerator-usgs-ortho-kaminski-5900.jpg ; commons.wikimedia.org/wiki/File:Beit_Alpha.jpg **License:** Public Domain

This page titled 23.2: Star Power is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.3: Star Classification



Why are the stars in the Orion constellation different colors?

In this view of Orion you can see that the stars are different colors. The red star in the upper left is Betelgeuse (pronounced BET-ul-juice). The blue star in the lower right is Rigel. The fuzzy patch in the sword is the Orion nebula. The nebula will be discussed in the concept "Star Formation."

Star Classification

With a quick look, stars look the same. Look closer, though, and you can see differences. The most obvious differences are in size and color.

Color and Temperature

Think about the coil of an electric stove as it heats up. The coil changes in color as its temperature rises. When you first turn on the heat, the coil looks black. The air a few inches above the coil begins to feel warm. As the coil gets hotter, it starts to glow a dull red. As it gets even hotter, it becomes a brighter red. Next it turns orange. If it gets extremely hot, it might look yellow-white, or even blue-white. Like a coil on a stove, a star’s color is determined by the temperature of the star’s surface. Relatively cool stars are red. Warmer stars are orange or yellow. Extremely hot stars are blue or blue-white.

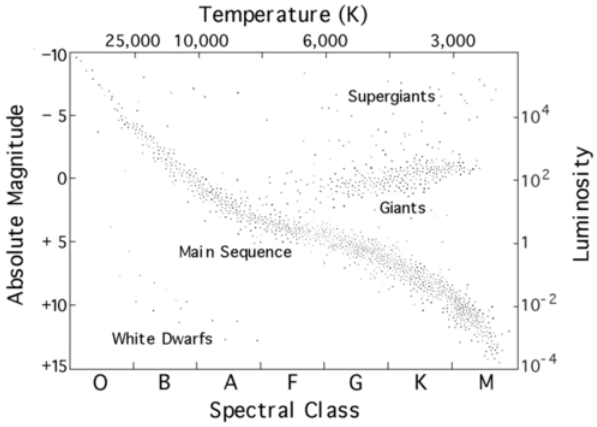
Star temperatures are measured in degrees kelvin. The lowest temperature on the kelvin scale is absolute zero. That means molecules have no motion. Kelvin is related to Celsius and Fahrenheit in these ways:

$[°C] = [K] - 273.15$

$[°F] = [K] \times 9/5 - 459.67$

Classification

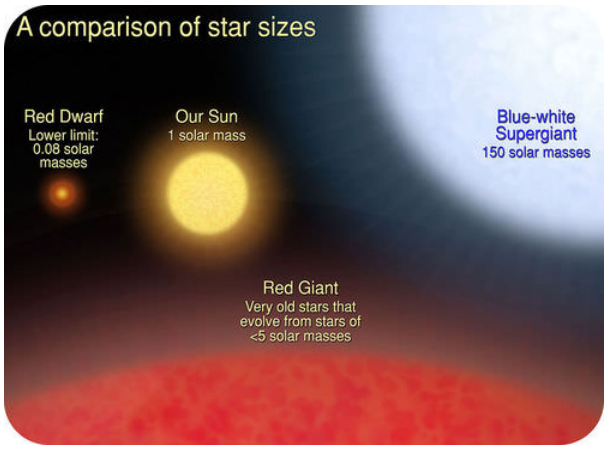
A graph of the brightness (absolute magnitude) of stars versus their color (temperature) is pictured below (**Figure** below). This is called Hertzsprung-Russell diagram.



The Hertzsprung-Russell diagram plots luminosity (absolute magnitude) against the color of the stars ranging from the high-temperature blue-white stars on the left side of the diagram to the low temperature red stars on the right side.

Most stars fall along the main sequence curve. Stars in the main sequence fuse hydrogen into helium in the core. The horizontal branch also has many stars. These fuse helium in the core and burn hydrogen surrounding the core. Other stars are found in other regions.

Object Size



Relative sizes of stars of different masses.

This illustration (**Figure** above) shows the relative sizes of stars and their mass compared to the Sun. **Red dwarfs** are less massive and much smaller in size than the Sun. This means they have a very long lifetime. Our Sun is a fairly common type of star and has an average lifespan. **Red giants** are what some main sequence stars (like our Sun) become near the end of their lives. They are much larger than our Sun. **Supergiants** are very massive stars and are larger than our Sun, but have a smaller radius than red giants. Supergiants have very short lifetimes.

Summary

- Stars are classified by color, which correlates with temperature. Red stars are the coolest and blue are the hottest.
- Stars are plotted on a Hertzsprung-Russell diagram.
- Star temperatures are found in a continuum ranging from 2000 K to more than 30,000 K.
- Kelvin is a temperature measure in which the lowest temperature is absolute zero.

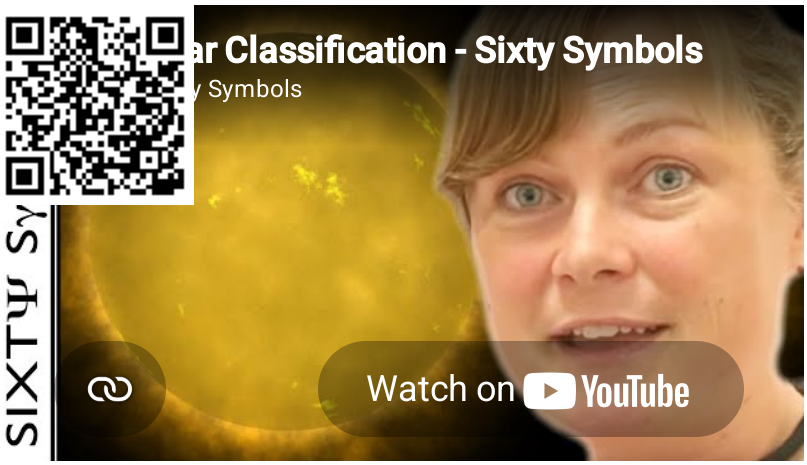
Review

1. Why are stars different colors?
2. Where do most stars fall on the Hertzsprung-Russel diagram? Why?

3. Why do stars that are different colors appear in the same constellation?
4. If a cluster of stars is all the same color, what could that mean?

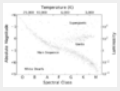
Explore More

Use the resource below to answer the questions that follow.



1. What unique characteristics of a star can be used to classify it?
2. What is the classification of our star?
3. What was the problem with the original classification system set up for stars?
4. What number was assigned to the brightest stars? What characterized stars later assigned the letter A? What did this characteristic mean?
5. Why didn't this characteristic turn out to be a very good way to gauge temperature?
6. What is the current letter classification, in order from hottest to coldest? What is the mnemonic device to remember that?
7. Why is the temperature of a star a really important thing to know?
8. What is identified on each axis of the Hertzsprung-Russell diagram?

References

Image	Reference	Attributions
	**[Figure 1]**	**Credit:** Courtesy of NASA **Source:** commons.wikimedia.org/wiki/File:Beit_Alpha.jpg **License:** Public Domain
	**[Figure 2]**	**Credit:** Courtesy of NASA/GSFC;Courtesy of NASA **Source:** http://imagine.gsfc.nasa.gov/docs/science/know_l2/stars.html ; commons.wikimedia.org/wiki/File:Beit_Alpha.jpg **License:** Public Domain
	**[Figure 3]**	**Credit:** Courtesy of NASA, ESA and A. Feild (STScI);Courtesy of NASA **Source:** http://www.spacetelescope.org/images/opo0505b/ ; commons.wikimedia.org/wiki/File:Beit_Alpha.jpg **License:** Public Domain

This page titled 23.3: Star Classification is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.4: Star Formation



Can you see stars being born?

On a dark night you can practically watch stars being born. The fuzzy area in the sword in the constellation Orion is the Orion nebula. A close up shows the nebula with around 3,000 stars. New stars are being born there.

Star Lives

Stars have a life cycle, just like people. Stars are born, grow, change over time, and eventually grow old and die. Most stars change in size, color, and class at least once in their lifetime. What astronomers know about the life cycles of stars comes from data gathered from visual, radio, and X-ray telescopes.

Nebulae

Stars are born in a cloud of gas and dust called a **nebula** (**Figure** below). Our Sun and solar system formed out of a nebula.



Stars are forming in the Rosette Nebula.

The Pillars of Creation (**Figure** below) are within the Eagle Nebula. The pillars are thought to be a large region where stars are forming. The dark areas may be stars that are about to begin.

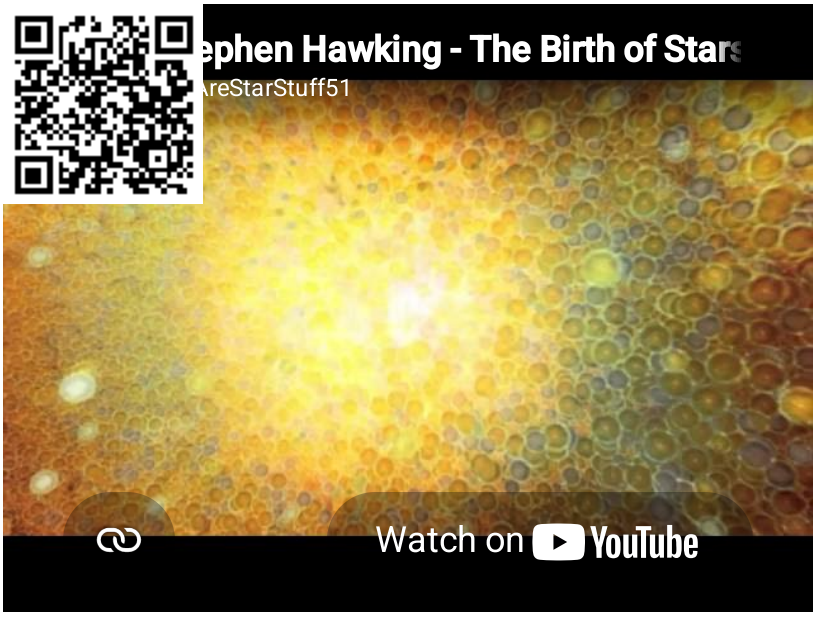


In the Pillars of Creation, gas and dust come together as a stellar nursery.

Star Formation

For a star to form, gravity pulls gas and dust into the center of the nebula. As the material becomes denser, the pressure and the temperature increase. When the temperature of the center becomes hot enough, nuclear fusion begins. The ball of gas has become a star!

Our Sun was probably born in a nebula, like Orion in the top image.



Summary

- Stars form in a nebula.
- A nebula is a cloud of dust and gas.
- Nebulae can be spotted with the naked eye or simple telescopes.

Review

1. What is a nebula?
2. How do stars form?
3. Why do scientists think the Pillars of Creation are where stars are forming?

References

Image	Reference	Attributions
	**[Figure 1]**	**Credit:** Courtesy of NASA, Jeff Hester, and Paul Scowen (Arizona State University);By Tyrogthekreeper at English Wikipedia, CC BY-SA 3.0, commons.wikimedia.org/w/inde...10273;Courtesy of H. Bond (STScI), and M. Barstow (University of Leicester), NASA/ESA **Source:** commons.wikimedia.org/wiki/File:Eagle_nebula_pillars.jpg ; By Tyrogthekreeper at English Wikipedia ; CC BY-SA 3.0 ; commons.wikimedia.org/w/index.php?curid=18110273 ; commons.wikimedia.org/wiki/File:Sirius_A_and_B_Hubble_photo.jpg **License:** Public Domain
	**[Figure 2]**	**Credit:** John Lanoue;CC BY-SA 3.0, commons.wikimedia.org/w/inde...ry/622142.html **Source:** commons.wikimedia.org/wiki/File:Rosette_nebula_Lanoue.png ; CC BY-SA 3.0 ; commons.wikimedia.org/w/index.php?curid=230867 ; http://keywordsuggest.org/gallery/622142.html **License:** Public Domain
	**[Figure 3]**	**Credit:** Courtesy of NASA, Jeff Hester, and Paul Scowen (Arizona State University);CC BY-SA 3.0, commons.wikimedia.org/w/inde...urid=230867;By Credit: NASA, Jeff Hester, and Paul Scowen (Arizona State University) - http://hubblesite.org/newscenter/new...003/34/image/a, Public Domain, commons.wikimedia.org/w/inde...p?curid=129538 **Source:** commons.wikimedia.org/wiki/File:Eagle_nebula_pillars.jpg ; CC BY-SA 3.0 ; commons.wikimedia.org/w/index.php?curid=230867 ; By Credit: NASA ; Jeff Hester ; and Paul Scowen (Arizona State University) - http://hubblesite.org/newscenter/newsdesk/archive/releases/2003/34/image/a ; Public Domain ; commons.wikimedia.org/w/index.php?

Image	Reference	Attributions
		curid=129538 **License:** Public Domain

This page titled 23.4: Star Formation is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.5: Beyond the Solar System- Challenge 1

1. Giant spheres of high temperature, glowing gas are ___.

stars

2. Stars appear to move across the sky every night because ___.

the earth rotates on its axis

3. The ancient ___ civilization created the Zodiac.

Babylonian

4. ___ are natural fusion reactors.

Stars

5. ___ keeps stars from collapsing under their own gravity.

Fusion reactions

6. Nuclear fusion is the process by which ___.

atoms join together and release a lot of energy

7. In the Hertzsprung-Russell Diagram, ___ is indicated on the y-axis.

luminosity

8. The main sequence stars range from ___ to ___.

large, blue stars; small, red stars

9. Zeta Ophiuchi is a ___ star.

blue-colored

10. The Pillars of Creation are a ___ in the Eagle Nebula.

stellar nursery

11. New stars form from ___ called ___.

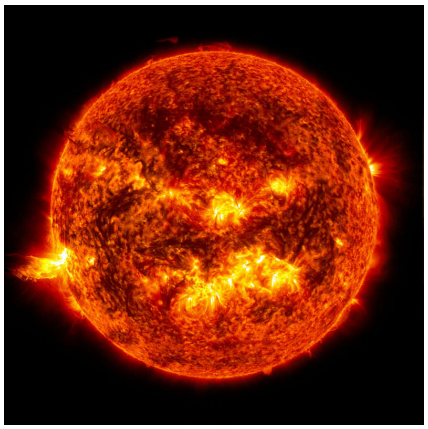
clouds of gas and dust; nebulae

12. ___ are stellar nurseries.

Nebulae

This page titled 23.5: Beyond the Solar System- Challenge 1 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.6: Main Sequence Star Lives



What do most stars look like?

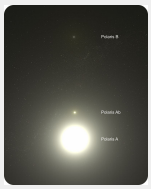
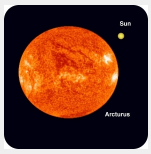
We have a main sequence star nearby. Our Sun is on the main sequence, classified as a yellow dwarf. Our Sun has been a main sequence star for about 5 billion years. As a medium-sized star, it will continue to shine for about 5 billion more years. Most stars are on the main sequence.

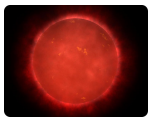
Main Sequence Stars

For most of a star's life, hydrogen atoms fuse to form helium atoms. A star like this is a **main sequence star**. The hotter a main sequence star is, the brighter it is. A star remains on the main sequence as long as it fuses hydrogen to form helium.

Classifying Stars by Color

The most common way of classifying main sequence stars is by color (**Table** below). Each class of star is given a letter, a color, and a range of temperatures. The letters don't match the color names because stars were first grouped as A through O. It wasn't until later that their order was corrected to go by increasing temperature. When you try to remember the order, you can use this phrase: "Oh Be A Fine Good Kid, Man."

Class	Color	Temperature Range (degrees Kelvin)	Sample Star
O	Blue	>30,000	 An artist’s depiction of the O class star Zeta Puppis.
B	Blue-white	10,000–30,000	 Computer generated image of Rigel, a Class B star.
A	White	7,500–10,000	 Sirius A is the brightest star that we see in the night sky. The dot on the right, Sirius B, is a white dwarf.
F	Yellowish-white	6,000–7,500	 There are two F class stars in this image, the supergiant Polaris A and Polaris B. What we see in the night sky as the single star “Polaris,” we also know as the North Star.
G	Yellow	5,500–6,000	 Our Sun: the most important G class star in the Universe, at least for humans.
K	Orange	3,500–5,000	 Arcturus is a Class K star that looks like the Sun but is much larger.
M	Red	2,000–3,500	There are two types of Class M

Class	Color	Temperature Range (degrees Kelvin)	Sample Star
			stars: red dwarfs and red giants.  An artist's depiction of a red dwarf star. Most stars are red dwarfs.  The red supergiant Betelgeuse is seen near Orion's belt. The blue star in the lower right is the Class B star Rigel.

The surface temperature of most stars is due to their size. Bigger stars produce more energy, so their surfaces are hotter. But some very small stars are very hot. Some very big stars are cool.

Large stars burn through their supply of hydrogen very quickly. These stars "live fast and die young!" A very large star may only be on the main sequence for 10 million years. A very small star could remain on the main sequence for tens to hundreds of billions of years—far longer than the current age of our Universe.

Summary

- Stars spend most of their lives on the main sequence. These stars fuse hydrogen into helium for energy.
- Large main sequence stars may be hotter than small stars—but not always.
- Large stars are not on the main sequence as long as small stars.

Review

1. What characteristic do all main sequence stars have?
2. What are the characteristics of our Sun compared with other stars?
3. What are the characteristics of large stars?
4. What are the characteristics of small stars?

Explore More

Use the resource below to answer the questions that follow.



1. What are main sequence stars converting?
2. What process releases energy in these stars?
3. What keeps these stars stable?
4. What is the mass range of main sequence stars compared to our Sun?

References

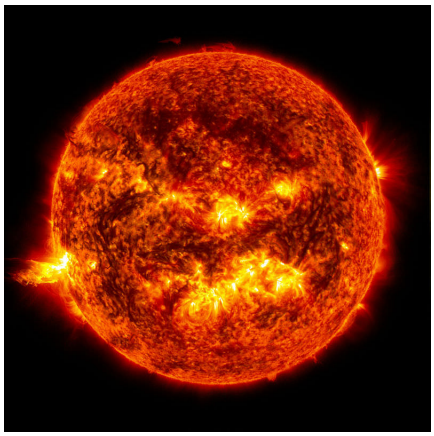
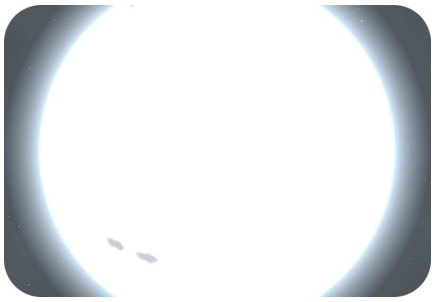
Image	Reference	Attributions
	**[Figure 1]**	**Credit:** Courtesy of NASA **Source:** commons.wikimedia.org/wiki/File:Beit_Alpha.jpg **License:** Public Domain
	**[Figure 2]**	**License:** CC BY-NC
	**[Figure 3]**	**License:** CC BY-NC
	**[Figure 4]**	**License:** CC BY-NC

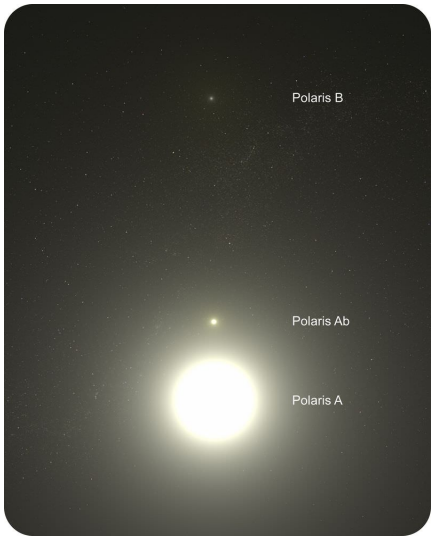
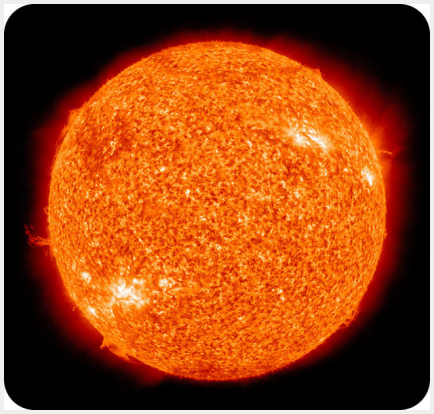
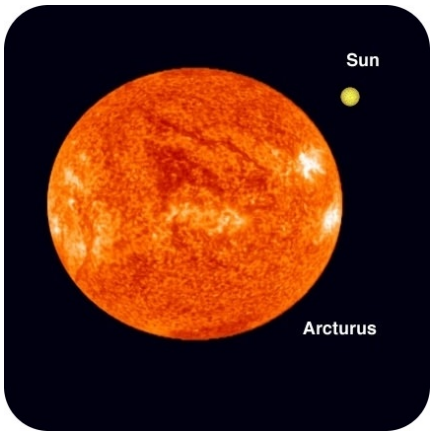
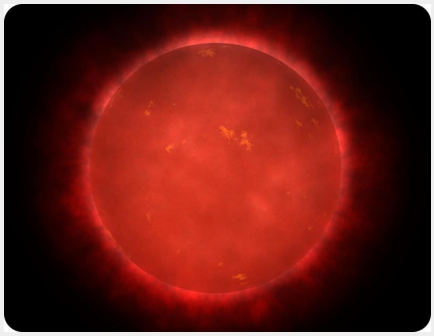
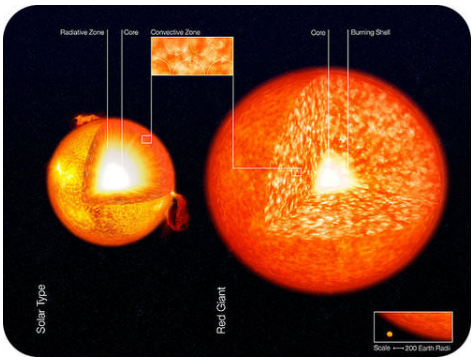
Image	Reference	Attributions
	**[Figure 5]**	**License:** CC BY-NC
	**[Figure 6]**	**License:** CC BY-NC
	**[Figure 7]**	**License:** CC BY-NC

Image	Reference	Attributions
	**[Figure 8]**	**License:** CC BY-NC
	**[Figure 9]**	**Credit:** Courtesy of Akira Fujii and the Hubble European Space Agency, modified by Henrykus;Courtesy of H. Bond (STScI), and M. Barstow (University of Leicester), NASA/ESA **Source:** commons.wikimedia.org/wiki/File:Betelgeuse_position_in_Orion.png ; commons.wikimedia.org/wiki/File:Sirius_A_and_B_Hubble_photo.jpg **License:** Public Domain

This page titled 23.6: Main Sequence Star Lives is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.7: Red Giants and White Dwarfs



What's next for the Sun?

What happens after our Sun comes off the main sequence? Our Sun will become an enormous red star. It will grow so large that it will extend beyond Mars to the edge of the asteroid belt. Obviously, it will engulf our Earth. Betelgeuse is a red giant star that you can see in the sky near Orion.

Red Giants

Eventually a main sequence star will use up all of its hydrogen. It then starts to fuse helium atoms into larger elements like carbon. At this time, the star's core will collapse inward. The star's outer layers will spread out and cool. The result is a larger star that is cooler on the surface, and red in color. The star is now a **red giant**.

White Dwarfs

Eventually a red giant burns up all of the helium in its core. What happens next depends on the star's mass. A star like the Sun stops fusion and shrinks into a white dwarf star. A **white dwarf** is a hot, white, glowing object about the size of Earth. Eventually, a white dwarf cools down, and its light fades out.

Sirius (**Figure** below) is seen as the brightest star in the sky. It is actually a binary star system. Sirius A is on the main sequence. Sirius B is a tiny white dwarf.



Sirius A is the large star. Sirius B is the tiny dot on the lower left.

Summary

- When stars fuse helium into larger atoms, they become red giants.
- In a red giant, the inner helium core contracts while the outer layers of hydrogen expand.
- When the helium is gone, the stars become white dwarfs.

Review

1. When does a star become a red giant?
2. What are the characteristics of a red giant?
3. When does a star become a white dwarf?
4. What are the characteristics of a white dwarf?

Explore More

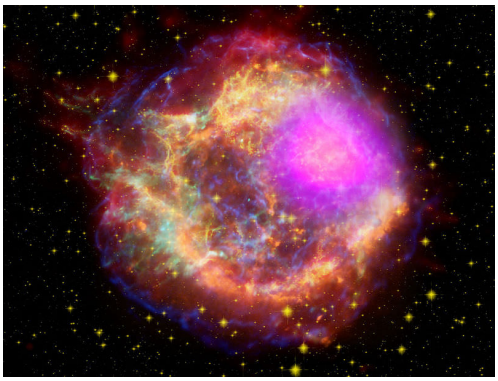
1. How long will it take for our Sun to become a red giant?
2. What is the Triple Alpha Process?
3. What will the Triple Alpha Process cause a star to do?
4. What will happen to Mercury, Venus, and possibly Earth when the Sun becomes a red giant?

References

Image	Reference	Attributions
	**[Figure 1]**	**Credit:** Courtesy of H. Bond (STScI), and M. Barstow (University of Leicester), NASA/ESA **Source:** commons.wikimedia.org/wiki/File:Sirius_A_and_B_Hubble_photo.jpg **License:** Public Domain
	**[Figure 2]**	**Credit:** Courtesy of H. Bond (STScI), and M. Barstow (University of Leicester), NASA/ESA **Source:** http://commons.wikimedia.org/wiki/File:Sirius_A_and_B_Hubble_photo.jpg **License:** Public Domain

This page titled 23.7: Red Giants and White Dwarfs is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.8: Supergiants and Supernovas



What if the sun was larger?

A larger star has a different fate. It will not just eventually fade away. A large star will explode. These explosions are very important for all of us. We could not exist without them. To see the results of supernova explosions, you need only look at yourself.

Supergiants

A more massive star ends its life in a more dramatic way. Very massive stars become red **supergiants**. Unlike a red giant, when all the helium in a red supergiant is gone, fusion continues. Lighter atoms fuse into heavier atoms up to iron atoms. Creating elements heavier than iron through fusion uses more energy than it produces. For this reason, stars do not ordinarily form any heavier elements. When there are no more elements for the star to fuse, the core succumbs to gravity and collapses.

Betelgeuse (**Figure** below) is a red supergiant. VY Canis Majoris, the largest known star, is even larger. It is classified as a red hypergiant.

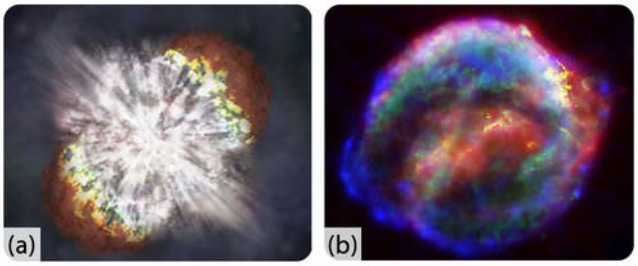


The red star Betelgeuse in Orion is a red supergiant.

In a red supergiant, fusion does not stop. Lighter atoms fuse into heavier atoms. Eventually iron atoms form.

Supernova

When there is nothing left to fuse, the star's iron core explodes violently. This is called a **supernova** explosion. The incredible energy released fuses heavy atoms together. The elements heavier than iron form in supernova explosions, including gold, silver, and uranium. A supernova can shine as brightly as an entire galaxy, but only for a short time, as illustrated below (**Figure** below).



(a) NASA's Chandra X-ray observatory captured the brightest stellar explosion so far, 100 times more energetic than a typical supernova. (b) This false-color image of the supernova remnant SN 1604 was observed as a supernova in the Milky Way galaxy. At its peak, it was brighter than all other stars and planets, except Venus, in the night sky.

The Importance of Supernovae

All chemical elements except hydrogen, helium, and lithium were created in stars. These chemical elements are found in our solar system and on Earth because of supernova explosions. This is what people mean when they say that we are all made of stardust.

Summary

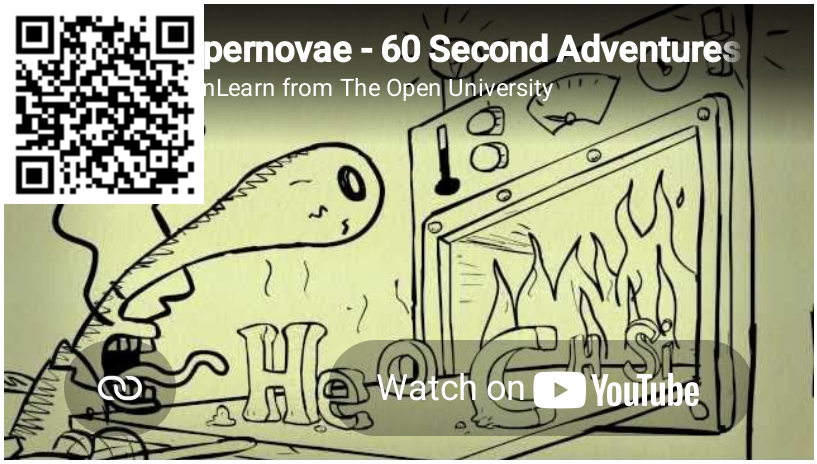
- When a massive star has no more elements left to fuse, it explodes as a supernova.
- Chemical elements heavier than lithium form in a supernova.
- A supernova explosion spreads the elements into nearby space. This is the source of most of our elements.

Review

1. Why do some stars become red supergiants?
2. How does a star become a supernova?
3. Why are supernovae important?

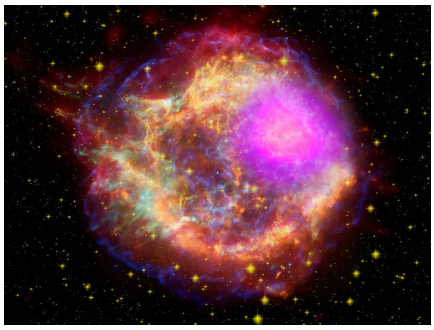
Explore More

Use the resource below to answer the questions that follow.



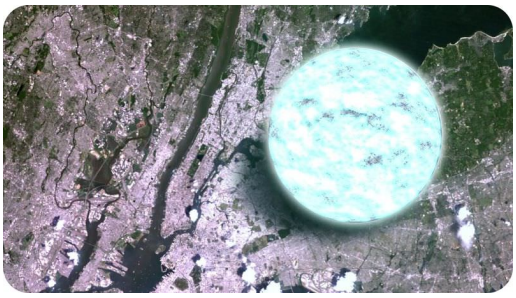
1. How and when did the object in space we now call the Crab Nebula form?
2. What is now at the center of the Crab Nebula?
3. What is the mass of the object at the center of the Crab Nebula?
4. What is created in a supernova?
5. Why do people say that everything is made of stardust?

References

Image	Reference	Attributions
	**[Figure 1]**	**Credit:** (a) Courtesy of NASA/CXC/M.Weiss; (b) Courtesy of NASA/ESA/JHU/R.Sankrit & W.Blair;Courtesy of H. Bond (STScI), and M. Barstow (University of Leicester), NASA/ESA **Source:** (a) http://www.nasa.gov/mission_pages/chandra/news/chandra_bright_supernova.html ; (b) commons.wikimedia.org/wiki/File:Keplers_supernova.jpg ; commons.wikimedia.org/wiki/File:Sirius_A_and_B_Hubble_photo.jpg **License:** Public Domain
	**[Figure 2]**	**Credit:** Courtesy of Akira Fujii and the Hubble European Space Agency, modified by Henrykus;Courtesy of H. Bond (STScI), and M. Barstow (University of Leicester), NASA/ESA **Source:** commons.wikimedia.org/wiki/File:Betelgeuse_position_in_Orion.png ; commons.wikimedia.org/wiki/File:Sirius_A_and_B_Hubble_photo.jpg **License:** Public Domain
	**[Figure 3]**	**Credit:** (a) Courtesy of NASA/CXC/M.Weiss; (b) Courtesy of NASA/ESA/JHU/R.Sankrit & W.Blair;Courtesy of H. Bond (STScI), and M. Barstow (University of Leicester), NASA/ESA **Source:** (a) http://www.nasa.gov/mission_pages/chandra/news/chandra_bright_supernova.html ; (b) commons.wikimedia.org/wiki/File:Keplers_supernova.jpg ; commons.wikimedia.org/wiki/File:Sirius_A_and_B_Hubble_photo.jpg **License:** Public Domain

This page titled 23.8: Supergiants and Supernovas is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.9: Neutron Stars and Black Holes



How dense can you get?

A neutron star has about 500,000 times Earth's mass. It is the size of Brooklyn, New York. These objects have an immense amount of gravity, but not as much as a black hole!

Neutron Stars

After a supernova explosion, the star's core is left over. This material is extremely dense. What happens next depends on the core's mass. The core might be less than about four times the mass of the sun. In this case, the star will become a neutron star. A **neutron star** (**Figure** below) is made almost entirely of neutrons. A neutron star has more mass than the sun, but it is only a few kilometers in diameter.



An artist's depiction of a neutron star.

A pulsar is a rotating neutron star that emits radiation in pulses. A pulsar can be seen only when the beam is pointing toward Earth. Pictured below is a nebula that looks like a cosmic hand (**Figure** below). There is a bright swirl of gas in the wrist of the hand. A very tiny but bright neutron star is in the center of that swirl.



A neutron star at the center of a nebula.

A pulsar sits in the center of this nebula.

Black Holes

The core remaining after a supernova could be more than about five times the mass of the sun. In this case, the core collapses to become a **black hole**. Black holes are unimaginably dense. Not even light can escape their gravity (**Figure** below)! This is why they are black. We can't see black holes.

How can we know something exists if radiation can't escape it? A black hole affects the objects around it. It affects them with its gravity. Some radiation may leak out around the edges of a black hole. A black hole isn't a hole at all. It is the tremendously dense core of a supermassive star.



The light of these galaxies is being bent by a black hole.

Summary

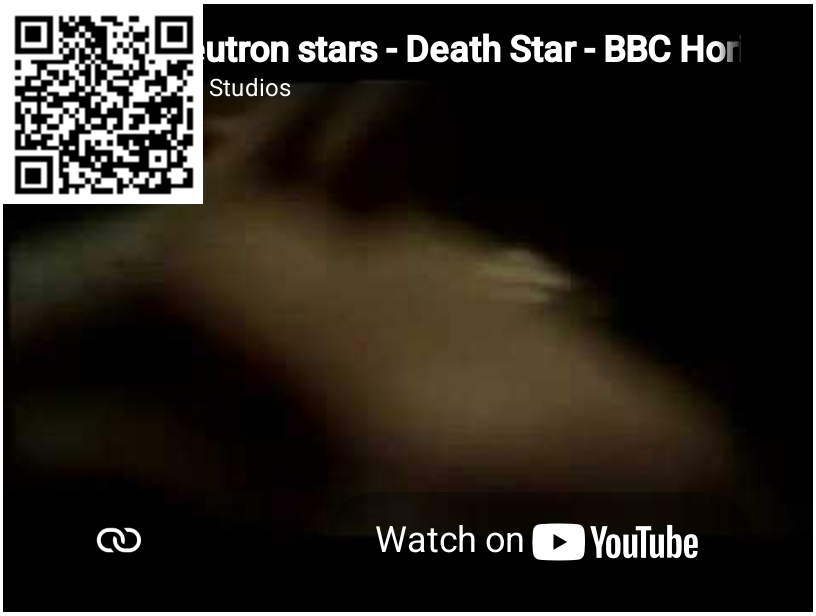
- After a supernova explosion, the star's core is left.
- If the core is less dense, it becomes a neutron star. A neutron star is made almost all of neutrons.
- If the core is more dense, it becomes a black hole. No light can escape a black hole.

Review

1. What are the characteristics of a neutron star?
2. What are the characteristics of a black hole?
3. How do scientists know that black holes exist?
4. Describe how a star forms a neutron star or a black hole and why it would form one or the other.

Explore More

Use the resources below to answer the questions that follow.



1. What is the most distinctive feature of neutron stars?
2. How large and how massive is a neutron star?

3. What might cause neutron stars to release gamma rays?
4. What if a neutron star exploded close to us in our galaxy?



5. What do black holes do in space?
6. What do black holes look like?

References

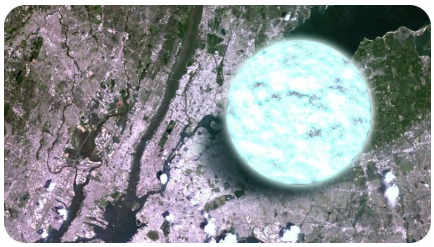
Image	Reference	Attributions
	**[Figure 1]**	**Credit:** Courtesy of NASA, ESA, J. Rigby (NASA Goddard Space Flight Center), K. Sharon (Kavli Institute for Cosmological Physics, University of Chicago) and M. Gladders and E. Wuyts (University of Chicago);(a) Courtesy of NASA/CXC/M.Weiss; (b) Courtesy of NASA/ESA/JHU/R.Sankrit & W.Blair;Courtesy of H. Bond (STScI), and M. Barstow (University of Leicester), NASA/ESA **Source:** commons.wikimedia.org/wiki/File:Gravitational_lensing_in_galaxy_cluster.jpg ; (a) http://www.nasa.gov/mission_pages/chandra/news/chandra_bright_supernova.html ; (b) commons.wikimedia.org/wiki/File:Keplers_supernova.jpg ; commons.wikimedia.org/wiki/File:Sirius_A_and_B_Hubble_photo.jpg **License:** Public Domain
	**[Figure 2]**	**Credit:** Courtesy of Casey Reed/Penn State University;By NASA - Original. Source (StarChild Learning Center). Directory listing., Public Domain, commons.wikimedia.org/w/inde...id=1657641;(a) Courtesy of NASA/CXC/M.Weiss; (b) Courtesy of NASA/ESA/JHU/R.Sankrit & W.Blair;Courtesy of H. Bond (STScI), and M. Barstow (University of Leicester), NASA/ESA **Source:** commons.wikimedia.org/wiki/File:Neutron_star_illustrated.jpg ; By NASA - Original. Source (StarChild Learning Center). Directory listing. ; Public Domain ; commons.wikimedia.org/w/index.php?curid=1657641 ; (a) http://www.nasa.gov/mission_pages/chandra/news/chandra_bright_supernova.html ; (b) commons.wikimedia.org/wiki/File:Keplers_supernova.jpg ; commons.wikimedia.org/wiki/File:Sirius_A_and_B_Hubble_photo.jpg **License:** Public Domain

Image	Reference	Attributions
	**[Figure 3]**	**Credit:** Courtesy of NASA/CXC/CfA/P. Slane et al.;(a) Courtesy of NASA/CXC/M.Weiss; (b) Courtesy of NASA/ESA/JHU/R.Sankrit & W.Blair;Courtesy of H. Bond (STScI), and M. Barstow (University of Leicester), NASA/ESA **Source:** commons.wikimedia.org/wiki/File:PSR_B1509-58_full.jpg ; (a) http://www.nasa.gov/mission_pages/chandra/news/chandra_bright_supernova.html ; (b) commons.wikimedia.org/wiki/File:Keplers_supernova.jpg ; commons.wikimedia.org/wiki/File:Sirius_A_and_B_Hubble_photo.jpg **License:** Public Domain
	**[Figure 4]**	**Credit:** Courtesy of NASA, ESA, J. Rigby (NASA Goddard Space Flight Center), K. Sharon (Kavli Institute for Cosmological Physics, University of Chicago) and M. Gladders and E. Wuyts (University of Chicago);(a) Courtesy of NASA/CXC/M.Weiss; (b) Courtesy of NASA/ESA/JHU/R.Sankrit & W.Blair;Courtesy of H. Bond (STScI), and M. Barstow (University of Leicester), NASA/ESA **Source:** commons.wikimedia.org/wiki/File:Gravitational_lensing_in_galaxy_cluster.jpg ; (a) http://www.nasa.gov/mission_pages/chandra/news/chandra_bright_supernova.html ; (b) commons.wikimedia.org/wiki/File:Keplers_supernova.jpg ; commons.wikimedia.org/wiki/File:Sirius_A_and_B_Hubble_photo.jpg **License:** Public Domain

This page titled 23.9: Neutron Stars and Black Holes is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.10: Beyond the Solar System- Challenge 2

1. ___ stars use up hydrogen quickly and have short lives.

Large

2. ___ are small, white stars that eventually fade away.

White dwarfs

3. When the Sun becomes a red giant, Earth ___.

will be engulfed by the Sun's outer layers

4. When a star like the Sun uses up all the helium in its core, it becomes a ___.

white dwarf

5. VY Canis Major, the largest known star, is a ___.

red hypergiant

6. When a red supergiant uses up all its helium, ___.

fusion continues, forming heavier atoms up to iron

7. A neutron star has about ___ more mass than Earth.

500,000 times

8. A neutron star is only about ___ in diameter.

a few kilometers

9. After a supernova, the remnants become either a ___ or a ___, depending on their mass.

black hole; neutron star

This page titled 23.10: Beyond the Solar System- Challenge 2 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.11: Star Clusters



Can you see a star cluster in the night sky?

The Pleiades are also called the seven sisters. Seven of the stars in this cluster are visible in the night sky with the naked eye. The Pleiades are easy to spot. They are bright and very close to each other.

Star Systems

Our solar system has only one star. But many stars are in **star systems** of two or more stars. Two stars that orbit each other are called a binary star system. If more than two stars orbit each other, it is called a multiple star system. Pictured below are two binary star systems orbiting each other (**Figure** below). This creates an unusual quadruple star system. The distance separating the two pairs is about the same as the distance from our Sun to Pluto.



This is an artist's depiction of HD 98800. This is a quadruple star system made of two binary star systems.

Star Clusters

Star clusters are small groups of stars. A star cluster is smaller than a galaxy. There are two main types, open clusters and globular clusters. Both types are held together by gravity.

Open Clusters

Open clusters are groups of up to a few thousand stars. The Jewel Box (**Figure** below), is an open cluster. Open clusters tend to be blue in color. They often contain glowing gas and dust. The stars in an open cluster are young stars that all formed from the same nebula.



These hot blue stars are in an open cluster known as the Jewel Box. The red star is a young red supergiant.

Globular Clusters

Globular clusters (**Figure** below) are groups of tens to hundreds of thousands of stars. Gravity holds these stars tightly together. Globular clusters have a definite, spherical shape. They contain mostly old, reddish stars. Near the center of a globular cluster, the stars are closer together. The heart of the globular cluster M13 has hundreds of thousands of stars. M13 is 145 light years in diameter. The cluster contains red and blue giant stars.



The globular cluster, M13, contains red and blue giant stars.

Summary

- Two or more stars may orbit each other in a star system.
- A group of stars, smaller than a galaxy, is a star cluster.
- The two main types of star clusters are open clusters and globular clusters.

Review

1. What are the characteristics of a star system?
2. What is the difference between an open cluster and a globular cluster?
3. How do star clusters stay together?

Explore More

Use the resource below to answer the questions that follow.



1. What is NGC 3603 and what does it contain?
2. What is happening in the star cluster? Where is it located?
3. What is the nebula?
4. When were the stars in this star cluster formed?
5. What type of stars are in the star cluster?
6. What is the significance of the dark regions in the nebula?
7. What stage of life is the blue supergiant in? What will happen to it next?
8. Why is the fate of the blue supergiant so significant?

References

Image	Reference	Attributions
	**[Figure 1]**	**Credit:** Courtesy of ESA/Hubble and NASA;Courtesy of NASA **Source:** commons.wikimedia.org/wiki/File:Heart_of_M13_Hercules_Globular_Cluster.jpg ; commons.wikimedia.org/wiki/File:Beit_Alpha.jpg **License:** Public Domain
	**[Figure 2]**	**Credit:** Courtesy of NASA/JPL-Caltech/T. Pyle (SSC);By Maximilien Brice - https://cds.cern.ch/record/1211045, CC BY-SA 4.0, commons.wikimedia.org/w/inde...44864;Courtesy of NASA **Source:** commons.wikimedia.org/wiki/File:HD_98800.jpg ; By Maximilien Brice - https://cds.cern.ch/record/1211045 ; CC BY-SA 4.0 ; commons.wikimedia.org/w/index.php?curid=47844864 ; commons.wikimedia.org/wiki/File:Beit_Alpha.jpg **License:** Public Domain; CC BY-NC 3.0
	**[Figure 3]**	**Credit:** ESO/Y. Beletsky;By Maximilien Brice - https://cds.cern.ch/record/1211045, CC BY-SA 4.0, commons.wikimedia.org/w/inde...44864;Courtesy of NASA **Source:** commons.wikimedia.org/wiki/File:A_Snapshot_of_the_Jewel_Box_cluster_with_the_ESO_VLT.jpg ; By Maximilien Brice - https://cds.cern.ch/record/1211045 ; CC BY-SA 4.0 ; https://commons.wikimedia.org/w/index.php?curid=47844864 ; commons.wikimedia.org/wiki/File:Beit_Alpha.jpg **License:** CC BY 3.0; CC BY-NC 3.0; Public Domain

Image	Reference	Attributions
	**[Figure 4]**	**Credit:** Courtesy of ESA/Hubble and NASA **Source:** commons.wikimedia.org/wiki/File:Heart_of_M13_Hercules_Globular_Cluster.jpg **License:** Public Domain

This page titled 23.11: Star Clusters is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.12: Galaxies



What's happening with those galaxies?

Find a clear night sky and get out a good pair of binoculars or a telescope. You can see this feature (although not quite as well). The Whirlpool galaxy has an enhanced spiral structure due to its interactions with its companion galaxy, NGC 5195.

Galaxies

Compared to Earth, the solar system is a big place. Compared to the solar system a star cluster is a big place. But galaxies are bigger—a lot bigger.

A **galaxy** is a very large group of stars held together by gravity. How enormous a galaxy is and how many stars it contains is impossible for us to really understand. A galaxy contains up to a few billion stars! Our solar system is in the Milky Way Galaxy. It is so large that if our solar system were the size of your fist, the galaxy's disk would be wider than the entire United States! There are several different types of galaxies, and there are billions of galaxies in the Universe.

Types of Galaxies

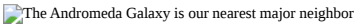
Galaxies are divided into three types, according to shape. There are spiral galaxies, elliptical galaxies, and irregular galaxies.

Spiral Galaxies

A **spiral galaxy** is a rotating disk of stars and dust. In the center is a dense bulge of material. Several **spiral arms** come out from the center. Spiral galaxies have lots of gas and dust and many young stars. **Figure** below shows a spiral galaxy from the side. You can see the disk and central bulge.

The Pinwheel Galaxy is a spiral galaxy displaying prominent arms.

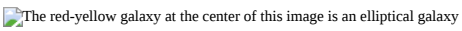
The closest spiral galaxy, the Andromeda Galaxy (**Figure** below) is 2,500,000 light years away and contains one trillion stars!



The Andromeda Galaxy is the closest major galaxy to our own.

Elliptical Galaxies

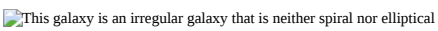
Pictured below is a typical **elliptical galaxy** (**Figure** below). As you might have guessed, elliptical galaxies are elliptical, or egg-shaped. The smallest elliptical galaxies are as small as some globular clusters. Giant elliptical galaxies can contain over a trillion stars. Elliptical galaxies are reddish to yellowish in color because they contain mostly old stars.



The large, reddish-yellow object in the middle of this figure is a typical elliptical galaxy. Can you find other galaxies in the figure? What kind?

Irregular Galaxies and Dwarf Galaxies

Look at the galaxy pictured below (**Figure** below). Do you think this is a spiral galaxy or an elliptical galaxy? It is neither one! Galaxies that are not clearly elliptical galaxies nor spiral galaxies are called **irregular galaxies**. Most irregular galaxies were once spiral or elliptical galaxies. They were then deformed either by gravitational attraction to a larger galaxy or by a collision with another galaxy.



This galaxy, called NGC 1427A, is an irregular galaxy. It has neither a spiral nor an elliptical shape.

Dwarf galaxies are small galaxies containing "only" a few million to a few billion stars. Most dwarf galaxies are irregular in shape. However, there are also *dwarf elliptical galaxies* and *dwarf spiral galaxies*. Dwarf galaxies are the most common type in the

CK-12 LICENSED UNDER CK-12 License © CK-12 Foundation • Visit us at ck12.org

Universe. However, because they are relatively small and dim, we don’t see as many dwarf galaxies as we do their full-sized cousins.



Summary

- A galaxy is composed of millions to billions of stars.
- Galaxies can be spiral, elliptical, or irregular.
- Dwarf galaxies are smaller. Any of the three types can be dwarf galaxies.

Review

1. Describe the characteristics of a spiral galaxy.
2. Describe the characteristics of an elliptical galaxy.
3. Describe the characteristics of an irregular galaxy.

References

Image	Reference	Attributions
	**[Figure 1]**	**Credit:** Courtesy of NASA, ESA, and The Hubble Heritage Team (STScI/AURA) **Source:** commons.wikimedia.org/wiki/File:Irregular_galaxy_NGC_1427A_%28captured_by_the_Hubble_Space_Telescope%29.jpg **License:** Public Domain
	**[Figure 2]**	**Credit:** Courtesy of NASA and ESA, K.D. Kuntz (GSFC), F. Bresolin (University of Hawaii), J. Trauger (JPL), J. Mould (NOAO), and Y.-H. Chu (University of Illinois, Urbana) **Source:** http://hubblesite.org/newscenter/archive/releases/2006/10/image/a/ **License:** Public Domain
	**[Figure 3]**	**Credit:** Adam Evans **Source:** commons.wikimedia.org/wiki/File:Andromeda_Galaxy_%28with_h-alpha%29.jpg **License:** CC BY 2.0; CC BY-NC 3.0
	**[Figure 4]**	**Credit:** Courtesy of NASA, ESA, and The Hubble Heritage Team (STScI/AURA) **Source:** commons.wikimedia.org/wiki/File:Abell_S740 ; _cropped_to_ESO_325-G004.jpg **License:** Public Domain
	**[Figure 5]**	**Credit:** Courtesy of NASA, ESA, and The Hubble Heritage Team (STScI/AURA) **Source:** commons.wikimedia.org/wiki/File:Irregular_galaxy_NGC_1427A_%28captured_by_the_Hubble_Space_Telescope%29.jpg **License:** Public Domain

This page titled 23.12: Galaxies is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.13: The Milky Way



Have you seen the Milky Way?

There is so much light pollution in most cities that many people have never seen the Milky Way. On a clear night away from lights, the view is of a bright white river of stars. You don't need a telescope or even binoculars to see it. The view of the Milky Way is so bright because you're looking at the stars in your own galaxy.

The Milky Way Galaxy

The **Milky Way Galaxy** is our galaxy. Home, sweet home. The Milky Way is made of millions of stars along with a lot of gas and dust. It looks different from other galaxies because we are looking at the main disk from within the galaxy. Astronomers estimate that the Milky Way contains 200 billion to 400 billion stars.

Shape and Size

It is difficult to know what the shape of the Milky Way Galaxy is because we are inside of it. Astronomers have identified it as a typical spiral galaxy containing about 100 billion to 400 billion stars (**Figure** below).



An artist’s rendition of what astronomers think the Milky Way Galaxy would look like seen from above. The sun is located approximately where the arrow points.

Like other spiral galaxies, our galaxy has a disk, a central bulge, and spiral arms. The disk is about 100,000 light-years across and 3,000 light-years thick. Most of the Galaxy’s gas, dust, young stars, and open clusters are in the disk.

The Milky Way Galaxy is a big place. If our solar system were the size of your fist, the Galaxy’s disk would still be wider than the entire United States!

Where Are We?

Our solar system, including the Sun, Earth, and all the other planets, is within one of the spiral arms in the disk of the Milky Way Galaxy. Most of the stars we see in the sky are also in this spiral arm. We are about 26,000 light-years from the center of the galaxy. We are a little more than halfway out from the center of the galaxy to the edge.

Just as Earth orbits the Sun, the solar system orbits the center of the galaxy. Astronomers have recently discovered that at the center of the Milky Way and most other galaxies, is a supermassive black hole.



Summary

- From inside, the Milky Way Galaxy looks like a river of stars.
- From outside the galaxy, the Milky Way would appear as a spiral.
- Our solar system is midway out a spiral arm of the Milky Way.

Review

1. Why do astronomers think that the Milky Way is a spiral galaxy?
2. Where is Earth in the Milky Way Galaxy?
3. What is at the center of the Milky Way Galaxy?

References

Image	Reference	Attributions
	**[Figure 1]**	**Credit:** Courtesy of NASA/JPL-Caltech/R. Hurt (SSC);Courtesy of NASA, ESA, and The Hubble Heritage Team (STScI/AURA) **Source:** www.spitzer.caltech.edu/images/2351-sig05-010-Milky-Way-Bar-annotated- ; commons.wikimedia.org/wiki/File:Irregular_galaxy_NGC_1427A_%28captured_by_the_Hubble_Space_Telescope%29.jpg **License:** Public Domain
	**[Figure 2]**	**Credit:** Courtesy of NASA/JPL-Caltech/R. Hurt (SSC);Courtesy of NASA, ESA, and The Hubble Heritage Team (STScI/AURA) **Source:** www.spitzer.caltech.edu/images/2351-sig05-010-Milky-Way-Bar-annotated- ; commons.wikimedia.org/wiki/File:Irregular_galaxy_NGC_1427A_%28captured_by_the_Hubble_Space_Telescope%29.jpg **License:** Public Domain

This page titled 23.13: The Milky Way is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.14: Universe



What's at the edge of the Universe?

This image is of the farthest away objects in the Universe. It was taken by the Hubble Space Telescope. The image looks back about 13 billion years. The galaxies in this image were all very young. It has taken 13 billion years for their light to reach us.

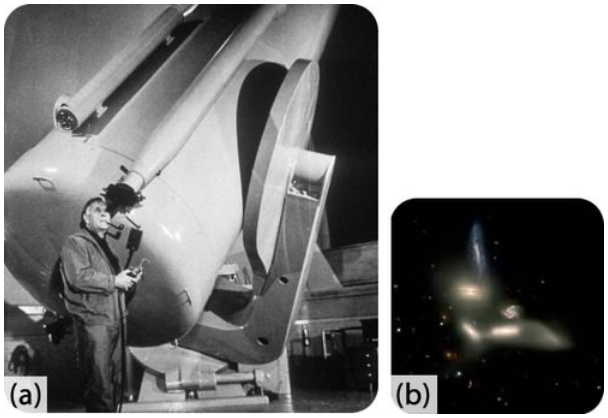
The Universe

The study of the Universe is called **cosmology**. Cosmologists study the structure and changes in the present Universe. The **Universe** contains all of the star systems, galaxies, gas, and dust. They also study all the matter and energy that exists now, existed in the past, will exist in the future. The Universe includes all of space and time.

Human Understanding of the Universe

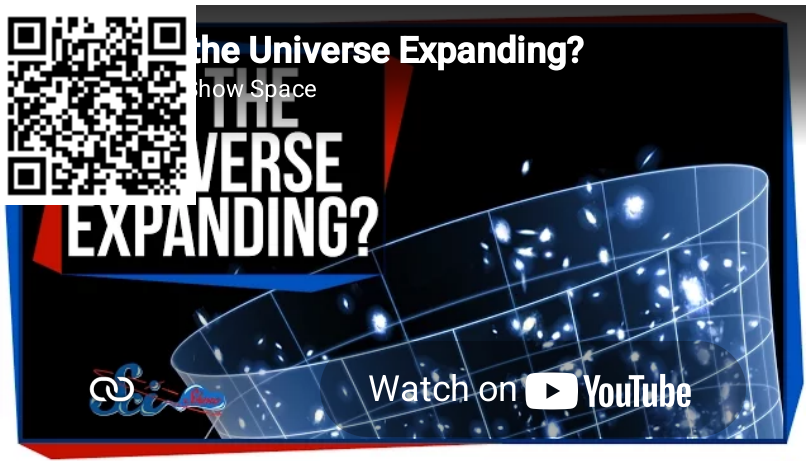
What did the ancient Greeks recognize as the Universe? Their Universe had Earth at the center, the Sun, the Moon, five planets, and a sphere to which all the stars were attached. This idea held for many centuries. Galileo and his telescope helped people recognize that Earth is not the center of the Universe. They also found out that there are many more stars than were visible to the naked eye. All of those stars were in the Milky Way Galaxy.

In the early 20th century, an astronomer named Edwin Hubble (**Figure** below) discovered something amazing. He showed that the Andromeda Nebula was over 2 million light years away. This was many times farther than the farthest distances that had ever been measured. Hubble realized that many of the objects that astronomers called nebulas were not actually clouds of gas. They were collections of millions or billions of stars. We now call these features galaxies.



(a) Edwin Hubble used the 100-inch reflecting telescope at the Mount Wilson Observatory in California to show that some distant specks of light were galaxies. (b) Hubble's namesake space telescope spotted this six galaxy group. Edwin Hubble demonstrated the existence of galaxies.

Hubble showed that the Universe was much larger than our own galaxy. Today, we know that the Universe contains about a hundred billion galaxies. This is about the same number of galaxies as there are stars in the Milky Way Galaxy.



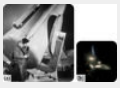
Summary

- The Universe contains about a hundred billion galaxies.
- The idea of a Universe has changed through human history.
- Edwin Hubble determined that there was much more to space than our own galaxy.

Review

1. What do cosmologists study?
2. What was the importance of Edwin Hubble seeing that the Andromeda nebula was actually a galaxy?
3. What makes up the Universe?

References

Image	Reference	Attributions
	**[Figure 1]**	**Credit:** (a) Courtesy of NASA; (b) Courtesy of NASA, J. English (U. Manitoba), S. Hunsberger, S. Zonak, J. Charlton, S. Gallagher (PSU), and L. Frattare (STScI) **Source:** (a) quest.arc.nasa.gov/hst/about/edwin.html ; (b) http://hubblesite.org/newscenter/archive/releases/2002/22/image/a/ **License:** Public Domain
	**[Figure 2]**	**Credit:** (a) Courtesy of NASA; (b) Courtesy of NASA, J. English (U. Manitoba), S. Hunsberger, S. Zonak, J. Charlton, S. Gallagher (PSU), and L. Frattare (STScI) **Source:** (a) quest.arc.nasa.gov/hst/about/edwin.html ; (b) http://hubblesite.org/newscenter/archive/releases/2002/22/image/a/ **License:** Public Domain

This page titled 23.14: Universe is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.15: Expansion of the Universe



Why does a siren change pitch as it passes you?

The sound of a siren on an emergency vehicle changes as it passes you. It shifts from higher to lower pitch. As the vehicle moves toward you, the sound waves are pushed together. As the vehicle moves past you, the waves are spread apart. This effect with light tells astronomers something about our Universe.

The Universe is Expanding

After discovering that there are galaxies outside our own, Edwin Hubble went on to measure the distance to hundreds of other galaxies. His data would eventually show us how the Universe is changing, and even give us clues as to how the Universe formed.

Redshift

If you look at a star through a prism, you will see a **spectrum**. The spectrum is the range of colors seen in a rainbow. The spectrum has specific dark bands where elements in the star have absorbed light of certain energies. An astronomer can use these lines to determine which elements are in a distant star. In fact, the element helium was first discovered in our Sun, not on Earth. This was done by analyzing the absorption lines in the spectrum of the sun.

Astronomers studied the spectra of light from distant galaxies. When they did this they noticed something strange. The dark lines in the spectrum were in the patterns they expected. But they were shifted toward the red end of the spectrum (**Figure** below). This shift of absorption bands toward the red end of the spectrum is known as **redshift**.



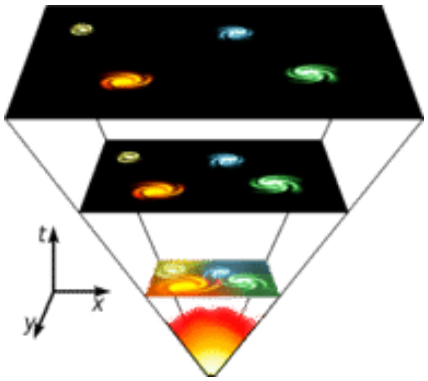
Redshift is a shift in absorption bands toward the red end of the spectrum. Redshift occurs when the light source is moving away from you or when the space between you and the source is stretched.

Redshift occurs when the source of light is moving away from the observer. So when astronomers see redshift in the light from a galaxy, they know that the galaxy is moving away from Earth. The strange part is that almost every galaxy in the Universe has a redshift. Of course, this means that almost every galaxy is moving away from us.

The Expanding Universe

Edwin Hubble combined his measurements of the distances to galaxies with other astronomers' measurements of redshift. He noticed a relationship, which is now called *Hubble's Law:* The farther away a galaxy is, the faster it is moving away from us. In other words, the Universe is expanding!

Pictured below is a simplified diagram of the expansion of the Universe (**Figure** below). Another way to picture this is to imagine a balloon covered with tiny dots. Each dot represents a galaxy. When you inflate the balloon, the dots slowly move away from each other because the rubber stretches in the space between them. If it were a giant balloon and you were standing on one of the dots, you would see the other dots moving away from you. Not only that, but dots farther away from you on the balloon would move away faster than dots nearby.



This is a simplified diagram of the expansion of the Universe over time. Note that the distance between galaxies gets bigger as you go forward in time, but the size of each galaxy stays about the same.

An inflating balloon is not exactly like the expanding Universe. But it is true that space itself is stretching out between galaxies like the rubber stretches when a balloon is inflated. This stretching of space, which causes the distance between galaxies to increase, is what astronomers mean by the expansion of the Universe.

One other difference between the Universe and our balloon model involves the actual size of the galaxies. On the inflating balloon, the dots you made will become larger in size as you inflate it. In our Universe, however, the galaxies stay the same size; it is just the space between the galaxies that increases as the Universe expands.

Summary

- Almost every galaxy is moving away from us.
- The spectrum from stars is shifted toward the red; this is known as red-shift. Red-shift of galaxies is evidence that the Universe is expanding.
- Hubble's Law states that the farther away a galaxy is, the faster it is moving away from us.

Review

1. How did Hubble determine that the Universe is expanding?
2. How do astronomers learn what stars are made of?
3. What is Hubble's Law?

Explore More

Use the resource below to answer the questions that follow.



1. What is redshift used to determine?
2. What is the Doppler shift?
3. How does the Doppler shift relate to light?
4. What does blueshift tell us?
5. Why is most of the galaxy redshifted?
6. What does cosmic redshift tell us?

References

Image	Reference	Attributions
	**[Figure 1]**	**Credit:** User:Gnixon/Wikipedia;(a) Courtesy of NASA; (b) Courtesy of NASA, J. English (U. Manitoba), S. Hunsberger, S. Zonak, J. Charlton, S. Gallagher (PSU), and L. Frattare (STScI) **Source:** commons.wikimedia.org/wiki/File:Universe_expansion2.png ; (a) quest.arc.nasa.gov/hst/about/edwin.html ; (b) http://hubblesite.org/newscenter/archive/releases/2002/22/image/a/ **License:** Public Domain
	**[Figure 2]**	**Credit:** User:Tkarcher_(usurped)/Wikimedia Commons;(a) Courtesy of NASA; (b) Courtesy of NASA, J. English (U. Manitoba), S. Hunsberger, S. Zonak, J. Charlton, S. Gallagher (PSU), and L. Frattare (STScI) **Source:** commons.wikimedia.org/wiki/File:Doppler_effect_diagrammatic.png ; (a) quest.arc.nasa.gov/hst/about/edwin.html ; (b) http://hubblesite.org/newscenter/archive/releases/2002/22/image/a/ **License:** Public Domain
	**[Figure 3]**	**Credit:** User:Gnixon/Wikipedia;(a) Courtesy of NASA; (b) Courtesy of NASA, J. English (U. Manitoba), S. Hunsberger, S. Zonak, J. Charlton, S. Gallagher (PSU), and L. Frattare (STScI) **Source:** commons.wikimedia.org/wiki/File:Universe_expansion2.png ; (a) quest.arc.nasa.gov/hst/about/edwin.html ; (b) http://hubblesite.org/newscenter/archive/releases/2002/22/image/a/ **License:** Public Domain

This page titled 23.15: Expansion of the Universe is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

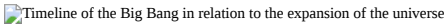
23.16: Big Bang



How did everything begin in the Big Bang?

The time when the Universe began is the explosion known as the Big Bang. Everything in the Universe was part of that explosion, although not in its current form.

The Big Bang Theory



Timeline of the Big Bang and the expansion of the Universe.

There is a great deal of evidence that the Universe started with a big bang. The **Big Bang theory** is the most widely accepted cosmological explanation of how the Universe formed. Think about the expanding Universe, then reverse it. If we start at the present and go back into the past, the Universe gets smaller. What is the end result of a contracting Universe? A point.

According to the Big Bang theory, the Universe began about 13.7 billion years ago. Everything that is now in the Universe was squeezed into a point. It was all in a single, hot, chaotic mass. Then an enormous explosion—a big bang—took place. The big bang caused the Universe to start expanding rapidly. All the matter and energy, even space itself, came out of this explosion (**Figure** above).

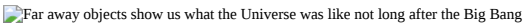
What came before the Big Bang? There is no way for scientists to know, since there is no remaining evidence.

After The Big Bang

In the first few moments after the Big Bang, the Universe was unimaginably hot and dense. As the Universe expanded, it became less dense. It began to cool. After only a few seconds, protons, neutrons, and electrons could form. After a few minutes, hydrogen came together. There was so much energy that nuclear fusion began. This created helium.

Clumps of matter were held together by gravity. Eventually, these clumps formed stars. There are now countless trillions of stars, billions of galaxies, and other structures that form the visible Universe.

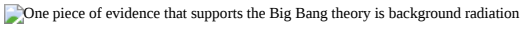
The galaxies at the edge of the Universe are a great distance away. But they are something else that is distant. Because it takes so long for light from so far away to reach us, they are also very far back in time (**Figure** below).



Images from very far away show what the Universe was like not too long after the Big Bang.

Background Radiation

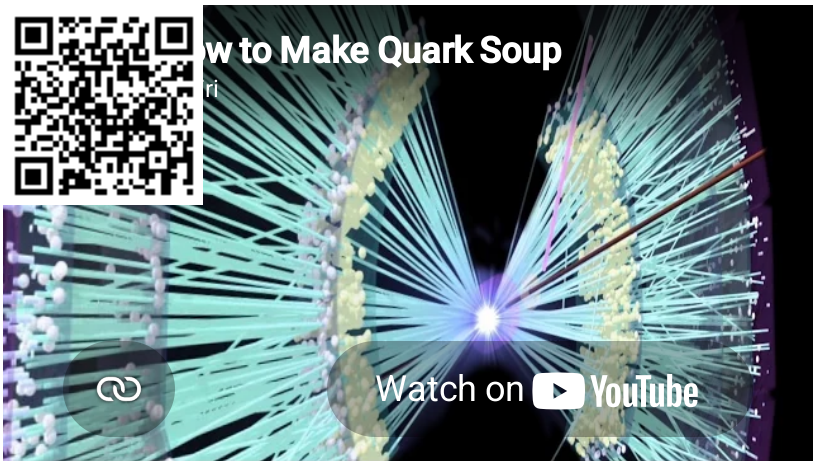
The Big Bang hypothesis was not immediately accepted. But an important line of evidence for the Big Bang was discovered in 1964. In a static Universe, the space between objects should have no heat at all. The temperature should measure 0 K (Kelvin is an absolute temperature scale). But two researchers at Bell Laboratories used a microwave receiver to measure the background radiation in the Universe. They discovered that it is not 0 K, but 3 K (**Figure** below). This tiny amount of heat is left over from the Big Bang. Nearly all astronomers and cosmologists now accept the Big Bang theory.



Background radiation in the Universe was good evidence for the Big Bang theory.

Science Friday: How to Make Quark Soup

What is a quark soup? Why is understanding a quark soup important to understanding the early universe? In this video by Science Friday, physicist Paul Sorensen explains what a quark soup is and some of the information it tells us about the early universe.



Summary

- The Big Bang theory states that the Universe began as a point and expanded outward.
- No one can know what came before the Big Bang.
- The tiny bit of background radiation in the Universe is energy remaining from the Big Bang.

Review

1. If the Universe is now expanding, why must it once have been a point?
2. What evidence is there that the Universe began in a big bang?
3. What happened in the first minutes after the Big Bang?

Explore More

Use the resource below to answer the questions that follow.



1. When did the Big Bang occur?
2. What did not exist before the Big Bang?
3. Describe the early Universe.
4. What was created at the Big Bang?
5. What happens when matter and antimatter collide?
6. Why is there a Universe at all?
7. When did the Universe become visible?

LibreTexts™

CK-12 LICENSED UNDER CK-12 License
© CK-12 Foundation • Visit us at ck12.org

References

Image	Reference	Attributions
	[Figure 1]	**Credit:** Courtesy of NASA/WMAP Science Team;(a) Courtesy of NASA; (b) Courtesy of NASA, J. English (U. Manitoba), S. Hunsberger, S. Zonak, J. Charlton, S. Gallagher (PSU), and L. Frattare (STScI) **Source:** commons.wikimedia.org/wiki/File:WMAP_2010.png ; (a) quest.arc.nasa.gov/hst/about/edwin.html ; (b) http://hubblesite.org/newscenter/archive/releases/2002/22/image/a/ **License:** Public Domain; CC BY-NC 3.0
	[Figure 2]	**Credit:** Courtesy of NASA/WMAP Science Team;(a) Courtesy of NASA; (b) Courtesy of NASA, J. English (U. Manitoba), S. Hunsberger, S. Zonak, J. Charlton, S. Gallagher (PSU), and L. Frattare (STScI) **Source:** commons.wikimedia.org/wiki/File:CMB_Timeline300_no_WMAP.jpg ; (a) quest.arc.nasa.gov/hst/about/edwin.html ; (b) http://hubblesite.org/newscenter/archive/releases/2002/22/image/a/ **License:** Public Domain; CC BY-NC 3.0
	[Figure 3]	**Credit:** Courtesy of NASA, ESA, S. Beckwith (STScI) and the HUDF Team;(a) Courtesy of NASA; (b) Courtesy of NASA, J. English (U. Manitoba), S. Hunsberger, S. Zonak, J. Charlton, S. Gallagher (PSU), and L. Frattare (STScI) **Source:** commons.wikimedia.org/wiki/File:Hubble_Ultra_Deep_Field_part_d.jpg ; (a) quest.arc.nasa.gov/hst/about/edwin.html ; (b) http://hubblesite.org/newscenter/archive/releases/2002/22/image/a/ **License:** Public Domain; CC BY-NC 3.0
	[Figure 4]	**Credit:** Courtesy of NASA/WMAP Science Team;(a) Courtesy of NASA; (b) Courtesy of NASA, J. English (U. Manitoba), S. Hunsberger, S. Zonak, J. Charlton, S. Gallagher (PSU), and L. Frattare (STScI)

Image	Reference	Attributions
		Source: commons.wikimedia.org/wiki/File:WMAP_2010.png ; (a) quest.arc.nasa.gov/hst/about/edwin.html ; (b) http://hubblesite.org/newscenter/archive/releases/2002/22/image/a/ **License:** Public Domain

This page titled 23.16: Big Bang is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.17: Dark Matter



Does science explain everything?

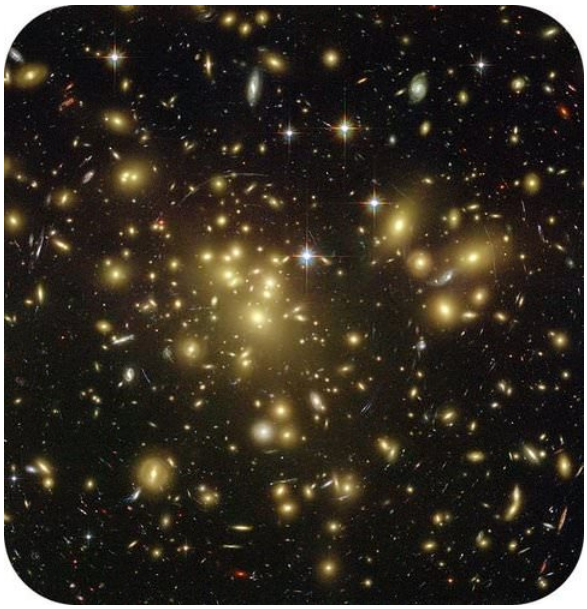
There are many things that science does not understand yet. There are some things that science may never understand. Science deals with things that are very far away. Or very old. Or that have left few traces of their existence. Some of the most difficult topics to study are in cosmology. The questions are age-old: What formed the Universe? What will be the fate of the Universe? These are exciting questions to work on! Dark matter and dark energy are two topics that are important to them.

Dark Matter

We see many objects out in space that emit light. We see other objects that emit other types of electromagnetic radiation. The matter we can see is contained in stars. The stars are contained in galaxies. Scientists think that stars and galaxies make up only a small part of the matter in the Universe. The rest of the matter is called **dark matter**.

Evidence for Dark Matter

Dark matter doesn't emit light, so we can't see it. We know it is there because it affects the motion of objects around it. For example, astronomers measure how spiral galaxies rotate. The outside edges of a galaxy rotate at the same speed as parts closer to the center. This can only be explained if there is a lot more matter in the galaxy than we can see. The way light bends around a very distant supermassive object is also due to dark matter (**Figure** below).



The arc around the galaxies at the center of this image is caused by gravitational lensing. The addition of gravitational pull from dark matter is required to explain this phenomenon.

What is Dark Matter?

What is dark matter? Actually, we don't really know. Dark matter could just be ordinary matter, like what makes up Earth. The Universe could contain lots of objects that don't have enough mass to glow on their own. There might just be a lot of black holes.

Another possibility is that the Universe contains a lot of matter that is different from anything we know. If it doesn't interact much with ordinary matter, it would be very difficult or impossible to detect directly.

Most scientists who study dark matter think it is a combination. Ordinary matter is part of it. They think it might be mixed with some kind of matter that we haven't discovered yet. Most scientists think that ordinary matter is less than half of the total matter in the Universe.

Dark Energy

We know that the Universe is expanding. Astronomers have wondered if it is expanding fast enough to escape the pull of gravity. Would the Universe just expand forever? If it could not escape the pull of gravity, would it someday start to contract? This means it would eventually get squeezed together in a big crunch. This is the opposite of the Big Bang.

Scientists may now have an answer. Recently, astronomers have discovered that the Universe is expanding even faster than before. What is causing the expansion to accelerate? One hypothesis is that there is energy out in the Universe that we can't see. Astronomers call this **dark energy**. We know even less about dark energy than we know about dark matter. Some scientists think that dark energy makes up more than half of the Universe.

KQED: Dark Energy

Meet one of the three winners of the 2011 Nobel Prize in Physics, Lawrence Berkeley Lab astrophysicist Saul Perlmutter. He explains how dark energy, which may make up 70 percent of the Universe, is causing our Universe to expand.



Science Friday: 4850 Feet Below: The Hunt for Dark Matter

Why is there a laboratory 4850 feet below the surface? It turns out the depth is a necessary component of the extremely sensitive detector called the Large Underground Xenon experiment. In this video by Science Friday, several scientists explain how this detector helps physicists look for extremely rare particles.



Summary

- Dark matter emits no electromagnetic radiation. For this reason it cannot be sensed by astronomers.
- Dark matter does have gravity. The effect of its gravity is seen on the motion of nearby objects.
- Dark matter may be ordinary matter that is dark. It may be different from ordinary matter. It may be a combination of the two.
- No one knows if dark energy exists. If it does, there may be a lot of it.

Review

1. Why can't scientists see dark matter?
2. What evidence is there for the existence of dark matter?
3. What could dark matter be?
4. What is dark energy? Does it exist?

Explore More

Use the resource below to answer the questions that follow.



1. What is dark matter?
2. What do scientists think dark matter does?
3. How much of the Universe is composed of dark matter?
4. How does dark matter affect the Universe?

References

Image	Reference	Attributions
	**[Figure 1]**	**License:** CC BY-NC
	**[Figure 2]**	**Credit:** Courtesy of NASA, N. Benitez (JHU), T. Broadhurst (Racah Institute of Physics/The Hebrew University), H. Ford (JHU), M. Clampin (STScI),G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory), the ACS Science Team and ESA;(a) Courtesy of NASA; (b) Courtesy of NASA, J. English (U. Manitoba), S. Hunsberger, S. Zonak, J. Charlton, S. Gallagher (PSU), and L. Frattare (STScI) **Source:** http://commons.wikimedia.org/wiki/File:Gravitationell-lins-4.jpg ; (a) quest.arc.nasa.gov/hst/about/edwin.html ; (b) http://hubblesite.org/newscenter/archive/releases/2002/22/image/a/ **License:** Public Domain

This page titled 23.17: Dark Matter is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

23.18: Beyond the Solar System- Challenge 3

1. The closest galaxy to ours is the ___.

Andromeda Galaxy

2. A ___ galaxy has pinwheel-like arms and rotates around a central bulge.

spiral

3. The three types of galaxies are ___.

spiral, elliptical, and irregular

4. Our solar system is located ___.

within one of the spiral arms of the Milky Way

5. The ___ of the Milky Way contains the oldest stars.

halo

6. There is a ___ in the center of the Milky Way.

black hole

7. Redshift is ___.

the phenomenon in which absorption bands are shifted towards the red end of the spectrum

8. According to the Doppler Effect, ___.

as waves moves closer to you, the waves pack closer together, and vice versa

9. Hubble's Law states that ___.

the farther away a galaxy is, the faster it is moving away from us

10. ___ and ___ are the most abundant gases in the universe.

Hydrogen; helium

11. During the immediate aftermath of the Big Bang, hydrogen nuclei collided and fused into ___ nuclei.

helium

12. According to the Big Bang Theory, the universe formed ___ years ago.

13.7 billion

This page titled 23.18: Beyond the Solar System- Challenge 3 is shared under a CK-12 license and was authored, remixed, and/or curated by CK12 via source content that was edited to the style and standards of the LibreTexts platform.

Index

D

dire

Glossary

Sample Word 1 | Sample Definition 1

Detailed Licensing

Overview

Title: Earth Science

Webpages: 424

Applicable Restrictions: Noncommercial

All licenses found:

- CK-12 License: 98.8% (419 pages)
- Undeclared: 1.2% (5 pages)

By Page

- Earth Science - *CK-12 License*
  - Front Matter - *CK-12 License*
    - TitlePage - *CK-12 License*
    - InfoPage - *CK-12 License*
    - Table of Contents - *Undeclared*
    - Licensing - *Undeclared*
  - 1: The Nature of Science - *CK-12 License*
    - 1.1: Scientific Explanations and Interpretations - *CK-12 License*
    - 1.2: Scientific Method - *CK-12 License*
    - 1.3: Developing Hypotheses - *CK-12 License*
    - 1.4: Testing Hypotheses - *CK-12 License*
    - 1.5: Correlation and Causation - *CK-12 License*
    - 1.6: The Nature of Science- Challenge 1 - *CK-12 License*
    - 1.7: Observations and Experiments - *CK-12 License*
    - 1.8: Theories - *CK-12 License*
    - 1.9: Evolution, Plate Tectonics, and Climate Change - *CK-12 License*
    - 1.10: Scientific Models - *CK-12 License*
    - 1.11: Scientific Community - *CK-12 License*
    - 1.12: The Nature of Science- Challenge 2 - *CK-12 License*
  - 2: Introduction to Earth Science - *CK-12 License*
    - 2.1: Branches of Earth Science - *CK-12 License*
    - 2.2: Earth Science Field Work - *CK-12 License*
    - 2.3: Uniformitarianism - *CK-12 License*
    - 2.4: Location - *CK-12 License*
    - 2.5: Direction - *CK-12 License*
    - 2.6: Elevation - *CK-12 License*
    - 2.7: Introduction to Earth Science- Challenge 1 - *CK-12 License*
    - 2.8: Maps - *CK-12 License*
    - 2.9: Map Projections - *CK-12 License*
    - 2.10: Topographic and Geologic Maps - *CK-12 License*
    - 2.11: Seafloor - *CK-12 License*
    - 2.12: Introduction to Earth Science- Challenge 2 - *CK-12 License*
    - 2.13: Telescopes - *CK-12 License*
    - 2.14: Study of Space by the Electromagnetic Spectrum - *CK-12 License*
    - 2.15: Satellites, Shuttles, and Space Stations - *CK-12 License*
    - 2.16: Introduction to Earth Science- Challenge 3 - *CK-12 License*
  - 3: Planet Earth - *CK-12 License*
    - 3.1: Atoms and Molecules - *CK-12 License*
    - 3.2: Earth's Shape - *CK-12 License*
    - 3.3: Earth's Magnetic Field - *CK-12 License*
    - 3.4: Earth's Rotations - *CK-12 License*
    - 3.5: Earth's Revolutions - *CK-12 License*
    - 3.6: Coriolis Effect - *CK-12 License*
    - 3.7: Seasons - *CK-12 License*
    - 3.8: Planet Earth- Challenge 1 - *CK-12 License*
    - 3.9: Eclipses - *CK-12 License*
    - 3.10: Solar Eclipses - *CK-12 License*
    - 3.11: Lunar Eclipses - *CK-12 License*
    - 3.12: Lunar Phases - *CK-12 License*
    - 3.13: Planet Earth- Challenge 2 - *CK-12 License*
    - 3.14: Earth's Interior - *CK-12 License*
    - 3.15: Earth's Outer Layers - *CK-12 License*
    - 3.16: Earth's Inner Layers - *CK-12 License*
    - 3.17: Earth's Crust - *CK-12 License*
    - 3.18: Earth's Mantle - *CK-12 License*
    - 3.19: Earth's Core - *CK-12 License*
    - 3.20: Lithosphere and Asthenosphere - *CK-12 License*
    - 3.21: Planet Earth- Challenge 3 - *CK-12 License*
  - 4: Earth's Minerals and Rocks - *CK-12 License*

- 4.1: Minerals - *CK-12 License*
- 4.2: Mineral Groups - *CK-12 License*
- 4.3: Mineral Identification - *CK-12 License*
- 4.4: Mineral Formation - *CK-12 License*
- 4.5: Earth's Minerals and Rocks- Challenge 1 - *CK-12 License*
- 4.6: Rocks - *CK-12 License*
- 4.7: Rock Cycle Processes - *CK-12 License*
- 4.8: Igneous Rocks - *CK-12 License*
- 4.9: Intrusive and Extrusive Igneous Rocks - *CK-12 License*
- 4.10: Igneous Rock Classification - *CK-12 License*
- 4.11: Earth's Minerals and Rocks- Challenge 2 - *CK-12 License*
- 4.12: Sedimentary Rocks - *CK-12 License*
- 4.13: Lithification of Sedimentary Rocks - *CK-12 License*
- 4.14: Sedimentary Rock Classification - *CK-12 License*
- 4.15: Metamorphic Rocks - *CK-12 License*
- 4.16: Metamorphic Rock Classification - *CK-12 License*
- 4.17: Earth's Minerals and Rocks- Challenge 3 - *CK-12 License*

5: Plate Tectonics - *CK-12 License*

- 5.1: Continental Drift - *CK-12 License*
- 5.2: Wegener and the Continental Drift Hypothesis - *CK-12 License*
- 5.3: Magnetic Polarity Evidence for Continental Drift - *CK-12 License*
- 5.4: Bathymetric Evidence for Seafloor Spreading - *CK-12 License*
- 5.5: Magnetic Evidence for Seafloor Spreading - *CK-12 License*
- 5.6: Seafloor Spreading Hypothesis - *CK-12 License*
- 5.7: Plate Tectonics- Challenge 1 - *CK-12 License*
- 5.8: Earth's Tectonic Plates - *CK-12 License*
- 5.9: Tectonic Plate Motions - *CK-12 License*
- 5.10: Theory of Plate Tectonics - *CK-12 License*
- 5.11: Divergent Plate Boundaries in the Ocean - *CK-12 License*
- 5.12: Divergent Plate Boundaries - *CK-12 License*
- 5.13: Transform Plate Boundaries - *CK-12 License*
- 5.14: Plate Tectonics- Challenge 2 - *CK-12 License*
- 5.15: Ocean-Continent Convergent Plates - *CK-12 License*
- 5.16: Ocean-Ocean Convergent Plate Boundaries - *CK-12 License*
- 5.17: Continent-Continent Convergent Plate Boundaries - *CK-12 License*
- 5.18: Continental Margins - *CK-12 License*
- 5.19: Supercontinent Cycle and Pangaea - *CK-12 License*
- 5.20: Intraplate Activity - *CK-12 License*
- 5.21: Plate Tectonics- Challenge 3 - *CK-12 License*

6: Geological Activity and Earthquakes - *CK-12 License*

- 6.1: Geological Stresses - *CK-12 License*
- 6.2: Principle of Horizontality - *CK-12 License*
- 6.3: Folds - *CK-12 License*
- 6.4: Faults - *CK-12 License*
- 6.5: Mountain Building - *CK-12 License*
- 6.6: Geological Activity and Earthquakes- Challenge 1 - *CK-12 License*
- 6.7: Earthquakes - *CK-12 License*
- 6.8: Earthquake Zones - *CK-12 License*
- 6.9: Earthquakes at Transform Plate Boundaries - *CK-12 License*
- 6.10: Earthquakes at Convergent Plate Boundaries - *CK-12 License*
- 6.11: Intraplate Earthquakes - *CK-12 License*
- 6.12: Seismic Waves - *CK-12 License*
- 6.13: Tsunami - *CK-12 License*
- 6.14: 21st Century Tsunami - *CK-12 License*
- 6.15: Geological Activity and Earthquakes- Challenge 2 - *CK-12 License*
- 6.16: Measuring Earthquake Magnitude - *CK-12 License*
- 6.17: Locating Earthquake Epicenters - *CK-12 License*
- 6.18: Earthquake Magnitude Scales - *CK-12 License*
- 6.19: Predicting Earthquakes - *CK-12 License*
- 6.20: Earthquake Damage - *CK-12 License*
- 6.21: Earthquake Safe Structures - *CK-12 License*
- 6.22: Staying Safe in an Earthquake - *CK-12 License*
- 6.23: Geological Activity and Earthquakes- Challenge 3 - *CK-12 License*

7: Geological Activity and Volcanoes - *CK-12 License*

- 7.1: Volcanoes - *CK-12 License*
- 7.2: Volcanoes at Plate Boundaries - *CK-12 License*
- 7.3: Volcanic Hot Spots - *CK-12 License*
- 7.4: Magma Composition - *CK-12 License*
- 7.5: Explosive Eruptions - *CK-12 License*
- 7.6: Effusive Eruptions - *CK-12 License*
- 7.7: Predicting Volcanic Eruptions - *CK-12 License*
- 7.8: Geological Activity and Volcanoes- Challenge 1 - *CK-12 License*
- 7.9: Types of Volcanoes - *CK-12 License*

- 7.10: Supervolcanoes - *CK-12 License*
- 7.11: Volcanic Landforms - *CK-12 License*
- 7.12: Hot Springs and Geysers - *CK-12 License*
- 7.13: Geological Activity and Volcanoes- Challenge 2 - *CK-12 License*

- 8: Earth's Fresh Water - *CK-12 License*
  - 8.1: Distribution of Water on Earth - *CK-12 License*
  - 8.2: States of Water - *CK-12 License*
  - 8.3: The Water Cycle - *CK-12 License*
  - 8.4: Uses of Water - *CK-12 License*
  - 8.5: Water Distribution - *CK-12 License*
  - 8.6: Safety of Water - *CK-12 License*
  - 8.7: Conserving Water - *CK-12 License*
  - 8.8: Earth's Fresh Water- Challenge 1 - *CK-12 License*
  - 8.9: Streams and Rivers - *CK-12 License*
  - 8.10: Ponds and Lakes - *CK-12 License*
  - 8.11: Flooding - *CK-12 License*
  - 8.12: Glaciers - *CK-12 License*
  - 8.13: Earth's Fresh Water- Challenge 2 - *CK-12 License*
  - 8.14: Groundwater - *CK-12 License*
  - 8.15: Groundwater Aquifers - *CK-12 License*
  - 8.16: Springs and Geysers - *CK-12 License*
  - 8.17: Earth's Fresh Water- Challenge 3 - *CK-12 License*
  - 8.18: Groundwater Depletion - *CK-12 License*
  - 8.19: Groundwater Pollution - *CK-12 License*
  - 8.20: Water Pollution - *CK-12 License*
  - 8.21: Protecting Water From Pollution - *CK-12 License*
  - 8.22: Cleaning Up Groundwater - *CK-12 License*
  - 8.23: Earth's Fresh Water- Challenge 4 - *CK-12 License*
- 9: Earth's Oceans - *CK-12 License*
  - 9.1: Importance of the Oceans - *CK-12 License*
  - 9.2: Seawater Chemistry - *CK-12 License*
  - 9.3: Ocean Zones - *CK-12 License*
  - 9.4: Earth's Oceans- Challenge 1 - *CK-12 License*
  - 9.5: Wind Waves - *CK-12 License*
  - 9.6: Tides - *CK-12 License*
  - 9.7: Surface Currents - *CK-12 License*
  - 9.8: Ocean Currents and Climate - *CK-12 License*
  - 9.9: Deep Currents - *CK-12 License*
  - 9.10: Earth's Oceans- Challenge 2 - *CK-12 License*
  - 9.11: Coastal Pollution - *CK-12 License*
  - 9.12: Ocean Garbage Patch - *CK-12 License*
  - 9.13: Oil Spills - *CK-12 License*
  - 9.14: Earth's Oceans- Challenge 3 - *CK-12 License*
- 10: Atmospheric Processes - *CK-12 License*
  - 10.1: Importance of the Atmosphere - *CK-12 License*
  - 10.2: Composition of the Atmosphere - *CK-12 License*
  - 10.3: Pressure and Density of the Atmosphere - *CK-12 License*
  - 10.4: Temperature of the Atmosphere - *CK-12 License*
  - 10.5: Atmospheric Processes- Challenge 1 - *CK-12 License*
  - 10.6: Troposphere - *CK-12 License*
  - 10.7: Stratosphere - *CK-12 License*
  - 10.8: Mesophere - *CK-12 License*
  - 10.9: Thermosphere and Beyond - *CK-12 License*
  - 10.10: Atmospheric Processes- Challenge 2 - *CK-12 License*
  - 10.11: Electromagnetic Energy in the Atmosphere - *CK-12 License*
  - 10.12: Solar Energy on Earth - *CK-12 License*
  - 10.13: Thermal Energy Transfer in the Atmosphere - *CK-12 License*
  - 10.14: Heat Budget of Planet Earth - *CK-12 License*
  - 10.15: Solar Energy and Latitude - *CK-12 License*
  - 10.16: Greenhouse Effect - *CK-12 License*
  - 10.17: Atmospheric Processes- Challenge 3 - *CK-12 License*
  - 10.18: Circulation in the Atmosphere - *CK-12 License*
  - 10.19: Local Winds - *CK-12 License*
  - 10.20: Global Wind Belts - *CK-12 License*
  - 10.21: Atmospheric Processes- Challenge 4 - *CK-12 License*
  - 10.22: Air Quality - *CK-12 License*
  - 10.23: Types of Air Pollution - *CK-12 License*
  - 10.24: Effects of Air Pollution on the Environment - *CK-12 License*
  - 10.25: Causes of Air Pollution - *CK-12 License*
  - 10.26: Acid Rain - *CK-12 License*
  - 10.27: Ozone Depletion - *CK-12 License*
  - 10.28: Reducing Air Pollution - *CK-12 License*
  - 10.29: Atmospheric Processes- Challenge 5 - *CK-12 License*
- 11: Weather - *CK-12 License*
  - 11.1: Introduction to Weather - *CK-12 License*
  - 11.2: Humidity - *CK-12 License*
  - 11.3: Clouds - *CK-12 License*
  - 11.4: Fog - *CK-12 License*
  - 11.5: Precipitation - *CK-12 License*
  - 11.6: Air Masses - *CK-12 License*
  - 11.7: Fronts - *CK-12 License*

- 11.8: Weather- Challenge 1 - *CK-12 License*
- 11.9: Thunderstorms - *CK-12 License*
- 11.10: Tornadoes - *CK-12 License*
- 11.11: Cyclones - *CK-12 License*
- 11.12: Hurricanes - *CK-12 License*
- 11.13: Blizzards - *CK-12 License*
- 11.14: Heat Waves and Droughts - *CK-12 License*
- 11.15: Weather- Challenge 2 - *CK-12 License*
- 11.16: Collecting Weather Data - *CK-12 License*
- 11.17: Predicting Weather - *CK-12 License*
- 11.18: Weather Maps - *CK-12 License*
- 11.19: Weather- Challenge 3 - *CK-12 License*

12: Climate - *CK-12 License*

- 12.1: Weather vs. Climate - *CK-12 License*
- 12.2: Effect of Latitude on Climate - *CK-12 License*
- 12.3: Effect of Atmospheric Circulation on Climate - *CK-12 License*
- 12.4: Effect of Continental Position on Climate - *CK-12 License*
- 12.5: Effect of Altitude and Mountains on Climate - *CK-12 License*
- 12.6: Climate- Challenge 1 - *CK-12 License*
- 12.7: Climate Zones and Biomes - *CK-12 License*
- 12.8: Tropical Moist Climates - *CK-12 License*
- 12.9: Dry Climates - *CK-12 License*
- 12.10: Temperate Climates - *CK-12 License*
- 12.11: Continental Climates - *CK-12 License*
- 12.12: Polar Climates - *CK-12 License*
- 12.13: Climate- Challenge 2 - *CK-12 License*
- 12.14: Climate Change in Earth History - *CK-12 License*
- 12.15: Short-Term Climate Change - *CK-12 License*
- 12.16: Carbon Cycle and Climate - *CK-12 License*
- 12.17: Global Warming - *CK-12 License*
- 12.18: Causes and Effects of Global Warming - *CK-12 License*
- 12.19: Impact of Continued Global Warming - *CK-12 License*
- 12.20: Reducing Greenhouse Gas Pollution - *CK-12 License*
- 12.21: Climate- Challenge 3 - *CK-12 License*

13: Weathering and Soils - *CK-12 License*

- 13.1: Weathering and Erosion - *CK-12 License*
- 13.2: Mechanical Weathering - *CK-12 License*
- 13.3: Chemical Weathering - *CK-12 License*
- 13.4: Influences on Weathering - *CK-12 License*
- 13.5: Weathering and Soils- Challenge 1 - *CK-12 License*
- 13.6: Soil Characteristics - *CK-12 License*
- 13.7: Soil Formation - *CK-12 License*
- 13.8: Soil Horizons and Profiles - *CK-12 License*
- 13.9: Types of Soils - *CK-12 License*
- 13.10: Soil Erosion - *CK-12 License*
- 13.11: Avoiding Soil Loss - *CK-12 License*
- 13.12: Weathering and Soils- Challenge 2 - *CK-12 License*

14: Erosion and Deposition - *CK-12 License*

- 14.1: Erosion by Streams - *CK-12 License*
- 14.2: Deposition by Streams - *CK-12 License*
- 14.3: Erosion by Groundwater - *CK-12 License*
- 14.4: Deposition by Groundwater - *CK-12 License*
- 14.5: Erosion and Deposition- Challenge 1 - *CK-12 License*
- 14.6: Erosion by Waves - *CK-12 License*
- 14.7: Deposition by Waves - *CK-12 License*
- 14.8: Protecting Shorelines - *CK-12 License*
- 14.9: Erosion by Wind - *CK-12 License*
- 14.10: Deposition by Wind - *CK-12 License*
- 14.11: Erosion and Deposition- Challenge 2 - *CK-12 License*
- 14.12: Erosion by Glaciers - *CK-12 License*
- 14.13: Deposition by Glaciers - *CK-12 License*
- 14.14: Landforms from Erosion and Deposition - *CK-12 License*
- 14.15: Erosion and Deposition- Challenge 3 - *CK-12 License*

15: Understanding Earth's History - *CK-12 License*

- 15.1: How Fossilization Creates Fossils - *CK-12 License*
- 15.2: Types of Fossilization - *CK-12 License*
- 15.3: Earth History and Clues from Fossils - *CK-12 License*
- 15.4: Understanding Earth's History- Challenge 1 - *CK-12 License*
- 15.5: Principles of Relative Dating - *CK-12 License*
- 15.6: Determining Relative Ages - *CK-12 License*
- 15.7: Correlation Using Relative Ages - *CK-12 License*
- 15.8: Geologic Time Scale - *CK-12 License*
- 15.9: Understanding Earth's History- Challenge 2 - *CK-12 License*
- 15.10: Tree Rings, Ice Cores, and Varves - *CK-12 License*
- 15.11: Radioactive Decay as a Measure of Age - *CK-12 License*
- 15.12: Radiometric Dating - *CK-12 License*
- 15.13: Age of Earth - *CK-12 License*

- 15.14: Understanding Earth's History- Challenge 3 - *CK-12 License*

- 16: Earth's History - *CK-12 License*
  - 16.1: Formation of the Sun and Planets - *CK-12 License*
  - 16.2: Formation of Earth - *CK-12 License*
  - 16.3: Formation of the Moon - *CK-12 License*
  - 16.4: Early Atmosphere and Oceans - *CK-12 License*
  - 16.5: Earth's History- Challenge 1 - *CK-12 License*
  - 16.6: Precambrian Continents - *CK-12 License*
  - 16.7: Paleozoic Plate Tectonics - *CK-12 License*
  - 16.8: Paleozoic and Mesozoic Seas - *CK-12 License*
  - 16.9: Mesozoic Plate Tectonics - *CK-12 License*
  - 16.10: Cenozoic Plate Tectonics - *CK-12 License*
  - 16.11: Earth's History- Challenge 2 - *CK-12 License*
- 17: Evolution and Populations - *CK-12 License*
  - 17.1: Modern Biodiversity - *CK-12 License*
  - 17.2: Characteristics and Origins of Life - *CK-12 License*
  - 17.3: Metabolism and Replication - *CK-12 License*
  - 17.4: Adaptation and Evolution of Populations - *CK-12 License*
  - 17.5: Theory of Evolution by Natural Selection - *CK-12 License*
  - 17.6: Population Size - *CK-12 License*
  - 17.7: Extinction and Radiation of Life - *CK-12 License*
  - 17.8: Evolution and Populations- Challenge 1 - *CK-12 License*
  - 17.9: Growth of Human Populations - *CK-12 License*
  - 17.10: Agriculture and Human Population Growth - *CK-12 License*
  - 17.11: Revolutions in Human Population - *CK-12 License*
  - 17.12: Overpopulation and Over-Consumption - *CK-12 License*
  - 17.13: Future Human Population Growth - *CK-12 License*
  - 17.14: Sustainable Development - *CK-12 License*
  - 17.15: Evolution and Populations- Challenge 2 - *CK-12 License*
- 18: Ecosystems - *CK-12 License*
  - 18.1: Biological Communities - *CK-12 License*
  - 18.2: Roles in an Ecosystem - *CK-12 License*
  - 18.3: Flow of Energy in Ecosystems - *CK-12 License*
  - 18.4: Flow of Matter in Ecosystems - *CK-12 License*
  - 18.5: Nitrogen Cycle in Ecosystems - *CK-12 License*
  - 18.6: Ecosystems- Challenge 1 - *CK-12 License*
  - 18.7: Fresh Water Ecosystems - *CK-12 License*
  - 18.8: Types of Marine Organisms - *CK-12 License*
  - 18.9: Marine Food Chains - *CK-12 License*
  - 18.10: Ocean Ecosystems - *CK-12 License*
  - 18.11: Ecosystems- Challenge 2 - *CK-12 License*
- 19: History of Life on Earth - *CK-12 License*
  - 19.1: Evolution of Simple Cells - *CK-12 License*
  - 19.2: Evolution of Eukaryotes to Multicellular Life - *CK-12 License*
  - 19.3: Life of the Phanerozoic Eon - *CK-12 License*
  - 19.4: History of Paleozoic Life - *CK-12 License*
  - 19.5: History of Mesozoic Life - *CK-12 License*
  - 19.6: History of Cenozoic Life - *CK-12 License*
  - 19.7: Human Evolution - *CK-12 License*
  - 19.8: Life and the Geologic Time Scale - *CK-12 License*
  - 19.9: History of Life on Earth- Challenge - *CK-12 License*
- 20: Earth's Energy - *CK-12 License*
  - 20.1: Energy Resources - *CK-12 License*
  - 20.2: Obtaining Energy Resources - *CK-12 License*
  - 20.3: Energy Conservation - *CK-12 License*
  - 20.4: Renewable vs. Nonrenewable Energy Resources - *CK-12 License*
  - 20.5: Earth's Energy- Challenge 1 - *CK-12 License*
  - 20.6: Fossil Fuel Formation - *CK-12 License*
  - 20.7: Coal Power - *CK-12 License*
  - 20.8: Petroleum Power - *CK-12 License*
  - 20.9: Natural Gas Power - *CK-12 License*
  - 20.10: Fossil Fuel Reserves - *CK-12 License*
  - 20.11: Nuclear Power - *CK-12 License*
  - 20.12: Earth's Energy- Challenge 2 - *CK-12 License*
  - 20.13: Solar Energy - *CK-12 License*
  - 20.14: Hydroelectric Power - *CK-12 License*
  - 20.15: Wind Energy - *CK-12 License*
  - 20.16: Geothermal Energy - *CK-12 License*
  - 20.17: Biomass Energy - *CK-12 License*
  - 20.18: Earth's Energy- Challenge 3 - *CK-12 License*
- 21: Earth's Materials - *CK-12 License*
  - 21.1: Materials Humans Use - *CK-12 License*
  - 21.2: Renewable vs. Nonrenewable Resources - *CK-12 License*
  - 21.3: Ore Deposits - *CK-12 License*
  - 21.4: Ore Mines - *CK-12 License*
  - 21.5: Ore Extraction - *CK-12 License*
  - 21.6: Earth's Materials- Challenge 1 - *CK-12 License*
  - 21.7: Environmental Impacts of Mining - *CK-12 License*
  - 21.8: Hazardous Waste - *CK-12 License*

- 21.10: Earth's Materials- Challenge 2 - *CK-12 License*
- 21.11: Availability of Natural Resources - *CK-12 License*
- 21.12: Natural Resource Conservation - *CK-12 License*
- 21.13: Earth's Materials- Challenge 3 - *CK-12 License*
- 21.8: Preventing Hazardous Waste Problems - *CK-12 License*

22: The Solar System - *CK-12 License*

- The Solar System: Challenge 1 - *CK-12 License*
- 22.1: Sun - *CK-12 License*
- 22.2: Interior of the Sun - *CK-12 License*
- 22.4: Surface Features of the Sun - *CK-12 License*
- 22.6: Planets of the Solar System - *CK-12 License*
- 22.7: Planet Orbits in the Solar System - *CK-12 License*
- 22.8: Gravity in the Solar System - *CK-12 License*
- 22.9: The Solar System- Challenge 2 - *CK-12 License*
- 22.10: Inner vs. Outer Planets - *CK-12 License*
- 22.11: Mercury - *CK-12 License*
- 22.12: Venus - *CK-12 License*
- 22.13: Moon - *CK-12 License*
- 22.14: Mars - *CK-12 License*
- 22.15: The Solar System- Challenge 3 - *CK-12 License*
- 22.16: Jupiter - *CK-12 License*
- 22.17: Saturn - *CK-12 License*
- 22.18: Uranus - *CK-12 License*
- 22.19: Neptune - *CK-12 License*
- 22.20: The Solar System- Challenge 4 - *CK-12 License*
- 22.21: Exoplanets - *CK-12 License*
- 22.22: Asteroids - *CK-12 License*
- 22.23: Comets - *CK-12 License*
- 22.24: Meteors - *CK-12 License*
- 22.25: Dwarf Planets - *CK-12 License*
- 22.26: The Solar System- Challenge 5 - *CK-12 License*
- 22.3: Outer Layers of the Sun - *CK-12 License*

23: Beyond the Solar System - *CK-12 License*

- 23.1: Star Constellations - *CK-12 License*
- 23.2: Star Power - *CK-12 License*
- 23.3: Star Classification - *CK-12 License*
- 23.4: Star Formation - *CK-12 License*
- 23.5: Beyond the Solar System- Challenge 1 - *CK-12 License*
- 23.6: Main Sequence Star Lives - *CK-12 License*
- 23.7: Red Giants and White Dwarfs - *CK-12 License*
- 23.8: Supergiants and Supernovas - *CK-12 License*
- 23.9: Neutron Stars and Black Holes - *CK-12 License*
- 23.10: Beyond the Solar System- Challenge 2 - *CK-12 License*
- 23.11: Star Clusters - *CK-12 License*
- 23.12: Galaxies - *CK-12 License*
- 23.13: The Milky Way - *CK-12 License*
- 23.14: Universe - *CK-12 License*
- 23.15: Expansion of the Universe - *CK-12 License*
- 23.16: Big Bang - *CK-12 License*
- 23.17: Dark Matter - *CK-12 License*
- 23.18: Beyond the Solar System- Challenge 3 - *CK-12 License*

Back Matter - *CK-12 License*

- Index - *Undeclared*
- Glossary - *Undeclared*
- Detailed Licensing - *Undeclared*