CHM101: CHEMISTRY AND GLOBAL AWARENESS



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Chemistry and Global Awareness

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Glossary

Detailed Licensing

Licensing

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

CHAPTER OVERVIEW

1: Introduction to Chemistry

What is chemistry? Simply put, chemistry is the study of the interactions of matter with other matter and with energy. This seems straightforward enough. However, the definition of chemistry includes a wide range of topics that must be understood to gain a mastery of the topic or even take additional courses in chemistry. Get ready for a fantastic journey through a world of wonder, delight, and knowledge. One of the themes of this book is “chemistry is everywhere,” and indeed it is; you would not be alive if it weren’t for chemistry because your body is a big chemical machine. If you don’t believe it, don’t worry. Every chapter in this book contains examples that will show you how chemistry is, in fact, everywhere. So enjoy the ride—and enjoy chemistry.

1.1: What is Chemistry?
1.2: Using the Scientific Method
1.3: Pure and Applied Research
1.4: Classification and Properties of Matter
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1.6: All About the Elements

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1.1: What is Chemistry?

Learning Objectives

- To recognize the breadth, depth, and scope of chemistry.
- Define chemistry in relation to other sciences.
- Identify the main disciplines of chemistry.
- Match a scientific project with the correct type of chemist.

Chemistry is the study of matter—what it consists of, what its properties are, and how it changes. Being able to describe the ingredients in a cake and how they change when the cake is baked is called chemistry. Matter is anything that has mass and takes up space—that is, anything that is physically real. Some things are easily identified as matter—this book, for example. Others are not so obvious. Because we move so easily through the air, we sometimes forget that it, too, is matter.

Chemistry is one branch of science. Science is the process by which we learn about the natural universe by observing, testing, and then generating models that explain our observations. Because the physical universe is so vast, there are many different branches of science (Figure **1.1.1**). Thus, chemistry is the study of matter, biology is the study of living things, and geology is the study of rocks and the earth. Mathematics is the language of science, and we will use it to communicate some of the ideas of chemistry.

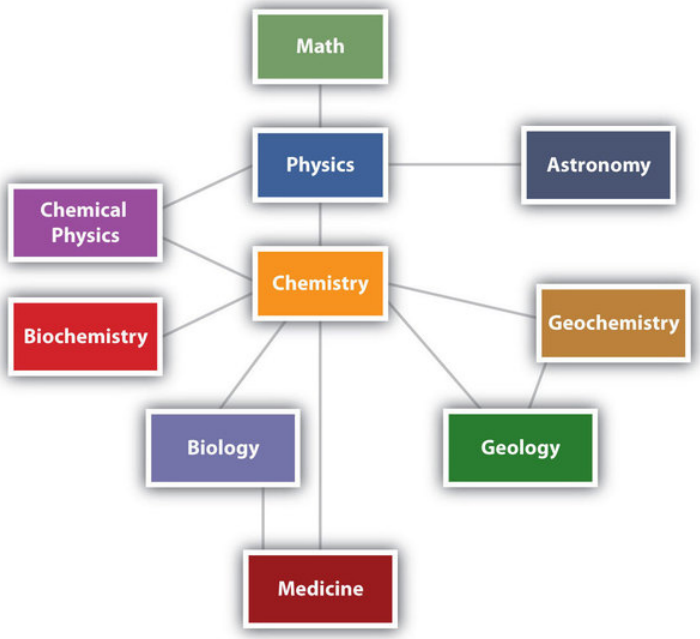


Figure **1.1.1**: The Relationships between Some of the Major Branches of Science. Chemistry lies more or less in the middle, which emphasizes its importance to many branches of science.

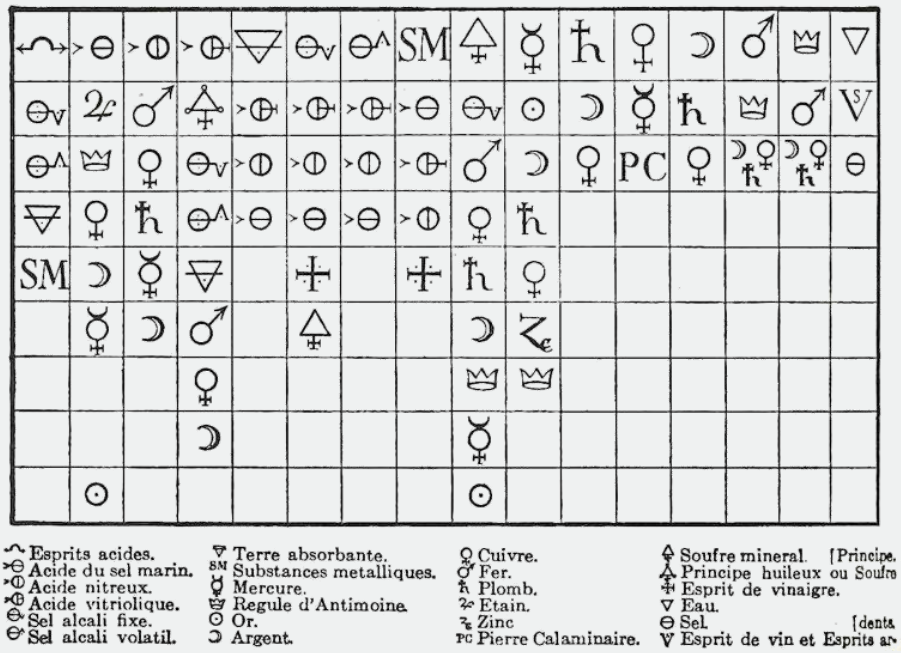
Although we divide science into different fields, there is much overlap among them. For example, some biologists and chemists work in both fields so much that their work is called biochemistry. Similarly, geology and chemistry overlap in the field called geochemistry. Figure **1.1.1** shows how many of the individual fields of science are related.

> *There are many other fields of science, in addition to the ones (biology, medicine, etc.) listed*

Alchemy Is in No way Chemistry!

As our understanding of the universe has changed over time, so has the practice of science. Chemistry in its modern form, based on principles that we consider valid today, was developed in the 1600s and 1700s. Before that, the study of matter was known as *alchemy* and was practiced mainly in China, Arabia, Egypt, and Europe.

Alchemy was a somewhat mystical and secretive approach to learning how to manipulate matter. Practitioners, called alchemists, thought that all matter was composed of different proportions of the four basic elements—fire, water, earth, and air—and believed that if you changed the relative proportions of these elements in a substance, you could change the substance. The long-standing attempts to “transmute” common metals into gold represented one goal of alchemy. Alchemy’s other major goal was to synthesize the philosopher’s stone, a material that could impart long life—even immortality. Alchemists used symbols to represent substances, some of which are shown in the accompanying figure. This was not done to better communicate ideas, as chemists do today, but to maintain the secrecy of alchemical knowledge, keeping others from sharing in it.



The first affinity table. Table of different relations observed in chemistry between different substances; Memoirs of the Royal Academy of Sciences, p. 202-212. Alchemists used symbols like these to represent substances.

In spite of this secrecy, in its time alchemy was respected as a serious, scholarly endeavor. Isaac Newton, the great mathematician and physicist, was also an alchemist.

Alchemy and the ACS (American Chemical Society)

While watching the video below and answer the following questions.



Questions

1. What was the chief goal of an alchemist according to the video?

2. What could the philosopher's stone do to urine?
3. Is Alchemy a true science?
4. When urine is boiled down to a white paste, what is the name and symbol for the element that was obtained?
5. List some properties of this element that were discussed in the video.
6. Did wealthy people produce more of this element than poorer people?
7. What types of applications (applied science) did this element lead us to?
8. Instead of collecting urine, how can one collect higher concentrations of this element?
9. The video discussed phosphoric acid (formula: H_3PO_4). Name all the elements in this compound.
10. What were the mentioned applications of phosphoric acid?
11. What are some of the organic and biochemical applications of element 13?

Areas of Chemistry

The study of modern chemistry has many branches, but can generally be broken down into five main disciplines, or areas of study:

- **Physical chemistry:** Physical chemistry is the study of macroscopic properties, atomic properties, and phenomena in chemical systems. A physical chemist may study such things as the rates of chemical reactions, the energy transfers that occur in reactions, or the physical structure of materials at the molecular level.
- **Organic chemistry:** Organic chemistry is the study of chemicals containing carbon with hydrogen. Carbon is one of the most abundant elements on Earth and is capable of forming a tremendously vast number of chemicals (over twenty million so far). Most of the chemicals found in all living organisms are based on carbon.
- **Inorganic chemistry:** Inorganic chemistry is the study of chemicals that do not, in general, contain carbon. Inorganic chemicals are commonly found in rocks and minerals. One current important area of inorganic chemistry deals with the design and properties of materials involved in energy and information technology.
- **Analytical chemistry:** Analytical chemistry is the study of the composition of matter. It focuses on separating, identifying, and quantifying chemicals in samples of matter. An analytical chemist may use complex instruments to analyze an unknown material in order to determine its various components.
- **Biochemistry:** Biochemistry is the study of chemical processes that occur in living things. Research may cover basic cellular processes up to understanding disease states so better treatments can be developed.



Figure **1.1.2**: (left) Measurement of trace metals using atomic spectroscopy. (right) Measuring hormone concentrations.

In practice, chemical research is often not limited to just one of the five major disciplines. A particular chemist may use biochemistry to isolate a particular chemical found in the human body such as hemoglobin, the oxygen-carrying component of red blood cells. He or she may then proceed to analyze the hemoglobin using methods that would pertain to the areas of physical or analytical chemistry. Many chemists specialize in areas that are combinations of the main disciplines, such as bioorganic chemistry or physical organic chemistry.

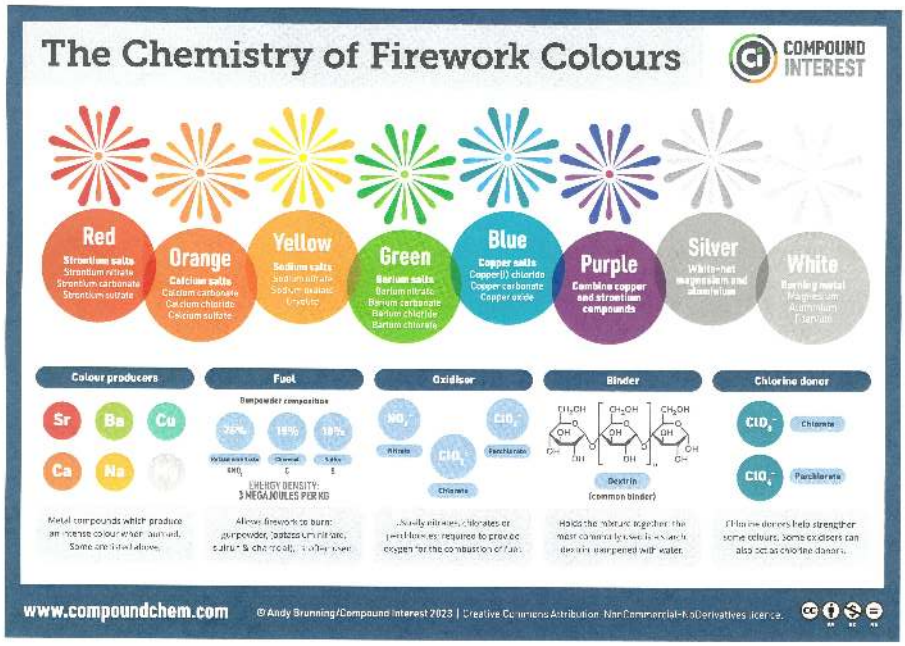


Figure **1.1.3**: The Chemistry of Firework Colours. (CC-BY-NC-ND; Andy Brunning)

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1.2: Using the Scientific Method

Learning Objectives

- To identify the components of the scientific method
- Classify measurements as being quantitative or qualitative.
- Evaluate science in the media.

The Scientific Method

Scientists search for answers to questions and solutions to problems by using a procedure called the scientific method. This procedure consists of making observations, formulating hypotheses, and designing experiments, which in turn lead to additional observations, hypotheses, and experiments in repeated cycles (Figure **1.2.1**).

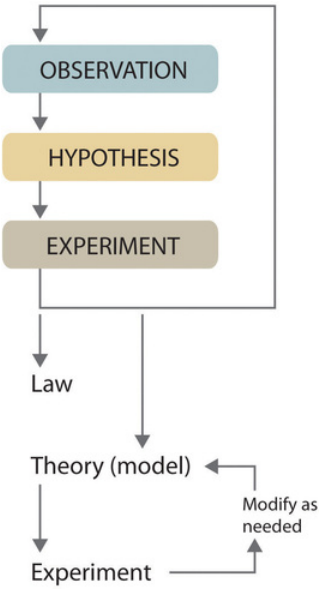


Figure **1.2.1**: The Steps in the Scientific Method. (CC BY-SA-NC; anonymous).

Step 1: Make observations

Observations can be qualitative or quantitative. **Qualitative observations** describe properties or occurrences in ways that do not rely on numbers. Examples of qualitative observations include the following: the outside air temperature is cooler during the winter season, table salt is a crystalline solid, sulfur crystals are yellow, and dissolving a penny in dilute nitric acid forms a blue solution and a brown gas. **Quantitative observations** are measurements, which by definition consist of both a number and a unit. Examples of quantitative observations include the following: the melting point of crystalline sulfur is 115.21° Celsius, and 35.9 grams of table salt—whose chemical name is sodium chloride—dissolves in 100 grams of water at 20° Celsius. For the question of the dinosaurs' extinction, the initial observation was quantitative: iridium concentrations in sediments dating to 66 million years ago were 20–160 times higher than normal.

Step 2: Formulate a hypothesis

After deciding to learn more about an observation or a set of observations, scientists generally begin an investigation by forming a hypothesis, a tentative explanation for the observation(s). The hypothesis may not be correct, but it puts the scientist's understanding of the system being studied into a form that can be tested. For example, the observation that we experience alternating periods of light and darkness corresponding to observed movements of the sun, moon, clouds, and shadows is consistent with either of two hypotheses:

a. Earth rotates on its axis every 24 hours, alternately exposing one side to the sun, or
b. the sun revolves around Earth every 24 hours.

Suitable experiments can be designed to choose between these two alternatives. For the disappearance of the dinosaurs, the hypothesis was that the impact of a large extraterrestrial object caused their extinction. Unfortunately (or perhaps, fortunately), this hypothesis does not lend itself to direct testing by any obvious experiment, but scientists can collect additional data that either support or refute it.

Step 3: Design and perform experiments

After a hypothesis has been formed, scientists conduct experiments to test its validity. Experiments are systematic observations or measurements, preferably made under controlled conditions—that is, under conditions in which a single variable changes.

Step 4: Accept or modify the hypothesis

A properly designed and executed experiment enables a scientist to determine whether the original hypothesis is valid. In which case he can proceed to step 5. In other cases, experiments often demonstrate that the hypothesis is incorrect or that it must be modified thus requiring further experimentation.

Step 5: Development into law and/or theory

More experimental data are then collected and analyzed, at which point a scientist may begin to think that the results are sufficiently reproducible (i.e., dependable) to merit being summarized in law, a verbal or mathematical description of a phenomenon that allows for general predictions. A law simply says what happens; it does not address the question of why.

One example of a law, the law of definite proportions, which was discovered by the French scientist Joseph Proust (1754–1826), states that a chemical substance always contains the same proportions of elements by mass. Thus, sodium chloride (table salt) always contains the same proportion by mass of sodium to chlorine, in this case, 39.34% sodium and 60.66% chlorine by mass, and sucrose (table sugar) is always 42.11% carbon, 6.48% hydrogen, and 51.41% oxygen by mass.

Whereas a law states only what happens, a theory attempts to explain why nature behaves as it does. Laws are unlikely to change greatly over time unless a major experimental error is discovered. In contrast, a theory, by definition, is incomplete and imperfect, evolving with time to explain new facts as they are discovered.

Because scientists can enter the cycle shown in Figure **1.2.1** at any point, the actual application of the scientific method to different topics can take many different forms. For example, a scientist may start with a hypothesis formed by reading about work done by others in the field, rather than by making direct observations.

A Real-World Application of the Scientific Method

In 2007, my husband and I journeyed to China to adopt our daughter. Upon arrival in Beijing, I became violently ill. Due to her visa paperwork, my husband, daughter, and I were required to stay in China for two weeks. Unfortunately, I was ill the entire time. Once the two-week period was up, the three of us flew back to the United States where I continued to be sick. For the next year, I remained ill and lost a total of 30 pounds. The picture below shows me holding my daughter eight months after we returned home from China.



Figure **1.2.2**: Mother and child. (CC BY-SA-NC; Elizabeth R. Gordon).

I would like you to attempt to perform the scientific method on my situation described above. List the steps of the scientific method along with some plausible explanations. * **Please have this ready to discuss in class**.*

Exercise \(\PageIndex{2}\)

Classify each statement as a law, a theory, an experiment, a hypothesis, a qualitative observation, or a quantitative observation.

a. Measured amounts of acid were added to a Rolaids tablet to see whether it really “consumes 47 times its weight in excess stomach acid.”
b. Heat always flows from hot objects to cooler ones, not in the opposite direction.
c. The universe was formed by a massive explosion that propelled matter into a vacuum.
d. Michael Jordan is the greatest pure shooter ever to play professional basketball.
e. Limestone is relatively insoluble in water but dissolves readily in dilute acid with the evolution of a gas.
f. Gas mixtures that contain more than 4% hydrogen in air are potentially explosive.

Answer a

experiment

Answer b

law

Answer c

theory

Answer d

hypothesis

Answer e

qualitative observation

Answer f

quantitative observation

Evaluating Science in the Media

A Rough Guide to

SPOTTING BAD SCIENCE

Being able to evaluate the evidence behind a scientific claim is important. Being able to recognise bad science reporting, or faults in scientific studies, is equally important. These 12 points will help you separate the science from the pseudoscience.

1. SENSATIONALISED HEADLINES

Article headlines are commonly designed to entice viewers into clicking on and reading the article. At times, they can over-simplify the findings of scientific research. At worst, they sensationalise and misrepresent them.

2. MISINTERPRETED RESULTS

News articles can distort or misinterpret the findings of research for the sake of a good story, whether intentionally or otherwise. If possible, try to read the original research, rather than relying on the article based on it for information.

3. CONFLICTS OF INTEREST

Many companies will employ scientists to carry out and publish research - whilst this doesn't necessarily invalidate the research, it should be analysed with this in mind. Research can also be misrepresented for personal or financial gain.

4. CORRELATION & CAUSATION

Be wary of any confusion of correlation and causation. A correlation between variables doesn't always mean one causes the other. Global warming increased since the 1800s, and pirate numbers decreased, but lack of pirates doesn't cause global warming.

5. UNSUPPORTED CONCLUSIONS

Speculation can often help to drive science forward. However, studies should be clear on the facts their study proves, and which conclusions are as yet unsupported ones. A statement framed by speculative language may require further evidence to confirm.

6. PROBLEMS WITH SAMPLE SIZE

In trials, the smaller a sample size, the lower the confidence in the results from that sample. Conclusions drawn can still be valid, and in some cases small samples are unavoidable, but larger samples often give more representative results.

7. UNREPRESENTATIVE SAMPLES USED

In human trials, subjects are selected that are representative of a larger population. If the sample is different from the population as a whole, then the conclusions from the trial may be biased towards a particular outcome.

8. NO CONTROL GROUP USED

In clinical trials, results from test subjects should be compared to a 'control group' not given the substance being tested. Groups should also be allocated randomly. In general experiments, a control test should be used where all variables are controlled.

9. NO BLIND TESTING USED

To try and prevent bias, subjects should not know if they are in the test or the control group. In 'double blind' testing, even researchers don't know which group subjects are in until after testing. Note, blind testing isn't always feasible, or ethical.

10. SELECTIVE REPORTING OF DATA

Also known as 'cherry picking', this involves selecting data from results which supports the conclusion of the research, whilst ignoring those that do not. If a research paper draws conclusions from a selection of its results, not all, it may be guilty of this.

11. UNREPLICABLE RESULTS

Results should be replicable by independent research, and tested over a wide range of conditions (where possible) to ensure they are consistent. Extraordinary claims require extraordinary evidence - that is, much more than one independent study!

12. NON-PEER REVIEWED MATERIAL

Peer review is an important part of the scientific process. Other scientists appraise and critique studies, before publication in a journal. Research that has not gone through this process is not as reputable, and may be flawed.

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1.3: Pure and Applied Research

Learning Objectives

- Distinguish between basic and applied chemistry
- Review the basics of the videos within in this section.

In science, we usually talk about two types of research: pure and applied. **Pure research** focuses on answering basic questions such as, "how do gases behave?" **Applied research** would be involved in the process of developing specific preparation for a gas in order for it to be produced and delivered efficiently and economically. This division sounds like it would be easy to make, but sometimes we cannot draw a clear line between what is "pure" and what is "applied".

Examples of "Pure" Research

A lot of "pure" research is of the "what is this?" or "how does it work?" variety. The early history of chemistry contains many examples. The ancient Greek philosophers debated the composition of matter (earth? air? fire? water? all of the above?). They did not intend to apply the knowledge gained from exploring the matter. Instead, they choose to focus on understanding the nature of matter.



Figure **1.3.1**: Ancient Greek philosophers."A Greek Philosopher and His Disciples", Antonio Zucchi

Applied Research (Technology)

There is a great deal of "applied" research taking place today. In general, no new science principles are discovered, but existing knowledge is used to develop a new product. A good example of this type of research is the application of x-rays in medicine. In the later part of the 1800s, Wilhelm Röentgen discovered how to produce x-rays by using a cathode ray. He noted that this new ray could go through the body. Immediately, Röentgen believed that x-rays would be very helpful in diagnosing and determining disease and injury in the body.

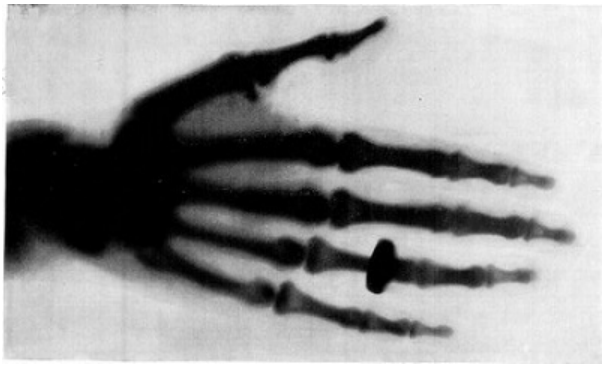


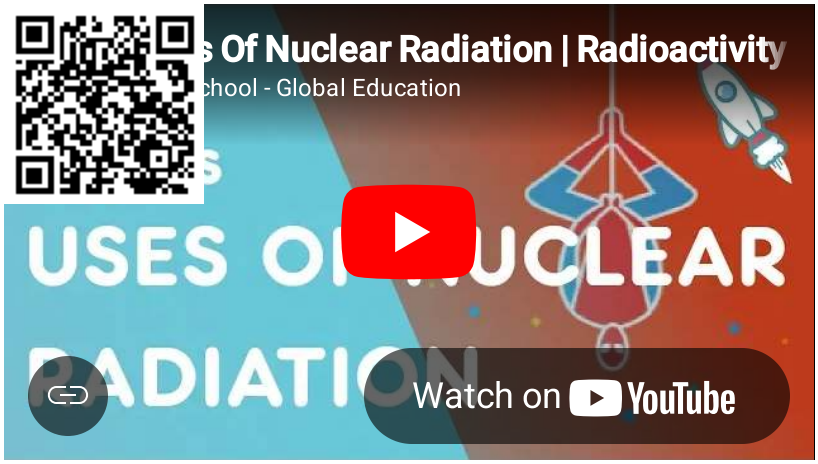
Figure **1.3.2**: Röentgen is the father of the X-ray. while working with experiments and procedures of previous scientists, Röentgen noticed that even through secured chambers for light, an unknown energy was emitted that reacted with phosphorescent materials he was using in his experiments. his discovery and subsequent papers earned him the Nobel Prize in Physics in 1901. He used his wife's hand to determine if the new rays could pass through the body.

The Conversion of Basic Research to Applied Research

Scientists and engineers desire to understand how the universe works. Many times, this leads to unimaginable applications for their works. During the early 20th century, physicists and engineers performed experiments probing atoms with electricity and/or magnets. This research led to the identification of the three subatomic particles of the atom- electron, proton, and neutron. After determining these particles, physical chemists and physicists began experimenting on the central core of atoms (called nuclei). By bombarding a nucleus with other particles (beta, alpha, or neutron), they were able to transform one element into another.



Artificial transmutation can only occur in the nuclear lab. Large pieces of equipment are needed to change the nucleus. This discovery of altering the nucleus led to the production of new isotopes (atoms of the same element that differ in mass and neutron count). These new isotopes now are used in nuclear medicine (diagnosing and treating disease), nuclear weapons (producing fuel for bombs), sanitizing food, spices, and cosmetics, and nuclear energy.



Video **1.3.1**: Click on the video to explore applications of nuclear science

Undergraduate Research at Furman University

All chemistry majors at our university are required to participate in undergraduate research. During the summertime, many of these students remain on campus to work in our laboratories. Students will join a group and research in one of the following areas: organic, inorganic, analytical, biochemistry, or physical chemistry. Some continue on their research in the calendar year. Upon graduation, all of our majors could enter industry immediately. Others will continue their chemical education by enrolling in Ph.D. programs. Lastly, many of our majors will continue on to become educators, patent attorneys, medical doctors, pharmacists, or physical therapists.

Application: Dr. Raychelle Burks

Listen to this 11-minute episode of the Shortwave Podcast. Answer the questions below about how Dr. Raychelle Burks distinguishes between good and bad science in the media.



1. Did Dr. Burks always dream of becoming a scientist?
2. How did Dr. Burks become interested in science?
3. Before exploring academia, what kind of work did Dr. Burks do?
4. Briefly explain the field of forensic science.
5. According to Dr. Burks which shows get the science correct? Which shows are inaccurate?
6. Provide some examples as to how the CSI shows have reported inaccurate science.
7. How are machines over-glorified in crime based television shows?
8. On the show, "Madam Secretary," what type of information did Dr. Burks provide to the show's, producers.
9. List the two WMD chemicals that were mentioned by Dr. Burks. How should scientists be dressed when they encounter them?
10. What type of chemist (recall the five types) is Dr. Burks?

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1.4: Classification and Properties of Matter

Learning Objectives

- Use physical and chemical properties, including phase, to describe matter.
- Distinguish between physical and chemical changes.
- Identify a sample of matter as an element, a compound, or a mixture (homogeneous/heterogeneous).
- Distinguish between organic and inorganic chemicals.
- Label all atoms within an organic or inorganic compound.
- Recognize physical methods used to separate mixtures.

Physical and Chemical Properties

The properties that chemists use to describe matter fall into two general categories. Physical properties are characteristics that **describe** matter. They include characteristics such as size, shape, color, and mass. Many of these properties can be quantitative in nature. For example, quantitative physical properties of water would be the boiling point (100 °C / 212 °F), melting point (0°C / 32 °F) and density (1.00 g/ml at 4.0°C.

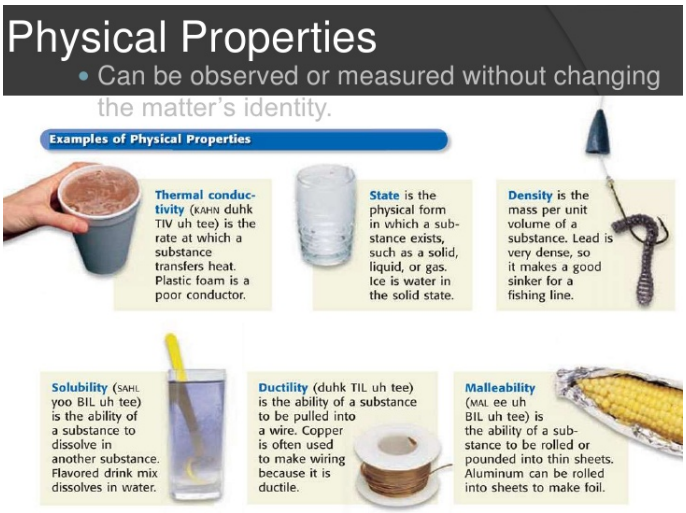


Figure 1.4.1: Physical Properties. (Copyright;https://www.slideshare.net/cfoltz/ph...cal-properties)

Chemical properties are characteristics that describe how matter **changes** its chemical structure or composition. An example of a chemical property is flammability—a material's ability to burn—because burning (also known as combustion) changes the chemical composition of a material. Oxidation, rusting, decomposition, and inertness (not reactive) are chemical properties as well. Click on this video and record the physical and chemical properties of the element sodium.

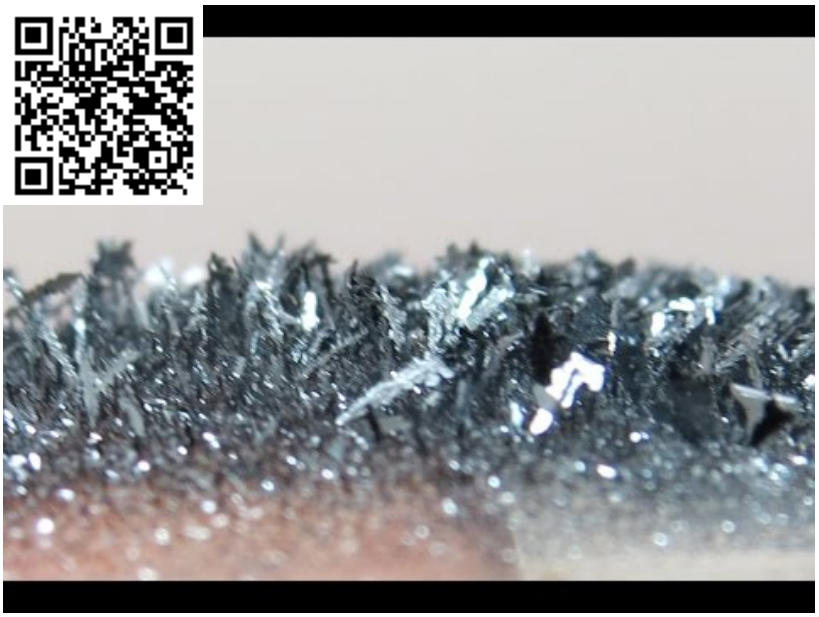


Figure 1.4.2: Port Royal, South Carolina oxidation of iron. Image courtesy of Elizabeth R. Gordon.

States of Matter (phases)

Another way to classify matter is to describe it as a solid, a liquid, or a gas, which was done in the examples of solutions. These three descriptions, each implying that the matter has certain physical properties, represent the three phases of matter. A solid has a

definite shape and a definite volume. Liquids ordinarily have a definite volume but not a definite shape; they take the shape of their containers. Gases have neither a definite shape nor a definite volume, and they expand to fill their containers. We encounter matter in each phase every day; in fact, we regularly encounter water in all three phases: ice (solid), water (liquid), and steam (gas).



Video**1.4.1**: Sublimation and deposition of Iodine.

We know from our experience with water that substances can change from one phase to another if the conditions are right. Typically, varying the temperature of a substance (and, less commonly, the pressure exerted on it) can cause a phase change, a physical process in which a substance goes from one phase to another (Figure **1.4.3**). Phase changes have particular names depending on what phases are involved, as summarized in Table **1.4.1**.

Table **1.4.1**: Phase Changes

Change	Name
solid to liquid	melting, fusion
solid to gas	sublimation
liquid to gas	boiling, evaporation
liquid to solid	solidification, freezing
gas to liquid	condensation
gas to solid	deposition

Classification of Matter

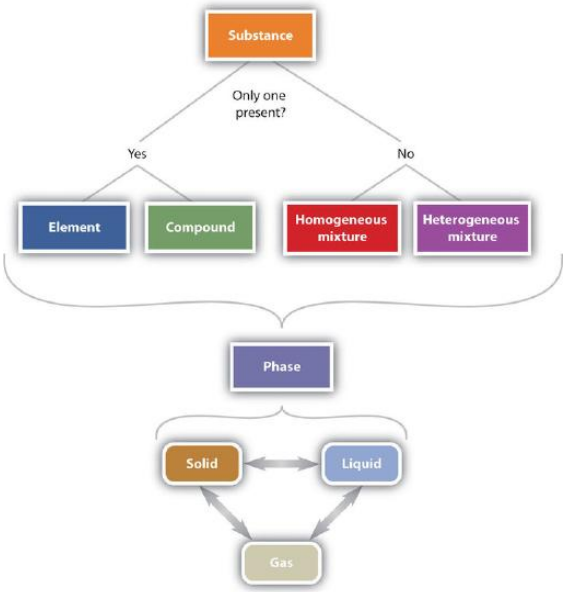


Figure 1.4.3: The Classification of Matter. Matter can be classified in a variety of ways, depending on its properties. (Cc BY-NC-SA; anonymous)

Elements and Compounds

Any sample of matter that has the same physical and chemical properties throughout the sample is called a substance. There are two types of substances. A substance that cannot be broken down into chemically simpler components is an element. Aluminum, which is used in soda cans, is an element. A substance that can be broken down into chemically simpler components (because it has more than one element) is a compound . Water is a compound composed of the elements hydrogen and oxygen. Today, there are 118 elements in the known universe. In contrast, scientists have identified tens of millions of different compounds to date.

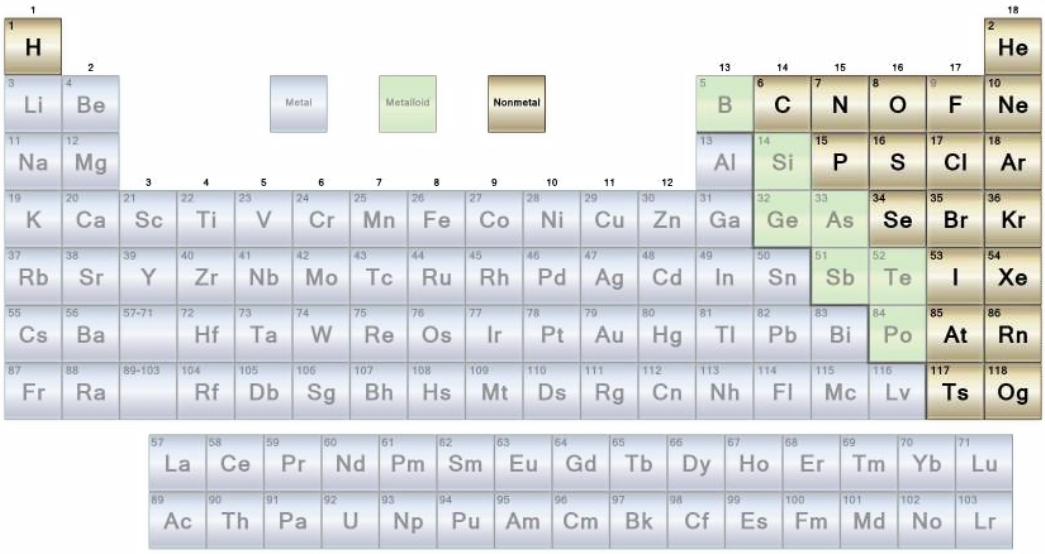


Figure 1.4.4: Periodic-Table-Metals.jpg. (CC-BY-SA-4.0), https://commons.wikimedia.org/w/inde...edit&redlink=1.

Sometimes the word *pure* is added to a substance, but this is not absolutely necessary. By definition, any single substance is pure.

The smallest part of an element that maintains the identity of that element is called an atom. Atoms are extremely tiny; to make a line 1 inch long, you would need 217 million iron atoms. The smallest part of a compound that maintains the identity of that compound is called a molecule. Molecules are composed of atoms that are attached together and behave as a unit. Scientists usually work with millions and millions of atoms and molecules at a time. When a scientist is working with large numbers of atoms or molecules at a time, the scientist is studying the macroscopic view of the universe.

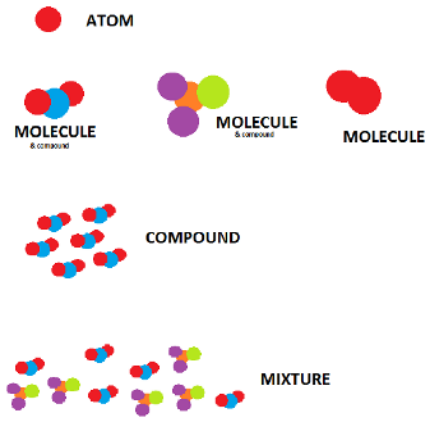


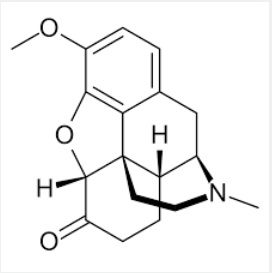
Figure **1.4.5**: Appreciating elements, molecules and compounds.

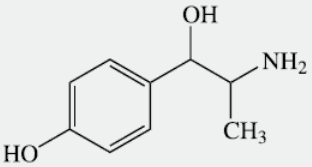
Inorganic and Organic Compounds

Compounds can be further classified as being inorganic or organic. Organic compounds contain carbon, hydrogen, and usually another element from the right side of the periodic table. Be careful when thinking about organic chemicals. In the real world, the term "organic" is typically used to describe products that have natural ingredients. In the world of science, the word "organic" is used to denote compounds that have carbon and hydrogen connections. Look at some of the structures below to get an appreciation of organic chemical structures.

Organic structures

The two molecules shown below are heavily used in the pharmaceutical industry. The compound on the left is known as hydrocodone. This is an opioid painkiller that is extremely addictive. It is regularly dispensed for surgical and chronic pain. The compound on the right is Adderall. This medication is used to treat ADHD and narcolepsy. Both of these medications are controlled by the DEA (Drug Enforcement Agency) and are illegal to possess unless you have a valid prescription.





Mixtures

A material composed of two or more substances is a mixture. In a mixture, the individual substances maintain their chemical identities. Many mixtures are obvious combinations of two or more substances, such as a mixture of sand and water. Such mixtures are called **heterogeneous mixtures**. In some mixtures, the components are so intimately combined that they act like a single

substance (even though they are not). Mixtures with a consistent composition throughout are called **homogeneous mixtures** (or **solutions**). Sugar dissolved in water is an example of a solution. A metal alloy, such as steel, is an example of a solid solution. Air, a mixture of mainly nitrogen and oxygen, is a gaseous solution.

✔ Exercise 1.4.1

How would a scientist categorize each type of matter?

a. saltwater
b. soil
c. water
d. oxygen

Solution

a. Saltwater acts as if it were a single substance even though it contains two substances—salt and water. Saltwater is a homogeneous mixture, or a solution.
b. Soil is composed of small pieces of a variety of materials, so it is a heterogeneous mixture.
c. Water is a substance; more specifically, because water is composed of hydrogen and oxygen, it is a compound.
d. Oxygen, a substance, is an element.

? Exercise 1.4.2

How would a chemist categorize each example of matter?

a. coffee
b. hydrogen
c. an egg

Answer a

Coffee could be a heterogeneous or homogeneous mixture. If insoluble parts are able to be identified, then it would be classified as being heterogeneous. If not, then coffee would be a homogeneous mixture or a solution.

Answer b

Hydrogen is an element. It can be located on the periodic table.

Answer c

An egg (assume raw) would be a heterogeneous mixture. The yolk and egg white are two different substances that can be easily seen.

? Exercise 1.4.3

a. Classify each as being element, compound, heterogeneous mixture, or homogeneous mixture (solution): air at Furman University, Furman Lake water, copper wire, and Furman tap water.
b. What is the difference between a heterogeneous mixture and a homogeneous mixture? Give an example of each.
c. Which is/are physical change(s): burning of fuel, digestion of food, salt dissolving in water, copper conducting electricity, and water boiling.

Answer a

Hopefully, Furman air is a homogenous mixture (solution). If there is no burning or dust build-up in the area, this is safe to assume. Furman Lake is definitely a heterogeneous mixture (in some areas it can get a bit swampy). Copper wire is an element. There are very few elements in nature. Lastly, Furman tap water is usually a homogeneous mixture. Natural and

man-made chemicals are in our tap water (trust me, you want the chlorine). Our toilets do use greywater which can look heterogeneous (ok for sewer but not to drink).

Answer b

A heterogeneous mixture is obviously a mixture, such as dirt; a homogeneous mixture behaves like a single substance, such as saltwater.

Answer c

The physical changes are salt dissolving water, copper conducting, and water boiling. If composition is not changed, then this is a physical change. If there is a method to physically separate the components (like boiling, evaporation, distillation, magnetism, or filtration), then a physical change has occurred.

Contributors and Attributions

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1.5: Applying Properties - MSDS/SDS

Learning Objectives

- Review physical and chemical properties.
- Know the purpose of a MSDS/SDS.
- Explain the bolded words on this page.

What is a MSDS/SDS?

A Material Safety Data Sheet (MSDS) or Safety Data Sheet (SDS) is designed to provide both workers and emergency personnel with the proper procedures for handling or working with a particular substance. MSDS's include information such as physical data (melting point, boiling point, flash point, etc.), toxicity, health effects, first aid, reactivity, storage, disposal, protective equipment, and spill/leak procedures. These are of particular use if a spill or other accident occurs.

The MSDS's are available from many sources such as the chemistry store, health and safety offices, material producing companies, etc. Any business or industry that has chemicals on site is required to have access to MSDS files for employers to be able to access at any time. If an employee is concerned about their exposure to chemicals, they can peruse an MSDS to obtain helpful information. Likewise, one could research household chemicals that could be dangerous to humans and animals. Many substances found around the home (pesticides, fuels, and cleaners) can be hazardous or harmless.

Safety Data Sheets Requirement Summary		
1	Identification	Product identifier, recommended use and restrictions on use, supplier contact information, emergency phone number
2	Hazard Identification	Classification (hazard class and category), label elements (including hazard pictogram, signal word, hazard statement and precautionary statements) and other hazards (e.g. thermal hazards).
3	Composition / Ingredients Information	For a hazardous product that is a substance: the chemical name, synonyms, CAS No. and the chemical name of impurities, stabilizing solvents and stabilizing additives where classified and that contribute to the classification of the product. For a hazardous product that is a mixture: for ingredients that present a health hazard, the chemical name, synonyms, CAS No. and concentration. Note: Confidential Business Information Rules may apply.
4	First Aid Measures	First-aid measures by route of exposure as well as most important symptoms/effects.
5	Fire Fighting Measures	Suitable (and unsuitable) extinguishing media, specific hazards, special equipment and precautions for fire fighters.
6	Accidental Release Measures	Protective equipment, emergency procedures, methods and materials for containment and clean up.
7	Handling and Storage	Precautions for safe handling, conditions for storage, including any incompatibilities.
8	Exposure Controls / Personal Protection	Exposure limits, engineering controls, personal protective equipment.
9	Physical and Chemical Properties	Appearance, odour, odour threshold, pH, melting/freezing point, boiling point and range, flash point, upper and lower flammable or explosive limits.
10	Stability and Reactivity	Reactivity, chemical stability, possible hazardous reactions, conditions to avoid, incompatible materials, hazardous decomposition products.
11	Toxicological Information	Description of various toxic effects by route of entry, including effects of acute or chronic exposure, carcinogenicity, reproductive effects, respiratory sensitization.
12	Ecological Information	Aquatic and terrestrial toxicity (if available), persistence and degradability, bioaccumulative potential, mobility in soil
13	Disposal Considerations	Safe handling and methods of disposal, including contaminated packaging.
14	Transport Information	UN number and proper shipping name, hazard classes, packing group.
15	Regulatory Information	Safety, health and environmental regulations specific to the product.
16	Other Information	Other information, including date of the latest revision of the SDS.

Figure 1.5.1: Categories of a MSDS/SDS document.

Other Terms Used in MSDS/SDS

Aspects of toxicity and how chemicals will affect a body can also be found in this resource. **Along with physical and chemical properties, you should be familiar with the terms below that could also be found in an MSDS/SDS document.**

- **Mutagen:** able to alter DNA and could result in carcinogenesis (a chemical example would be nitrosamine)
- **Carcinogen:** able to cause cancer (this can get complicated, animal and human carcinogens both exist). There are very few chemicals classified as being human carcinogens. (benzene, radon, asbestos)
- **Neurotoxin:** affects the nervous system (chemical examples include lead and mercury)

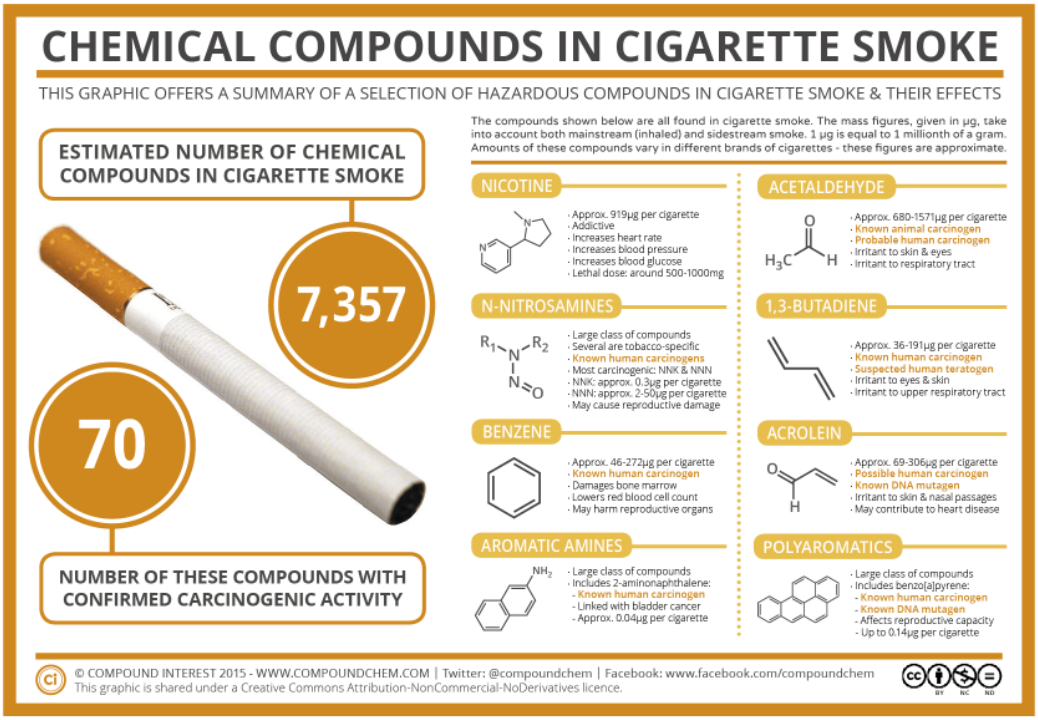


Figure **1.5.2**: Chemical Compounds in Cigarette Smoke. (CC-BY-NC-ND; Andy Brunning).

- **Teratogen**: affects developing fetus or embryo (pharmaceutical examples would be thalidomide and Accutane)
- **Corrosive**: can chemically destroy things easily (acids/bases are examples)
- **Flammable/Combustible**: able to catch on fire (examples would include gasoline and acetone)
- **Volatile**: a liquid that can transform into gas easily (examples would include gasoline and acetone)
- **LD50:** lethal dose (ingest,inhale, or inject) to kill 50% of a studied population (toxicology terminology)

MSDS/SDS's can be several pages long. A complete MSDS/SDS guide for acetic acid (also known as vinegar) can be viewed by clicking on this here. Although this chemical might appear dangerous, it used in the production of vinegar, ketchup, and barbeque sauce. *After looking over vinegar's entire MSDS/SDS sheet, write down any questions for your instructor regarding unfamiliar terminology.*

Exercise 1.5.1

After looking at the MSDS for acetic acid, answer the questions below:

a. Is this chemical a carcinogen?
b. Does acetic acid react with metals?
c. What odor does acetic acid produce?
d. If this chemical is ingested, should you induce vomiting to remove it from the body?
e. Does this chemical have a color?

Answer a

Acetic acid is not a carcinogen. It will not alter cause cancer.

Answer b

Acetic acid reacts with metals. This is a chemical property of this substance.

Answer c

Acetic acid smells like vinegar.

Answer d

Acetic acid is very corrosive and will eat biological tissues. If swallowed, vomiting should not be induced.

Answer e

This chemical is colorless



Figure 1.5.3: IARC's carcinogenic classifications. (CC-BY-NC-ND, Andy Brunning)

? Exercise 1.5.1

Read over the cigarette infographic and write down all the chemicals listed that are known human carcinogens. Research chemicals used in vapes and record these on a sheet of paper. Using the MSDS/SDS toxicological section for each chemical, record all known human carcinogens in vapes.

Answer

For traditional cigarettes, aromatic amines, nitrosamines, benzene, acetaldehyde, 1,3-butadiene, and polyaromatics. For vapes, this will vary and we will discuss this in class.

Contributors and Attributions

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1.6: All About the Elements

Learning Objectives

- Identify groups and periods on the periodic table.
- Provide an element that was named after a person and an element named after a place.
- Identify all atoms within a compound.
- Classify a compound as being organic or inorganic.
- Research an element using the link provided below.

Basic Arrangement of Periodic Table

In Chapter 3, we will delve more into the initial construction and modifications of today's periodic table. For now, you need to be aware that the periodic table has columns (known as **families**/**groups**). Horizontal rows are called **periods**. On the table below, the element symbols are either one or two letters. Previously, some of the newly discovered elements (see period seven on other tables) used three-letter symbols. These three-letter symbols corresponded to a Latin numbering system until the elements were given official names.

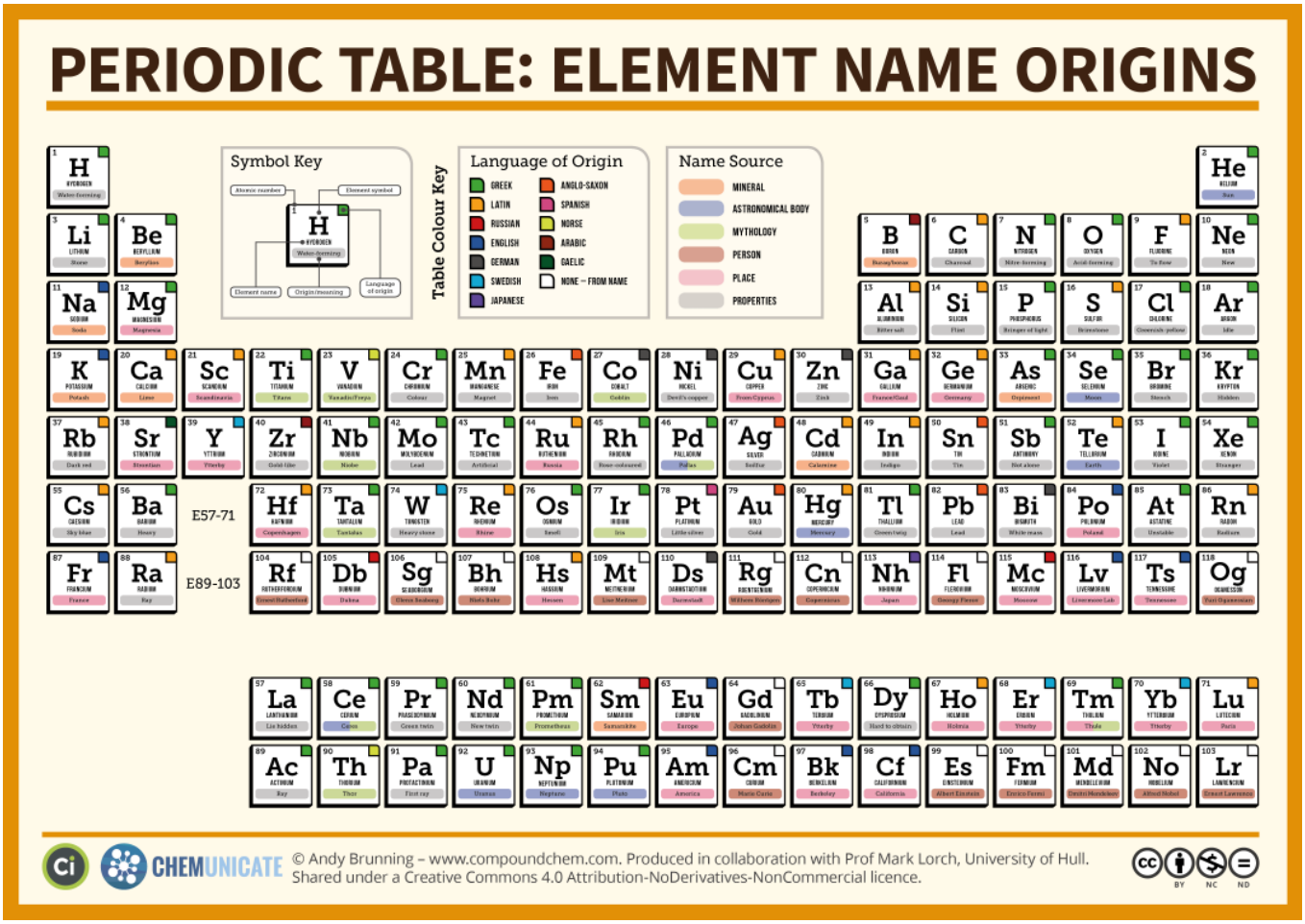
Languages of Element Names

Interestingly, different languages are used on the periodic table. Depending on your background, you might be more familiar with some elemental symbols than others. *For* example, Hydrogen is represented by the symbol H. This element's name is derived from the Greek hydro, and genes which means to generate water. Other elemental symbols like copper (which has a symbol of Cu) are not so predictable. This particular element's name originated from the Latin *cuprum* (from the island of Cyprus). A variety of languages are displayed on the periodic table. For example, Swiss roots are present in the element Tungsten. The symbol for this element is W which corresponds to the Swedish word, wolfram. **For this particular class, you will find a list of required elements/symbols that need to be memorized. Please locate this document on the moodle page for this course.**

Meanings of Element Names

Many elements are named in honor of people. Some familiar names you might see are curium (Marie and Pierre Curie), einsteinium (Albert Einstein), and mendelevium (Dimitri Mendeleev). IUPAC (International Union of Pure and Applied Chemistry) requires these types of names to be done posthumously. In other words, the scientist who discovered the element could not name it after her/himself or anyone who is still currently living. Over the years, there have been two exceptions. The elements of seaborgium (Sg) and oganesson (Og) were named while Glen Seaborg and Yuri Oganessian were still living. Seaborgium was named in honor of an American nuclear chemist who synthesized the element plutonium. He is also credited with assisting the discovery of other elements like c, americium (element 95), curium (element 96), and fermium (element 100). His accomplishments encouraged his fellow researcher, Albert Ghiorso, to name Seaborgium in honor of him. As for element 118 (oganessian), a joint research commission of Russian and American scientists named this element for Russian physicist, Yuri Oganessian. As of 2017, Oganessian is still living and is responsible for the discovery of superheavy elements. **For midterm, please research an element that has not been mentioned on this page or on your list to be memorized. By accessing this link, information about a selected element can be obtained. You will need to provide the symbol and interesting factoid for five-point question.**

It is acceptable to name an element in honor of a geographical location. Some notable Earth locations would include Am (americium, American continent), Ge (germanium, Germany), Fr (francium, France), and Eu (europium, European continent). Some scientists have ventured past Earth to name their elements in honor of other places. Examples of these would include Pu (plutonium, Pluto), U (uranium, Uranus), and Np (neptunium, Neptune).



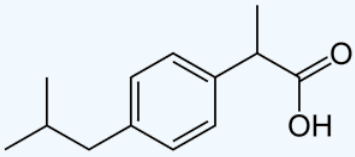
Example 1.6.1

List the element names contained in the compounds below. Classify each compound as being organic or inorganic.

a. Na_2SO_4

b. HCl

c. $Cu(NO_3)_2 \cdot H_2O$

d. 

e. CO_2

Solution

a. sodium, sulfur, and oxygen. This compound is inorganic.

b. hydrogen and chlorine. This compound is inorganic

c. copper, nitrogen, oxygen, and hydrogen. This compound is inorganic.

d. The corners of each line drawing represent carbons. You can assume for the single lines, the carbons have hydrogens attached (organic chemists tend not to draw all atoms). This compound is organic and contains carbon, hydrogen, and oxygen.

e. carbon and oxygen. This compound is inorganic.

Example 1.6.2

Locate and name all the elements you see below in the compounds that are given below. Circle the organic compounds.

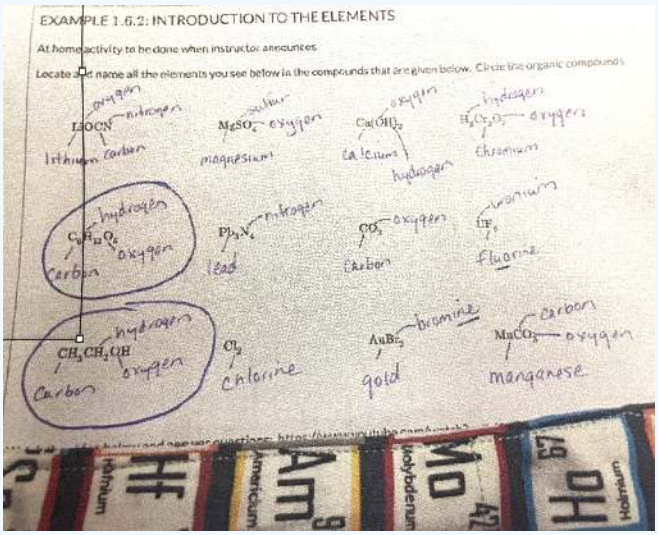
$LiOCN$	$MgSO_4$	$Ca(OH)_2$	$H_2Cr_2O_7$
$C_6H_{12}O_6$	Pb_3N_4	CO_2	UF_6
CH_2CH_2OH	Cl_2	$AuBr_2$	$MnCO_3$

Recently, elements 113-118 received their official names. Watch this ACS video and answer the questions below.

a. How were the last four elements made?
b. How many total elements do we have now?
c. How many elements are named in honor of female scientists?
d. What would you name your new element and what would its symbol be?

Answer

(elements only)



Contributors and Attributions

- Elizabeth R. Gordon (Furman University)
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CHAPTER OVERVIEW

2: The Mathematics of Chemistry

Mathematics is used widely in chemistry and are absolutely necessary to explore important concepts in chemistry. Without some basic mathematics skills, these calculations, and therefore chemistry itself, will be extremely difficult. However, with a basic knowledge of some of the mathematics that will be used in your chemistry course, you will be well prepared to deal with the concepts and theories of chemistry.

2.1: Measuring Matter

2.2: Dimensional Analysis

2.3: Density

2.4: Temperature

2.E: The Mathematics of Chemistry (Exercises)

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2.1: Measuring Matter

Learning Objectives

- Connect basic glassware and equipment with metric units.
- Provide SI units for mass, temperature, and length.
- Practice scientific notation and calculator skills (entering powers of ten).
- Memorize or place the bolded conversion factors on your reference card.

A variety of instruments are available for making direct measurements of the macroscopic properties of a chemical substance. For example, we usually measure the **volume** of a liquid sample with pipettes, burets, graduated cylinders, and volumetric flasks (Figure **2.1.1**), whereas we usually measure the mass of a solid or liquid substance with a balance (Figure **2.1.2**).

Instruments that Measure Volume

Many academic scientists report their volume measurements with the milliliter unit. On the other hand, analytical chemists tend to work with much smaller volumes, and they would use nanoliter and microliter samples in their laboratory. When considering the industrial realm, scientists work with larger volumes and would thus employ the liter unit of measurement. Scientists use beakers and flasks to contain liquids. For measuring this type of matter, graduated cylinders and pipettes are utilized.

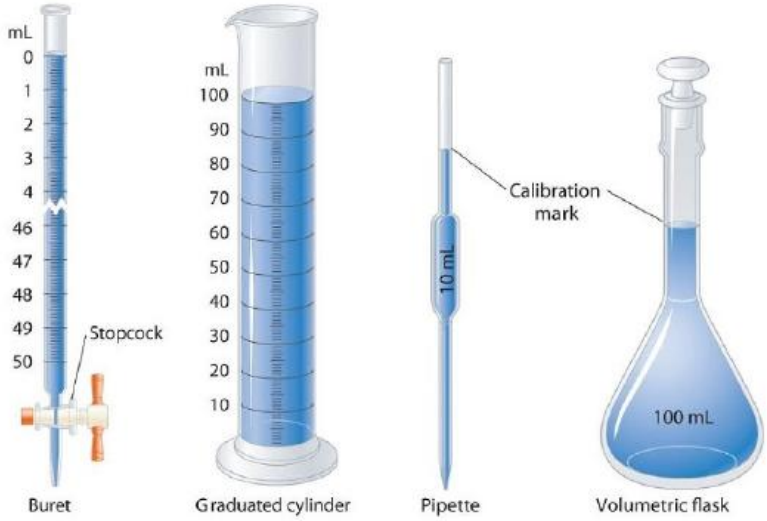


Figure **2.1.1**: (left two) Graduated glassware is used to deliver variable volumes of liquid. (right two) Volumetric glassware is used to deliver (pipette) or contain (volumetric flask) a single volume accurately when filled to the mark. (CC BY-SA-NC 3.0; anonymous).

Instruments that Measure Mass

Balances are utilized to measure the **mass** of matter. Typically, high school and middle schools will use triple beam balances for laboratory activities. Colleges will rely on digital balances. For larger quantities of materials, top-loading digital balances are employed. For higher sensitivity and accuracy, some chemists use analytical balances.



Figure **2.1.2**: Triple beam balance (image from: upload.wikimedia.org/wikiped...m_balance2.JPG. Digital top-loading balance (upload.wikimedia.org/wikiped...00-2M_-_01.jpg) and an analytical balance (upload.wikimedia.org/wikiped...-NaCl-1mol.jpg)

In the academic laboratory (like Furman University's), a chemist will commonly use the gram, or the even smaller unit, the milligram. Industrial chemists making larger quantities of material would work with kilograms of materials. Analytical chemists (industrial or academic), environmental scientists, and toxicologists are typically more concerned with the smaller units of the metric system. For example, many chemicals found in drinking water and air are regulated in concentrations like nanograms and or micrograms.

Tools that Measure Length

Length is measured using a metric stick or a metric ruler marked in millimeters and centimeters. Most devices used to measure length (in the United States) contain both English and metric markings.

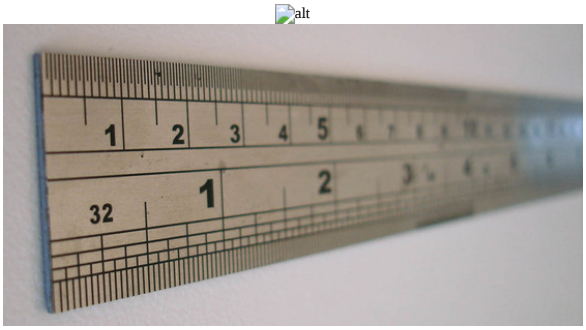


Figure **2.1.3**: Metric and English measuring devices. (CC BY-SA 4.0; Ejay).

SI Units

All reported measurements must include an appropriate unit of measurement. To say that a substance has "a mass of 10" does not tell whether the mass was measured in grams, pounds, tons, or some other unit. For example, a nurse giving morphine to a patient needs to be specific in the unit dosages. A volume of liters would kill a patient quickly while a milliliter amount would provide sufficient pain relief. To establish worldwide standards for the consistent measurement of significant physical and chemical properties, an international body called the General Conference on Weights and Measures devised the Système Internationale d'unités (or SI). The International System of Units is based on metric units and requires that measurements be expressed in decimal form. Table **2.1.1** lists the seven base units of the SI system; all other SI units of measurement are derived from them.

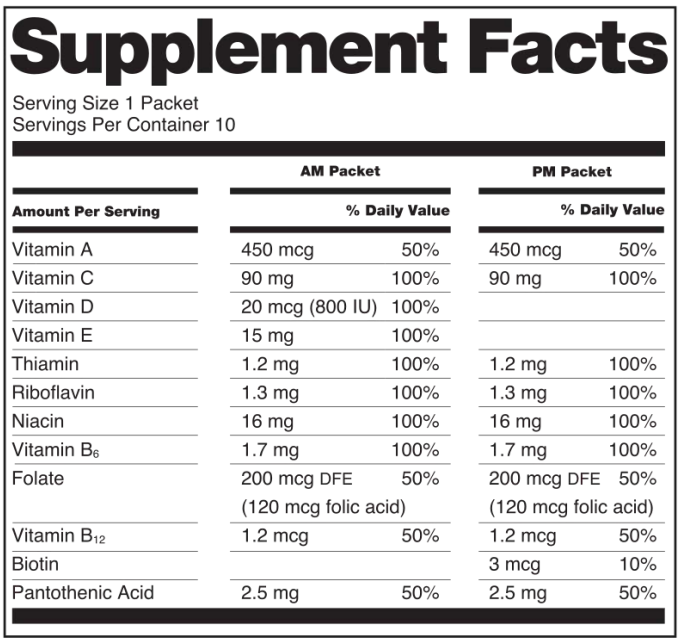
Table **2.1.1**: *SI Units*

Base Quantity	Unit Name	Abbreviation
mass	**kilogram**	**kg**
length	**meter**	**m**
time	**second**	**s**
temperature	**Kelvin**	**K**
amount of substance	mole	mol
intensity of light	candela	cd

The Metric System

Table **2.1.2**: *Prefixes Used with metric bases of meter, liter, and gram*

Prefix	Symbol	Value	Power of 10	Meaning
tera	T	1,000,000,000,000	10^{12}	trillion
giga	**G**	**1,000,000,000**	**10^{9}**	**billion**
mega	**M**	**1,000,000**	**10^{6}**	**million**
kilo	**k**	**1000**	**10^{3}**	**thousand**
hecto	h	100	10^{2}	hundred
deca	da	10	10^{1}	ten
—	—	1 (this is base unit which could be gram, liter, or meter)	10^{0}	one
deci	d	0.1	10^{-1}	tenth
centi	**c**	**0.01**	**10^{-2}**	**hundredth**
milli	**m**	**0.001**	**10^{-3}**	**thousandth**
micro	**μ (medical community uses mcg)**	**0.000001**	**10^{-6}**	**millionth**
nano	**n**	**0.000000001**	**10^{-9}**	**billionth**
pico	p	0.000000000001	10^{-12}	trillionth
femto	f	0.000000000000001	10^{-15}	quadrillionth



Supplement Facts

Serving Size 1 Packet
Servings Per Container 10

	AM Packet		PM Packet	
Amount Per Serving		**% Daily Value**		**% Daily Value**
Vitamin A	450 mcg	50%	450 mcg	50%
Vitamin C	90 mg	100%	90 mg	100%
Vitamin D	20 mcg (800 IU)	100%		
Vitamin E	15 mg	100%		
Thiamin	1.2 mg	100%	1.2 mg	100%
Riboflavin	1.3 mg	100%	1.3 mg	100%
Niacin	16 mg	100%	16 mg	100%
Vitamin B_6	1.7 mg	100%	1.7 mg	100%
Folate	200 mcg DFE (120 mcg folic acid)	50%	200 mcg DFE (120 mcg folic acid)	50%
Vitamin B_{12}	1.2 mcg	50%	1.2 mcg	50%
Biotin			3 mcg	10%
Pantothenic Acid	2.5 mg	50%	2.5 mg	50%

Ingredients: Sodium ascorbate, ascorbic acid, calcium pantothenate, niacinamide, dl-alpha tocopheryl acetate, microcrystalline cellulose, dextrin, starch, mono- and diglycerides, vitamin A acetate, magnesium stearate, gelatin, FD&C Blue #1, FD&C Red #3, artificial colors, thiamin mononitrate, pyridoxine hydrochloride, citric acid, lactose, sorbic acid (preservative), tricalcium phosphate, sodium benzoate (preservative), sodium caseinate, preservatives (methylparaben, potassium sorbate, BHA, BHT), ergocalciferol, cyanocobalamin, and artificial flavors.

Figure **2.1.4**: Example of Supplement Facts by the FDA. (Public Domain, FDA.gov)

Two methods of Memorization for the Metric System

Using negative exponents (see above) is the traditional way to memorize the metric system. Many students who have been taught outside of the United States approach the metric system this way. For their conversion factors, students who have been taught the metric system in the United States tend to use positive exponents. Either method is fine, pick one method and use it consistently.

Two different ways to memorize the metric systems (be sure to know all bolded conversion factors listed in section 2.1 of this OER)

1 gigabase = 1 x10^9 base
1 megabase = 1x10^6 base
1 kilobase = 1x10^3base

- **1 centibase = 1x10^{-2}base** **or 1x10^2 centibase = 1 base**
- **1 millibase = 1x10^{-3}base** **or 1x10^3 millibase = 1 base**
- **1 microbase = 1x10^{-6}base** **or 1x10^6 microbase = 1 base**
- **1 nanobase = 1x10^{-9}base** **or 1x10^9 nanobase = 1 base**

Note: A base unit can be gram (mass), meter (length), volume (liter), and joules (energy).

Additional Units

When traveling to different regions of the globe, it is helpful to be able to convert from English to Metric units. **Please be sure to commit the bolded conversions below to memory**.

Unit Conversion
2.21 pounds = 1.00 kilograms
1 mile = 1.61 kilometers
1.00 inch = 2.54 centimeters
1.00 mL = 1.00 cc (cubic centimeters) = 1.00 cm^3
1 teaspoon (tsp) = 5.00 mL
12 in = 1.00 ft.
16 oz. = 1.00 pounds

Scientific Notation

Chemists often work with numbers that are exceedingly large or small. For example, entering the mass in grams of a hydrogen atom into a calculator requires a display with at least 24 decimal places. A system called scientific notation avoids much of the tedium and awkwardness of manipulating numbers with large or small magnitudes. In scientific notation, these numbers are expressed in the form

$$N \times 10^n$$

where N is greater than or equal to 1 and less than 10 ($1 \le N < 10$), and n is a positive or negative integer ($10^0 = 1$). The number 10 is called the base because it is this number that is raised to the power n. Although a base number may have values other than 10, the base number in scientific notation is always 10.

A simple way to convert numbers to scientific notation is to move the decimal point as many places to the left or right as needed to give a number between 1 to 10 (N). The magnitude of n is then determined as follows:

- If the decimal point is moved to the left n places, n is positive.
- If the decimal point is moved to the right n places, n is negative.

Another way to remember this is to recognize that as the number N decreases in magnitude, the exponent increases, and vice versa. The application of this rule is illustrated in Example **2.1.1**.

Example 2.1.1: scientific notation

Convert each number to scientific notation.

a. 637.8
b. 0.0479
c. 7.86
d. 12,378
e. 0.00032
f. 61.06700
g. 2002.080
h. 0.01020

Solution

Explanation	Solution
To convert 637.8 to a number from 1 to 10, we move the decimal point two places to the left: 6.378 Because the decimal point was moved two places to the left, n = 2.	$637.8 = 6.378 \times 10^{2}$
To convert 0.0479 to a number from 1 to 10, we move the decimal point two places to the right: 4.79 Because the decimal point was moved two places to the right, n = −2.	$0.0479 = 4.79 \times 10^{-2}$
This is usually expressed simply as 7.86. (Recall that $10^{0} = 1$).	7.86×10^{0}
Move the decimal point four places to the left and note a positive exponent.	1.2378×10^{4}
Move the decimal place four places to the right a note a negative exponent.	3.2×10^{-4}
Move the decimal place one space to the left and note a positive exponent.	6.106700×10^{1}
Move the decimal place three places to the left and note a positive exponent.	2.002080×10^{3}
Move the decimal place two places to the right and note a negative exponent.	1.020×10^{-2}

Using the Scientific Calculator

Please be sure to obtain a calculator that has an exponent button on it. It will either say "exp" or have an "ee" key indicating this function. This key represents the function of 10^{x}. You do not need to enter a 10 for an exponent when using this particular function. Read the steps below and practice on your calculator.

Use of Calculator

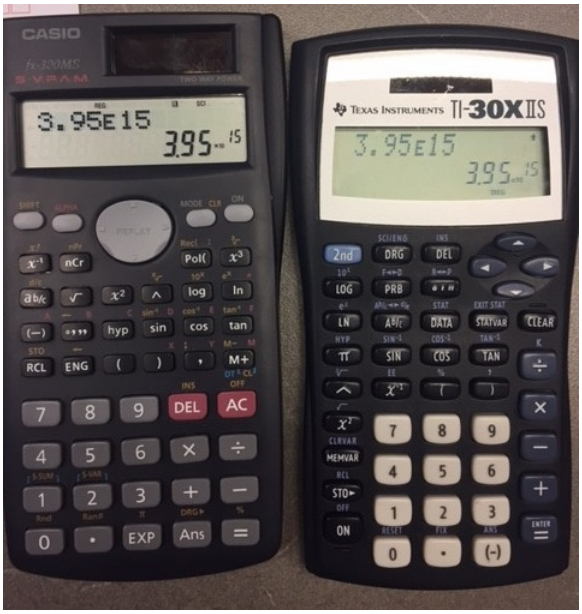
To input powers of ten:

1. Locate the ee or exp button on your calculator. Do not use the carrot (looks like the ^ button).
2. Put the coefficient number in and then hit "ee" or "exp."
3. If you need to have a negative "exp," then locate the +/- or small - button.
4. Lastly, input your power of ten. You do not need to put the actual number ten in for the exponent.

Table **2.1.3***: Examples*

Number	**How to Input in a calculator**
3.95×10^{15}	Put 3.95 in as the coefficient number. Hit the "ee" or "exp" button. Lastly, enter the 15 for the exponent. Your calculator should say $3.95e^{15}$.
9.26×10^{-4}	Put 9.26 in as the coefficient number. Hit the "ee" or "exp" button. Locate the small +/- button for negative (not minus function). Next, enter the number four. Your calculator should say $9.26e^{-4}$.

This is an image of suggested calculators for CHM101. You will need a non-programmable, scientific calculator that does not have metric conversion functions. In this picture, you will see the correct way to input one of the numbers shown in the example above. Please take time to practice with your calculator before tests and quizzes.



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2.2: Dimensional Analysis

Learning Objective

- Convert metric and English based units.
- Report converted values in correct scientific notation with the corresponding units.
- Master using your calculator.

Conversion Factors

We have an expression,

$$\frac{3\,ft}{1\,yd} = 1 \tag{2.2.1}$$

Equation 2.2.1 is a strange way to write 1, but it makes sense: 3 ft equal 1 yd, so the quantities in the numerator and denominator are the same quantity, just expressed with different units. The expression in Equation 2.2.1 is called a conversion factor and it is used to formally change the unit of a quantity into another unit. (The process of converting units in such a formal fashion is sometimes called *dimensional analysis* or the *factor label method*.)

To see how this happens, let us start with the original quantity: $4\,yd$ and let us multiply this quantity by 1. Rather than multiplying by just 1, let us write 1 as

$$1 = \frac{3\,ft}{1\,yd}$$

When you multiply anything by 1, you don't change the value of the quantity.

$$\begin{aligned} 4\,yd &= 4\,yd \times 1 \\ &= 4\,yd \times \frac{3\,ft}{1\,yd} \end{aligned}$$

The 4 yd term can be thought of as yd/1; that is, it can be thought of as a fraction with 1 in the denominator. We are essentially multiplying fractions. If the same thing appears in the numerator and denominator of a fraction, they cancel. In this case, what cancels is the unit yard:

$$4\,\cancel{yd} \times \frac{3\,ft}{1\,\cancel{yd}}$$

That is all that we can cancel. Now, multiply and divide all the numbers to get the final answer:

$$\frac{4 \times 3\,ft}{1} = \frac{12\,ft}{1} = 12\,ft$$

Again, we get an answer of 12 ft, just as we did originally. But in this case, we used a more formal procedure that is applicable to a variety of problems.

How many millimeters are in 14.66 m? To answer this, we need to construct a conversion factor between millimeters and meters and apply it correctly to the original quantity. One method would entail using the conversion factor of $1\,mm = 1 \times 10^{-3}\,m$

$$14.66\,\cancel{m} \times \frac{1\,mm}{10^{-3}\,\cancel{m}} = 14660\,mm \tag{2.2.2}$$

$$= 1.46 \times 10^{4}\,mm \tag{2.2.3}$$

Which conversion factor do we use? The answer is based on *what unit you want to get rid of in your initial quantity*. The original unit of our quantity is meters, which we want to convert to millimeters. Because the original unit is assumed to be in the numerator, to get rid of it, we want the meter unit in the *denominator*; then they will cancel. Using the positive metric exponents, we have an alternative method to calculate the same answer as shown previously. Canceling units and performing the mathematics, we get:

$$14.66 \cancel{m} \times \frac{1000\,mm}{1\,\cancel{m}} = 14660\,mm \tag{2.2.4}$$

$$= 1.46 \times 10^4\,mm \tag{2.2.5}$$

Note how m cancels, leaving mm, which is the unit of interest.

The ability to construct and apply proper conversion factors is a very powerful mathematical technique in chemistry. You need to master this technique if you are going to be successful in this and future science courses.

Example 2.2.1

a. Convert 35.9 kL to liters.
b. Convert 555 nm to meters.

Solution

a. We will use the fact that 1 kL = 1,000 L. Of the two conversion factors that can be defined, the one that will work is 1000L/1kL. Applying this conversion factor, we get:

$$35.9 \cancel{kL} \times \frac{1000\,L}{1\,\cancel{kL}} = 35,900\,L$$

b. We will use the fact that 1 nm = 1/1,000,000,000 m, which we will rewrite as 1,000,000,000 nm = 1 m, or 10^9 nm = 1 m. Of the two possible conversion factors, the appropriate one has the nm unit in the denominator:

$$\frac{1\,m}{10^9\,m}$$

Applying this conversion factor, we get

$$555 \cancel{nm} \times \frac{1\,m}{10^9\,\cancel{nm}} = 0.000000555\,m$$

$$= 5.55 \times 10^{-7}\,m$$

In the final step, we expressed the answer in scientific notation.

Exercise 2.2.1

a. Convert 67.08 µL to liters.
b. Convert 56.8 m to kilometers.

Answer a

6.708×10^{-5} L

Answer b

5.68×10^{-2} km

Exercise 2.2.2

How many milliliters are in 607.8 kL?

Answer

This problem involves multiple steps that require going through the metric base of liters. Think of a pathway of a conversion before setting up these types of problems. The suggested pathway would be mL ⇒ L ⇒ kL

$$607.8\,kL \times \frac{1000\,L}{1\,kL} = 6.08 \times 10^5\,L$$
$$= 6.08 \times 10^5\,L \frac{1000\,mL}{1\,L}$$
$$= 608000000\,mL$$
$$= 6.08 \times 10^8\,mL$$

? Exercise 2.2.3

Kathleen Hsu Barron (Furman University, Class of 2011) is exploring Switzerland with her husband Patrick Barron (Furman University, Class of 2011). The sign she is pointing to is a typical speed in km/hr. Convert this distance to miles/hr and feet/hr.



Figure 2.2.1: Kathleen Hsu Barron standing by speed limit sign. (CC-BY-NC-ND, Patrick Barron)

Answer

Again, this problem is a multi-step problem. There are multiple ways that one could proceed to solve this problem. With the conversion factors in this course, the suggested round would be miles ⇒ kilometers ⇒ meters ⇒ centimeters ⇒ inches ⇒ feet. Another method could utilize miles ⇒ feet.

18.6 miles/hr, 9.8 x 10^4 ft/hr

In this course, we will not use significant figures. You will need to read the directions on your assignment, quiz, or test and round accordingly.

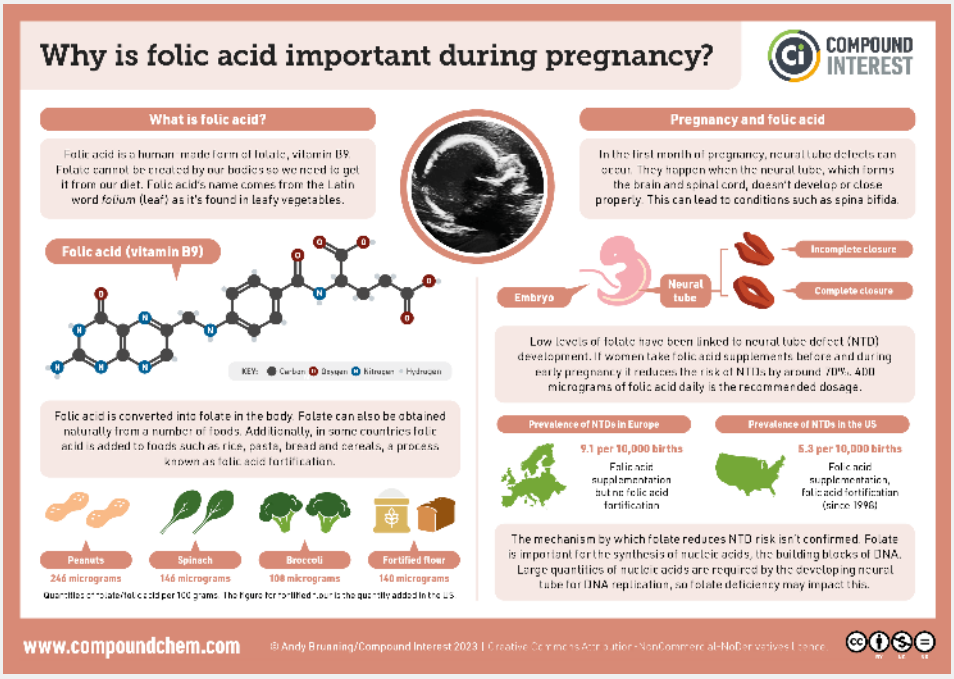


Figure **2.2.2**: Why is folic acid important in pregnancy. (CC-BY-NC-ND, Andy Brunning).

Question: The FDA recommends taking .400 mg of folic acid a day before pregnancy. How many micrograms is this dosage? Hint- think of the pathway mg⇒? ⇒µg

Need More Practice?

- Turn to Section 2.E of this OER and work problems #1, #3, #5, #6, and #8.

Contributors and Attributions

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2.3: Density

Learning Objectives

- Calculate density, mass, or volume when given 2 of these three variables.
- Identify what units are required for the density equation.
- Review metric conversions.
- Compare densities of different chemical substances.
- Classify a substance as being a heterogeneous or homogeneous mixture if solubility date is provided.
- Identify where a chemical would appear in water if solubility and density data are provided.
- Compare any chemical substance's density to the density of water (please memorize this value).

Density is a physical property that is defined as a substance's mass divided by its volume:

$$\text{density} = \frac{\text{mass}}{\text{volume}} \tag{2.3.1}$$

$$d = \frac{m}{V} \tag{2.3.2}$$

Density is usually a measured property of a substance, so its numerical value affects the significant figures in a calculation. Notice that density is defined in terms of two dissimilar units, mass and volume. That means that density overall has *derived units*, just like velocity. Common units for density include g/mL, g/cm^3, g/L, kg/L, and even kg/m^3. Densities for some common substances are listed in Table **2.3.1**. **Memorize the density of water with its appropriate units**.

Table **2.3.1**: Densities of Some Common Substances

Substance	Density (g/mL or g/cm^3)
water	**1.0**
gold	19.3
mercury	13.6
air	0.0012
cork	0.22–0.26
aluminum	2.7
iron	7.87



Figure **2.3.1**: Separatory Funnel containing oil and colored water to display density differences. (CC BY-SA 3.0; PRHaney via Wikipedia).

Because of how it is defined, density can act as a conversion factor for switching between units of mass and volume. For example, suppose you have a sample of aluminum that has a volume of 7.88 cm^3. How can you determine what mass of aluminum you have without measuring it? You can use the volume to calculate it. If you multiply the given volume by the known density (Table **2.3.1**), the volume units will cancel and leave you with mass units, telling you the mass of the sample:

Start with Equation 2.3.1

$$\text{density} = \frac{m}{V}$$

and insert the relevant numbers

$$\frac{2.7g}{cm^3} = \frac{m}{7.88\,cm^3}$$

Cross multiplying both sides (right numerator x left denominator = left numerator x right denominator), we get the following expression with answer and appropriate unit.

$$7.88\,\cancel{cm^3} \times \frac{2.7\,g}{\cancel{cm^3}} = 21g \text{ of aluminum}$$

Example 2.3.1: Mercury

What is the mass of 44.6 mL of mercury? If you need to review how to isolate variables, please click here for a short tutorial.

Solution

Use the density value for mercury from Table **2.3.1** and the definition of density (Equation 2.3.1)

$$density = \frac{mass}{volume} \Rightarrow d = \frac{m}{V}$$

$$\frac{13.6g}{mL} = \frac{m}{44.6\,mL}$$

Remember to cross multiply here in order to isolate variable. Then, report answer with correct units.

$$44.6\,\cancel{mL} \times \frac{13.6\,g}{\cancel{mL}} = 607\,g$$

The mass of the mercury is 607 g.

? Exercise 2.3.1

What is the mass of 25.0 cm^3 of iron?

Answer

Use the density value for iron from Table 2.3.1

$$density = \frac{mass}{volume} \Rightarrow d = \frac{m}{V}$$

$$\frac{7.87g}{cm^3} = \frac{m}{25.0\,cm^3}$$

Cross multiplying both sides (right numerator x left denominator = left numerator x right denominator), we get the following expression with answer and appropriate unit.

$$25.0\,\cancel{cm^3} \times \frac{7.87\,g}{\cancel{cm^3}} = 197g \text{ of iron}$$

Another way of looking at density (some students choose to perform calculations using this method)

Density can also be used as a conversion factor to convert mass to volume—but care must be taken. We have already demonstrated that the number that goes with density normally goes in the numerator when density is written as a fraction. Take the density of gold, for example:

$$d = 19.3\,g/mL = \frac{19.3\,g}{mL}$$

Although this was not previously pointed out, it can be assumed that there is a 1 in the denominator:

$$d = 19.3\,g/mL = \frac{19.3\,g}{mL}$$

That is, the density value tells us that we have 19.3 grams for every 1 milliliter of volume, and the 1 is an exact number. When we want to use density to convert from mass to volume, the numerator and denominator of density need to be switched—that is, we must take the *reciprocal* of the density. In so doing, we move not only the units but also the numbers:

$$\frac{19.3\,\cancel{g}}{mL} = \frac{45\,\cancel{g}}{V}$$

Cross multiplying denominators with numerators, we obtain the following algebraic equation.

$$19.3V = 45.9\,mL$$

then you will need to isolate the variable (volume)

$$V = \frac{45.9\,mL}{19.3}$$

After multiplication, the answer would be

$$V = 2.38\,mL$$

✔ Example 2.3.2: Wine Cork

A cork stopper from a bottle of wine has a mass of 3.78 g. If the density of cork is 0.22 g/mL, what is the volume of the cork? *Regardless of the method that is used, you should still be able to obtain the same (and correct) answer.*

Solution

To use density as a conversion factor, we need to take the reciprocal so that the mass unit of density is in the denominator. Taking the reciprocal, we find

$$\frac{0.22\ \cancel{g}}{mL} = \frac{3.78\ \cancel{g}}{V}$$

Cross multiplying denominators with numerators, we obtain the following algebraic equation.

$$0.22V = 3.78\,mL$$

then you will need to isolate the variable (volume)

$$V = \frac{3.78\,mL}{0.22}$$

so, the volume of the cork is 17.2 mL.

? Exercise 2.3.2

What is the volume of 3.78 g of gold?

Answer

Before attempting this question, be sure to obtain the density of gold in the table above. If you were to need this value on a quiz or a test, then it would be provided. Once you have this value, plug it into the density equation. Next, you will need to isolate the volume variable (basic algebra). The final answer should be 0.196 cm^3.

Care must be used with density as a conversion factor. Make sure the mass units are the same or the volume units are the same, before using density to convert to a different unit. Often, the unit of the given quantity must be first converted to the appropriate unit before applying density as a conversion factor.

Using Density in Environmental Applications

Along with solubility, density can help determine how a contaminant could affect an aquatic system. For example, imagine mercury has been spilled in Furman Lake. Looking at this element's density value and comparing it to liquid water, one could determine the location of the insoluble (you would be given solubility information) mercury layer. The more dense mercury layer would reside on the bottom of Furman Lake. If one were to take a cross-section of the lake, you could see that a heterogeneous mixture would result.

In contrast, spilling ethanol (density = 0.789g/mL) would result in the formation of a homogeneous mixture. Ethanol (grain alcohol) is soluble in water. This would make it miscible (mixable to form a solution) in water and one would not be able to denote separate layers. According to the density, an alcohol layer would remain on top, but would ultimately dissolve.

Applications

What difficulties would arise from the separation and removal of contaminants?

1. Hg in Furman Lake
2. Ethanol in Furman Lake
3. oil (less dense, insoluble) in Furman Lake

Watch this video and record your observations.

1. What component was different in the two types of beverages (mass or volume)?
2. How does the above-mentioned difference affect the density equation?
3. Which beverage is denser than water?

Need More Practice?

- Turn to Section 2.E of this OER and work problems #2 and #9.

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2.4: Temperature

Learning Objectives

- Learn about the various temperature scales that are commonly used in chemistry and other cultures.
- Memorize temperature equations for **Celsius, Kelvin, and Fahrenheit conversions**.
- Differentiate between various thermometers (alcohol or mercury-based).
- Understand how body temperature can vary.
- Provide some examples of how cryogenics is used in the real-world.

Temperature Scales

One of the fundamental quantities in science is temperature, which is a measure of the average amount of energy of motion, or *kinetic energy*, a system contains. Temperatures are expressed using scales that use units called degrees. There are three scales used for reporting temperatures. Figure **2.4.1** compares the three temperature scales.

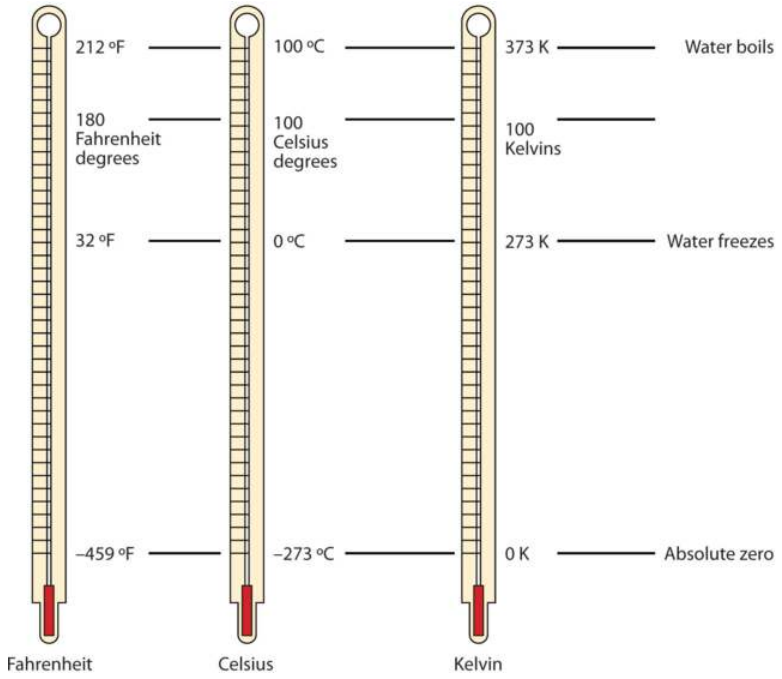


Figure **2.4.1**: Fahrenheit, Celsius, and Kelvin Temperatures. A comparison of the three temperature scales. These thermometers have a red-colored liquid which contains alcohol and food coloring. Silver looking thermometers contain mercury, which is a neurotoxin.

In the United States, the commonly used temperature scale is the *Fahrenheit scale* (symbolized by °F and spoken as “degrees Fahrenheit”). On this scale, the freezing point of liquid water (the temperature at which liquid water turns to solid ice) is 32 °F, and the boiling point of water (the temperature at which liquid water turns to steam) is 212 °F.

Science also uses other scales to express temperature. For example, the Celsius scale (symbolized by °C and spoken as “degrees Celsius”) defines 0°C as the freezing point of water and 100 °C as the boiling point of water. This scale is divided into 100 divisions between these two landmarks and extended higher and lower as well. By comparing the Fahrenheit and Celsius scales, a conversion between the two scales can be determined:

$$^{\circ}C = (^{\circ}F - 32) \times \frac{5}{9} \tag{2.4.1}$$

$$^{\circ}F = \left(^{\circ}C \times \frac{9}{5}\right) + 32 \tag{2.4.2}$$

Note that science uses the Celsius and Kelvin scales almost exclusively; virtually no practicing chemist expresses laboratory-measured temperatures with the Fahrenheit scale. (In fact, the United States is one of the few countries in the world that still uses the Fahrenheit scale on a daily basis. People driving near the borders of Canada or Mexico may pick up local radio stations on the other side of the border that express the daily weather in degrees Celsius, so do not get confused by their weather reports.)

Example 2.4.1: Conversions

a. What is 98.6°F in degrees Celsius?
b. What is 25.0°C in degrees Fahrenheit?

Solution

a. Using Equation 2.4.1, we have

$$\begin{aligned} ^\circ C &= (98.6 - 32) \times \frac{5}{9} \\ &= 66.6 \times \frac{5}{9} \\ &= 37.0^\circ C \end{aligned}$$

b. Using Equation 2.4.2, we have

$$\begin{aligned} ^\circ F &= (25.0 \times \frac{9}{5}) + 32 \\ &= 45.0 + 32 \\ &= 77.0^\circ F \end{aligned}$$

For more examples of how to perform these types of problems, click on this video to see your professor in action.

Exercise 2.4.1

a. Convert 0°F to degrees Celsius.
b. Convert 212°C to degrees Fahrenheit.

Answer a

−17.8°C

Answer b

414°F

The fundamental unit of temperature in SI is the Kelvin (K). The Kelvin temperature scale (note that the name of the scale capitalizes the word *Kelvin*, but the unit itself is lowercase) uses degrees that are the same size as the Celsius degree, but the numerical scale is shifted up by 273.15 units. That is, the conversion between the Kelvin and Celsius scales is as follows:

$$K =^\circ C + 273.15 \tag{2.4.3}$$

For most purposes, it is acceptable to use 273 instead of 273.15 in Equation 2.4.3.

Note that the Kelvin scale does not use the word *degrees*; a temperature of 295 K is spoken of as “two hundred ninety-five kelvin” and not “two hundred ninety-five degrees Kelvin.”

The reason that the Kelvin scale is defined this way is that there exists a minimum possible temperature called absolute zero (zero Kelvin). The Kelvin temperature scale is set so that 0 K is absolute zero, and the temperature is counted upward from there. Normal room temperature is about 295 K, as seen in the following example.

Example 2.4.2: Room Temperature

If the normal room temperature is 72.0°F, what is room temperature in degrees Celsius and kelvin?

Solution

First, we use Equation 2.4.1 to determine the temperature in degrees Celsius:

$$\begin{aligned} ^{\circ}C &= (72.0 - 32) \times \frac{5}{9} \\ &= 40.0 \times \frac{5}{9} \\ &= 22.2^{\circ}C \end{aligned}$$

Then we use Equation 2.4.3 to determine the temperature in the Kelvin scale:

$$\begin{aligned} K &= 22.2^{\circ}C + 273.15 \\ &= 295.4K \end{aligned}$$

So, room temperature is about 295 K.

Health APPlication: Body temperature

Normal body temperature is defined as being 98.6°F (+/- 1.0°F). To determine body temperature, thermometers can be placed inside or on the surface of the body. The two best methods of obtaining body temperature are placing the thermometer either under the tongue or inside the rectum. Typically, children are capable of holding a thermometer in their mouths around the age of four (have fun before that age).

Fever is defined as body temperature being above 100°F (adults). High fever status occurs at and above 104°F. For adults, these adults should seek medical attention immediately if the fever exceeds 104°F. For children, these values are much lower.

Hyperthermia (inability of the body to regulate heat) occurs when normal body temperature is exceeded. Conditions that can cause hyperthermia are fever (infection), heat stroke, thyroid disorders, heart attack, or traumatic injury. Medications for cancer, arthritis, and thyroid patients can cause the body temperature to rise. Symptoms of hyperthermia include sweating, confusion, nausea, and dizziness.

Hypothermia (exposure to cold environments) occurs when normal body temperature dips below 95.0°F. When this occurs, the affected person(s) should seek immediate medical attention. During hypothermia, the body has problems producing heat. Medical conditions like diabetes, infection, and thyroid dysfunction can cause hypothermia. Watch this video of American Marines attempting to survive extreme environments. Symptoms of this condition involve shivering, confusion, and sluggish behavior.

Treating hyperthermia could involve hydrating a patient. If a fever is due to infection, analgesics (like Tylenol, Advil, aspirin, or Aleve) can help alleviate fever. Placing someone in a cool bath can also relieve symptoms.

To combat hypothermia, one must remove wet clothing, redress in warm materials, and participate in physical movement.

The Science of Cryogenics

Cryogenics is branch of physics that incorporates the production and effects of substances at temperatures ranging between -150ºC to -273°C. In the late 1870's, cryogenic science began with the cooling of gaseous oxygen. At -183ºC, O_2 condensed from a clear gas into a blue liquid. Changing the state of oxygen enables it to be transported easier. Both the aircraft and medical industries rely on the liquid form of this molecule to provide breathable oxygen for pilots, travelers, and patients.



Figure **2.4.2**: Liquid oxygen (O_2) exhibits a bluish hue.

Besides oxygen, other gases have been condensed as well. These permanent gases, meaning these substances normally exist in the gaseous state, include nitrogen (N_2), hydrogen (H_2), chlorine (Cl_2), and helium (He). By manipulating pressure and/or temperature, many chemists and physicists have attempted to produce the lowest, theoretical temperature possible. At absolute zero (-273°C or 0 K), the particles of a material have a minimum kinetic energy. Click on this video to determine if scientists can ever reach absolute zero in their laboratories.

Investigating a Cryogenic material: N_2 (l)

With a boiling point of -196°C (-321°F), liquid nitrogen has a variety of cryogenic uses. This clear, odorless liquid is used widely in the field of dermatology. For patients that have warts, skin tags (see image below), or precancerous moles, physicians can spray a selected area of skin. Typically, the unwanted skin lesion will fall off the body after being exposed to this cryogenic material. If this does not occur, then the dermatologist will use a scalpel to remove the frozen area of skin.



Figure **2.4.1**: Liquid nitrogen is stored in insulated flasks called Dewars. Image courtesy of Elizabeth R. Gordon

Liquid N_2 is also utilized to freeze biological samples. Fertility clinics freeze semen, eggs, and embryos that can be used at a later date for couples who chose to undergo InVitro Fertilization (IVF). Umbilical cord blood and stem cells can be preserved in liquid nitrogen for future applications.

Culinary Arts employ liquid nitrogen for preparing various dishes and interesting cocktails. In the following video, chefs are freezing components of salads and desserts for their customers. When using liquid nitrogen for any application, chemists, chefs, and other individuals should protect their skin and eyes from the extremely cold (-196ºC) temperature. Wearing thick rubber gloves and goggles can prevent frostbite. When ingesting materials that have been frozen with liquid nitrogen, there is

concern that internal burns can occur. Lastly, indoor use of liquid nitrogen could induce asphyxiation. Kitchens and labs should have adequate ventilation to ensure sufficient oxygen remains in the atmosphere.



Video **2.4.2**: At the Bazaar restaurant: Cooking with liquid nitrogen, more

References

- https://www.bbc.com/news/magazine-19870668
- https://ehs.research.uiowa.edu/liqui...rogen-handling

Need More Practice?

- Turn to Section 2.E of this OER and work problems #4, #7, and #10.

Contributors and Attributions

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2.E: The Mathematics of Chemistry (Exercises)

End of Chapter Exercises

1) Convert 45.0 cm^3 to L.

2) Acetone (CH_3COCH_3) has a density of .791g/mL. Assuming this compound is soluble in water, how many grams are present in 3.0 L of acetone. If acetone was spilled in Furman Lake, what would you expect to see and how would this be classified in the matter scheme (element,compound, heterogeneous, or homogeneous mixture?

3) Convert the distance from Greenville, South Carolina to Atlanta, Georgia. The measured length of the trip is approximately 235 kilometers. Convert this distance to meters and miles.

4) In January, the average temperature of eastern Siberia is -50°C. Calculate this temperature in Fahrenheit and Kelvin. Of the three temperature units, which one is the SI unit for temperature. (Kelvin temperature answer is incorrect on answer key should be 223.15K)

5) The mass of an adult human eyeball is 7.5 grams. Convert this value to kilograms and ounces. What type of lab equipment is used to measure mass?

6) How many milliliters and gallons are contained in a 2.0L Coca-Cola drink? (1 gallon = 3.79 L)

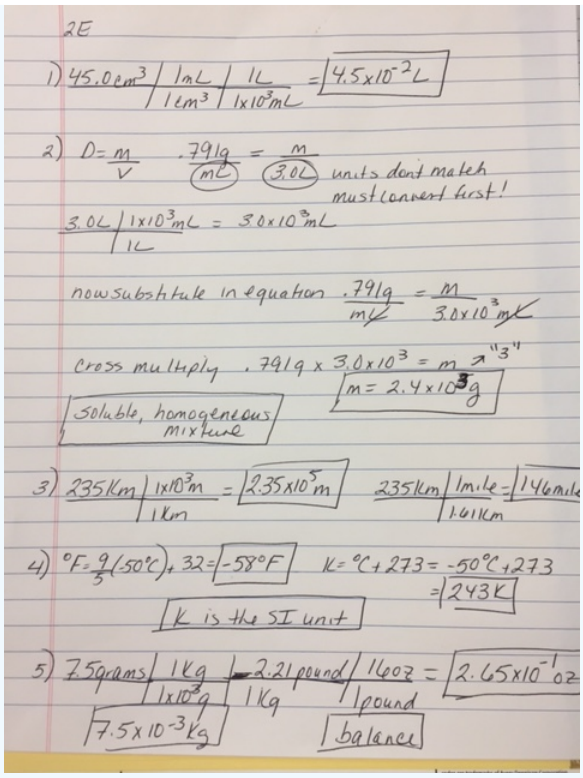
7) Convert your body temperature to °F and K.

8) Your cat needs .5 tsp of Tylenol. How many milliliters is this dosage?

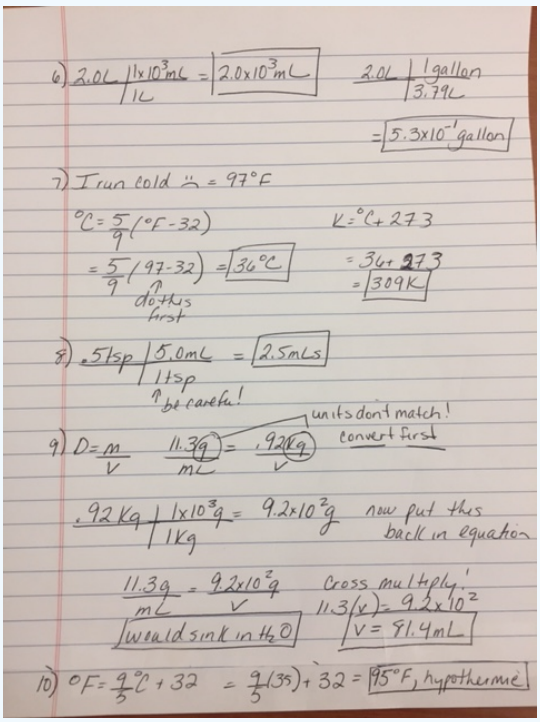
9) The density of lead is 11.3g/mL. If you measured out .92 kg, how many milliliters would this mass displace? Based upon density only, would you expect lead to sink or float in water?

10) If you have a body temperature of 35°C, are you hypothermic or hyperthermic?

Solutions



*** #4 should be 223K***



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CHAPTER OVERVIEW

3: Atoms and the Periodic Table

3.1: Basic Atomic Theory

3.2: Development of the Modern Periodic Table

3.3: Subatomic Particles - Electrons, Protons, and Neutrons

3.4: Atomic Mass and Atomic Number

3.5: Isotopes

3.6: The Importance of Ions to a Chemist

3.E: Atoms and the Periodic Table (Exercises)

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3.1: Basic Atomic Theory

Learning Objectives

- Give a short history of the concept of the atom.
- Describe the contributions of Democritus and Dalton to atomic theory.
- Summarize Dalton's atomic theory and explain its historical development.

Democritus and the Greek Philosophers

Around 2,500 years ago, early Greek philosophers believed the entire universe was a single, huge, entity. In other words, "everything was one." They believed that all objects, all matter, and all substances were connected as a single, big, unchangeable "thing." Democritus was one of the first people to propose the term "atoms." As an alternative to the beliefs of the Greek philosophers, he suggested that **atomos**, or atomon - tiny, indivisible, solid objects - make up all matter in the universe.



Figure **3.1.1**: Democritus by Hendrick ter Brugghen, 1628. Democritus was known as the "laughing philosopher." It was a good thing he liked to laugh, because most other philosophers were laughing at his theories.

Early Greek philosophers tried to understand the nature of the world through reason and logic, not through experiment and observation. As a result, they had some very interesting ideas, but they felt no need to justify their ideas based on life experiences. In many ways, you can think of the Greek philosophers as being "all thought and no action." It's truly amazing how much they achieved using their minds, but because they never performed any experiments, they missed or rejected many discoveries that they could have made otherwise. Greek philosophers dismissed Democritus' theory entirely. Unfortunately, it took over two millennia before the theory of atomos (or "atoms," as they're known today) was fully accepted.



Video **3.1.1**: Since ancient Greek times, philosophers and scientists have tried to figure out what an atom looks like. For a couple thousand years, humans could only speculate on the structure and other properties of the smallest unit of matter. It wasn't until the 1980s that chemists could see individual atoms. Bestselling author Sam Kean takes us through the nearly 2,400-year quest to see the atom in a new episode of the "Legends of Chemistry" series.

While it must be assumed that many more scientists, philosophers, and others studied composition of matter after Democritus, a major leap forward in our understanding of the composition of matter took place in the 1800's with the work of the British

scientists John Dalton. He started teaching school at age twelve, and was primarily known as a teacher. In his twenties, he moved to the growing city of Manchester, where he was able to pursue some scientific studies. His work in several areas of science brought him a number of honors. When he died, over 40,000 people in Manchester marched at his funeral.

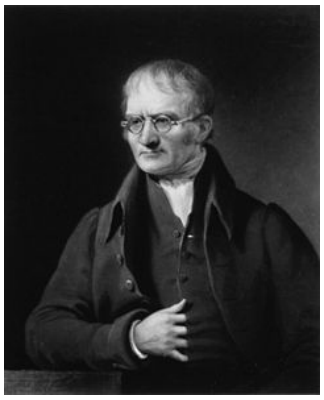


Figure **3.1.3**: British physicist and chemist John Dalton (1766-1844). Unlike the greek philosophers, John Dalton believed in both logical thinking and experimentation.

Dalton studied the weights of various elements and compounds. He noticed that matter always combined in fixed ratios based on weight, or volume in the case of gases. Chemical compounds always contain the same proportion of elements by mass, regardless of amount, which provided further support for Proust's law of definite proportions. Dalton also observed that there could be more than one combination of two elements.

From his experiments and observations, as well as the work from peers of his time, Dalton proposed a new theory of the atom (1803). This later became known as Dalton's **atomic theory**. The published (1808) tenets of this theory were as follows:

- All matter is composed of extremely small particles called atoms.
- Atoms of a given element are identical in size, mass, and other properties. Atoms of different elements differ in size, mass, and other properties.
- Atoms cannot be subdivided, created, or destroyed.
- Atoms of different elements can combine in simple whole number ratios to form chemical compounds.
- In chemical reactions, atoms are combined, separated, or rearranged.

Dalton's Eyes

As a scientist, John Dalton was also interested in colorblindness. Both he and his brother suffered from red/green colorblindness. At this time (1794), no other scientist had explored this medical issue. He devised theories (although not correct) as to why he could not differentiate between red and green. In addition, he named this medical condition "Daltonism." Upon his death (1844), he donated his eyes to a medical research facility in Manchester, England. Today, his eyes are still on display at the Museum of Science and Industry in Manchester, England.



Figure **3.1.3**: Image taken from: https://c1.staticflickr.com/3/2823/1...37dd23af_b.jpg

The evidence for atoms is so great that few doubt their existence. In fact, individual atoms are now routinely observed with state-of-the art technologies. Moreover, atoms can even be used for making pretty images or as IBM research demonstrate in Video **3.1.2**, control of individual atoms can be use used create animations. A Boy and His Atom is a 2012 stop-motion animated short film released by IBM Research. The movie tells the story of a boy and a wayward atom who meet and become friends. It depicts a boy playing with an atom that takes various forms. It was made by moving carbon monoxide molecules viewed with a scanning tunneling microscope, a device that magnifies them 100 million times. These molecules were moved to create images, which were then saved as individual frames to make the film.

Video **3.1.2**: A Boy And His Atom: The World's Smallest Movie

Dalton was not completely correct

Dalton's atomic theory has been largely accepted by the scientific community, with the exception of three changes. We know now that:

1. An atom is composed of smaller particles (electrons, protons, and neutrons).
2. All atoms of an element are not identical. The existence of isotopes illustrates this phenomena.
3. Through the use of nuclear reactions, atoms of one element can be changed into atoms of another element.

The first two will be be discussed later in this chapter, while the last requires introducing "nuclear chemistry" and will be discussed in a different chapter.

References

1. https://pubs.acs.org/subscribe/archi...3chemchron.pdf

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3.2: Development of the Modern Periodic Table

Learning Objectives

- Appreciate how the modern periodic table was constructed.
- Explain how elements are organized into the periodic table.
- Describe how some characteristics of elements relate to their positions on the periodic table.
- Distinguish between the A (atomic mass) value and the Z (atomic number) value when viewing the periodic table.
- Compare and contrast Mendeleev's and Moseley's ordering of the periodic table.

In 1864, Julius Lothar Meyer, a German chemist, organized the elements by atomic mass and grouped them according to their chemical properties. Later that decade, Dmitri Mendeleev, a Russian chemist, organized all the known elements according to similar properties. He left gaps in his table for what he thought were undiscovered elements, and he made some bold predictions regarding the properties of those undiscovered elements. When elements were discovered whose properties closely matched Mendeleev's predictions, his version of the table gained favor in the scientific community. Because certain properties of the elements repeat regularly throughout the table (that is, they are periodic), it became known as the periodic table.

	4 werthig	3 werthig	2 werthig	1 werthig	1 werthig	2 werthig
	-	-	-	-	Li = 7,03	(Be =9,3?)
Differenz =	-	-	-	-	16,02	(14,7)
	C = 12,0	N = 14,04	O = 16,00	Fl = 19,0	Na = 23,05	Mg = 24,0
Differenz =	16,5	16,96	16,07	16,46	16,08	16,0
	Si = 28,5	P = 31,0	S = 32,07	Cl = 35,46	K = 39,13	Ca = 40,0
Differenz =	89,1 /2 = 44,55	44,0	46,7	44,51	46,3	47,6
	-	As = 75,0	Se = 78,8	Br = 79,97	Rb =85,4	Sr = 87,6
Differenz =	89,1 /2 = 44,55	45,6	49,5	46,8	47,6	49,5
	Sn = 117,6	Sb = 120,6	Te = 128,3	J =126,8	Cs = 133,0	Ba = 137,1
Differenz =	89,4 = 2*44,7	87,4 = 2*43,7	-	-	(71 = 2*35,5)	-
	Pb = 207,0	Bi = 208,0	-	-	(Tl = 204?)	-

Figure **3.2.1**: Copy of table on page 137 of (Julius) Lothar Meyer: "Die modernen Theorien der Chemie" (1864). (Copyright;By Kawarayaki - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/inde...curid=75552705)

Dimitri Mendeleev (1834–1907)

The father of the modern periodic table, Dmitri Mendeleev was born in Siberia. He was the youngest of fourteen living children. Shortly after Dmitri's birth, his father lost his sight. When Dmitri was thirteen, his father died suddenly. His mother was left to manage the family's glass factory to support the family. In 1848, their glass factory burned down leaving the family with little resources. Dmitri's mother chose to take her son to St. Petersburg, Russia. Here, he would study chemistry at his father's alma mater (Main Pedagogical Institute which is not called St. Petersburg University). After several illnesses and his mother's death, he would earn his doctorate in chemistry in 1865.

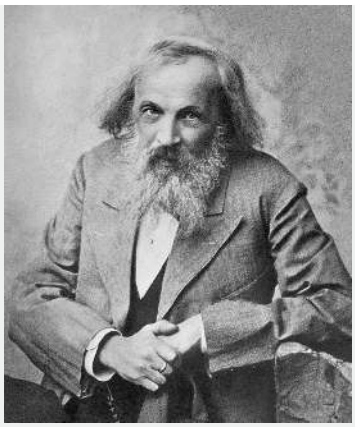


Figure **3.2.2**: Dmitri Mendeleev, the father of the modern periodic table.

From 1867 to 1890, Dmitri served as a professor of general chemistry at St. Petersburg University. In his lifetime, he published more than 400 articles and books. Two of these works were noted in textbooks of general and organic chemistry.

As for his personal life, Dmitri Mendeleev married twice (his first marriage ended in a controversial divorce). Dmitri fathered a total of six children from both marriages. In 1907, he passed away from influenza complications. He was honored for his works by having element 101 (Mendelevium) named for him. Watch the video below to see how Mendeleev ordered his table of elements.



Mendeleev's Periodic Table

Mendeleev, who first published his periodic table in 1869 (Figure **3.2.1**), is usually credited with the origin of the modern periodic table. The key difference between his arrangement of the elements and that of Meyer and others is that Mendeleev did not assume that all the elements had been discovered (actually, only about two-thirds of the naturally occurring elements were known at the time). Instead, he deliberately left blanks in his table at atomic masses 44, 68, 72, and 100, in the expectation that elements with those atomic masses would be discovered. Those blanks correspond to the elements we now know as scandium, gallium, germanium, and technetium.

Reihen	Gruppe I. — R^2O	Gruppe II. — RO	Gruppe III. — R^2O^3	Gruppe IV. RH^4 RO^2	Gruppe V. RH^3 R^2O^5	Gruppe VI. RH^2 RO^3	Gruppe VII. RH R^2O^7	Gruppe VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	— =44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	— =68	— =72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	— =100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce= 40	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

Figure **3.2.3**: Mendeleev's Periodic Table, as Published in the German Journal Annalen der Chemie und Pharmacie in 1872. The column headings "Reihen" and "Gruppe" are German for "row" and "group." Formulas indicate the type of compounds formed by each group, with "R" standing for "any element" and superscripts used where we now use subscripts. Atomic masses are shown after equal signs and increase across each row from left to right.

The groups in Mendeleev's table are determined by how many oxygen or hydrogen atoms are needed to form compounds with each element. For example, in Group I (referred to as Gruppe 1), two atoms of each element (hydrogen, lithium, potassium) bond with one atom of oxygen to form compounds. In Group VII (Gruppe VI), one atom of fluorine, F, chlorine, Cl, and bromine, Br, reacts with one atom of hydrogen to form respective compounds. According to Mendeleev, elements in the same column of the periodic table produced similar types of compounds. This trend could not predict the types of hydrogen/oxygen-based compounds resulting from the middle section of the periodic table. Mendeleev had difficulty explaining the chemical nature of this part of the table now referred to as the transition metals.

The most convincing evidence in support of Mendeleev's arrangement of the elements was the discovery of two previously unknown elements whose properties closely corresponded with his predictions (Table **3.2.1**). Two of the blanks Mendeleev had left in his original table were below aluminum and silicon, awaiting the discovery of two as-yet-unknown elements, eka-aluminum and eka-silicon (from the Sanskrit eka, meaning "one," as in "one beyond aluminum"). The observed properties of gallium and germanium matched those of eka-aluminum and eka-silicon so well that once they were discovered, Mendeleev's periodic table rapidly gained acceptance.

When the chemical properties of an element suggested that it might have been assigned the wrong place in earlier tables, Mendeleev carefully reexamined its atomic mass. He discovered, for example, that the atomic masses previously reported for beryllium, indium, and uranium were incorrect. The atomic mass of indium had originally been reported as 75.6, based on an assumed stoichiometry of InO for its oxide. If this atomic mass were correct, then indium would have to be placed in the middle of the nonmetals, between arsenic (atomic mass 75) and selenium (atomic mass 78). Because elemental indium is a silvery-white *metal*, however, Mendeleev postulated that the stoichiometry of its oxide was really In_2O_3 rather than InO. This would mean that indium's atomic mass was actually 113, placing the element between two other metals, cadmium, and tin.

Table **3.2.1**: Comparison of the Properties Predicted by Mendeleev in 1869 for eka-Aluminum and eka-Silicon with the Properties of Gallium (Discovered in 1875) and Germanium (Discovered in 1886)

Property	*eka*-Aluminum (predicted)	Gallium (observed)	*eka*-Silicon (predicted)	Germanium (observed)
atomic mass	68	69.723	72	72.64
element	metal	metal	dirty-gray metal	gray-white metal
	low mp*	mp = 29.8°C	high mp	mp = 98°C
	d = 5.9 g/cm^3	d = 5.91 g/cm^3	d = 5.5 g/cm^3	d = 5.323 g/cm^3
oxide	E_2O_3	Ga_2O_3	EO_2	GeO_2
	d = 5.5 g/cm^3	d = 6.0 g/cm^3	d = 4.7 g/cm^3	d = 4.25 g/cm^3
chloride	ECl_3	$GaCl_3$	ECl_4	$GeCl_4$
	volatile	mp = 78°C bp* = 201°C	bp < 100°C	bp = 87°C

*mp = melting point; bp = boiling point.

One group of elements absent from Mendeleev's table is the noble gases, all of which were discovered more than 20 years later, between 1894 and 1898, by Sir William Ramsay (1852–1916; Nobel Prize in Chemistry 1904). Initially, Ramsay did not know where to place these elements in the periodic table. Argon, the first to be discovered, had an atomic mass of 40. This was greater than chlorine's and comparable to that of potassium, so Ramsay, using the same kind of reasoning as Mendeleev, decided to place the noble gases between the halogens and the alkali metals.

The Role of the Atomic Number in the Periodic Table

Despite its usefulness, Mendeleev's periodic table was based entirely on empirical observation supported by very little understanding. It was not until 1913, when a young British physicist, H. G. J. Moseley (1887–1915), while analyzing the frequencies of x-rays emitted by the elements, discovered that the underlying foundation of the order of the elements was by the *atomic number*, not the atomic mass. Moseley hypothesized that the placement of each element in his series corresponded to its atomic number Z, which is the number of positive charges (protons) in its nucleus. Argon, for example, although having an atomic mass greater than that of potassium (39.9 amu versus 39.1 amu, respectively), was placed *before* potassium in the periodic table. While analyzing the frequencies of the emitted x-rays, Moseley noticed that the atomic number of argon is 18, whereas that of potassium is 19, which indicated that they were indeed placed correctly. Moseley also noticed three gaps in his table of x-ray frequencies, so he predicted the existence of three unknown elements: technetium (Z = 43), discovered in 1937; promethium (Z = 61), discovered in 1945; and rhenium (Z = 75), discovered in 1925.

H. G. J. Moseley (1887–1915)

Moseley left his research work at the University of Oxford to join the British army as a telecommunications officer during World War I. He was killed during the Battle of Gallipoli in Turkey.



Figure 3.2.4:G.J. Moseley

Features of the Periodic Table

Elements that have similar chemical properties are grouped in columns called groups (or families). As well as being numbered, some of these groups have names—for example, *alkali metals* (the first column of elements), *alkaline earth metals* (the second column of elements), *halogens* (the next-to-last column of elements), and *noble gases* (the last column of elements). The word *halogen* comes from the Greek for "salt maker" because these elements combine with other elements to form a group of compounds called salts.

Each row of elements on the periodic table is called a **period**. Periods have different lengths; the first period has only 2 elements (hydrogen and helium), while the second and third periods have 8 elements each. The fourth and fifth periods have 18 elements each, and later periods are so long that a segment from each is removed and placed beneath the main body of the table.

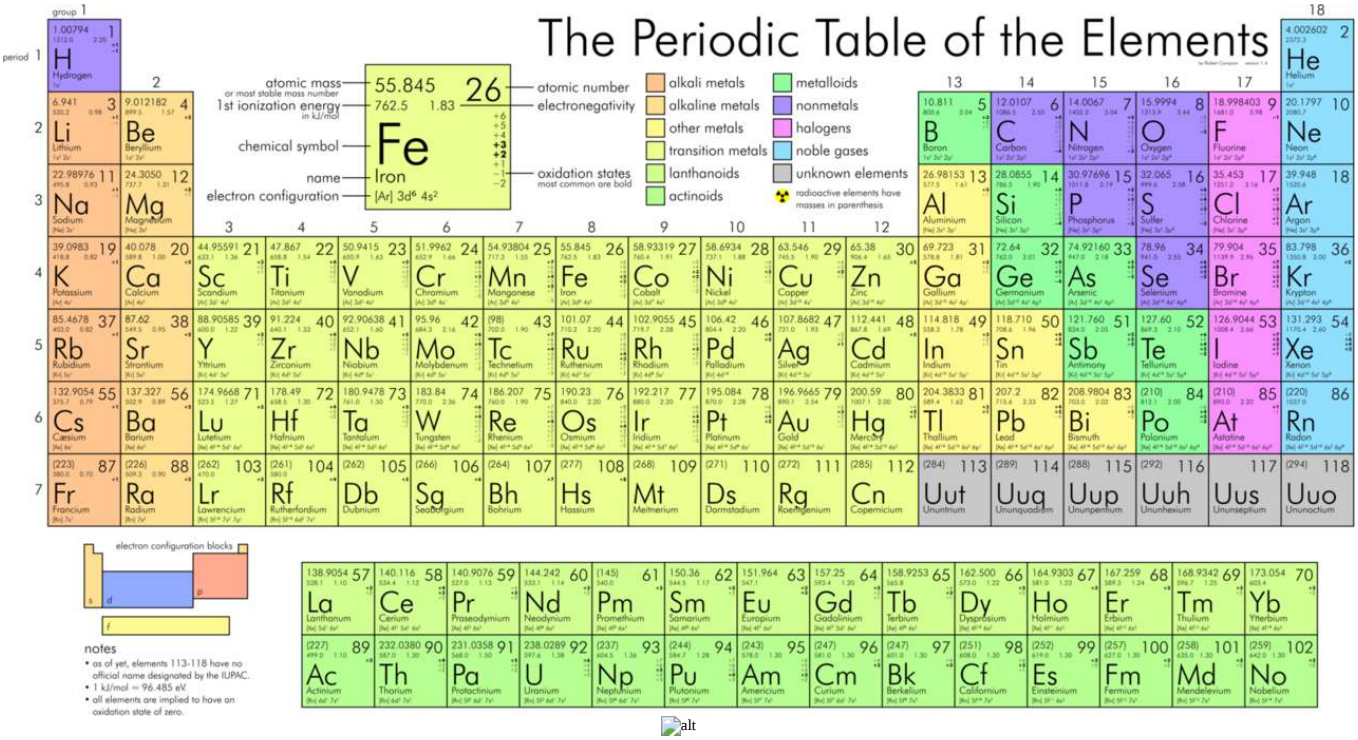


Figure 3.2.5: Types of Elements. Elements are either metals, nonmetals, or metalloids. Each group is located in a different part of the periodic table. An interactive Periodic table can be found here. (Public Domain; 2012rc).

Certain elemental properties become apparent in a survey of the periodic table as a whole. Every element can be classified as either a metal, a nonmetal, or a metalloid (or semi-metal), as shown in Figure 3.2.5. A **metal** is a substance that is shiny, typically (but not always) silvery in color, and an excellent conductor of electricity and heat. Metals are also malleable (they can be beaten into thin

sheets) and ductile (they can be drawn into thin wires). A **nonmetal** is typically dull and a poor conductor of electricity and heat. Solid nonmetals are also very brittle. As shown in Figure **3.2.5**, metals occupy the left three-fourths of the periodic table, while nonmetals (except for hydrogen) are clustered in the upper right-hand corner of the periodic table. The elements with properties intermediate between those of metals and nonmetals are called **metalloids**. Elements adjacent to the bold line in the right-hand portion of the periodic table have semimetal properties.

Example 3.2.1

Based on its position in the periodic table, classify each element below as metal, a nonmetal, or a metalloid.

a. Se
b. Mg
c. Ge

Solution

a. In Figure **3.2.5**, selenium lies above and to the right of the diagonal line marking the boundary between metals and nonmetals, so it should be a nonmetal.
b. Magnesium lies to the left of the diagonal line marking the boundary between metals and nonmetals, so it should be metal.
c. Germanium lies within the diagonal line marking the boundary between metals and nonmetals, so it should be a metalloid.

The first two columns on the left and the last six columns on the right are called the main group elements. The ten-column block between these columns contains the **transition metals**. The two rows beneath the main body of the periodic table display the **inner transition metals**. The elements in these two rows are also referred to as, respectively, the **lanthanide metals** and the **actinide metals**.

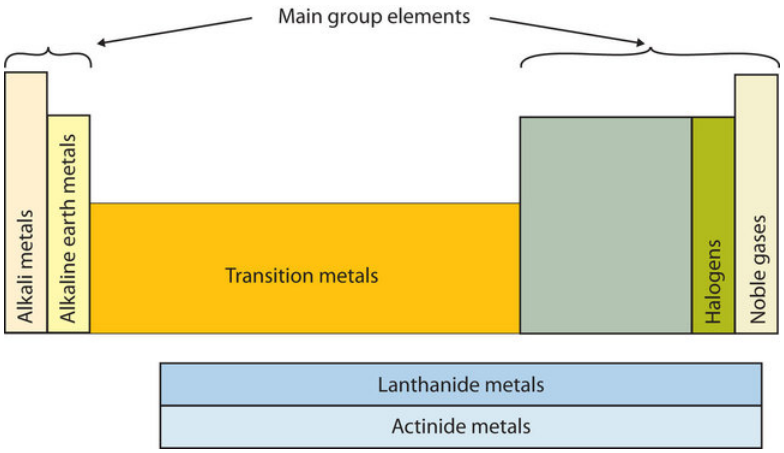


Figure **3.2.6**: Some sections of the periodic table have specific names. Be sure to know the section names for quizzes and tests.

Descriptive Names

As previously noted, the periodic table is arranged so that elements with similar chemical behaviors are in the same group. Chemists often make general statements about the properties of the elements in a group using descriptive names with historical origins. To watch a video of your instructor presenting these groups and periods, access your Moodle class chapter 3 documents.

Group 1: The Alkali Metals

The alkali metals are lithium, sodium, potassium, rubidium, cesium, and francium. Hydrogen is unique in that it is generally placed in Group 1, but it is not a metal. The compounds of the alkali metals are common in nature and daily life. One example is table salt (sodium chloride); lithium compounds are used in greases, in batteries, and as drugs to treat patients who exhibit manic-depressive, or bipolar, behavior. Although lithium, rubidium, and cesium are relatively rare in nature, and francium is so unstable and highly radioactive that it exists in only trace amounts, sodium and potassium are the seventh and eighth most abundant elements in Earth's crust, respectively.

Group 2: The Alkaline Earth Metals

The alkaline earth metals are beryllium, magnesium, calcium, strontium, barium, and radium. Beryllium, strontium, and barium are rare, and radium is unstable and highly radioactive. In contrast, calcium and magnesium are the fifth and sixth most abundant elements on Earth, respectively; they are found in huge deposits of limestone and other minerals.

Group 17: The Halogens

The halogens are fluorine, chlorine, bromine, iodine, and astatine. The name halogen is derived from the Greek words for "salt-forming," which reflects that all the halogens react readily with metals to form compounds, such as sodium chloride and calcium chloride (used in some areas as road salt). Compounds that contain fluorine ions (fluoride) are added to toothpaste and the water supply to prevent dental cavities. Fluorine is also found in Teflon coatings on kitchen utensils. Although chlorofluorocarbon propellants and refrigerants are believed to lead to the depletion of Earth's ozone layer and contain both fluorine and chlorine, the latter is responsible for the adverse effect on the ozone layer. Bromine and iodine are less abundant than chlorine, and astatine is so radioactive that it exists in only negligible amounts in nature.

Group 18: The Noble Gases

The noble gases are helium, neon, argon, krypton, xenon, and radon. Because noble gases are composed of only single atoms, they are called monatomic. At room temperature and pressure, they are unreactive gases. Because of their lack of reactivity, for many years they were called inert gases or rare gases. However, the first chemical compounds containing noble gases were prepared in 1962. Although the noble gases are relatively minor constituents of the atmosphere, natural gas contains substantial amounts of helium. Because of its low reactivity, argon is often used as an unreactive (inert) atmosphere for welding and in light bulbs. The red light emitted by neon in a gas discharge tube is used in neon lights.

Example 3.2.2: Groups

Provide the family/group names and period numbers (horizontal values)of each element.

a. Li
b. Ar
c. Ra

Solution:

a. Lithium is an alkali metal. It is located in period two.
b. Argon is a noble gas. It is located in period three.
c. Radium is an alkaline metal. It is located in period seven.

Example 3.2.3: Classification of Elements

Provide elemental names for the following combinations:

a. The alkali metal in period three.
b. The halogen in period two
c. A metalloid in period four
d. A transition metal in period three

Solution:

a. Sodium
b. Fluorine
c. Germanium or Arsenic
d. There are no transition metals in period three (gotcha!)

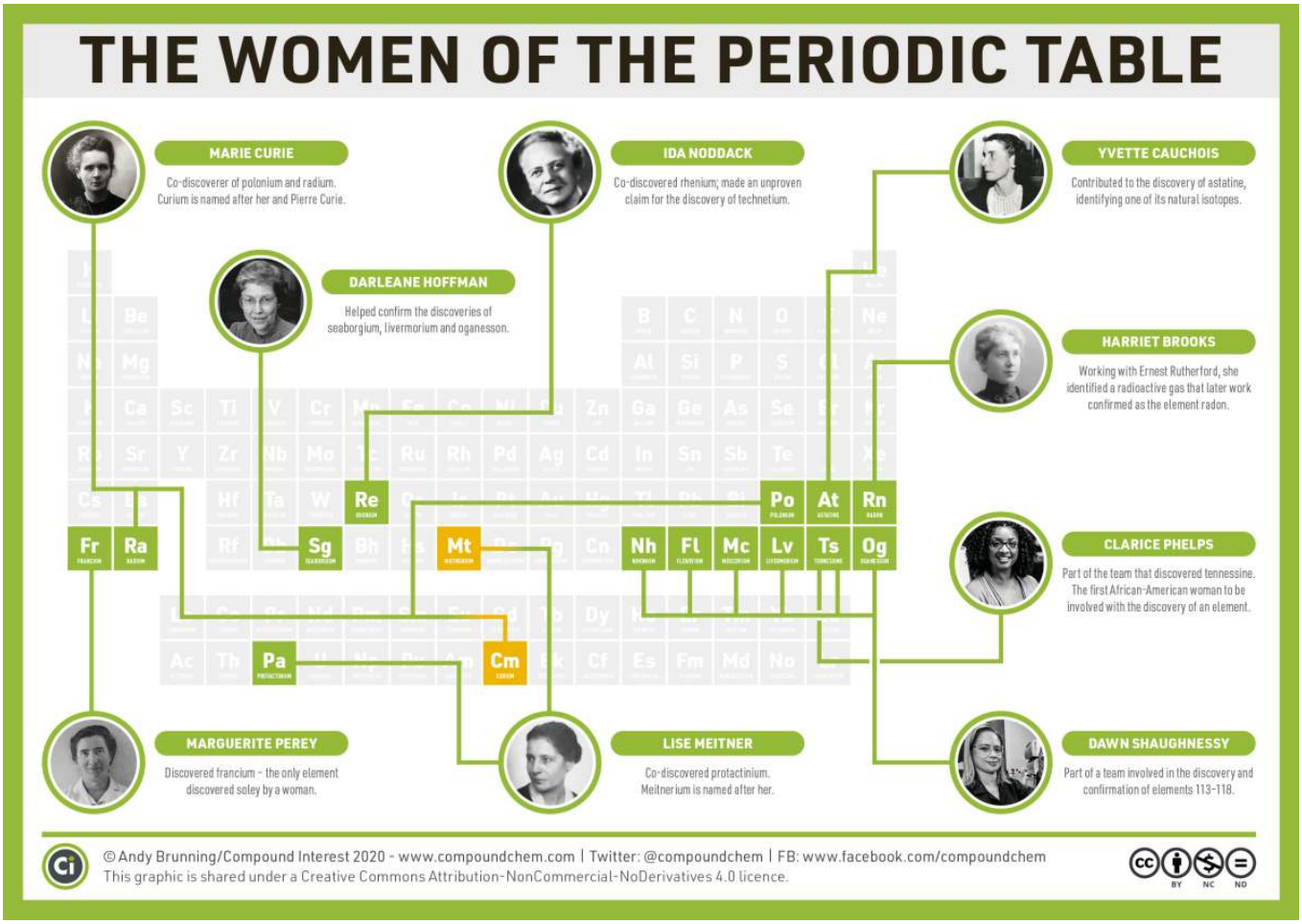


Figure **3.2.7**: The Women of the Periodic Table Graphic by Andy Brunning.

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1. Petrucci, Ralph H., William S. Harwood, F. G. Herring, and Jeffrey D. Madura. General Chemistry: Principles and Modern Applications. 9th ed. Upper Saddle River: Pearson Education, Inc., 2007.
2. Sisler, Harry H. Electronic structure, properties, and the periodic law. New york; Reinhold publishing corporation, 1963.
3. Petrucci, Ralph H., Carey Bissonnette, F. G. Herring, and Jeffrey D. Madura. General Chemistry: Principles and Modern Applications. Custom Edition for CHEM 2. Pearson Learning Solutions, 2010.

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3.3: Subatomic Particles - Electrons, Protons, and Neutrons

Learning Objectives

- Know the basics of the experiments involving the discoveries of the three subatomic particles
- Memorize relative charge values and amu masses of the three subatomic particles.
- Describe the location of the proton, electron, and neutron inside the atomic model.

Identifying and Locating the Subatomic Particles

In 1897, the British physicist J. J. Thomson (1856–1940) proved that atoms were not the most basic form of matter. His experiments involved the use of cathode ray tubes (CRT). Under a vacuumed environment, these devices produce invisible rays that originate from a negative electrode (cathode) and continue to a positive electrode (anode). In these experiments, Thomson demonstrated that cathode rays could be deflected, or bent, by magnetic or electric fields, which indicated that cathode rays consist of charged particles . More importantly, by measuring the extent of the deflection of the cathode rays in magnetic or electric fields of various strengths, Thomson was able to calculate the mass-to-charge ratio of the particles. Because like charges repel each other and opposite charges attract, Thomson concluded that the particles had a net **negative charge**; these particles are now called **electrons**. Most relevant to the field of chemistry, Thomson found that the mass-to-charge ratio of cathode rays is independent of the nature of the metal electrodes or the gas, which suggested that electrons were fundamental components of all atoms.



Video **3.3.1**: A chemistry instructor explains the nature of a cathode ray tube and the discovery of the electron.

During the 1910s, experiments with x-rays led to the useful conclusion: the magnitude of the **positive charge** in the nucleus of every atom of a particular element is the same. In other words, all atoms of the same element have the same number of **protons**. Furthermore, different elements have a different number of protons in their nuclei, so the number of protons in the nucleus of an atom is characteristic of a particular element. This discovery was so important to our understanding of atoms that the number of protons in the nucleus of an atom is now called the atomic number. These experiments were performed by Ernest Rutherford. He is credited with defining the central location of the atom, which has now been named the nucleus.

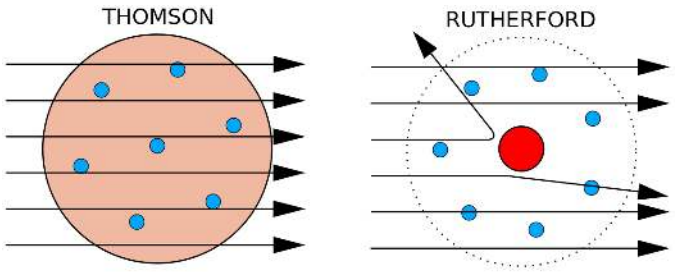


Figure **3.3.1**: Expected results: alpha particles passing through the plum pudding model of the atom with negligible deflection. Bottom: Observed results: a small portion of the particles were deflected by the concentrated positive charge of the nucleus. (Public Domain).

Rutherford was aware that the protons were inside this region. One of Ernest Rutherford's colleagues, James Chadwick, performed and studied radioactive reactions of beryllium. Upon hitting a beryllium nucleus with alpha particles, a **neutron** particle was emitted. In 1932, James Chadwick announced the existence of a third subatomic particle, the neutron. This particle has a mass of 1 atomic mass unit, but **does not have any charge**. After this discovery, nuclear science and technology started immediately.

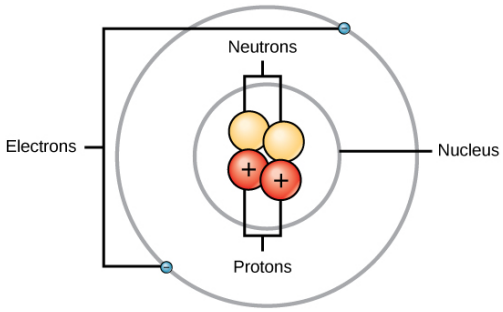


Figure **3.3.2**: Elements, such as helium, depicted here, are made up of atoms. Atoms are made up of protons and neutrons located within the nucleus, with electrons in orbitals surrounding the nucleus.

Masses for the three subatomic particles can be expressed in amu (**atomic mass units**) or grams. For simplicity, we will use the amu unit for the three subatomics. Both neutrons and protons are assigned as having masses of 1 amu each. In contrast, the electron has a negligible mass of .0005 amu. This subatomic's mass is not represented in the decimal mass that is displayed on the periodic table. Only protons and neutrons contribute to an atom's mass value.

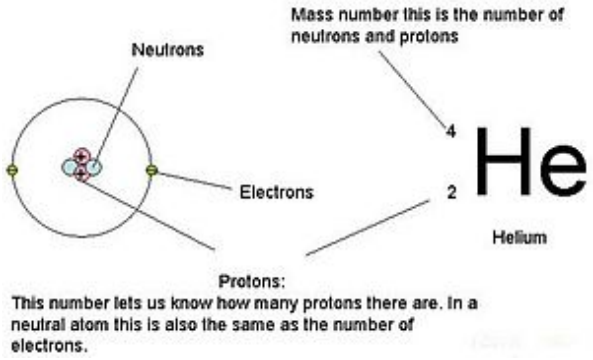


Figure **3.3.3**: An explanation of the superscripts and subscripts seen in atomic number notation. (Copyright; en:User:Materialscientist)

For atoms (neutral species), the number of electrons is equivalent to the number of protons. As a result, all atoms have an overall charge of zero. For discussion of ions (atoms that gain or lose electrons), look to the latter part of this chapter. Atoms that differ in neutron and mass values from the table are called isotopes. These particular species can be seen in the following section of the text.

Table **3.3.1**: Properties of Subatomic Particles

Subatomic particle	Symbol	Relative charge	Location	Amu mass
Proton	p	+1	inside the nucleus	1
Neutron	n	0	inside the nucleus	1
Electron	e^-	-1	outside the nucleus	0.0005 (~0)

Example 3.3.1

Which is true?

a. The nucleus contains protons and electrons.
b. The mass of an electron is included in the mass of the atom

c. For an atom, the number of protons = number of electrons.

Solution

a. False, the nucleus contains the protons and the neutrons. Electrons are outside the core.

b. False, electrons do not contribute to the mass number of an atom.

c. True, all atoms are neutral and must have the same number of protons as electrons.

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3.4: Atomic Mass and Atomic Number

Learning Outcomes

- Define atomic and mass numbers.
- Determine the number of protons, neutrons, and electrons in an atom.
- Identify the charge and relative mass of subatomic particles.
- Label the location of subatomic particles in the atom.
- Determine the mass of an atom based on its subatomic particles.
- Write A/Z and symbol-mass format for an atom.

Atoms are the fundamental building blocks of all matter and are composed of protons, neutrons, and electrons. Because atoms are electrically neutral, the number of positively charged protons must be equal to the number of negatively charged electrons. Since neutrons do not affect the charge, the number of neutrons is not dependent on the number of protons and will vary even among atoms of the same element.

Atomic Number

The **atomic number (represented by the letter Z)** *of an element is the number of protons in the nucleus of each atom of that element*. An atom can be classified as a particular element based solely on its atomic number. For example, any atom with an atomic number of 8 (its nucleus contains 8 protons) is an oxygen atom, and any atom with a different number of protons would be a different element. The periodic table (see figure below) displays all of the known elements and is arranged in order of increasing atomic number. In this table, an element's atomic number is indicated above the elemental symbol. Hydrogen, at the upper left of the table, has an atomic number of 1. Every hydrogen atom has one proton in its nucleus. Next on the table is helium, whose atoms have two protons in the nucleus. Lithium atoms have three protons, beryllium atoms have four, and so on.

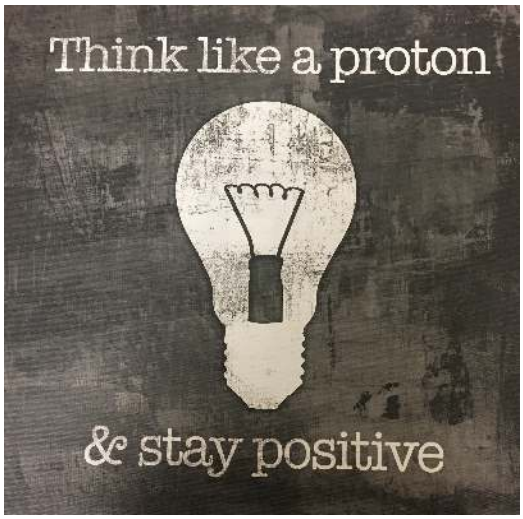


Figure **3.4.1**: The social security number subatomic-the proton.

Since atoms are neutral, the number of electrons in an atom is equal to the number of protons. Hydrogen atoms all have one electron occupying the space outside of the nucleus. Helium, with two protons, will have two electrons. In the chemical classroom, the proton count will always be equivalent to an atom's atomic number. This value will not change unless the nucleus decays or is bombarded (nuclear physics).

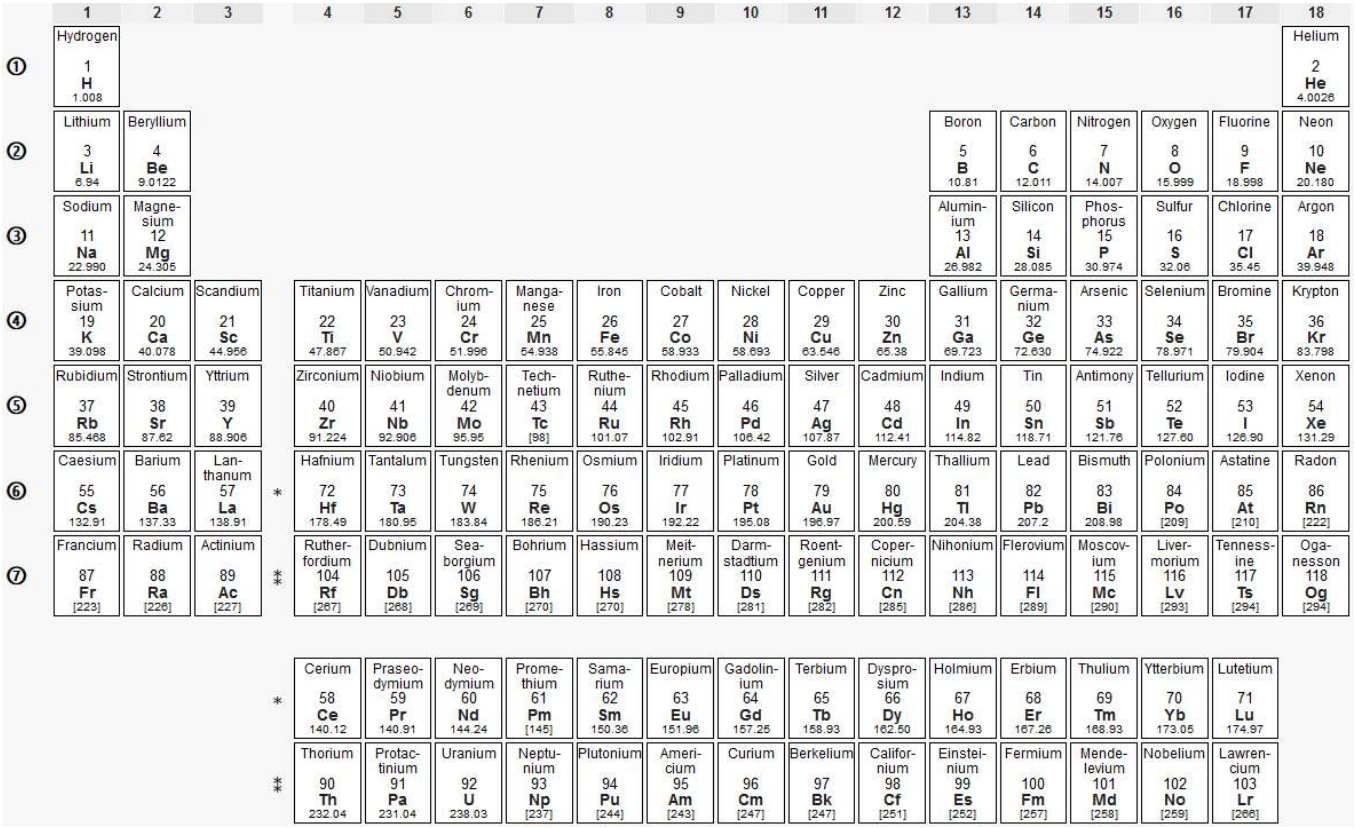


Figure **3.4.3**: The periodic table of the elements. (CC BY-SA 4.0 International; DePiep via Wikipedia).

Mass Number

Experimental data showed that the vast majority of the mass of an atom is concentrated in its nucleus, which is composed of protons and neutrons. The **mass number (represented by the letter A)** *is defined as the total number of protons and neutrons in an atom.* Consider the table below, which shows data from the first six elements of the periodic table.

Table **3.4.1**: Atoms of the First Six Elements

Name	Symbol	Atomic Number (Z)	Protons	Neutrons	Electrons	Mass Number (A) (rounded to two decimals)
hydrogen	**H**	1	1	0	1	1.01
helium	**He**	2	2	2	2	4.00
lithium	**Li**	3	3	4	3	6.94
beryllium	**Be**	4	4	5	4	9.01
boron	**B**	5	5	6	5	10.18
carbon	**C**	6	6	6	6	12.01

Consider the element helium. Its atomic number is 2, so it has two protons in its nucleus. Its nucleus also contains two neutrons. Since $2 + 2 = 4$, we know that the mass number of the helium atom is 4. Finally, the helium atom also contains two electrons, since the number of electrons must equal the number of protons. This example may lead you to believe that atoms have the same number of protons and neutrons, but a further examination of the table above will show that this is not the case. Lithium, for example, has three protons and four neutrons, giving it a mass number of 7.

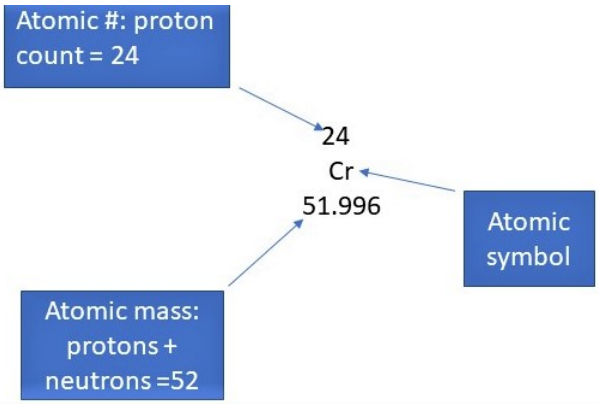


Figure 3.4.4: A/Z format and finding subatomics for elementChromium (Copyright; Elizabeth R. Gordon)

Knowing the mass number and the atomic number of an atom allows you to determine the number of neutrons present in that atom by subtraction.

$$\textbf{Number of neutrons} = \textbf{ rounded mass number} - \textbf{atomic number}$$

Atoms of the element chromium $(\mathbf{Cr})$ have an atomic number of 24 and a mass number of 52. How many neutrons are in the nucleus of a chromium atom? To determine this, you would subtract as shown:

$$\mathbf{52 - 24 = 28 \text{ neutrons in a chromium atom}}$$

The composition of any atom can be illustrated with a shorthand notation called A/Z format. Both the atomic number and mass are written to the left of the chemical symbol. The "A" value is written as a superscript while the "Z" value is written as a subscript. For an example of this notation, look to the chromium atom shown below:

$$\mathbf{^{52}_{24}Cr}$$

Another way to refer to a specific atom is to write the mass number of the atom after the name, separated by a hyphen. The symbol-mass format for the above atom would be written as Cr-52. In this notation, the atomic number is not included. You will need to refer to a periodic table for proton values.

Example 3.4.1

Calculate each of the three subatomic particles and give specific group or period names for each of the following:

a. mercury
b. platinum
c. bromine

Solutions

a. Hg (transition metal)- has 80 electrons, 80 protons, and 121 neutrons
b. Pt (transition metal)- has 78 electrons, 78 protons, and 117 neutrons
c. Br (halogen)- has 35 electrons, 35 protons, and 45 neutrons

Example 3.4.2

Write both A/Z and symbol-mass formats for the atoms in Example 3.4.1.

Solutions

a. $\mathbf{^{201}_{80}Hg}$ and Hg-201
b. $\mathbf{^{195}_{78}Pt}$ and Pt-195
c. $\mathbf{^{80}_{35}Br}$ and Br-80

Example 3.4.3

Identify the elements based on the statements below.

a. Which element has 25 protons?
b. Which element has 0 neutrons?
c. Which element has 83 electrons?

Solutions

a. manganese

b. hydrogen

c. bismuth

Need More Practice?

- Turn to section 3.E of this OER and answer questions #1-#2, #4, and #8.

Contributors and Attributions

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3.5: Isotopes

Learning Objectives

- Calculate subatomic particles (protons, neutrons, and electrons) for any element by looking at the periodic table.
- Calculate subatomic particles (protons, neutrons, and electrons) for any element by looking at symbol-mass and A/Z format.
- Understand how isotopes differ in particles and mass.
- Identify the most abundant isotope when given specific values.
- Calculate the atomic mass of an element from the masses and relative percentages of the isotopes of the element.
- Define LEU/HEU with percentages and applications.

Isotopes are atoms of the same element that contain different numbers of neutrons. For these species, the number of electrons and protons remains constant. This difference in neutron amount affects the atomic mass (**A**) but not the atomic number (**Z**). In a chemical laboratory, isotopes of an element appear and react the same. For this reason, it is difficult to distinguish between an atom's isotopes. In contrast, nuclear scientists can identify and separate different types of atomic nuclei (Figure **3.5.1**). The technology required for this process is more sophisticated than what could be found in a typical chemical laboratory.

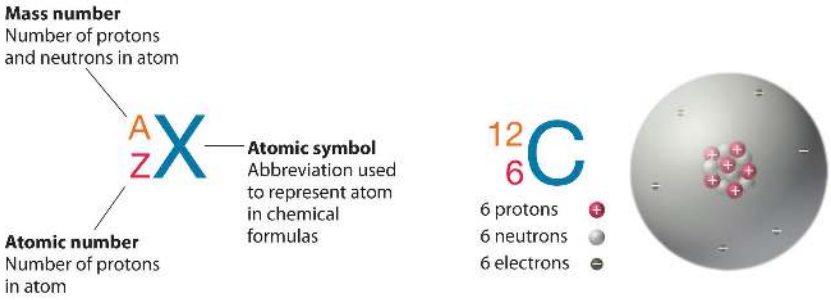


Figure **3.5.1**: Unlike protons, the number of neutrons is not absolutely fixed for most elements. Atoms that have the same number of protons, and hence the same atomic number, but different numbers of neutrons are called isotopes. All isotopes of an element have the same number of protons and electrons, which means they exhibit the same chemistry. The isotopes of an element differ only in their atomic mass, which is given by the mass number (A), the sum of the numbers of protons and neutrons. (CC BY-NS-SA; anonymous by request)

The element carbon (**C**) has an atomic number of 6, which means that all neutral carbon atoms contain 6 protons and 6 electrons. In a typical sample of carbon-containing material, 98.89% of the carbon atoms also contain 6 neutrons, so each has a mass number of 12. An isotope of any element can be uniquely represented as $^{A}_{Z}X$where X is the atomic symbol of the element. The isotope of carbon that has 6 neutrons is therefore $^{12}_{6}C$ The subscript indicating the atomic number is actually redundant because the atomic symbol already uniquely specifies *Z*. Consequently, it is more often written as ^{12}C, which is read as “carbon-12.” Nevertheless, the value of Z is commonly included in the notation for *nuclear* reactions because these reactions involve changes in Z.

Most elements on the periodic table have at least two stable isotopes. For example, in addition to ^{12}C, a typical sample of carbon contains 1.11% $^{13}_{6}C$, with 7 neutrons and 6 protons, and a trace of $^{14}_{6}C$, with 8 neutrons and 6 protons. The nucleus of $^{14}_{6}C$ is not stable, however, but undergoes a slow radioactive decay that is the basis of the carbon-14 dating technique used in archaeology. Many elements other than carbon have more than one stable isotope; tin, for example, has 10 isotopes. There are about twenty elements that exist in only one isotopic form (sodium and fluorine are examples of these). Most scientists cannot tell you how many isotopic forms exist unless they consult an isotopic table.

An important series of isotopes is found with hydrogen atoms. Most hydrogen atoms have a nucleus with only a single proton. About 1 in 10,000 hydrogen nuclei, however, also has a neutron; this particular isotope is called *deuterium*. An extremely rare hydrogen isotope, *tritium*, has 1 proton and 2 neutrons in its nucleus. Figure **3.5.2** compares the three isotopes of hydrogen.

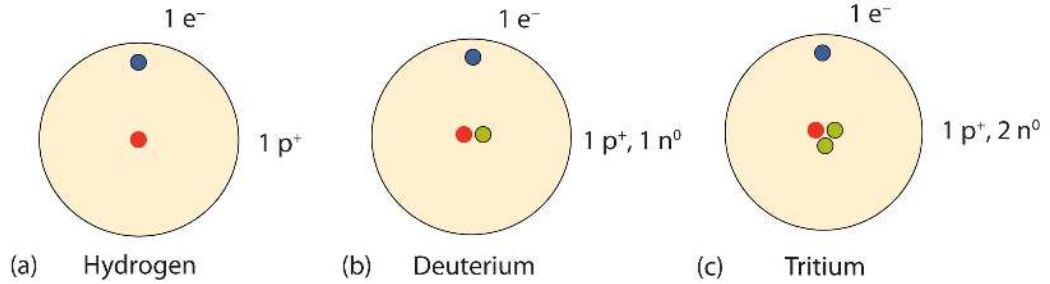


Figure **3.5.2**: a). A small amount of hydrogen exists as the isotope deuterium, which has one proton and one neutron in its nucleus (b). A tiny amount of the hydrogen isotope tritium, with one proton and two neutrons in its nucleus, also exists on Earth (c). The nuclei and electrons are proportionately much smaller than depicted here.

There are currently over 3,500 isotopes known for all the elements. When scientists discuss individual isotopes, they need an efficient way to specify the number of neutrons in any particular nucleus. A/Z and symbol-mass formats (refer to Section 3.4) can be used to display periodic table information. When viewing either of these two notations, isotopic differences can be obtained.

> *The discovery of isotopes required a minor change in Dalton's atomic theory. Dalton thought that all atoms of the same element were exactly the same.*

Look at the **A/Z formats** for the three isotopes of hydrogen in Table **3.5.1**. Note how the atomic number (bottom value) remains the same while the atomic masses (top number) are varied. All isotopes of a particular element will vary in neutrons and mass. This variance in mass will be visible in the **symbol-mass format** of same isotopes as well.

Table **3.5.1**

Common Name	A/Z formats	symbol-mass format	Expanded Name
Hydrogen	$^{1}_{1}\mathrm{H}$	**H-1**	hydrogen-1
Deuterium	$^{2}_{1}\mathrm{H}$	**H-2**	hydrogen-2
Tritium	$^{3}_{1}\mathrm{H}$	**H-3**	hydrogen 3

Using a periodic table, A/Z or symbol-mass formats can be utilized to determine the number of subatomic particles (protons, neutrons, and electrons) contained inside an isotope. When given either format, these mass values should be used to calculate the number of neutrons in the nucleus.

✔ Exercise 3.5.1

How many neutrons are in each atom?

a. $^{36}_{17}\mathrm{Cl}$
b. $^{58}_{26}\mathrm{Fe}$
c. C-14

Solution

a. In $^{36}_{17}\mathrm{Cl}$ there are 19 neutrons in this nucleus. To find this value, subtract A-Z or 36 − 17.
b. In $^{58}_{26}\mathrm{Fe}$ there are 32 neutrons in this nucleus. Again, subtract A-Z or 58-26.
c. In this example, the C-14 represents symbol-mass format. Once the atomic number is located (look at periodic table), subtract 14-6. The final answer will be 8 neutrons.

? Exercise 3.5.2

For the species below, translate the A/Z format to symbol-mass. Then, calculate the number of subatomics for each atom.

a. $^{197}_{79}\mathrm{Au}$
b. $^{23}_{11}\mathrm{Na}$

c. $^{239}_{94}\text{Pu}$

Answer a

Au-197 contains 79 protons, 79 electrons, and 118 neutrons.

Answer b

Na-23 contains 11 protons, 11 electrons, and 12 neutrons.

Answer c

Pu-239 contains 94 protons, 94 electrons, and 145 neutrons.

Calculating Atomic Mass

The **atomic mass** of an element is the weighted mass of all the naturally presented isotopes. On the periodic table, it is assumed that this mass has units of amu (atomic mass unit) which can be abbreviated by using the letter u. To determine the most abundant isotopic form of an element, compare given isotopes to the weighted average on the periodic table. For example, the three hydrogen isotopes (shown above) are H-1, H-2, and H-3. The atomic mass or weighted average of hydrogen is around 1.008 amu (look again at the periodic table). Of the three hydrogen isotopes, H-1 is closest in mass to the weighted average; therefore, it is the most abundant. The other two isotopes of hydrogen are rare but are very exciting in the world of nuclear science.

Example 3.5.2

Identify the true statements:

a. Al-27 is more abundant than Al-25.
b. An appropriate isotope of bromine could be Br-35.
c. A chemist could easily distinguish between Cs-132 and Cs-133 by noting chemical and physical properties.
d. Most scientists know that calcium has 24 isotopes.

Answer a

This statement is true. Aluminum with a mass of 27 is closest to the mass on the periodic table. It would be more abundant than Al-25.

Answer b

This statement is false. An appropriate mass number of an isotope of bromine would be in around 80 amu (atomic mass units), not 35 (which is the atomic number).

Answer c

Chemists cannot distinguish between isotopes by looking at various properties. Most isotopes have similar solubilities, densities, and colors.

Answer d

Unless a scientist works heavily with a particular atom, he or she is not aware of the many forms that cannot exist. They would need a reference guide to know how many natural and artificial isotopes exist for a particular element.

You can calculate the atomic mass (or average mass) of an element provided you know the **relative abundances** (the fraction of an element that is a given isotope), the element's naturally occurring isotopes, and the masses of those different isotopes. We can calculate this by the following equation:

$$\text{Atomic mass} = (\%_1)\,(\text{mass}_1) + (\%_2)\,(\text{mass}_2) + \cdots \tag{3.5.1}$$

To confirm your answer, compare the calculated value to the weighted mass displayed on the periodic table.

> *An element's atomic mass can be calculated provided the relative abundances of the element's naturally occurring isotopes and the masses of those isotopes are known. If all*

> *the abundances are not provided, it is safe to assume that all numbers should add up to 100%.*

Example 3.5.3: Atomic mass of Boron

Boron has two naturally occurring isotopes. In a sample of boron, 20% of the atoms are B-10, which is an isotope of boron with 5 neutrons and mass of 10 amu. The other 80% of the atoms are B-11, which is an isotope of boron with 6 neutrons and a mass of 11 amu. What is the atomic mass of boron?

Solution

Boron has two isotopes. We will use the Equation 3.5.1:

$$\text{Atomic mass} = (\%_1)\,(\text{mass}_1) + (\%_2)\,(\text{mass}_2) + \cdots$$

Substitute these into the equation, and we get:

$$\begin{aligned}\text{Atomic mass} &= (0.20)\,(10) + (0.80)\,(11)\\ &= 10.8\ \text{amu}\end{aligned}$$

The mass of an average boron atom, and thus boron's atomic mass, is 10.8 amu.

Example 3.5.4: Atomic mass of Neon

Neon has three naturally occurring isotopes. In a sample of neon, 90.92% of the atoms are Ne-20, which is an isotope of neon with 10 neutrons and a mass of 19.99 amu. Another 0.3% of the atoms are Ne-21, which is an isotope of neon with 11 neutrons and a mass of 20.99 amu. The final 8.85% of the atoms are Ne-22, which is an isotope of neon with 12 neutrons and a mass of 21.99 amu. What is the atomic mass of neon?

Solution

Neon has three isotopes. We will use the equation:

$$\text{Atomic mass} = (\%_1)\,(\text{mass}_1) + (\%_2)\,(\text{mass}_2) + \cdots$$

Substitute these into the equation, and we get:

$$\begin{aligned}\text{Atomic mass} &= (0.9092)\,(19.99) + (0.003)\,(20.99) + (0.0885)\,(21.99)\\ &= 20.18\ \text{amu}\end{aligned}$$

The mass of an average neon atom is 20.18 amu

Applications of Isotopes

During the Manhattan project, the majority of federal funding dedicated the separation of uranium isotopes. The two most common isotopes of uranium are U-238 and U-235. About 99.3% of uranium is of the U-238 variety, this form is not fissionable and will not work in a nuclear weapon or reaction. The remaining .7% is U-235 which is fissionable but first had to be separated from U-238. This separation process is called *enrichment*. During World War II, a nuclear facility was built in Oak Ridge, Tennessee to accomplish this project. At the time, the enrichment process only produced enough U-235 for one nuclear weapon. This fuel was placed inside the smaller of the two atomic bombs (Little Boy) dropped over Japan.



Figure **3.5.3**: A billet of highly enriched uranium recovered from scrap processed at the Y-12 National Security Complex Plant. Original and unrotated.

Uranium is a natural element that can be found in several different countries. Countries that do not have natural uranium supplies would need to obtain it from one of the countries below. Most nuclear reactors that provide energy rely on U-235 as a source of fuel. Fortunately, reactors only need 2-5% U-235 for the production of megawatts or even gigawatts of power. If the purification process exceeds this level, then it is likely a country is focusing on making nuclear weapons. For example, Manhattan Project scientists enriched U-235 up to 90% in order to produce the Little Boy weapon.

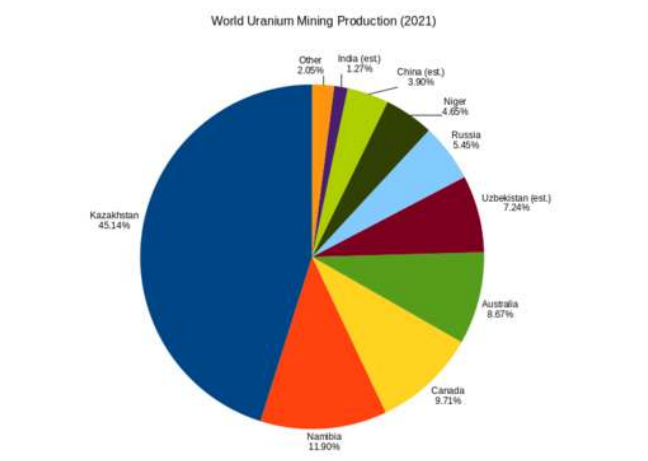


Figure **3.5.4**: World Uranium Mining Production 2021. (CC BY-SA-4.0; by Liberum scientia).

Abbreviations like HEU (highly enriched uranium) and LEU (low-enriched uranium) are used frequently by nuclear scientists and groups. HEU is defined as being over 20% pure U-235 and would not be used in most commercial nuclear reactors. This type of material is used to fuel larger submarines and aircraft carriers. If the purification of U-235 reaches 90%, then the HEU is further classified as being weapons-grade material. This type of U-235 could be used to make a nuclear weapon (fission or even fusion-based). As for LEU, its U-235 level would be below this 20% mark. LEU would be used for commercial nuclear reactors and smaller, nuclear-powered submarines. LEU is not pure enough to be used in a conventional nuclear weapon but could be used in a dirty bomb. This type of weapon uses conventional explosives like dynamite to spread nuclear material. Unlike a nuclear weapon, dirty bombs are not powerful enough to affect large groups of buildings or people. Unfortunately, the spread of nuclear material would cause massive chaos for a community and would result in casualties.

Need More Practice?

- Turn to Section 3.E of this OER and work problems #3, #6, #7, and #10.

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3.6: The Importance of Ions to a Chemist

Learning Objectives

- Identify how a charge affects the electron count of an element.
- Apply a provided charge when calculating the number of subatomic particles.
- Realize that cations are atoms that lose electrons resulting in an overall positive charge.
- Realize that anions are atoms that gain electrons resulting in an overall negative charge.
- Locate regions of the periodic table where cations and anions tend to form.
- Know that chemical energy corresponds to electrons, while nuclear energy results from changing the nucleus.
- Compare and contrast chemical and nuclear energy.
- Relate ion solubility to the Flint River Crisis (see infographic at bottom).

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Chemists appreciate isotopes and use them in basic and applied research. However, they are more concerned with the movement of electrons. When an atom gains or loses electrons, it becomes a charged species or an ion. When this occurs, the nucleus is not altered. For atoms that lose electrons, an overall positive charge will result (**#protons > #electrons**). Atoms that form these types of ions are called cations. Metal atoms (located on the left side of the periodic table) always lose electrons to become cations.

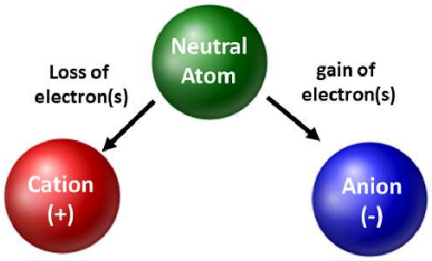
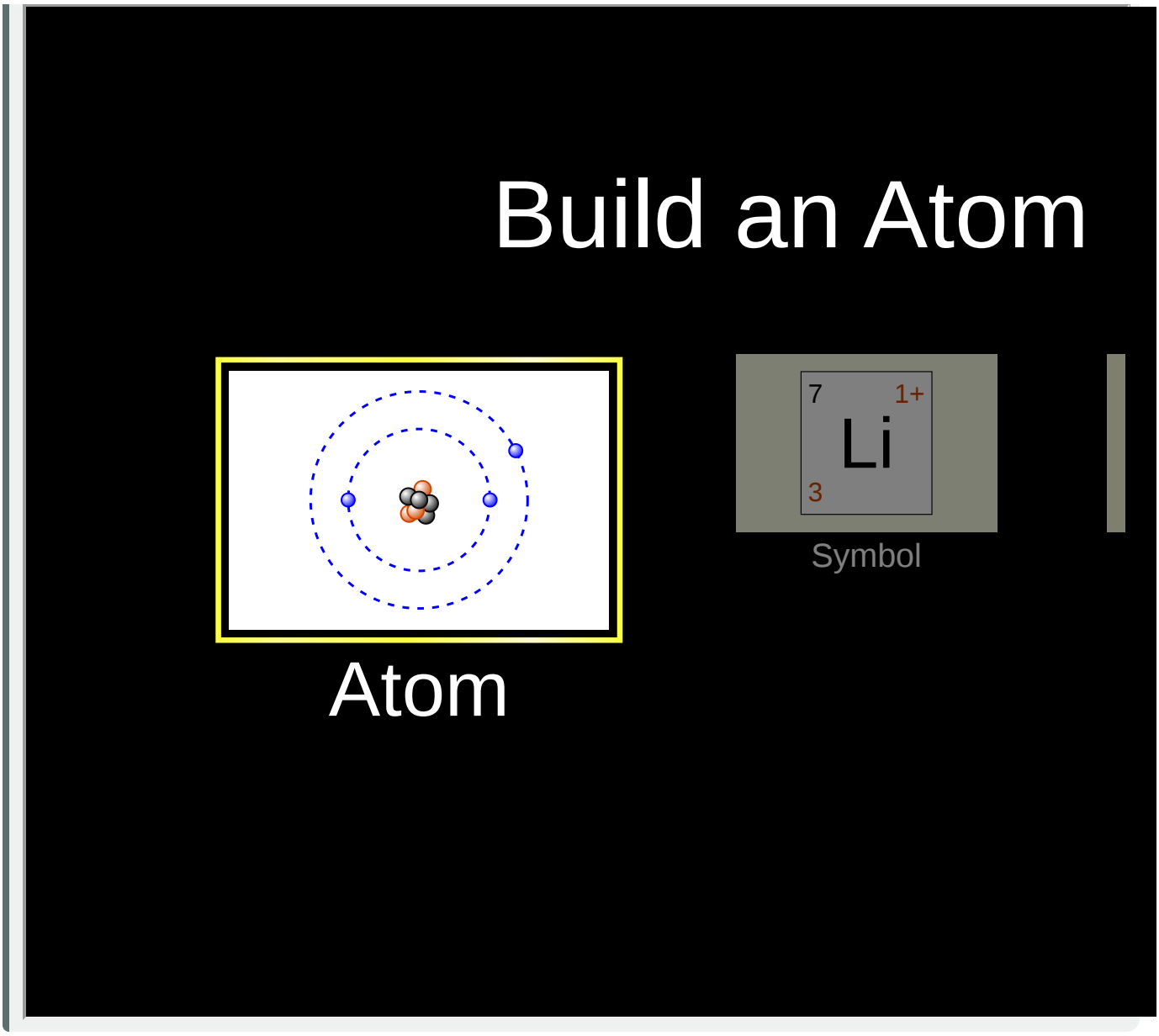


Figure **3.6.1**: Neutral atoms become ions by either losing an electron (to form positively charged cations) or gaining electrons (to form negatively charged anions). (Public Domain; Delmar Larsen)

Unlike metal atoms, nonmetals will gain electrons to become anions. These types of ions have an overall negative charge (**#electrons > #protons**). With the exception of the noble gases, all atoms on the periodic table will lose or gain electrons to achieve electronic stability. Different types of bonding occur when atoms lose, gain, or share electrons. These types of atomic connections will be further discussed in chapter 4 of your textbook.

Interactive: Building an Atom

Build an atom out of protons, neutrons, and electrons, and see how the element, charge, and mass change. Then play a game to test your ideas!



At this point, you should be able to calculate all subatomic particles when given a specific ion charge. In addition, you should master classifications of ions (recognizing cations are positive and anions are negative). Memorizing charges of specific ions will be required when working on chapter 4 in the textbook. **For now, ion charges will be provided and should not be memorized**. Note and appreciate the ion charges for main group elements in the periodic table below. Lastly, chemists do not write a number for charges involving the number one (1). For these species, you will only see a + or - sign. Charges of higher magnitude will always have a number associated with the elemental symbol.

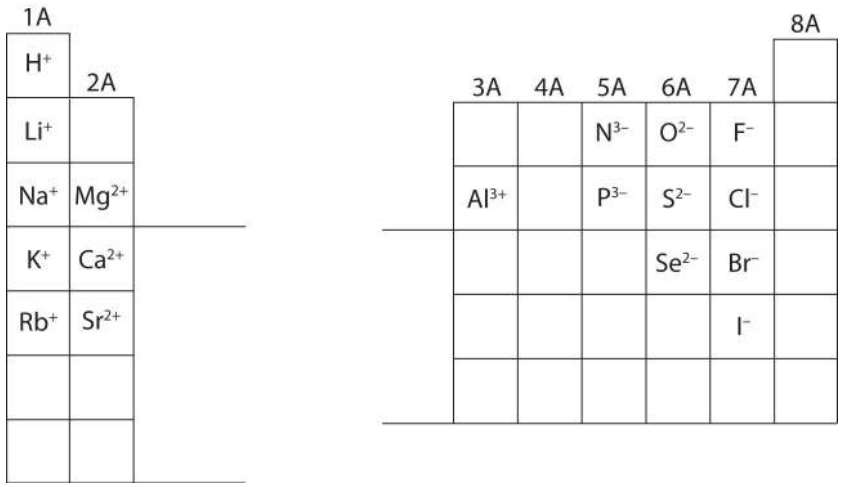


Figure **3.6.2**: Periodic Table with ion charges of common main group elements. The charge that an atom acquires when it becomes an ion is related to the structure of the periodic table. Within a group (family) of elements, atoms form ions of a certain charge. Please note that hydrogen can adopt a + or - charge. When the word hydride is used, this means that hydrogen has a - charge.

✔ Example 3.6.1: IOnic Classification

Calculate the subatomic particles for the species below using the information in Figure **3.6.2**. Label each as being an atom, cation, or anion. Refer to the periodic table for masses, atomic numbers, and specific ion charges.

a. Aluminum ion
b. Zirconium atom
c. Sulfur ion

Solutions

a. There are 13 protons, 14 neutrons, and 10 electrons in the aluminum ion. This ion is positively charged which means it has lost electrons and forms a cation.
b. There are 40 protons, 51 neutrons, and 40 electrons in the zirconium atom. This is an atom which has no overall charge.
c. There are 16 protons, 16 neutrons, and 18 electrons in the sulfur ion. This ion is negatively charged which means it has gained electrons and forms and anion.

✔ Example 3.6.2: A/Z and symbol mass notations

Write A/Z and symbol mass notations for the ions/atom in the previous question.

Solutions

a. $^{27}_{13}Al^{3+}$ and Al-27
b. $^{91}_{40}Zr$ and Zr-91
c. $^{32}_{16}S^{2-}$ and S-32

If an atom gains or loses electrons, this should be represented on the A/Z format. The symbol-mass format does not display ion charge. Remember, neutrons and protons are not affected by changes of electrons.

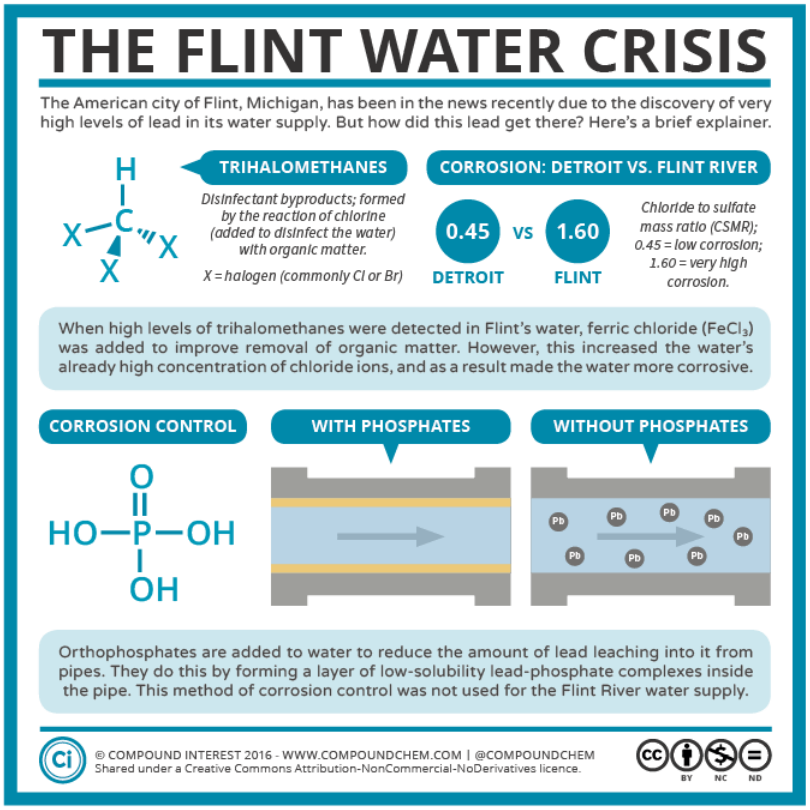


Figure **3.6.3**: The Flint Water Crisis. (Andy Brunning, CC-By-NC-ND)

When compounds are soluble in water, they form homogeneous mixtures or solutions. Disinfectants are compounds (usually chlorine or bromine based) added to water to kill pathogens. These types of chemicals are typically bromine, iodine, or chlorine based. When these species are added, they react with water to produce disinfectant byproducts. Before disinfection, the Flint River was corrosive. After disinfection, the chlorine/bromine ions increased the corrosivity of the water. As a result, the insoluble pipe became soluble releasing iron, copper, and lead atoms in the water. The water turned brownish in color due to the presence of iron cations. Copper and lead ions did not affect the color of the water.



Need More Practice?

- Turn to Section 3.E of this OER and work problems #5 and #9.

Contributors

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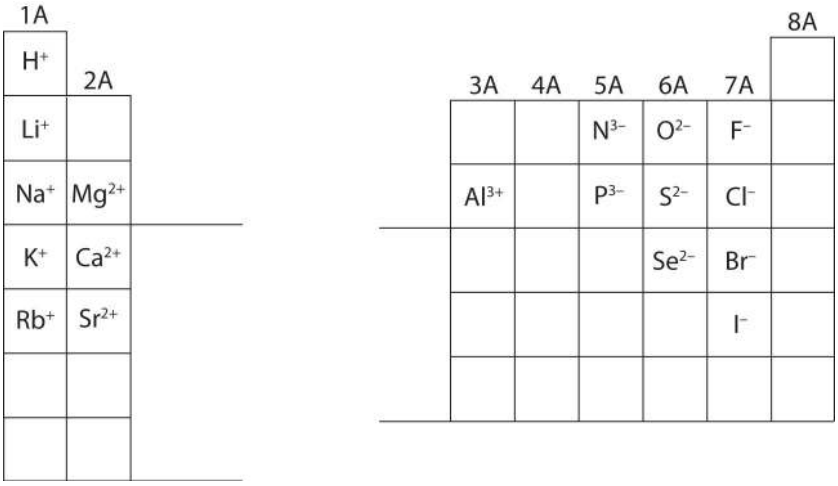
3.E: Atoms and the Periodic Table (Exercises)

Concept Review Exercises

1. Why is the atomic number so important to the identity of an atom?
2. What is the relationship between the number of protons and the number of electrons in an atom?
3. How do isotopes of an element differ from each other?
4. What is the mass number of an element?
5. Calculate the subatomic particles for
    a. Zn-67,
    b. radium,
    c. the aluminum cation,
    d. Mg-23, and
    e. the phosphorus anion.
6. Which element(s) has/have 32 neutrons: germanium, cobalt, or Mn-57?
7. Which natural isotope of platinum is most abundant?
8. Which element has 19 electrons?
9. Write A/Z format for the species in question #5.
10. Calculate the weighted average of nitrogen. N-14 has an exact mass of 14.003074u and is 99.63% abundant. N-15 has a mass of 15.000108u.

Solutions

1. The atomic number defines the identity of an element.
2. In an electrically neutral atom, the number of protons equals the number of electrons.
3. Isotopes have different numbers of neutrons in their nuclei.
4. The mass number is the sum of the numbers of protons and neutrons in the nucleus of an atom.
5. For ion charges, refer to the table for assistance:



Species	Protons	Electrons	Neutrons
Zn-67	30	30	37 (is isotope)
Radium	88	88	138
Aluminum cation	13	10 (look up charge, 3+)	14
Mg-23	12	12	11 (is isotope)
Phosphorus anion	15	18 (look up charge, 3-)	16

6. Both cobalt and Mn-57 have 32 neutrons. Germanium has 41 neutrons.
7. Pt-195 is closest to the weighted average (found on periodic table) and would be the most abundant.
8. If an ion charge is not given, locate the electrons of the element by looking to the atomic number. Potassium is the only atom of these three that would have 19 electrons.
9. $^{67}_{30}\mathrm{Zn}$, $^{226}_{88}\mathrm{Ra}$, $^{27}_{13}\mathrm{Al}^{3+}$, $^{23}_{12}\mathrm{Mg}$ and $^{31}_{15}\mathrm{P}^{3-}$
10. For this problem, you need to assume that all percentages add up to 100%. Since the problem provided 99.63%, you will need to subtract this given percentage from 100.00%.

$$\text{Atomic mass} = (0..9963)\,(14.003074) + (0.0037)\,(15.000108) = 14.01\ \text{amu} \tag{3.E.1}$$

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CHAPTER OVERVIEW

4: Valence Electrons and Bonding

Valence electrons are outer shell electrons with an atom and can participate in the formation of chemical bonds. In single covalent bonds, typically both atoms in the bond contribute one valence electron in order to form a shared pair.

4.1: Atomic Models of the Twentieth Century
4.2: Understanding Atomic Spectra
4.3: Atomic Spectroscopy Applications
4.4: Predicting Ion Charges
4.5: Lewis Dot and Bonding
4.6: Ionic Formula Writing
4.7: Applications and Solubility of Ionic Compounds
4.8: Covalent Bonding and Formula Writing
4.9: Free Radicals and the Environment
4.10: Free Radicals and Health
4.11: Applications and Solubility of Covalent Compounds
4.12: Arrhenius Acids and Bases
4.E: Valence Electrons and Bonding (Exercises)

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4.1: Atomic Models of the Twentieth Century

Learning Objectives

- Compare different theories regarding electron arrangement within the atom.
- Understand the concept of quantized energy.
- Draw modified Bohr models for every element up through atomic number 20.
- Identify the valence electrons in a Bohr model.
- Realize the Roman numeral group numbers on the periodic table represent valence electrons.

Plum Pudding and Bohr Models

In the early twentieth century, scientists attempted to construct plausible models of the atom. One of first theories was proposed by J.J. Thomson, the physicist who discovered the electron. Thomson believed that the atom contained both positive and negative charges. He was not aware of the existence of a third neutrally charged particle (neutron). Using a plum pudding (today's comparison could be chocolate chip cookie dough) dessert for a visual representation, Thomson stated that the positive mass could be represented by the actual pudding component of the dessert. The negative species inside each atom would be scattered randomly like the plums in pudding (or chocolate chips in cookie dough).

Figure **4.1.1**: Plum pudding **Figure 4.1.2:** Thomson's depiction of a plum pudding atom.

By 1911, Ernest Rutherford discovered a centrally located positive core of the atom. Rutherford's nucleus would house the positive protons while the negative electrons would remain outside this core. Chemists and physicists immediately abandoned the plum pudding model and looked to describe electron placement in more detail. In 1915, the Danish physicist Niels Bohr proposed a new model of the atom that involved electrons orbiting the nucleus. Stationary states or energy levels would be fixed distances from the nucleus (see below). In this model, these energy levels or shells would be represented by the letter "n."

Figure **4.1.3**: The Bohr model of the atom illustrating levels of electrons.

This planetary model of the atom was attractive to scientists because it was similar to something with which they were already familiar, namely the solar system. Unfortunately, there was a serious flaw in the planetary model. It was already known that when a charged particle (such as an electron) moves in a curved path, it gives off some form of light and loses energy in doing so. This is, after all, how we produce TV signals. If the electron circling the nucleus in an atom loses energy, it would necessarily have to move closer to the nucleus as it loses energy and would eventually crash into the nucleus. These difficulties cast a shadow on the planetary model and indicated that, eventually, it would have to be replaced.



Figure **4.1.4**: Scientists who attended the 1927 Fifth Solvay International Conference on Electrons and Photons. Niels Bohr is seated in the second row on the far right. Image taken from: https://www.flickr.com/photos/iharsten/8710094055

Energy Levels

Bohr's electrons reside in energy levels or shells. These levels are denoted with the letter "n" and are associated with a precise energy value (units would be in Joules). Shells (or levels) closer to the nucleus would require smaller amounts of energy for an electron while orbits farther from the nucleus would require the electrons to have a greater amount of energy.

Bohr hypothesized that the only way electrons could gain or lose energy would be to move from one energy level to another, thus gaining or losing precise amounts of energy. The energy levels are **quantized**, meaning that only specific amounts are possible. To imagine this phenomenon, note the ladder in the image below. Ladders contain rungs that are spaced at specified distances from the ground. On the ladder, an individual must remain on one of the rungs. He or she cannot step between the rungs and remain on the ladder successfully. The lowest rung required the least amount of energy for a person to exert. Moving to higher levels on the ladder would involve inputting more energy or effort.

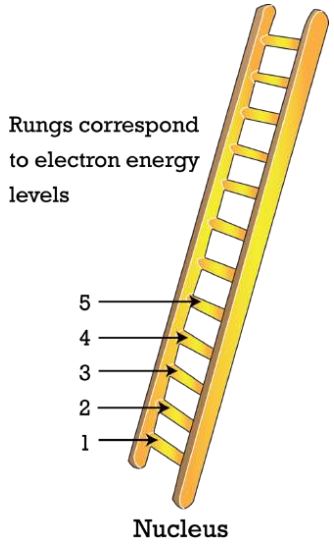


Figure **4.1.5**: The concept of energy levels can be view within the context of a ladder. Each allowed electronic state has an energy. For an atom, the rungs are not equally spaced.

In the Bohr atom, the rungs represent energy levels. Electrons remain in these levels until they absorb or emit a quantum of energy. When an electron gains energy, then it will move further away from the nucleus to a higher energy level. Upon emission of energy (see the red arrow in the image below), the electron will fall back to a lower energy level. The energy absorbed or emitted during these transitions is quantized.

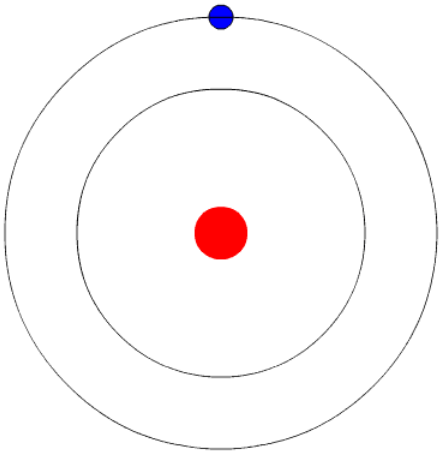


Figure **4.1.6**: In Bohr's Model of the atom, electrons absorb energy to move to a higher level and release energy to move to lower levels. (CC BY-SA 3.0; Kurzon).

Drawing Bohr Models

Although not completely correct, the Bohr model can give us a visual representation of electronic levels in atoms. Bohr used the formula $2n^2$ to calculate maximum number of electrons that could be housed in an energy level or shell. In this formula, "n" represents the particular energy level. When substituting an integer above the number zero, one can obtain maximum electrons for each shell. For example, the first energy level would be n =1 and this level could hold $2(1)^2 = 2$ maximum electrons. The second energy level could accommodate $2(2)^2 = 8$ electrons. In drawing Bohr diagrams, different amounts of shells are required to store a specific atom's electrons. Looking at a Bohr diagram for the carbon atom, one can see that two energy levels/shells are required for its six electrons.

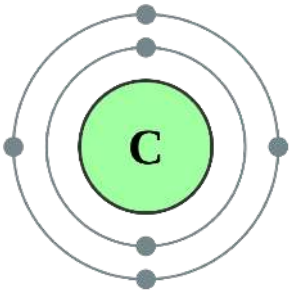


Figure **4.1.7**: Electron shell diagram for carbon, the 6th element in the periodic table of elements. (CC BY-SA 2.0(UK); Pumbaa)

Bohr diagrams for a variety of elements are illustrated in chart below **.** When determining the number of electrons of an atom, remember to refer to the atomic number (the whole number) on the periodic table.

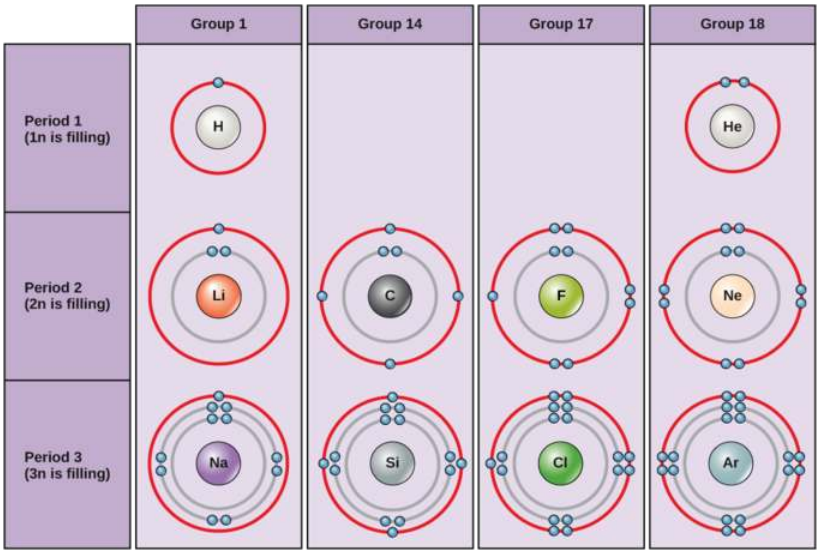


Figure **4.1.8**: Bohr models of different groups/families of elements from the periodic table.

In this course, we will be using a **modified Bohr model**. In other words, we will limit each shell after n=1 to a maximum of eight total electrons. We will also be limited in drawing Bohr diagrams of only the first twenty elements on the periodic table. This process will allow us to identify the **valence** or active electrons of these particular elements. Watch this video of your professor drawing Bohr models and identifying valence electrons.

✔ Example **4.1.1**: Drawing BOhr Diagrams

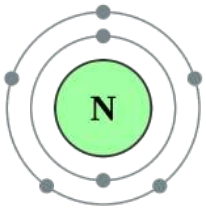
Draw modified Bohr diagrams for

a. nitrogen
b. calcium
c. sulfur

Feb 18, 2018, 6:12 PM

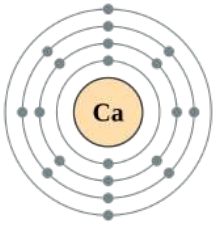
commons.wikimedia.org/wiki/E...-_no_label.svg

Answer a



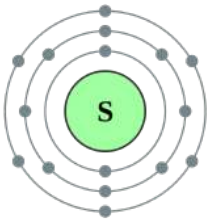
Bohr model of nitrogen: (CC BY-SA 2.0 uk; *Greg Robson):*

Answer b



Bohr model of calcium: (CC BY-SA 2.0 uk;*Greg Robson):*

Answer b



Bohr model of sulfur: (CC BY-SA 2.0 uk; Greg Robson).

Valence electrons are located in the highest energy level of an atom. When drawing a Bohr diagram, the valence electrons would be present in the outermost electronic level/shell (furthest away from the nucleus). An atom can have from one to eight valence electrons. In the bonding process, atoms will either gain, lose, or share valence electrons to become more stable. A quick method of checking valence electrons is to refer to an element's group number (in Roman numerals) on the periodic table. Even if you cannot draw a Bohr diagram (Bohr's are limited to elements with atomic numbers (Z)< 21), you can still determine valence electrons by looking to the group number.

Example 4.1.2: Identifying Valence Electrons

From the Bohr Diagrams constructed in Example **4.1.1**, how many valence electrons are on each atom.

Answer a

Five.

Answer b

Two

Answer c

Six

Quantum Theory

The Bohr Theory failed to explain why the electron did not spiral into the nucleus after a certain amount of revolutions around the nucleus. In addition, this theory had difficulty diagramming multi-electron systems (atoms or ions with more than one electron). For these reasons, scientists turned to the quantum mechanical theory. Since 1927, this has been the working theory that most chemistry courses use (we will not use this theory in our course). For a more detailed explanation of quantum mechanics, click here.

Summary

- The Bohr model postulates that electrons orbit the nucleus at fixed energy levels.
- Orbits further from the nucleus exist at higher energy levels.
- When electrons return to a lower energy level, they emit energy in the form of light.
- Bohr's model suggests each atom has a set of unchangeable energy levels and electrons in the electron cloud of that atom must be in one of those energy levels..

Vocabulary

- Energy levels: Possible orbits that an electron can have in the electron cloud of an atom.
- Quantized: requiring or possessing specific amounts of energy.

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4.2: Understanding Atomic Spectra

Learning Objectives

- Differentiate between a continuous and discontinuous spectrum
- Classify all types of radiation as being ionizing or nonionizing.
- Understand that ionizing radiation can knock electrons off DNA.
- Know that radiation of short wavelength is toxic.
- Understand the processes of absorption and emission.
- Explain the science behind fireworks.
- Realize that chemists and other scientists use AA/AE in quantitative and qualitative analyses

Continuous Spectrum

A rainbow is an example of a continuous spectrum. Here, the colors displayed are within the visible spectrum (between 380-760 nm). Light in this wavelength range is visible to the naked eye. Unlike the visible spectrum, light that is of different wavelengths (see the electromagnetic spectrum below) is not visible. Looking at Figure **4.2.1**, note the different areas of the light (or electromagnetic spectrum). Areas of light that possess short wavelengths are located on the left of the spectrum. All wavelengths from UV (ultraviolet) to γ (gamma) range have the potential to ionize tissues and/or DNA. As a result, individuals who have been exposed to large amounts of these types of radiation in acute time periods could develop cancer. In contrast, visible light (see the rainbow area in Figure **4.2.1**) and radiation on the right side of the spectrum has longer wavelengths and does not have the potential to ionize tissues and/or DNA. Visible, infrared (labeled IR), microwave, and radio waves are classified as being nonionizing radiation and have not been linked to cancer.

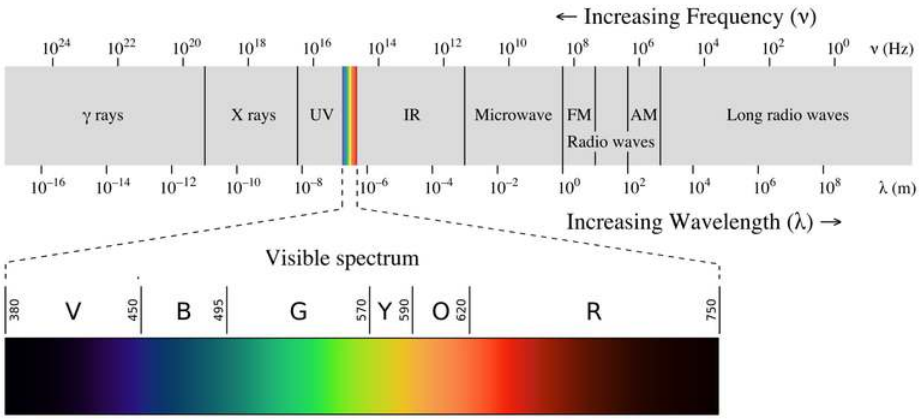


Figure **4.2.1**: The electromagnetic spectrum is an example of a continous spectrum. It contains various frequencies (cycle/time) and wavelengths. (CC BY-SA 3.0; Philip Ronan, Gringer).

Please be aware of what types of light are ionizing and nonionizing. Do not memorize the wavelengths or frequencies of the electromagnetic spectrum. It is important that you know that the electromagnetic spectrum is an example of a continuous spectrum.

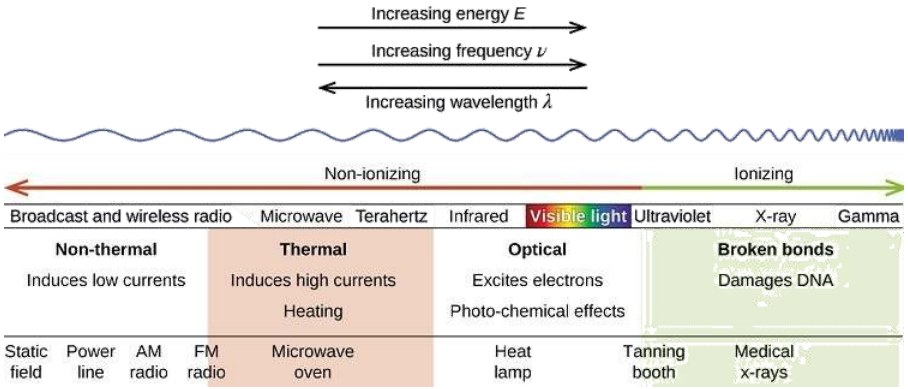


Figure 4.2.2: Lower frequency, lower-energy electromagnetic radiation is nonionizing, and higher frequency, higher-energy electromagnetic radiation is ionizing. (CC BY-SA, OpenStax).

Examples of Radiation

For each section of the electromagnetic spectrum, be sure to know a source or application of each type (example for radio waves would be cell phones). Also, also have a good understanding of how the UV portion can be expanded. Review UV information, by clicking on this link. Please do not memorize the ABCDE's of cancer nor the types of skin cancer that occur.

Atomic Emission Spectra

The electrons in an atom tend to be arranged in such a way that the energy of the atom is as low as possible. The **ground state** of an atom is the lowest energy state of the atom. When those atoms are given energy, the electrons absorb the energy and move to a higher energy level. These energy levels of the electrons in atoms are quantized, meaning again that the electron must move from one energy level to another in discrete steps rather than continuously. An **excited state** of an atom is a state where its potential energy is higher than the ground state. An atom in the excited state is not stable. When it returns back to the ground state (Figure 4.2.3), it releases the energy that it had previously gained often in the form of electromagnetic radiation (although it can be released via heat).

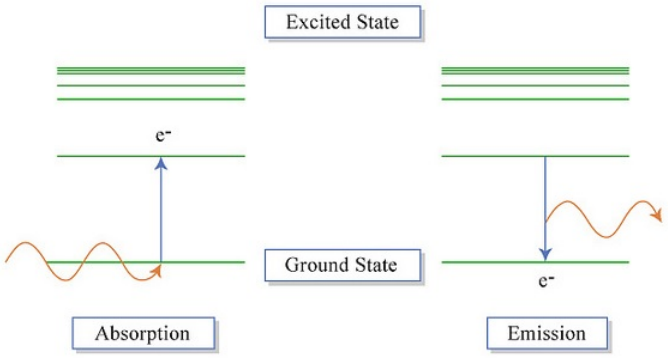


Figure 4.2.3: Atomic absorption and emission in excited and ground states. (CC BY-SA-NC 4.0; MIT OpenCourseWare).

Atoms can gain energy to induce these transitions from various sources. The gases in the image below have been excited with the use of electrical current. The atoms in each of these noble gases produce distinctive colors that can be used to identify the elements (Figure 4.2.4). Each of these species contains a different number of electrons that can undergo different types of excitations. In turn, each gas produces a signature color.

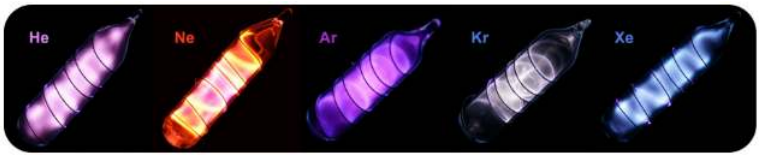


Figure 4.2.4: Gas discharge tubes are enclosed glass tubes filled with a gas at low pressure through which an electric current is passed. Electrons in the gaseous atoms first become excited, and then fall back to lower energy levels, emitting light of a distinctive color in the process. Shown ar gas discharge tubes of helium, neon, argon, krypton, and xenon.

Flames can be utilized to excite atoms as well. During a flame test experiment, metal chlorides are directly placed into a flame. The intense heat will promote the metal's electrons to an excited state. Upon emission, this extra energy is released in the form of visible light. If a reference panel is provided, the flame color can be used to identify a metal atom (Table 4.2.1).



Video 4.2.1: Burning Salts/Flame Test demonstration: Sully Science

Table 4.2.1: Flame colors corresponding to elements

Metal Ion	Flame Color		Metal Ion	Flame Color
Li	Red		K	Light Purple
Na	Orange		Ba	Light Green
Ca	Orange-Red		Cu	Blue
Sr	Red			

Fireworks are similar to flame test experiments. Firework manufacturers select certain metal atoms to produce desired colors for these devices. Individual detonators will explode the metal compounds to emit radiant colors of light. Watch the video below to see the largest aerial firework shell explode over the United Arab Emirates on December 31, 2017. While watching the video, compare the colors you see to the chart above to identify the atoms that were used in the display.



Video **4.2.2**: Guinness World Record For World's Largest Aerial Firework Shell

Discontinous Spectra

If the light emitted from the excited atoms is viewed through a prism, then individual patterns of lines will be produced. These lines are called spectra and correspond to fingerprint wavelengths (symbol for wavelength is **λ**) for a specific element. Figure **4.2.5** illustrates how the light from excited electrons can be diffracted to produce line spectra for the elements of hydrogen, helium, and iron. The specific elements produce wavelengths within the visible spectrum (between 400-700 nm) and can be seen by the naked eye. In order to obtain the numerical wavelengths (in nanometers), one would need to employ some type of detector.

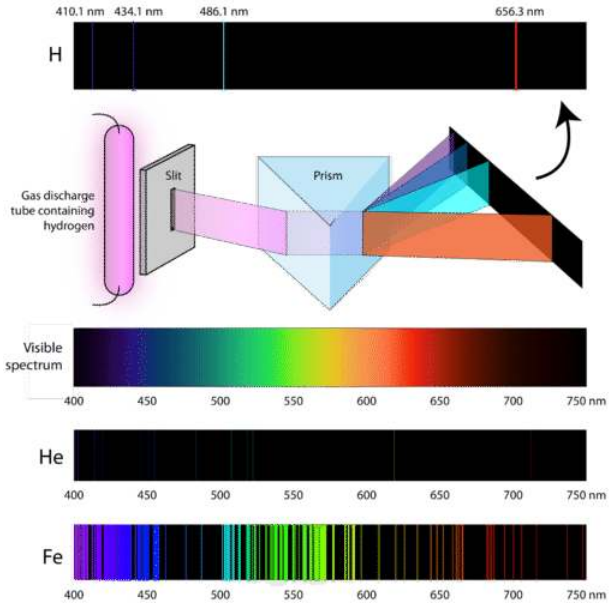


Figure **4.2.5**: When light from a hydrogen gas discharge tube is passed through a prism, the light is split into four visible lines. Each of these spectral lines corresponds to a different electron transition from a higher energy state to a lower energy state. Every element has a unique atomic emission spectrum, as shown by the examples of helium (**He**) and iron (**Fe**). (CC BY-NC-SA 3.0; Christopher Auyeung via CK-12 Foundation)

Atomic Absorption Spectra

In addition to emission studies, chemists will also use atomic absorption to identify and quantify. Noting the energy changes from ground to excited states, chemists can obtain another type of discontinuous spectrum (see image below). Once again, a fingerprint wavelength pattern is produced that can be used to identify an atom. Academia and Industry could employ either an AA (atomic absorption) or AE (atomic emission) spectrometer to analyze the atoms within a sample.

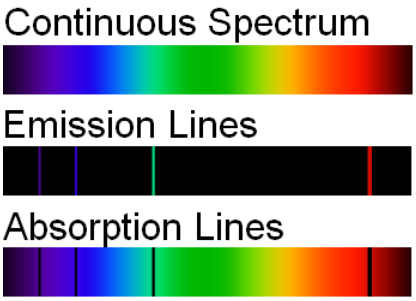


Figure **4.2.6**: Spectral lines. (Public Domain; Jhausauer via Wikipedia).

Example 4.2.1:

Which statements is/are true?

a. Microwaves can give you cancer.
b. When exploding fireworks, you will see the color when the metal atoms absorb energy from the detonater.
c. When using an AA or an AE spectrometer, a scientist will obtain a line spectra, not continuous spectra.
d. The flame test gives specific colors for metal atoms.
e. Gamma rays are ionizing and can cause cancer.
f. In the light spectrum, you can see IR and visible with only your eyes.
g. Continuous spectra can be used to identify an atom.

Answer a

False, they do not possess enough energy to knock electrons off tissues or DNA

Answer b

False, the color is given off during the emission or falling back process.

Answer c

True, scientists need those fingerprint wavelengths to identify atoms.

Answer d

True, the metals are the species that become excited and eventually emit the visible light.

Answer e

True, ultraviolet, gamma, and x-ray are powerful forms of radiation that can cause cancer.

Answer f

False, you can only see images in the visible spectrum (people who are colorblind are even more limited).

Answer g

False, chemists need those specific wavelengths to identify atoms, not a spectrum that shows a continuous flow of wavelengths.

Summary

Atomic emission spectra are produced when excited electrons return to the ground state.

- When electrons return to a lower energy level, they emit energy in the form of light.
- Bohr's model suggests each atom has a set of unchangeable energy levels and electrons in the electron cloud of that atom must be in one of those energy levels.
- Bohr's model suggests that the atomic spectra of atoms are produced by electrons gaining energy from some source, jumping up to a higher energy level, then immediately dropping back to a lower energy level and emitting the energy difference between the two energy levels.

- The existence of the atomic spectra is support for Bohr's model of the atom.
- Bohr's model was only successful in calculating energy levels for the hydrogen atom.
- The emitted light corresponds to energies of the specific electrons.

Vocabulary

- Emission spectrum (or atomic spectrum): The unique pattern of light given off by an element when it is given energy
- Ground state: to be in the lowest energy level possible.
- Excited state: to be in a higher energy level.

Contributors and Attributions

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4.3: Atomic Spectroscopy Applications

Learning Objectives

- Understand why samples need to be digested.
- Know what type of elements are detected by using AA or AE
- Recall practical applications of AA or AE (what businesses use these methods)

Sample Preparation for Atomic Absorption/Emission

Chemists employ atomic spectrophotometers to determine the identity and/or concentration of a metallic species. Samples must be in liquid form before being placed in the analyzer. To do this, a chemist will use certain acids (nitric or hydrochloric) to extract the metallic component of a sample. This process is called digestion and will not affect the analysis of the sample.



Video **4.3.1**Acid Digestion of Metals by Advanced Chemical.

Once the sample has transformed into liquid form, it enters the spectrophotometer by a capillary tube. Then, it is atomized, or transformed into fine mist, by a flame. A light source (cathode lamp) bombards the misted sample. The metallic atoms inside the sample gain energy from the light source and jump to excited states. At different intervals of time, the excited atoms release energy and fall back to their ground states. This quantized energy that is involved in the absorption (AA) or emission (AE) process corresponds to a fingerprint wavelength pattern that can be used to identify a specific metal atom.



Video **4.3.2**: A combination of animation, commentary, and application to supplement the lab experience with FAA spectroscopy.

Applications

AA or AE spectrometers have been used in many different industrial and academic settings. For example, a medical laboratory could detect the type and amount of toxic metals that could be present in patient's urine or blood. Environmental scientists could monitor metal pollutants in soil and water. The pharmaceutical industry uses these machines to determine if a metal catalyst after a drug has been purified. Lastly, the mining industry would utilize these devices to detect the quantity and presence of precious metals like gold and silver.



Figure 4.3.1: View of a flame atomic absorption spectroscopy instrument. Image taken from: from de.wikipedia to Commons by Leyo using CommonsHelper.

Academic and industrial laboratories consider several factors before selecting spectrometer. For example, some labs require a large number of samples to be analyzed in one day while other labs might use the instrument occasionally. Specific analyzers might require a smaller amount of sample. In addition, a toxicology lab might need an instrument to report values in micro or nanograms. Lastly, academic (more often than industrial) facilities must consider the cost of the analyzer before purchasing.

Other options besides flame based AA/AE are graphite furnace (GFAA) and inductively coupled plasma (ICP-AE or ICP-OES). With the GFAA method, a furnace is used to excite the metallic sample. This technique can detect lower concentrations of metal than a flame AA/AE. Also, smaller volumes of sample are needed for a GFAA. ICP machines utilize a plasma (gas with charged ions) for the excitation process. Some of these instruments can directly analyze solid samples. Unfortunately, ICP-AE instruments are slower in producing data. Peruse Table 4.3.1 and note the general differences between the instruments.

Table 4.3.1: Common instrument attributes for spectrometers.

Instrument	Levels of detection	Volume of sample required	Elements analyzed per unit of time	Range of cost
Flame AA/AE	High ppb	> 5.0 mL	1 element per 3-10 seconds	$15,000-$25,000
Graphite Furnace AA	Mid ppb	< 5.0 mL	1 element per 2-3 minutes	$40,000-$70,000
ICP-AE	Mid ppb	> 5.0 mL	73 different elements per minute	$70,000-$100,000

Units of Low Concentration: Parts per billion (ppb)

The letters ppb represent a concentration parts per billion. This translates to the metal atom being one part while the sample contains a billion parts. Imagine measuring one inch in 16,000 miles or counting one cent in $10 million dollars. These two values are comparable to one ppb. In water chemistry, ppb is often referred to as µg of contaminant per liter of a sample. Table 4.3.1 above shows that a flame AA/AE detects only large amounts of ppb. This would be the least sensitive technique of the three listed.

Exercise 4.3.1: Analysis of Materials Using AA and AE

Click on this link about Forensic science and brushfires in Australia and answer the questions below.

a. In this article, what material are scientists analyzing? Why are they doing this?
b. What method-AA or AE are they using the determine the metals of the interest?
c. What metals does this article mention?
d. Why are they using XRD in this article?

Answer a

They are comparing different types of matches (unburned and burned) for arson investigations (wildfires)

Answer b

They used ICP-AE (you just need to be concerned with the AE part).

Answer c

Mg, Al, Ca, Fe, Zn, and Ba

Answer d

They used XRD (x-ray diffraction) to determine which burned matches corresponded to the unburned matches (comparing different brands).

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4.4: Predicting Ion Charges

Learning Objectives

- Recall how to locate valence electrons for all atoms (except transition and inner transition metals).
- Realize that metals will lose electrons to form cations and nonmetals gain electrons to form anions.
- Predict charges (using the modified Bohr model, Z < 20) for the following groups of elements: alkali, alkaline and halogens.
- Predict charges (using the modified Bohr model) for the following elements: phosphorus, nitrogen, sulfur, oxygen, and aluminum.
- Memorize charges for silver and zinc
- Label your periodic table with predicted charges from Bohr model.

Earlier, we located the valence electrons for elements Z < 20 by drawing modified Bohr structures. We can obtain these values quicker by referring to the roman numeral numbers above each family on the periodic table. The total number of valence electrons for an atom can vary between one and eight. If an element is located on the left side of the table (metal) and has less than three valence electrons, it will lose its valence in order to become stable and achieve an octet. In contrast, elements on the right side of the table (nonmetals) will gain up to eight electrons to achieve octet status.

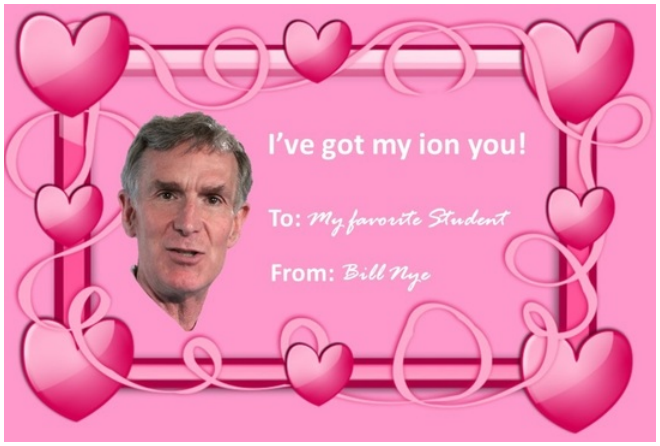


Figure **4.4.1**: Valentine image constructed from Pink Hearts Frame from 365PSD.com and photo of Bill Nye by Gage Skidmore (CC-BY=SA 2.0).

Cations

A neutral sodium atom is likely to achieve an octet in its outermost shell by losing its one valence electron.

$$\mathbf{Na} \rightarrow \mathbf{Na^+ + e^-}$$

The cation produced in this way, Na^+, is called the sodium ion to distinguish it from the element. The outermost shell of the sodium ion is the second electron shell, which has eight electrons in it. The octet rule has been satisfied. Figure **4.4.1** is a graphical depiction of this process.

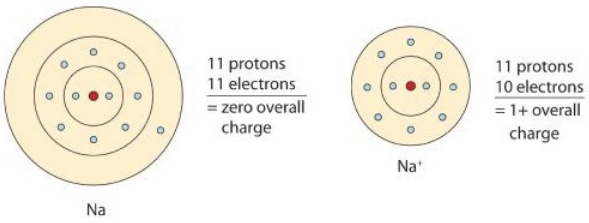


Figure **4.4.2**: The Formation of a Sodium Ion. On the left, a sodium atom has 11 electrons. On the right, the sodium ion only has 10 electrons and a 1+ charge. (CC BY-SA-NC 3.0; anonymous)

Atoms vs. Cations

While they are atoms, most metals are visible. You are aware that lead is a gray, solid metal.



A piece of lead, cut through, is silvery for a short time, before the surface oxidizes. This was the left piece of the previous image, it was cut with a sharp knife, using a hammer. (CC By 3/0; http://images-of-elements.com/lead.php)

When lead becomes a cation, it will not be visible and can become water soluble. If lead ions enter a drinking water system, one would not be able to detect them visually. For years, lead pipes were installed to transport water to consumers in many countries including the United States. If corrosive water were to enter a lead-based pipe, it would produce soluble lead ions. These charged species could be ingested unknowingly by residents of the community. Watch the video below and note how lead has affected the city of Flint, Michigan.



Follow-up questions

1. Why was the drinking water source changed from Lake Huron to Flint River?
2. Did the Flint River contain lead? If not, how did the lead enter the drinking water?
3. How did the residents describe their drinking water? Please realize the discoloration of the water is due to excess iron and not lead.
4. How can lead damage the body? Who does it affect the most?
5. What could have been added to the water before releasing it to the pipes? Why did you think officials didn't add this chemical?
6. What were all the contaminants this video mentioned?
7. How did boiling the water help and hurt the residents of Flint, Michigan?

Anions

Some atoms have nearly eight electrons in their valence shell and can gain additional valence electrons until they have an octet. When these atoms gain electrons, they acquire a negative charge because they now possess more electrons than protons. Negatively charged ions are called anions. Most nonmetals become anions when they make ionic compounds.

A neutral chlorine atom has seven electrons in its outermost shell. Only one more electron is needed to achieve an octet in chlorine’s valence shell. (In table salt, this electron comes from the sodium atom.)

$$e^- + Cl \longrightarrow Cl^-$$

In this case, the ion has the same outermost shell as the original atom, but now that shell has eight electrons in it. Once again, the octet rule has been satisfied. The resulting anion, Cl^-, is called the chloride ion; note the slight change in the suffix (*-ide* instead of *-ine*) to create the name of this anion. Figure **4.4.2** is a graphical depiction of this process.

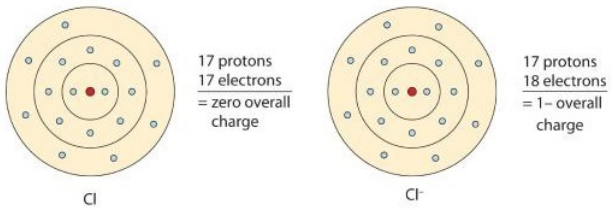
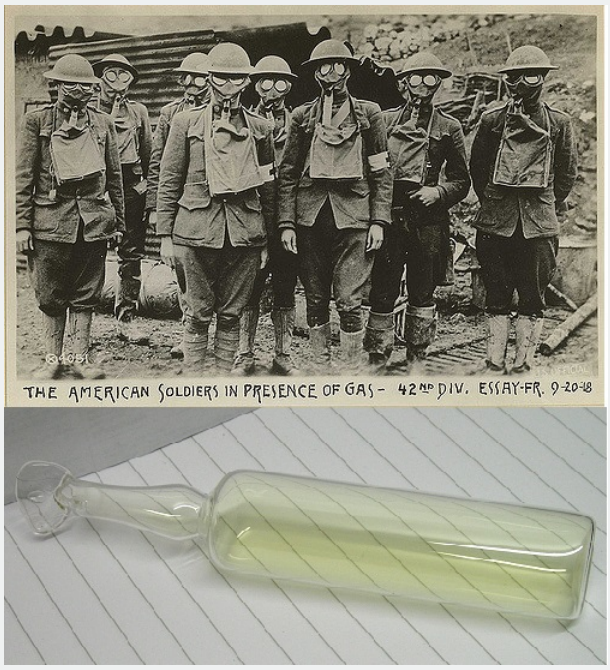


Figure **4.4.3**: The Formation of a Chlorine Ion. On the left, the chlorine atom has 17 electrons. On the right, the chloride ion has 18 electrons and has a 1− charge. (CC BY-SA-NC 3.0; anonymous)

> *The names for positive and negative ions are pronounced CAT-eye-ons and ANN-eye-ons, respectively.*

Anions Vs. Atoms

Like cations, anions could be come soluble in a liquid. This would make the negatively charged species invisible to the naked eye. In this example, we will compare the element chlorine (which exists as Cl_2) to the chlorine ion (Cl^-). Chlorine is a toxic,yellow, and corrosive gas. This element was one of the first chemical weapons and was used during WWI. As an ion, chloride is used to disinfect water supplies (pools and drinking water). This colorless ion can still be corrosive, but not to the degree that chlorine gas would be.



(top) American soldiers in presence of gas (Reeve 037283), National Museum of Health and Medicine. (CC BY 2.0; National Museum of Health and Medicine. (bottom) Chlorine gas in an ampoule. (CC BY-SA 3.0; W. Oelen).

In many cases, elements that belong to the same group (vertical column) on the periodic table form ions with the same charge because they have the same number of valence electrons. Thus, the periodic table becomes a tool for remembering the charges on many ions. For example, all ions made from alkali metals, the first column on the periodic table, have a 1+ charge. Ions made from alkaline earth metals, the second group on the periodic table, have a 2+ charge. On the other side of the periodic table, the next-to-

last column, the halogens, form ions having a 1− charge. Figure **4.4.3** shows how the charge on many ions can be predicted by the location of an element on the periodic table.

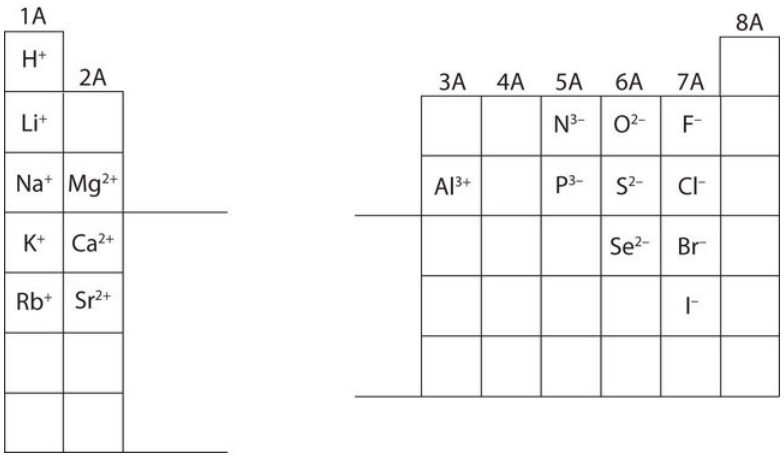


Figure **4.4.3**: Predicting Ionic Charges. The charge that an atom acquires when it becomes an ion is related to the structure of the periodic table. Within a group (family) of elements, atoms form ions of a certain charge. Be sure to memorize silver (Ag^{+}) and zinc (Zn^{2+}) charges in addition to this chart.

Example 4.4.1:

Will the species below lose or gain electrons?

a. aluminium
b. halogens
c. metals in general
d. silver
e. oxygen

Answer a

Aluminum is a metal that will always lose three electrons.

Answer b

The halogens all have seven valence electrons. Each one of these elements wants to gain one electron to achieve an octet.

Answer c

Metals will always lose electrons to form cations.

Answer d

Silver is a metal that will always lose one electron. Commit this to memory!

Answer e

Oxygen is a nonmetal that has six valence electrons. It will gain two electrons to achieve an octet.

Contributors and Attributions

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4.5: Lewis Dot and Bonding

Learning Objectives

- Realize that valence electrons can be represented by dots.
- Know that there are two types of bonding: ionic and covalent.
- Know that ionic bonding involves a metal and a nonmetal with a transfer of electrons.
- Know that covalent bonding involves two nonmetals or a metalloid with a nonmetal sharing electrons.

Bonding (Ionic and Covalent Basics)

When two atoms approach each other, they have the potential to bond (or connect). If a **metal and a nonmetal interact,** then an **ionic bond** will result. These types of bonds involve the metal donating it(s) valence electron(s) to a nonmetal. As the electronic transfer occurs, both atoms will achieve more stabile confirmations. The end result will be a less reactive compound. These type of species are composed of both cations and anions. In addition, they are crystalline and solid in nature. A few examples of real-world ionic compounds would be NaCl (table salt) and NaF (active ingredient in toothpaste).



Figure **4.5.1**: NaCl crystals. (Public Domain; NASA).

If two nonmetals interact, then a covalent bond will result. The connection that forms is due to each atom sharing it(s) valence electron(s). In this type of bonding, each atom (except for H, B, and Be) obtains an octet and becomes stable. Metalloids and nonmetals can bond to form covalent compounds as well. Solid covalent compound are not crystalline in texture. Unlike ionic compounds. covalent compounds can be liquids or even gases.



Figure **4.5.2**: Covalent compounds NO_2 and N_2O_4 contained in glass bottles. Image taken from: commons.wikimedia.org/wiki/File:NO2-N2O4.jpg

Table **4.5.1**: Comparing ionic and covalent compounds

Ionic Bonding	Covalent Bonding
Metal/nonmetal combination	nonmetal/nonmetal or metalloid/nonmetal combination
Metal loses valence electrons and nonmetal gains up to eight.	Both elements share valence electrons to achieve stability
Individual species have cation/anion charges	No charges are present in these compounds
All ionic compounds are solids	Covalent compounds can be solid, liquid, or gas.
Examples could include: Li_2CO_3, Fe_2O_3, and $MgSO_4$	Examples include: CO_2, H_2O, and CH_3CH_2OH

Lewis Symbols

At the beginning of the 20th century, an American physical chemist G. N. Lewis (1875–1946) devised a system of symbols—now called *Lewis electron dot symbols* (often shortened to *Lewis dot symbols*) that can be used for predicting the number of bonds formed by most elements in their compounds. Each Lewis dot symbol consists of the chemical symbol for an element surrounded by dots that represent its valence electrons. Lewis knew that incorporating models into his teaching would enable students to visualize chemical bonding easier. Gilbert Lewis was known for his interactive teaching methods and his interest in student success. Unfortunately, his nervous personality limited his ability to lecture in front of large groups of people.

Regarding his research, Lewis constructed his own theory to explain the nature of acids and bases. He was the first to synthesize D_2O (heavy water) and wrote numerous textbooks for his courses. In World War I, he served as a Major in the Gas Service unit of the American Army. He trained over 200 soldiers a week on how to adequately protect themselves from gas warfare. From these efforts, he helped reduce fatalities due to chemical gas exposures and was awarded the Distinguish Service Medal in 1922.

Lewis was nominated over thirty times for the Nobel Prize. He never received this award and does not have an element named in honor of him. For more on Gilbert Lewis, click on this link.

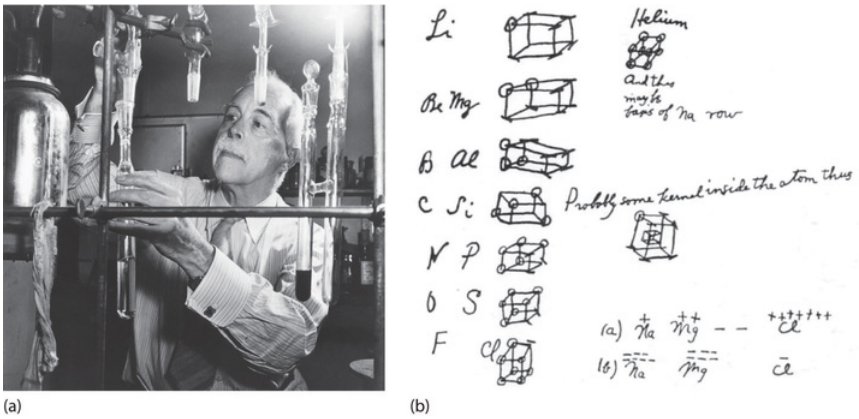


Figure **4.5.3**: G. N. Lewis and the Octet Rule. (a) Lewis is working in the laboratory. (b) In Lewis's original sketch for the octet rule, he initially placed the electrons at the corners of a cube rather than placing them as we do now.

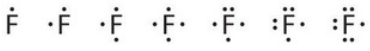
Lewis Dot symbols

- convenient representation of valence electrons
- allows scientists to keep track of valence electrons during bond formation
- consists of the chemical symbol for the element plus a dot for each **valence** electron

To write an element's Lewis dot symbol, we place dots representing its valence electrons, one at a time, around the element's chemical symbol. Up to four dots are placed above, below, to the left, and to the right of the symbol (in any order, as long as elements with four or fewer valence electrons have no more than one dot in each position). The next dots, for elements with more than four valence electrons, are again distributed one at a time, each paired with one of the first four. For example, the element sulfur has six valence electrons (note roman numeral above group on the periodic table) and its Lewis symbol would be:



Fluorine, for example, has seven valence electrons, so its Lewis dot symbol is constructed as follows:



The number of dots in the Lewis dot symbol is the same as the number of valence electrons, which is the same as the last digit of the element's group number in the periodic table. Lewis dot symbols and electron configurations (not a topic for this course) for the elements in period 2 are given in Table 4.5.2.

***Table* 4.5.2:** *Lewis Dot Symbols for the Elements in Period 2*

Group	1	2	13	14	15	16	17	18
Electron Configuration	[He]$2s^1$	[He]$2s^2$	[He]$2s^2 2p^1$	[He]$2s^2 2p^2$	[He]$2s^2 2p^3$	[He]$2s^2 2p^4$	[He]$2s^2 2p^5$	[He]$2s^2 2p^6$
Lewis Dot Symbol	Li ·	·Be·	· B ·	· C ·	· N ·	: O ·	: F ·	:Ne:

Ionic compounds are produced when a metal bonds with a nonmetal. Stability is achieved for both atoms once the transfer of electrons has occurred. The image below shows how sodium and chlorine bond to form the compound sodium chloride. Unlike a sodium atom, the resulting compound is not explosive and less corrosive than chlorine. Ionic bonding can be viewed by noting the donation of valence electrons from a metal atom to a nonmetal atom by using the Bohr model. From this theory, we will move on the Lewis structure with an understanding that metals will always lose valence electrons and nonmetals will gain up to eight in order to form stable compounds.

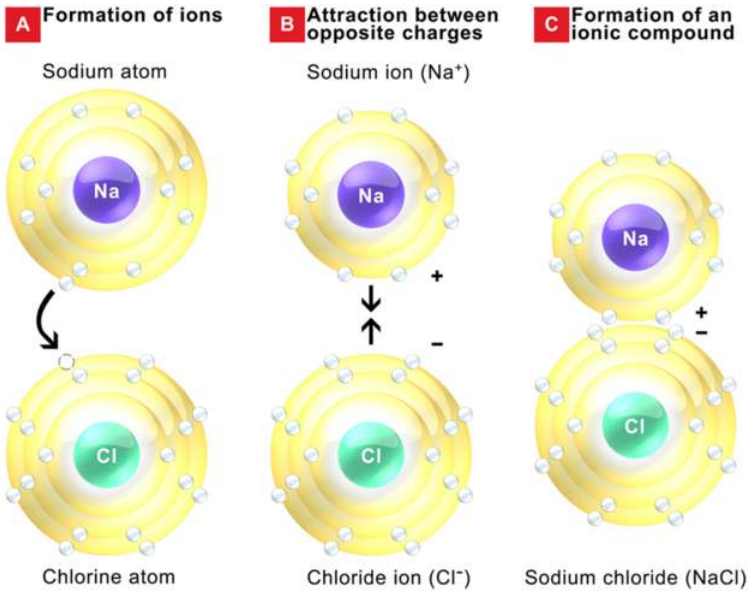


Figure 4.5.4: Formation of an ionic bond between sodium and chlorine. Image courtesy of By BruceBlaus - Own work, CC BY-SA 4.0, commons.wikimedia.org/w/inde...curid=44968540

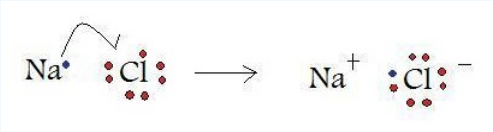
Rules for Drawing IOnic Lewis structures

When drawing Lewis structures for compounds formed from the combination of a metal/nonmetal, use the list of rules shown below:

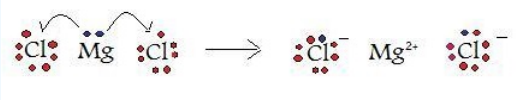
a. Locate the elements of interest and recall how many valence electrons each species has.
b. Draw dots around each element individually.
c. To obtain successful octets, the metal must transfer all of its valence electrons to the nonmetal.

d. At this point, the metal should have no electrons around it. In addition, the nonmetal will have an octet. If this does not occur, then refer to step e.
e. Additional atoms of the same two elements may be brought in to accomplish rules a-c.
f. **Cation and anion charges must be on Lewis structure to receive full credit (this is an ionic compound).**
g. To check structure, quickly write a formula for the ionic compound. This involves crossing down the charges diagonally and losing signs. You must reduce subscripts if they are divisible by a factor.

Example 4.5.1: Chloride Salts



In this example, the sodium atom is donating its 1 valence electron to the chlorine atom. This creates a sodium cation and a chlorine anion. Notice that the net charge of the resulting compound is 0. Only one atom of each element is needed to obtain a stable compound.



In this example, the magnesium atom is donating both of its valence electrons to chlorine atoms. Each chlorine atom can only accept 1 electron before it can achieve an octet; therefore, 2 atoms of chlorine are required to accept the 2 electrons donated by the magnesium. Notice that the net charge of the compound is 0. This Lewis structure requires two anions per one cation to produce a stable compound.

For more rigorous examples, access the CHM101 Furman moodle page (chapter 4 documents), to view a lightboard video of your instructor.

Contributors and Attributions

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4.6: Ionic Formula Writing

Learning Objectives

- Write formulas for binary ionic compounds
- Relate the Lewis structure to the chemical formula for binary ionic compounds.
- Commit bolded polyatomic formulas to memory.
- Write formulas for ternary (polyatomic) ionic compounds.

Ionic Formulas

Chemical formulas for ionic compounds are called ionic formulas. A proper ionic formula has a cation and an anion in it; an ionic compound is never formed between two cations or two anions only. The key to writing proper ionic formulas is simple: the total positive charge must balance the total negative charge. Because the charges on the ions are characteristic, sometimes we have to have more than one cation or an anion to balance the overall positive and negative charges. It is conventional to use the lowest ratio of ions that are needed to balance the charges.

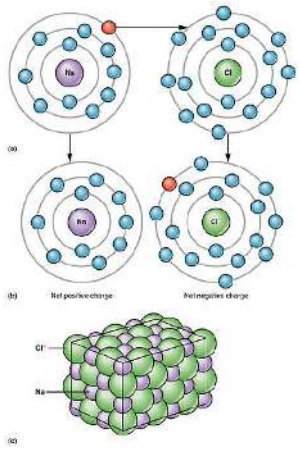


Figure **4.6.1**: Image taken from: upload.wikimedia.org/wikiped...my_Bonding.JPG

For example, consider the ionic compound between $\mathbf{Na^+}$ and $\mathbf{Cl^-}$. Each ion has a single charge, one positive and one negative, so we need only one ion of each to balance the overall charge. When writing the ionic formula, we follow two additional conventions:

1. write the formula for the cation first and the formula for the anion next, but
2. cross the charges down diagonally.

Thus, for the compound between $\mathbf{Na^+}$ and $\mathbf{Cl^-}$, we have the ionic formula $\mathbf{NaCl}$ (Figure **4.6.1**). The formula $\mathbf{Na_2Cl_2}$ also has balanced charges, but the convention is to use the lowest ratio of ions, which would be one of each. (Remember from our conventions for writing formulas that we do not write a 1 subscript if there is only one atom of a particular element present.) For the ionic compound between magnesium cations ($\mathbf{Mg^{2+}}$) and oxide anions ($\mathbf{O^{2-}}$, again we need only one of each ion to balance the charges. By convention, the formula is $\mathbf{MgO}$.



Figure 4.6.2: NaCl is the formular for Table Salt. The ionic compound NaCl is very common. Red rock salt from the Khewra Salt Mine in Pakistan. (CC BY-SA 4.0; Hubertl).

Rules for Writing Ionic Formulas

Recall ionic compound can be of the following combination: metal/nonmetal or ammonium/nonmetal

1. Recall the cation charge. Superscript this charge to the right of the cation ($Ca^{2+)}$. If metal is multi charged metal (like most transitions and metals below metalloid staircase), then the charge is indicated by a Roman numeral (Lead IV would translate to Pb^{4+}).
2. Recall the anion charge. Superscript this charge to the right of the anion (S^{2-}). If polyatomic ion is present, then put poly in parentheses and superscript charge to the right of this species.
3. Cross charges down diagonally and lose signs. Subscripts that are divisible by the same number must be reduced (ionics are simple compounds). Do not change what is inside a poly. You may keep your parentheses around polyatomic ions.

* Binary compound names will end with ide (except cyanide and hydroxide). This means the anion will come from the periodic table.

** Compounds that contain polyatomic ions will end in ate/ite or the two weird ides (cyanide/hydroxide). You will need to memorize the polyatomic ion table below.**

Example 4.6.1:

Write the formulas for the combinations of ions below:

a. Ca^{2+} and Cl^{-}
b. Al^{3+} and F^{-}
c. Li^{+} and O^{2-}

Solution

a. The proper ionic formula is $CaCl_2$.
b. The formula for this compound is AlF_3.
c. After crossing charges diagonally down, the formula will be Li_2O.

? Exercise 4.6.2

Write the proper ionic formulas for each of the two given ions.

a. Fe^{2+} and S^{2-}
b. Fe^{3+} and S^{2-}

Answer a

FeS, Subscripts must be reduced for ionic compounds. If this is not done, then the answer will be incorrect.

Answer b

Fe_2S_3, These subscripts cannot be reduced because they are not divisible by the same number.

There also exists a group of ions that contain more than one atom. These are called **polyatomic ions**. Table **4.6.1** lists the formulas, charges, and names of some common polyatomic ions. Only one of them, the ammonium ion, is a cation; the rest are anions. Most of them also contain oxygen atoms, so sometimes they are referred to as ***oxyanions***. Some of them, such as nitrate and nitrite, and sulfate and sulfite, have very similar formulas and names, so care must be taken to get the formulas and names correct. Note that the -ite polyatomic ion has one less oxygen atom in its formula than the -ate ion but with the same ionic charge.

Table **4.6.1**: Common Polyatomic Ions

Name	Formula and Charge		Name	Formula and Charge
ammonium	$(NH_4)^+$		nitrate	$(NO_3)^-$
acetate	$(C_2H_3O_2)^-$		nitrite	$(NO_2)^-$
bicarbonate (hydrogen carbonate)	$(HCO_3)^-$		carbonate	$(CO_3)^{2-}$
hydroxide	$(OH)^-$		sulfate	$(SO_4)^{2-}$
chlorate	$(ClO_3)^-$		sulfite	$(SO_3)^{2-}$
hypochlorite	$(ClO)^-$		phosphate	$(PO_4)^{3-}$
cyanide	$(CN)^-$		phosphite	$(PO_3)^{3-}$

You will need to commit Table **4.6.1** to memory for future tests and quizzes. There are more polyatomic ions than the ones listed in the table above. You will be provided with a list of these additional polyatomic ions for use on tests/quizzes. In our class, this list (List O' Polyatomics) will have the ones you are required to memorize in bold print.

Writing the formulas of ionic compounds has one important difference. If more than one polyatomic ion is needed to balance the overall charge in the formula, enclose the formula of the polyatomic ion in parentheses and write the proper numerical subscript to the right and *outside* the parentheses. Thus, the formula between calcium ions, Ca^{2+}, and nitrate ions, $NO3^-$, is properly written $Ca(NO3)2$, not $CaNO32$ or $CaN2O6$. In our course, I encourage you to keep your polyatomics insides parentheses at all times. Refer back to your rules for writing ionic formulas.

✓ Example 4.6.4:

After writing these formulas, watch your instructor teach more examples of this concept by clicking on this link.

a. ammonium sulfide
b. aluminum phosphate
c. iron II phosphite

Solution

a. Ammonium is a polyatomic ion (cation). These species will go first in the formula. Take ammonium $(NH_4)^+$ and combine it with sulfide S^{2-}(ide = periodic table, except for hydroxide/cyanide). While keeping the polyatomic formula within parentheses, cross the ion charges down and lose signs. The resulting formula will be **$(NH_4)_2S$**.

b. Aluminum is Al^{3+} and phosphate is $(PO_4)^{3-}$. While keeping the polyatomic ion inside parentheses, cross charges down and reduce subscripts outside. The final formula for the compound will be **$Al(PO_4)$**. For more advanced chemistry courses, students are encouraged to drop the parentheses if a subscript is not present once charges have been crossed down. I am fine with you always keeping parentheses.

c. Transition metal charges (except for silver and zinc) will always be noted by a Roman numeral. This charge is always positive for the metal ion. Place this charge to the top right corner of the metal atom, Fe^{2+}. Next, recall that phosphite is the polyatomic, $(PO_3)^{3-}$. Cross the charges down diagonally and keep the polyatomic inside the parentheses. The final result will be **$Fe_3(PO_3)_2$**.

? Exercise 4.6.4

Write the formulas for the following ionic compounds:

a. ammonium bicarbonate
b. cobalt III nitrite
c. lead IV oxide
d. potassium hydroxide
e. silver phosphide
f. mercury I sulfite

Answer a

$(NH_4)(HCO_3)$, there are no numbers outside the parentheses so you could write NH_4HCO_3 for the answer. Do not combine the hydrogen atoms in the formula.

Answer b

$Co(NO_2)_3$, the parentheses must be kept for this answer.

Answer c

PbO_2, after the charges have been crossed, subscripts must be reduced by the division of common factor

Answer d

$K(OH)$, you could drop ()

Answer e

Ag_3P, phosphide is from the periodic table, not the polyatomic table. Know your endings!!

Answer f

$Hg_2(SO_3)$, you could drop ()

Key Takeaways

- Ions form when atoms lose or gain electrons.
- Ionic compounds have positive ions and negative ions.
- Ionic formulas balance the total positive and negative charges.

Contributors and Attributions

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4.7: Applications and Solubility of Ionic Compounds

Learning Objectives

- Read the solubility of an ionic compound by using a provided table.
- Use the abbreviations (aq) and (s) appropriately.
- Realize soluble compounds will form homogeneous mixtures in water.
- Realize insoluble compounds will form heterogeneous mixtures in water.
- Know applications of the compounds contained on this page.
- Be able to match polyatomic names with their uses/properties shown in the chart of this section.

Determining Ionic Solubility

Inorganic compounds can be dissolved to sanitize drinking water. Water distributors may use a variety of methods to disinfect water. Chemical disinfection of water typically involves adding a form of chlorine. This can be done by either bubbling chlorine gas into a system or adding soluble inorganic chlorinated compounds. Using chlorine gas involves a great bit of skill due to its toxic nature. This yellow-green gas is denser than air and has previously been used as a chemical weapon. On the other hand, soluble chlorinated compounds are more stable and less toxic to handle. Regardless of its form, chlorine can be quite corrosive.



Figure* 4.7.1*: *Chlorine gas in a Florence flask and concentrated liquid solutions for use in swimming pool. (CC BY-SA 4.0; gas flask - Larenmclane and pool chlorine - Maksym Kozlenko)*

In order to kill bacteria and viruses, the chlorinated compound must be soluble in water. Chlorine-based ions that become soluble can deactivate most all microorganisms except protozoans (examples would be giardia and cryptosporidium). In determining whether an inorganic chlorine compound will be soluble, chemists refer to a solubility table. The table below shows the solubilities of various compounds, in water, at a pressure of 1 atm and at room temperature (~293 K). Any box that reads "aq" results in an aqueous product in which no solid remains, while "s" indicated that the compound will not dissolve in water. Boxes marked "d" mean that the compound decomposes on reacts with water.

Ionic solubility can be important when ingesting minerals for nutrition. Vitamins are packaged to contain compounds with specific metallic ions. Click on this libretext link to see the various trace minerals the body needs.

Solubility can be altered by manipulating temperature. Typically, many insoluble compounds can be dissolved at higher temperatures; however, this trend does not apply to every compound. For example, for Flint River residents, boiling their drinking water increased the solubility of the lead compounds that were already present. This action made the lead more concentrated and produced higher ppb levels. Please do not memorize the solubility table for this class. A chart will always be accessible for tests and quizzes.

Table **4.7.1**: Solubility chart of ionic compounds in water (s = solid, aq = aqueous/soluble, and d= decomposes)

Ion	acetate	carbonate	chlorate	chloride	fluoride	hydroxide	nitrate	nitrite	phosphate	sulfate	sulfide	sulfite
aluminum	s	s	aq	aq	s	s	aq		s	aq	d	d
ammonium	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq
barium	aq	s	aq	aq	s	aq	aq	aq	s	s	s	s
calcium	aq	s	aq	aq	s	s	aq	aq	s	s	d	s
cobalt II	aq	s	aq	aq	s	s	aq		s	aq	s	s
iron III	s	s	s	aq	aq	s	aq		s	aq	s	s
copper II	aq	s	aq	aq	s	s	aq		s	aq	s	s
lead II	aq	s	aq	s	s	s	aq	aq	s	s	s	s
lithium	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq
magnesium	aq	s	aq	aq	s	s	aq	aq	s	aq	-------	aq
nickel II	aq	s	aq	aq	aq	s	aq		s	aq	s	s
potassium	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq
silver	s	s	aq	s	aq	s	aq	s	s	s	s	s
sodium	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq
zinc	aq	s	aq	aq	aq	s	aq		s	aq	s	s

Encountering Ionics in the Home

There are many real-world applications of ionic compounds. For example, sodium chloride (table salt) is used to season food. Consuming large amounts of sodium ion (regardless if it is from sodium chloride, sodium glutamate, or sodium benzoate) can lead to cardiovascular and kidney problems. The American Heart Association recommends that individuals limit their sodium intake to less than 2300 mg per day. Watch the video below to obtain more information about sodium:



Video 4.7.1: Where do Americans get most of their sodium? According to a study published in the journal Circulation, restaurant and processed foods accounted for nearly 71 percent of consumer's dietary sodium in a study of three U.S. regions.

People who still want to season their food without sodium can opt to use potassium chloride, a table salt substitute. Unfortunately, this compound can taste extremely bitter. For this reason, some table salt substitutes will contain a mixture of both of these compounds.

Another ionic compound that can be commonly found is calcium carbonate. This compound is also known as chalk and is contained in antacids like Tums and Rolaids. The carbonate portion of this formula helps to neutralize excess stomach acid to help soothe the stomach. When purchasing these over the counter medications, remember to buy generic forms of these products.



Figure 4.7.2: Bottle of Antacid tablets. (CC BY-SA 3.0; Midnightcomm).

These type of antacids are quick acting and should be used for short-term stomach problems. If you experience chronic reflux or upset stomach, a health care professional would suggest a different type of medication (like Nexium, Zantac, or Prilosec) that does not neutralize excess stomach acid. Instead, these three medications deactiviate enzymes that produce the excess stomach acid.

Antacids that contain carbonates and bicarbonates will produce carbon dioxide gas inside the body. Unless an antigas ingredient is added in these products, then the patient will feel quite gaseous. Other side effects that can occur from taking these medications would be diarrhea (**if magnesium is present**) or constipation (**if aluminum is present**).

Two common compounds used to sanitize are ammonium hydroxide and sodium hypochlorite. Ammonia has a pungent odor and a basic pH (value greater than 7.0). Derivatives of ammonia are used as fertilizers and smelling salts (stimulant). When working with ammonia-based compounds, individuals need to be aware of its corrosive nature. In addition, this compound can be extremely deadly to people who have lung impairments like asthma or COPD.



Figure **4.7.3**: Generic smelling salts can be used to revive a person who has fainted. Image taken from: https://www.flickr.com/photos/28581290@N08/6333856944

The common name for sodium hypochlorite is bleach. It is less volatile than ammonia but still has a distinct smell. This chemical is used to remove stains from clothing and can be used to disinfect water. Both ammonia and bleach are effective in killing most germs. However, these two chemicals should never be combined to make a new household cleaner. The resulting product of this reaction would be chlorine gas.

Real-world applications of specific polyatomic ions

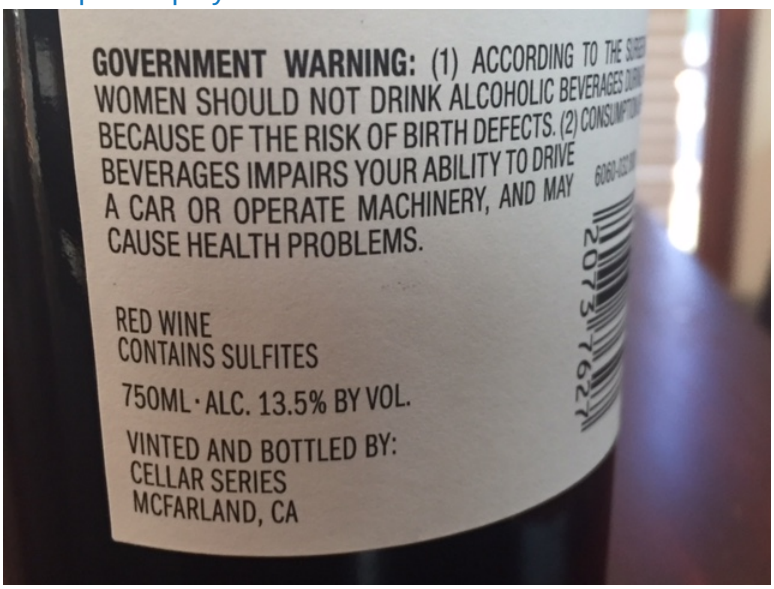


Figure **4.7.4**: This red wine contains sulfite preservatives. Image made by Elizabeth R. Gordon

Ionic compounds that contain certain polyatomics can have a variety of applications. The table below gives a sample of where you might encounter polyatomic ions. For this class, it is important to match a polyatomic with its application or stated property.

Polyatomic Ion	Uses/Facts
Carbonates and Bicarbonates CO_3^{2-}/HCO_3^-	Short-term antacids, act as bases (high pH)
Nitrates NO_3^-	Fertilizers, explosives, and preserved meats (mutagen and probable carcinogen)(a suspected cause of migraines)
Nitrites NO_2^-	Preservative for meats (mutagen and probable carcinogen)(a suspected cause of migraines)
Phosphates PO_4^{3-}	Fertilizers (gives the green color to plants, if not present in sufficient amounts plants will die)
Alkali Hydroxides OH^-	Very corrosive bases, found in dry batteries, soaps, Drano, and oven cleaner
Sulfites SO_3^{2-}	Preservative found in dried fruit and red wine (possible allergen)
Cyanides CN^-	Poison used in Tylenol Murders and Jim Jones cases. Smells like almonds

Click on the video below to watch a short production of how cyanide affected the United States in 1982. After viewing, note how drug packaging changed following this event.



***Figure* 4.7.5:** *Tylenol 1982 Murders - PR Strategy*

? Exercise 4.7.1

a. When a compound dissolves in water, what abbreviation do you place beside the chemical formula?
b. Which compounds (when dissolved in individual containers) would produce heterogeneous mixtures in water: silver sulfate, iron III chlorate, lithium hydroxide, magnesium phosphate, or lead II nitrate.
c. Which compounds could be used to preserve meats: KNO_3, KOH, or K_2CO_3?
d. Write all the chemical formulas for the aqueous compounds in #2.
e. Which compound in question c could be used as an antacid?

Answer a

Place the abbreviation (aq) to the right of the chemical formula to indicate compound is water soluble.

Answer b

Iron III chlorate and magnesium phosphate are both insoluble compounds. These ionic compounds would form heterogeneous mixtures with water.

Answer c

KNO_3 contains a nitrate which could be used as a chemical preservative.

Answer d

LiOH(aq), $Al_2(SO_4)_3$ (aq), and $Pb(NO_3)_2$(aq) are all water soluble.

Answer e

K_2CO_3 contains a carbonate which can safely neutralize excess stomach acid.

Contributors and Attributions

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4.8: Covalent Bonding and Formula Writing

Learning Objectives

- To know what types of elements bond to form covalent compounds.
- To appreciate how atoms share their valence electrons in covalent bonding.
- Memorize numerical prefixes used in covalent nomenclature
- Understand that covalent compound subscripts are never reduced.

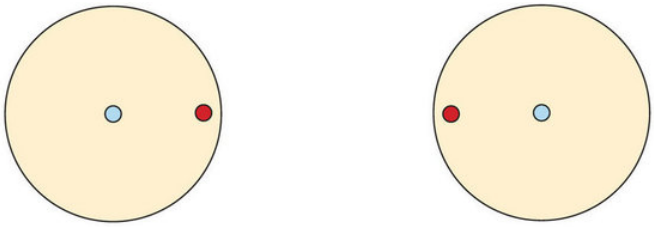
Electron Sharing

Previously, we discussed ionic bonding where electrons can be transferred from one atom to another so that both atoms have an energy-stable outer electron shell. Because most filled electron shells have eight electrons in them, chemists called this tendency the octet rule. However, there is another way an atom can achieve a full valence shell: atoms can *share* electrons. This type of bonding would be a covalent bond. Two combinations of atoms can produce this type of bonding: nonmetal/nonmetal or metalloid/nonmetal. **In this class, we will not discuss the option of metallic bonding which is a form of covalent bonding.**

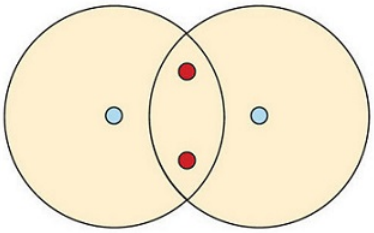


Figure **4.8.1**: Sharing is caring, especially for atoms that participate in covalent bonding. (CC BY-2.0; Carlos Maya).

This concept can be illustrated by using two hydrogen atoms, each of which has a single electron in its valence shell. (For small atoms such as hydrogen atoms, the valence shell will be the first shell, which holds only two electrons.) We can represent the two individual hydrogen atoms as follows:



In contrast, when two hydrogen atoms get close enough together to share their electrons, they can be represented as follows:



By sharing their valence electrons, both hydrogen atoms now have two electrons in their respective valence shells. Because each valence shell is now filled, this arrangement is more stable than when the two atoms are separate. The sharing of electrons between atoms is called a covalent bond, and the two electrons that join atoms in a covalent bond are called a bonding pair of electrons. A discrete group of atoms connected by covalent bonds is called a molecule—the smallest part of a compound that retains the chemical identity of that compound.

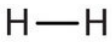
Chemists frequently use Lewis diagrams to represent covalent bonding in molecular substances. For example, the Lewis diagrams of two separate hydrogen atoms are as follows:



The Lewis diagram of two hydrogen atoms sharing electrons looks like this:



This depiction of molecules is simplified further by using a dash to represent a covalent bond. The hydrogen molecule is then represented as follows:



Remember that the dash, also referred to as a single bond, represents a *pair* of electrons.

The bond in a hydrogen molecule, measured as the distance between the two nuclei, is about 7.4×10^{-11} m, or 74 picometers (pm; 1 pm = 1×10^{-12} m). This particular bond length represents a balance between several forces: the attractions between oppositely charged electrons and nuclei, the repulsion between two negatively charged electrons, and the repulsion between two positively charged nuclei. If the nuclei were closer together, they would repel each other more strongly; if the nuclei were farther apart, there would be less attraction between the positive and negative particles.

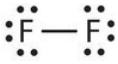
Fluorine is another element whose atoms bond together in pairs to form *diatomic* (two-atom) molecules. Two separate fluorine atoms have the following electron dot diagrams:



Each fluorine atom contributes one valence electron, making a single bond and giving each atom a complete valence shell, which fulfills the octet rule:



The circles show that each fluorine atom has eight electrons around it. As with hydrogen, we can represent the fluorine molecule with a dash in place of the bonding electrons:



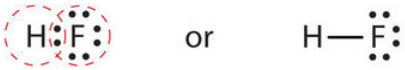
Each fluorine atom has six electrons, or three pairs of electrons, that are not participating in the covalent bond. Rather than being shared, they are considered to belong to a single atom. These are called nonbonding pairs (or **lone pairs**) of electrons.

Covalent Bonds between Different Atoms

Now that we have looked at electron sharing between atoms of the same element, let us look at covalent bond formation between atoms of different elements. Consider a molecule composed of one hydrogen atom and one fluorine atom:



Each atom needs one additional electron to complete its valence shell. By each contributing one electron, they make the following molecule:



In this molecule, the hydrogen atom does not have nonbonding electrons, while the fluorine atom has six nonbonding electrons (three lone electron pairs). The circles show how the valence electron shells are filled for both atoms.

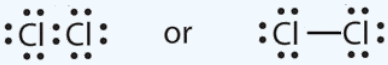
Example 4.8.1

Draw the Lewis diagram for each compound.

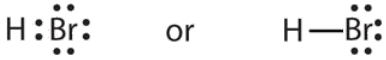
a. a molecule composed of two chlorine atoms
b. a molecule composed of a hydrogen atom and a bromine atom

Solution

a. Chlorine has the same valence shell electron configuration as fluorine, so the Lewis diagram for a molecule composed of two chlorine atoms is similar to the one for fluorine:



- Bromine has the same valence shell electron configuration as fluorine, so the Lewis diagram for a molecule composed of a hydrogen atom and a bromine atom is similar to that for hydrogen and fluorine:

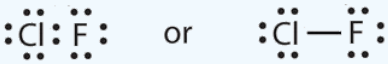


Exercise 4.8.1

Draw the Lewis diagram for each compound (show both formats).

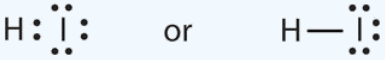
a. a molecule composed of one chlorine atom and one fluorine atom
b. a molecule composed of one hydrogen atom and one iodine atom

Answer a



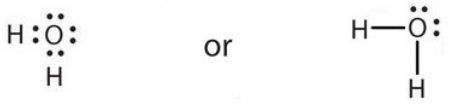
Chlorine monofluoride is a volatile interhalogen compound.

Answer b



HI is used in organic and inorganic synthesis as one of the primary sources of iodine.

Larger molecules are constructed in a similar fashion, with some atoms participating in more than one covalent bond. For example, water, with two hydrogen atoms and one oxygen atom can be represented as follows:



and methane (CH_4), with one carbon atom and four hydrogen atoms, can also be represented as follows:

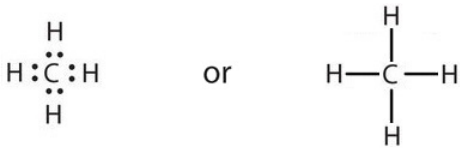


Figure **4.8.1** shows the number of covalent bonds various atoms typically form.

Rules for drawing Covalent Lewis Structures

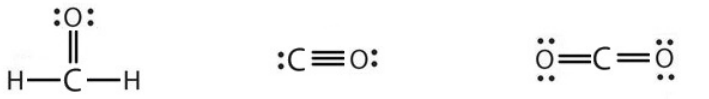
These apply to either nonmetal/nonmetal or metalloid/nonmetal combinations.

1. Tally up all valence electrons that are to be used. Remember valence electrons are the roman numerals above the element.
2. Determine which atom is to be central. Carbon is always central and Hydrogen is a terminal atom. If these atoms are not present, then go with the atom you have least of in the formula.
3. Connect each atom to the central atom using single bonds first.
4. For simple molecules or ions (only have two atoms), try single bonds, then double, and finally triple to achieve octets around each atom (except for B, Be, and H)
5. For more complex molecules or ions (3 or more atoms), try one multiple bond at a time if single bonds achieve octets.
6. My series for molecules/ions that need more than single bonds can be seen below (keeping in mind H, B, and Be only have single bonds)
    - Single/single ($-$, $-$) ,
    - then single/double ($-$, $=$),
    - then double/double ($=$, $=$),
    - and if that does not work try triple/single ($\equiv$, $-$)
7. In our class, we do not use multiple bonds for halogens.

Double and Triple Bonds

In covalent bonding, using double (four total electrons) or triple (six total electrons) is an option in order to achieve a stable octet. If a single bond does not work, then you may incorporate a multiple bond. Please note the rules above on which atoms will never achieve octets (hydrogen and boron). Although it is mathematically feasible, halogens will not use multiple bonds to become stable either.

Let's look at a few molecules that utilize multiple bonds:



Formaldehyde Carbon Monoxide Carbon Dioxide

Atoms that could employ multiple bonds would be oxygen, nitrogen, sulfur, phosphorus, and carbon. If an octet can be achieved with a single bond, do not incorporate multiple bonds into the structure.



Oxygen Difluoride (Incorrect) Oxygen Difluoride (Correct)

https://chem.libretexts.org/@go/page/96867

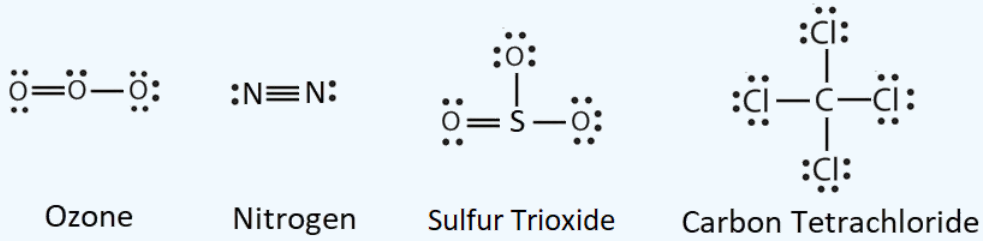
Multiple bonds involve more that one type of connection. For this reason, it is more difficult to break or cleave a multiple bond than it would be a single bond or a bond of a lower order (when comparing the same connected atoms). For example, the triple bond found in carbon monoxide is harder to break than one of the double bonds found in carbon dioxide. When reading about smog production or ozone depletion, consider the bond strengths of the chemicals involved in this environmental problems.

Example 4.8.1

Before drawing the structures below, access the Furman University CHM101 moodle documents, Here, you will see a lightboard video of your instructor drawing Lewis structures for a variety of covalent compounds. Then, try to construct structures of the other molecules in this example.

a. O_3 (ozone)
b. N_2 (nitrogen)
c. SO_3 (sulfur trioxide)
d. CCl_4 (carbon tetrachloride)

Solutions



Formula Writing for Covalent Compounds

Covalent compounds use prefixes to indicate the numbers of atoms in their formulas. In order to write correct formulas, you will need to **memorize** Table **4.8.1** below.

Table **4.8.1**: Prefix to occurrence correlations.

Prefix name	Number of Atoms
Mono	1
Di (not bi)	2
Tri	3
Tetra (not quad)	4
Penta	5
Hexa	6
Hepta (not septa)	7
Octa	8
Nona	9
Deca	10

Rules for Writing Covalent formulas

1. There are no charges involved with covalent compounds.
2. Interpret the prefixes to represent the number of atoms or the subscript.
3. Do not cross or reduce subscripts (unlike ionic compounds).
4. The formula should reflect the name of the compound.

Example 4.8.1

Write formulas for the following covalent compounds:

a. dinitrogen pentoxide
b. boron trihydride
c. sulfur hexafluoride
d. carbon tetrachloride
e. silicon dioxide
f. dihydrogen dioxide

Answer a

N_2O_5

Answer b

BH_3

Answer c

SF_6

Answer d

CCl_4

Answer e

SiO_2

Answer f

H_2O_2, don't reduce subscripts in covalent compounds

Contributors and Attributions

- Elizabeth R. Gordon (Furman University)
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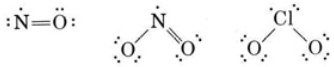
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4.9: Free Radicals and the Environment

Learning Objectives

- Recognize the structures of free radicals.
- Understand how free radicals affect the environment and biological systems.
- Know specific compounds that form photochemical smog.
- Understand how photochemical smog affects the environment and people.
- Realize that ozone in the stratosphere protects the earth from UV rays.
- Explain the basics of the Chapman Cycle.
- Provide sources of chemicals that deplete the ozone layer at an accelerated rate.
- Know where areas of depleted ozone are on the planet.
- Differentiate between CFCs, HCFC, HFC, and halons.
- Know the meaning and environmental impact of ODS and GWP.
- Appreciate the Montreal Protocol.

The majority of molecules or complex ions discussed in general chemistry courses are demonstrated to have *pairs* of electrons. However, there are a few stable molecules which contain an odd number of electrons. These molecules, called ***"free radicals"***, contain at least one unpaired electron, a clear violation of the octet rule. Free radicals play many important roles a wide range of applied chemistry fields, including biology, medicine, and environmental chemistry. Three well-known examples of such molecules are nitrogen monoxide, nitrogen dioxide, and chlorine dioxide. The most plausible Lewis structures for these molecules are



In this course, you need to be concerned with identifying free radical species. It is not necessary for you to know where to place the spare electron. In addition, please focus on the problems with free radicals that are discussed in the sections below.

Photochemical Smog

The two nitrogen-containing compounds above are classified as being NO_{xs}. These free radicals are produced from high-temperature combustion of fuel by vehicles and industry. NO_{xs} can also be produced by natural processes. For example, lightning and volcanic eruptions produce these species. These gases do differ from one another. Nitrogen monoxide (also known as nitric oxide) is a colorless and non-flammable gas. In contrast, nitrogen dioxide is a reddish-orange gas that is extremely flammable. Nitrogen monoxide has a slight odor, while nitrogen dioxide has a very sharp, acrid smell.

Once NO_{xs} are produced, they can react with ultraviolet light to produce more free radicals. After a series of reactions, these species produce ground-level ozone (O_3) which is referred to as smog. In regards to the environment, smog reduces visibility and smog precursors NO_{xs} and SO_{xs} react with water to produce acid rain. As for humans, NO_{xs} can affect lung, heart, and immunity functioning. Photochemical smog is more of an issue in highly populated cities that rely heavily on transportation sources and electrical power plants. Fortunately, the United States Environmental Protection Agency (EPA) regulates NO_{xs} amounts for vehicles and power plants.



Figure **4.9.2**: Arial photograph of photochemical smog in Manhattan, New York. Documerica was a program sponsored by the Environmental Protection Agency to photographically document subjects of environmental concern in America during the 1970s.

Consumers of American cars can review smog ratings before purchasing a vehicle. Cars and trucks produce other chemicals besides NOxs that contribute to smog formation. For a basic rating on smog-producing ability, click here and input your vehicle's information. On this website, smog ratings are assigned to mobile sources (cars, trucks, sports utility vehicles) from one to ten. A low score indicates that the vehicle produces a large number of smog precursors.

Protective Ozone (O_3)

Ozone or O_3 can be harmful or helpful depending on where it is located. In the troposphere (see image below), ozone is referred to as smog. This particular species can be formed from free radicals. Previously, you have learned the harmful effects of being exposed to ground level ozone. However, ozone acts as a protective shield in the stratosphere. Of the three forms of ultraviolet radiation, ozone completely screens the Earth's surface from UV-C radiation. Portions of UV-B (causes more burning of skin) and UV-A (causes more tanning of skin) still reaches the terrestrial environment.

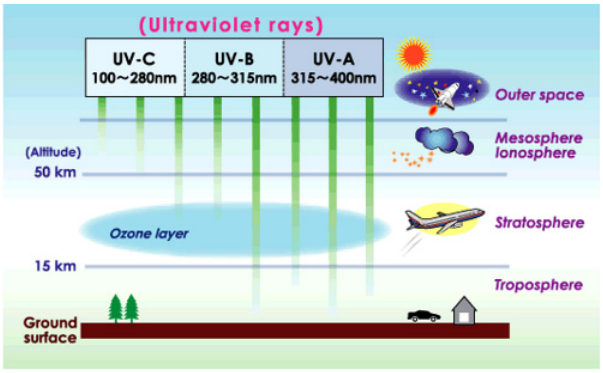


Figure **4.9.3**: Levels of the atmosphere and location of the O_3 layer. Image is taken from commons.wikimedia.org/wiki/F...5%E0%B8%81.jpg

If all the ozone in the atmosphere were combined, it would have a thickness of less than 0.5 cm (.20 inches). Ozone is most concentrated in the lowest 15 km portion of the stratosphere. NASA and other atmospheric scientists utilize the Dobson scale to represent the concentration of ozone molecules. One Dobson Unit (DU) is the number of ozone molecules that could create a 0.01 mm layer of thickness (conditions of 0ºC and 1.0 atm). NASA reports the average thickness of the ozone layer to be **300 DU** which translates to **3 mm**. A depleted ozone layer would register as being equal to or less than **100 DU** or a thickness of **1 mm.** The NASA image below depicts a purplish-blue region that corresponds to the largest area of ozone depletion. First detected in 1985, the ozone hole has grown to a maximum of 7.6 million square miles (or 2.5 times the size of the United States. NASA reported this peak value on September 11, 2017.

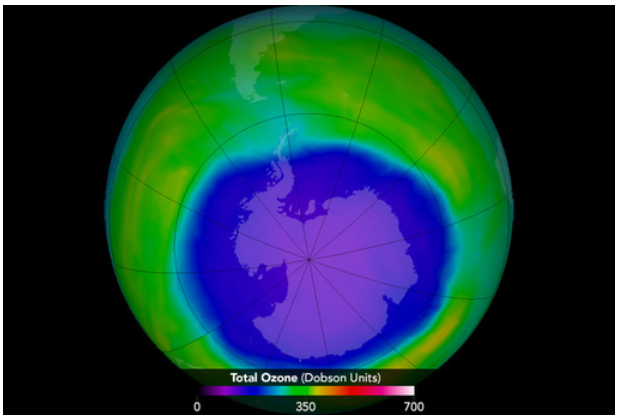


Figure **4.9.4**: NASA image of Dobson units that correlates to O_3 concentration. (Public Domain; NASA)

Ozone is made and decomposed naturally via the Chapman cycle. In the stratosphere, ultraviolet light breaks the double bond of the diatomic oxygen molecule. From this reaction, spare oxygen (O) atoms encounter more diatomic oxygen (O_2) molecules to produce ozone. Ultraviolet light can attack ozone molecules BY CLEAVING ONE oxygen bond in the structure. This natural cycle of ozone production and decomposition repeats in the Chapman Cycle.

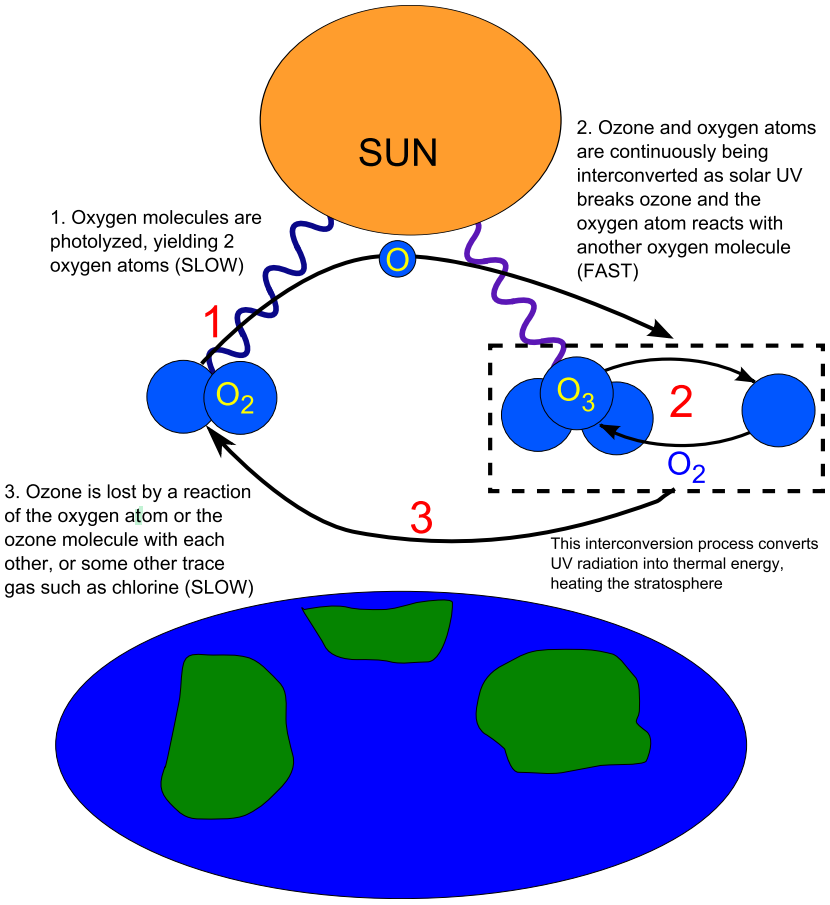


Figure **4.9.5**: Production and decomposition of ozone via the Chapman Cycle. (Public Domain via Wikipedia)

Understanding Stratospheric Ozone

Watch The following video and then answer the questions below:



a. What is the formula for ozone? what types of bonds does this molecule have (you will need to draw)?
b. How many ozone molecules are present per 10 million molecules of air?
c. What percentage of UV rays does ozone layer absorb?
d. What chemicals are responsible for depleting ozone?
e. What are the uses of the chemicals in question #4?
f. When UV light hits ozone-depleting chemicals, what atom is liberated? How many valence electrons does this atom have?
g. Where are the areas on the earth that have ozone holes or patches?
h. Why is the largest area of depletion over Antartica?
i. At this time, is the ozone hole growing or shrinking?
j. What protocol banned the production of ozone-depleting chemicals?

Answer a

Ozone (O_3), which this molecule has a single and a double bond. The single bond is much weaker and longer. It would be easier to break this bond.

Answer b

3

Answer c

98%

Answer d

CFCs are organic compounds that contain different combinations of carbon, chlorine, fluorine, and sometimes hydrogen. The chlorine portion is particularly toxic to the ozone layer.

Answer e

Chlorine gas or chlorine that is used to disinfect drinking water is not a CFC.

Answer f

When ultraviolet light hits a CFC, chlorine is freed and becomes a free radical. This reactive species attacks the ozone molecule at the single bond location. Chlorine atom has seven valence electrons.

Answer g

Both poles contain areas that are lacking in O_3.

Answer h

The CFCS used in northern hemisphere eventually migrated to the cold areas of Antarctica. The temperatures in this area catalyze (speed up) the free radical reactions. This produces more chlorine atoms that will attack ozone molecules.

Answer i

The hole is shrinking!

Answer j

Montreal Protocol

Causes of Depletion

Before the 1920's, the mechanism of chemical refrigeration required such toxic chemicals as ammonia or sulfur dioxide. Frigidaire scientists focused on synthesizing safer compounds to be used in this industry. This research lead to the production of CFCs or compounds that contained a combination of chlorine, carbon, and fluorine. Chemists found these colorless liquids to be very volatile and inert. By the 1970's, the chemical industry was producing one million tons a year of these chemicals to be used as refrigerants, propellants, and foaming agents.



Figure **4.9.6**: Asthma inhaler with CFC propellant. (Public Domain; US Govnerment).

Perhaps the most common CFC made was dichlorodifluoromethane. This CFC is also known as Freon-12 and was used as a refrigerant for cars, commercial, and industrial air conditioning systems. Today, the United States is no longer able to make this compound and distributors must have a Freon license to distribute existing supplies. Even though you might use the term "freon" to describe air conditioning coolant, you are not using this particular chemical due to environmental restrictions.

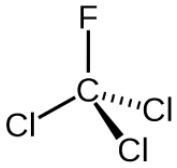


Figure **4.9.7**: Chemical structure of Freon-12.

In the early to late 1970's, many international studies determined CFCs and other halons (once used as fire retardants), particularly those containing bromine, contributed to the destruction of the ozone layer. It was not until the mid-1980's that an international treaty was formulated to reduce the production of certain ODS (ozone depleting substance). In 1987, over 190 countries signed the Montreal Protocol. Upon signature, countries would agree to reduce and then eliminate ODS chemicals that contained chlorine or bromine. Countries that could not afford to find suitable replacements for ODS would be given time extensions and funding.



Figure **4.9.8**: Label indicating ozone friendly packaging. Picture courtesy of Elizabeth R. Gordon

Operation Cool breeze

Even though freon production in the United States has halted, this chemical is still used in refrigeration systems that cannot switch to ozone-friendly replacements. This has opened an illegal smuggling of freon into countries that have signed the Montreal Protocol. In the United States, freon smuggling is an environmental crime. Violators that have been prosecuted have paid fines and/or served time in prison. Read the article in this link and record main ideas regarding EPA/s Operation Cool Breeze.

The United States and several other countries replaced many CFCs with HCFC compounds. By adding hydrogen, this allowed a CFC compound to retain its chlorine atoms. In other words, ultraviolet light would not be able to break the C-Cl bond releasing a chlorine free radical. Unfortunately, HCFCs were found to have higher global warming potentials (GWP) and would need to be phased out as well. For most countries, this HCFC reduction would occur in 2010. During this time, countries substituted HFCs for both HCFC and CFC compounds. HFCs have the lowest OD potential but still, have high GWP. Today, countries are focusing on finding more environmentally friendly replacements for these chemicals as well. Keep in mind, each chemical substitution that has been mentioned is costly and still affects the environment.

Table **4.9.1**: Comparing CFCs, HCFCs, HFCs, and halons.

Chemicals Formula	Classification	Atmospheric lifetime (years)	ODP	GWP
CF_2Cl_3	CFC	69	1.0	4660
CF_2Cl_2	CFC	195	1.0	10,200
CF_3Br	Halon	65	13	6300
CF_2ClBr	Halon	20	5.0	1750
$CHClF_2$	HCFC	13	.055	1760
$CHCl_2CF_3$	HCFC	1.4	.02	80
CH_2F_2	HFC	5	0	677
CHF_2CF_3	HFC	29	0	3170

Free radical formation from the cleavage (breaking) of the C-Cl bond by ultraviolet light can be seen in the reactions below. It is **not** important for you to memorize these series of reactions. However, it should be noted that chlorine and bromine cause ozone depletion when they are freed from ozone-depleting substances.

Ultraviolet radiation, denoted by $h\nu$, breaks the carbon chlorine bond to form two free radicals

$$CF_2Cl_2 + h\,\nu \rightarrow CF_2Cl^{\cdot} + Cl^{\cdot} \tag{4.9.1}$$

Chlorine atom being highly reactive reacts with ozone (O_3).

$$Cl^{\cdot} + O_3 \rightarrow ClO^{\cdot} + O_2 \tag{4.9.2}$$

The monoxide of chlorine further reacts with another molecule of O_3

$$ClO^{\cdot} + O_3 \rightarrow Cl^{\cdot} + 2\,O_2 \tag{4.9.3}$$

The chlorine atom so obtained reacts with another ozone molecule. Hence, steps 4.9.2 and 4.9.3 are repeated again and again and, leads to the depletion of concentration of ozone.

The Montreal Protocol

International policy efforts to restrict production of ozone depleting CFCs culminated in the 1987 treaty known as the **Montreal Protocol** in which signing nations agreed to cut CFC production in half by 1998. At least five follow-up agreements since then helped to deepen the cuts, advanced timetables for compliance, and addressed additional ozone-depleting substances such as halons, methyl chloroform, carbon tetrachloride, and hydrochlorofluorocarbons (HCFCs). Most countries around the world have phased out production of the substances covered by the agreements and industry has been able to shift to safer alternative chemicals. As a result, there's evidence that the Antarctic ozone hole has stopped growing worse, although recovery is not expected anytime soon. Phasing out CFCs and HCFCs is also beneficial in protecting the earth's climate, as these substances are also very damaging greenhouse gases.

As part of the United States' commitment to implementing the Montreal Protocol, the U.S. Congress amended the Clean Air Act (section 6.7), adding provisions for protection of the ozone layer. Most importantly, the amended Act required the gradual end to the production of chemicals that deplete the ozone layer. The Clean Air Act amendments passed by Congress requires the Environmental Protection Agency (EPA) to develop and implement regulations for the responsible management of ozone-depleting substances in the United States. Under the Clean Air Act, EPA has created several regulatory programs to address numerous issues, including:

- ending the production of ozone-depleting substances,
- ensuring that refrigerants and halon fire extinguishing agents are recycled properly,
- identifying safe and effective alternatives to ozone-depleting substances,
- banning the release of ozone-depleting refrigerants during the service, maintenance, and disposal of air conditioners and other refrigeration equipment,
- requiring that manufacturers label products either containing or made with the most harmful ozone depleting substances.

References

1. https://www.nap.edu/read/5744/chapter/5#23
2. https://www.epa.gov/ozone-layer-prot...ing-substances

Contributors and Attributions

- Elizabeth R. Gordon (Furman University)
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- The Montreal Protocol contributed by Caralyn Zehnder et al.

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4.10: Free Radicals and Health

Learning Objectives

- Realize how free radicals can affect your health.
- Name some health conditions and diseases that can result from excessive free radical exposure.
- Provide examples of foods and beverages that contain antioxidants.
- Recognize chemicals in skin care products that can slow the effects of aging

Free radicals can be generated from a variety of processes. For example, combustion of any material will produce $OH^{\cdot}$ (not hydroxide), $NO^{\cdot}$ free radicals. Once inhaled, OH can enter the body and affect cells. Watch the video below to see how free radicals affect biological systems.



Video **4.10.1**: How do antioxidants keep you healthy? Our body is under constant attack from oxidative stress. By wrong lifestyle choices, we make billions of free radicals in our body leading to oxidative stress. This can also increase when we are physically and/or emotionally stressed. Oxidative stress occurs when there is an imbalance of free radicals and antioxidants (too many free radicals and too few antioxidants). It is a condition that results when our body does not have enough antioxidants to counter free radicals in our body.

Free Radicals and Disease

Free radical exposure has been linked to cancer and a number of autoimmune diseases. One way of fighting free radicals is to consume or apply antioxidants. By providing sources of electrons, antioxidants can detour free radicals from attacking healthy cells in the body. The word wall below displays a variety of foods that are rich in antioxidants. Foods and beverages that are rich in vitamins A, C, and E provide sources of electrons for free radicals. Minerals like selenium are also antioxidants. For a more comprehensive list of foods are labeled as being antioxidants, click here.



Figure **4.10.1**: Word wall art displaying antioxidants. Image is taken from pixabay.com/en/cloud-concept...dants-18527

Free Radicals and Aging

Some studies have linked biological free radical production to aging. In a cell's mitochondria, reactive oxygen species are naturally made. These substances damage fats, proteins, and mitochondria DNA. During this process, more free radicals are produced in the cell. Two of these destructive free radicals are superoxide (O_2-) and nitrogen monoxide (NO). These radicals have been linked to cancer, skin aging, heart disease, stroke, and other chronic diseases.

By eating more fruits and vegetables, many nutritionists believe the free radical effect can be reduced in regards to chronic disease. As for aging, many scientists believe that not just one theory can explain why aging occurs. For care of skin, dermatologists recommend that you reduce UV exposure. Ionizing radiation is a source of free radicals that can be minimized. Once the skin has been exposed to UV radiation, there is very little that can be done to counteract its effects.



Figure **4.10.2**: Skin comparison of a younger to an older person (Public Domain; via Wikipedia). Hand creams (Public Dominal Elizabeth R. Gordon)

Dermatologists and nutritionists recommend a diet rich in antioxidants (vitamins C, E, selenium, and coenzyme Q) to protect skin from damaging free radicals. Lotions, moisturizers, and sunscreens can contain these ingredients as well.

Skin Care products

Watch the following video to understand how to care for your skin



1. What are the purposes of the Epidermis and dermis in your skin?
2. What do GAGS do:
3. How can UVB help the body?
4. What do the letters ROS represent?
5. How do free radicals affect DNA, proteins, Fats, and the Dermis?
6. What types of chemicals help repair damaged skin?
7. When should the chemicals in question #6 not be used?
8. How does Salicylic acid make skin appear more youthful?
9. What is the purpose of applying hyaluronic (it is a humectant) acid to skin?
10. Why are peptide products useless?
11. According to this video, what is the best anti-aging product you can purchase?

***Figure* 4.10.11** *Retinol*

Manufacturers of anti-aging lotions or creams might use the scientific chemical names for the antioxidant ingredients. When purchasing these products, remember to translate them accordingly. Consumers often spend excessive amounts of money on anti-aging creams and lotions. The best way to reduce advanced aging is to protect your skin from ultraviolet exposure. In addition, selecting a skin-care product that contains a combination of some of the antioxidants below is helpful. Lastly, there is no need to pay a large amount of money for an anti-aging product.

Table **4.10.2**: Antioxidants and their effect on skin

Antioxidant	Effect on skin
Vitamin E (also known as Alpha-lipoic acid, 3-5%)	protects skin from sun damage
Vitamin A (also known as Retinoic acid, 0.01-0.1%)	treats fine wrinkles, age spots, and rough skin
Flavonoids (extracts from green tea or chocolate)	reverses sun damage
Vitamin B_6	treats fine wrinkles and protects skin from sun damage
Lycopene (a carotene that is present in tomatoes, watermelon, asparagus, and grapefruit)	protects skin from sun damage

References

1. https://www.nap.edu/read/5744/chapter/5#23
2. https://www.epa.gov/ozone-layer-prot...ing-substances

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4.11: Applications and Solubility of Covalent Compounds

Learning Objectives

- Know the basic difference between the terms polar and nonpolar.
- Apply the like dissolves like solubility rule for covalent compounds
- Understand why molecular shapes are important to pharmaceutical chemists and biologists.
- Appreciate how medications/vitamins need to be soluble in the body.
- Pick a vitamin and memorize highlighted information
- Realize that molecules are three-dimensional.
- Know the applications of covalent compounds in this section

The Solubility of Covalent Compounds

Unlike ionic solubility, covalent compound solubility cannot be determined by a table. Instead, structures and three-dimensional shapes must be drawn. Once a correct geometry has been determined, the compound would be classified as being polar or nonpolar. Polar species are soluble in water, while nonpolar species are soluble in oils and fats. Covalent solubility uses the like-dissolves-like rule. This means that substances with the same type of polarity will be soluble in one another. Moreover, compounds with differing polarities will be insoluble in one another.

Oil and water form a heterogeneous mixture due to their differing polarities; these substances are immiscible (not mixable) (Figure **4.11.1***a*). In contrast, alcohol dissolves in water to form a homogeneous mixture (Figure **4.11.1***b*).



Figure **4.11.1**: Two phases (water and oil) in the same state of aggregation (liquid). Images used with permission (CC BY-SA 4.0; Victor Blacus and Elizabeth R. Gordon, respectively L to R)

In this class, we will not explore molecular geometries that are used to determine polarity. Instead, the polarity of a substance will be provided. It is important to remember that water is polar and oil/fat is nonpolar. If the polarity of a substance is given, you should be able to classify it as being water or oil/fat soluble.

Phet Simulation: Molecular Shapes

PhET: Molecule Shapes: Basics

In determining polarity, chemists look to the power of atom's' nucleus. The protons from an atom's nucleus are capable of attracting another atom's electrons. Within a covalent bond, valence electrons are pulled toward's an atom that has a more powerful nucleus. This pull is called electronegativity. If different atoms are connected in a bond, then one tends to be more electronegative than the other. Molecules that have an overall pull in one direction are labeled as being polar species. Look at the structure of water that is shown below. This structure of this molecule shows the bonding electrons being pulled towards oxygen. Therefore, oxygen has a more powerful nucleus than hydrogen. Water's bent molecular shape does not cancel out the individual dipole pulls. As a result, water has an overall pull and is classified as being polar.

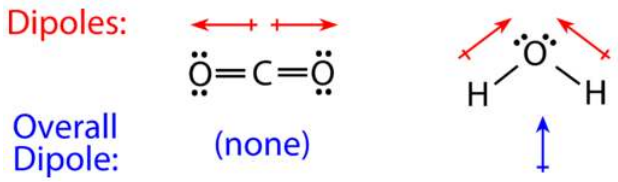


Figure **4.11.2**: *The molecular geometry of a molecule affects its polarity. Each CO bond has a dipole moment, but they point in opposite directions so that the net CO2 molecule is nonpolar. In contrast, water is polar because the OH bond moments do not cancel out.*

Carbon dioxide also has local dipoles (arrows) that pull in opposing directions. This molecule does not have an overall pull in one direction and is classified as being nonpolar. Some other molecules are shown in the figure below. The top three asymmetrical molecules are all polar. They all have dipoles (pulls) that do not cancel. All of these molecules would be soluble in water. The bottom three molecules are nonpolar. These are symmetrical molecules that have dipoles that cancel. Both of these molecules would be oil or fat-soluble.

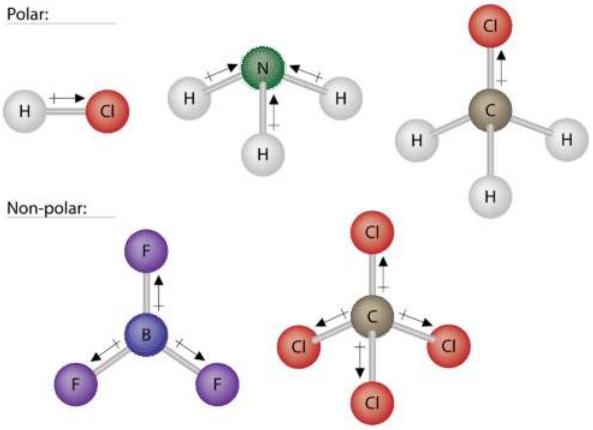


Figure **4.11.3**: Some examples of polar and nonpolar molecules based on molecular geometry.

Covalent solubility is important in the pharmaceutical industry. If a medication is not water soluble, then it will not dissolve in the bloodstream and react in the active site of the body in a timely and potent fashion. Watch the video below to obtain a basic understanding of how ibuprofen travels through the body to reduce pain and/or inflammation.



The polarity of vitamins can affect how long they remain in the body. Vitamins B and C are both water soluble and remain in the body for a short period of time. Our bodies must intake these vitamins more frequently. On the other hand, vitamins A, D, E, and K are all fat or oil soluble. Nutrients that are fat soluble remain in the body longer. These vitamins accumulate easily and can be toxic if recommended doses are surpassed.

Exercise

Pick one vitamin from the table below and memorize the common/chemical names, one source, and one function. In addition, note the solubility (water or fat) of your selected vitamin.

Vitamin	Origination	Functions
A (retinol)	Ingested in a precursor form. Found in animal sources such as milk and eggs. Also found carrots and spinach (contain pro vitamin A carotenoids).	Vitamin A is a fat-soluble vitamin. It helps cells differentiate, also lowering your risk of getting cancer. Vitamin A helps to keep vision healthy. It is required during pregnancy. Vitamin A also influences the function and development of sperm, ovaries and placenta and is a vital component of the reproductive process.
B1 (thiamine)	Found in wheat germ, whole wheat, peas, beans, enriched flour, fish, peanuts and meats.	Vitamin B1 is a water-soluble vitamin that the body requires to break down carbohydrates, fat and protein. The body needs vitamin b in order to make adenine triphosphate (ATP). Vitamin B1 is also essential for the proper functioning of nerve cells.
B2 (riboflavin)	Found in milk cheese, leafy green vegetables, liver, soybeans yeast and almonds. Exposure to light destroys riboflavin.	Vitamin B2 is a water-soluble vitamin that helps the body process amino acids and fats. Activated vitamin B6 and folic acid helps convert carbohydrates to adenosine triphosphate (ATP). Sometimes vitamin B2 can act as an antioxidant.
B3 (niacin)	Found in beets, brewer's yeast, beef liver, beef kidney, pork, turkey, chicken, veal, fish, salmon, swordfish, tuna, sunflower seeds, and peanuts.	Vitamin B3 is required for cell respiration and helps release the energy in carbohydrates, fats, and proteins. It helps with proper circulation and healthy skin, functioning of the nervous system, and normal secretion of bile and stomach fluids. It is used in the synthesis of sex hormones, treating schizophrenia and other mental illnesses, and as a memory-enhancer.
C	Found citrus fruits such as oranges, grapefruit and lemon.	Vitamin C is an essential water-soluble vitamin. It is needed to make collagen. Vitamin C also aids in the formation of liver bile which helps to detoxify alcohol and other substances. Evidence indicates that vitamin C levels in the eye decrease with age and this may be a cause of cataracts. Vitamin C has been reported to reduce activity of the enzyme, aldose reductase, which helps protect people with diabetes. It may also protect the body against accumulation or retention of the toxic mineral, lead.
D	Produced by the human body during exposure to the ultraviolet rays of the sun.	Vitamin D is a fat-soluble vitamin that helps maintain blood levels of calcium. Vitamin D is necessary for healthy bones and teeth. Vitamin D plays a role in immunity and blood cell formation and also helps cells differentiate this lowers your chance of getting cancer.
E	Found in vegetable oils, nuts, and green leafy vegetables. Fortified cereals are also an important source of vitamin E in the United States.	Vitamin E is an antioxidant that protects cell membranes and other fat-soluble parts of the body, such as LDL cholesterol (the "bad" cholesterol), from damage.
K	Found in kale, collard greens, spinach, mustard greens, turnip greens and Brussels sprouts. Also found vegetable oils such as soybean, canola, cottonseed, and olive.	Vitamin K by helping transport Ca, vitamin K is necessary for proper bone growth and blood coagulation.
Folic Acid	Found in many vegetables including, broccoli, peas, asparagus, spinach, green leafy types. Also found in fresh fruit, liver and yeast.	Folic acid reduces the risk of a child having spine and brain defects called neural tube defects (NTDsing)
B12	Found in meat, fish, eggs and milk but not in vegetables.	Vitamin B12 is used in helping anemia.
B6 (pyridoxine)	Found in cereals, yeast, liver, and fish.	Vitamin B6 is a coenzyme in amino acid synthesis.

Figure 4.11.4: *Vitamins with their sources and functions.* Image taken from: upload.wikimedia.org/wikiped...mins_Table.png

Applications of Covalent Compounds

Carbon dioxide is the gas that all living animals and humans exhale. In addition, it is also produced in the combustion process of fossil fuels (natural gas, coal, and petroleum products) and the burning of materials (wood). This covalent molecule is one of many global warming gases. The Environmental Protection Agency (EPA) does not regulate carbon dioxide emissions for industrial manufacturing or energy-producing facilities.

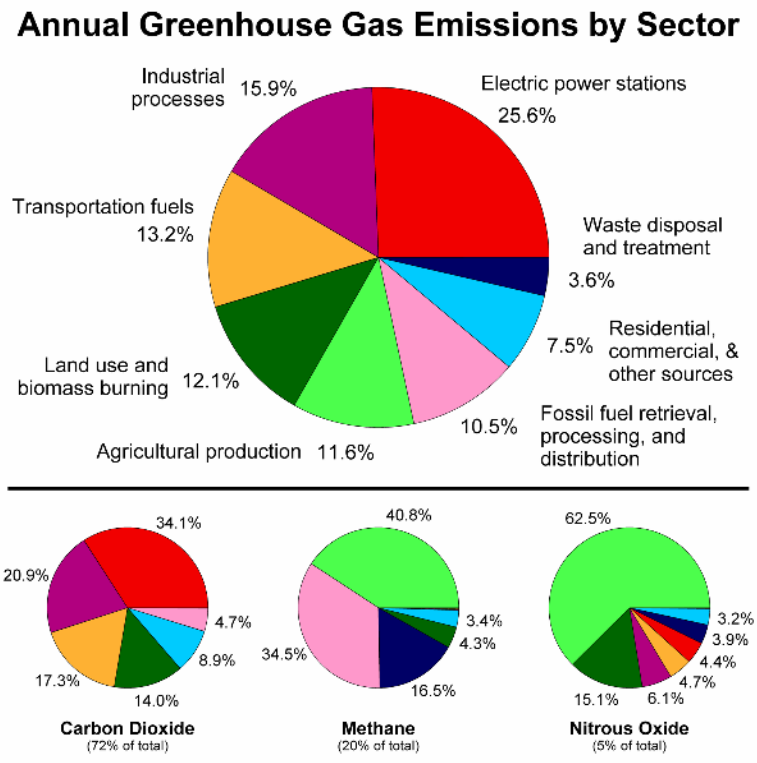


Figure **4.11.4**: Annual greenhouse gases by sector. Image taken from: https://images.app.goo.gl/gCZT9sNY4jG3VtkdA

Carbon monoxide results from the incomplete burning of wood and fossil fuels. During the combustion process, both carbon monoxide and carbon dioxide are produced. If burning occurs in an environment deficient in oxygen concentration, then more carbon monoxide is produced. In addition, burning in a colder temperature setting allows carbon monoxide to increase in an area. When burning any type of fuel, it is important to allow fumes to ventilate and not collect in a closed environment. For example, you should not sit in your garage with your car engine running. It is safer to crank your vehicle and immediately move it out of the confined space of your garage.

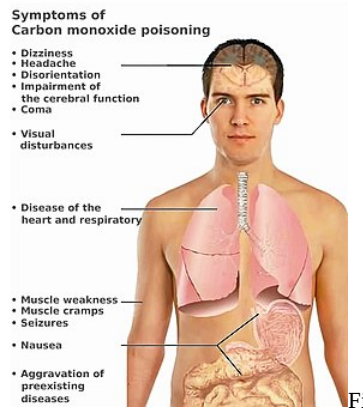


Figure **4.11.5**: Symptoms of carbon monoxide poisoning. Image taken from:CO toxicity symptoms (en) - Carbon monoxide poisoning - Wikipedia. This file was derived from: Simptomi trovanja CO.jpg:

If you have gas-powered energy or portable combustible fuel space heaters, it is important to have a carbon monoxide detector. These types of devices should be used in addition to a regular smoke detector. Carbon monoxide is an odorless, tasteless, and colorless gas. Exposure to this chemical can mimic a stomach virus. Unfortunately, carbon monoxide kills quickly with little warning. In terms of air quality, the EPA monitors and sets limits for industrial carbon monoxide production.

Dihydrogen monosulfide is a byproduct of the petroleum industry. In addition, paper mills, tanneries, sewage treatment factories, and coke ovens emit this gas into the atmosphere. People expel dihydrogen monosulfide when they pass gas. In nature, volcanoes

continuously make this and other sulfur-based gases. This colorless and corrosive gas smells like rotten eggs.



Figure 4.11.6: Image taken from:https://images.app.goo.gl/KT5gwTgFU2sbdtvY7

SO_x (sulfur dioxide and sulfur trioxide gases) result from the combustion of sulfur-based fuels (coal and diesel). Like $H_2S(g)$, volcanoes produce these two sulfur-based gases. Cleaner-based fossil fuels reduce the amount of sulfur based compounds before burning. SO_x gases can combine with water to produce acid rain. If rain water has a pH equal to or below 5.6, the EPA classifies this precipitation as being acid rain (on a normal pH scale an acid pH would be equal to or below 6.9). Acid rain can destroy plant life, dissolve materials like marble, and lower the pH of aquatic environments. For more information regarding the harmful effects of acid rain, click here and explore the EPA's webpage.

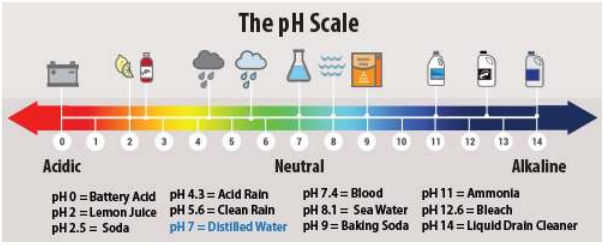


Figure 4.11.6: Image taken from: https://www.epa.gov/acidrain/what-acid-rain

SOx gases can combine with particles to form a black-brown color that is called industrial smog. This type of pollution is commonly seen in more urban and industrialized areas. The burning of coal and diesel will reduce the air quality in a region where it is heavily used. For these reasons, the petroleum-based SOx_x gas production for all industries in the United States.



Figure 4.11.7: Image taken from: https://pixnio.com/architecture/city-downtown/smoke-pollution-smog-sky-tower-condensation-industry

All types of burning produce NO_x (nitrogen monoxide and nitrogen dioxide) gases. The combustion of wood, gasoline, diesel, natural gas, coal, and other petroleum base products will produce NO_xs. Lightning naturally emits these compounds as well. Environmental problems associated with NO_xs are photochemical smog and acid rain. Areas with high concentrations of NO_x typically have a large amount of mobile sources (cars, trains, and trucks) and industrial plants. For more information about NO_x, click on this EPA link. Like SO_x and carbon monoxide, the EPA regulates industrial emissions of NO_x.

- Elizabeth R. Gordon (Furman University)
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4.12: Arrhenius Acids and Bases

Learning Outcomes

- Understand that all Arrhenius Acids produce H^+ or protons in water.
- Understand that all Arrhenius Bases produce OH^- or hydroxide in water.
- Write formulas for binary and ternary Arrhenius Acids.
- Write formulas for Arrhenius Bases.
- Appreciate the pH scale.
- Know applications of selected Arrhenius Acids and Bases.
- Describe the properties of acids and bases.
- Describe how to neutralize an acid and a base.
- Know what chemical is used to absorb neutralized acid/base mixtures.

pH Scale

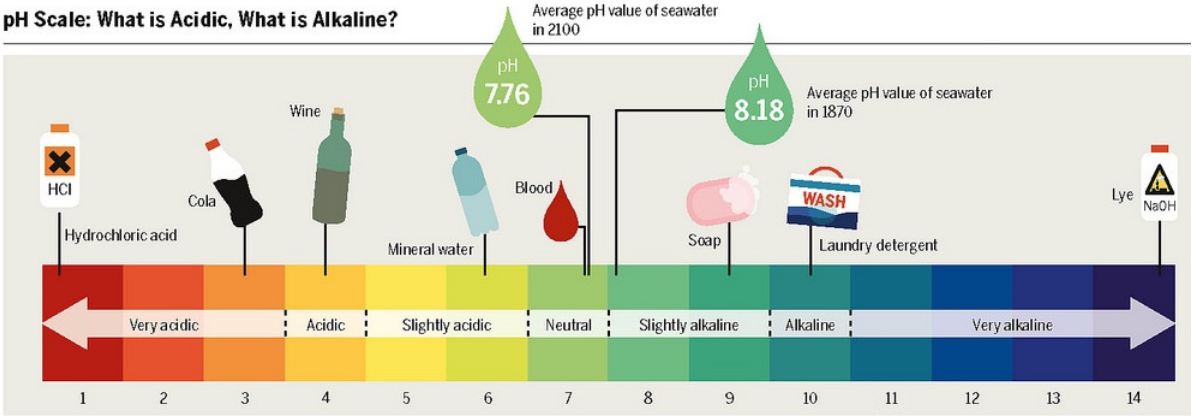


Figure **4.12.0**: Average pH value of seawater in 1870 and 2100 (estimated). The difference may seem small, but the decline in the pH value from 1970 to 2100 would mean a 170 % increase in the acidity. Much small changes already post problems fro many sea creatures. pH value of various substances (Hydrochloric acid, Cola, Sopa, Laundry detergent, and more). (CC BY-SA 2.0; Generic; Heinrich-Böll-Stiftung).

Arrhenius Definitions

The Swedish chemist Svante Arrhenius (1859 - 1927) was the first to propose a theory to explain the observed behavior of acids and bases. Because of their ability to conduct a current, he knew that both acids and bases contained ions in solution. An **Arrhenius acid** *is a compound which ionizes to yield hydrogen ions* (H^+) *in aqueous solution*. An **Arrhenius base** *is a compound which ionizes to yield hydroxide ions* (OH^-) *in aqueous solution*.

Acid Properties

Acids are very common in some of the foods that we eat. Citrus fruits such as oranges and lemons contain citric acid and ascorbic acid, which is better known as vitamin C (see figure below). All carbonated beverages contain carbonic acid. This chemical easily decomposes to produce bubbly carbon dioxide and water. Acids can be commonly found in many places. For example, your stomach uses gastric acid (hydrochloric) to dissolve food. Vinegar is a mixture of water and acetic acid. This solution preserves condiments like ketchup and barbeque sauce.

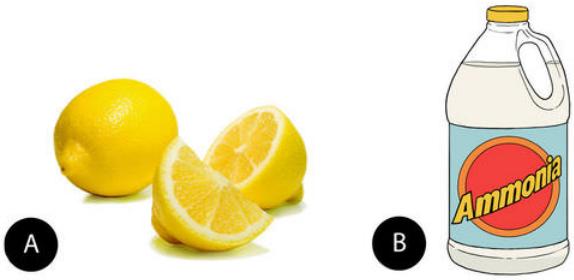


Figure **4.12.1**: (A) Lemons and other citrus fruits contain citric and ascorbic acids. (B) Ammonia is a base that is present in many household cleaners.

Acids are a distinct class of compounds because of the properties of their aqueous solutions. Those properties are outlined below.

1. Aqueous solutions of acids are electrolytes, meaning that they conduct an electrical current. Some acids are strong electrolytes because they ionize completely in water. Other acids are weak electrolytes which partially ionize when dissolved in water.
2. Acids have a sour taste. Lemons, vinegar, and sour candies all contain acids.
3. Acids change the color of certain acid-base indicators .Two common indicators are litmus and phenolphthalein. Blue litmus turns red in the presence of an acid, while phenolphthalein remains colorless.
4. Acids react with some metals to yield hydrogen gas.
5. Acids (pH < 7.0) react with bases (pH > 7.0) to produce a salt and water. When equal moles of an acid and a base are combined, the acid is neutralized by the base. The resulting mixture will have a more neutral pH.

Acids in your world



Formula writing and Applications of Arrhenius Acids

If the acid name begins with the prefix " hydro" then it is a binary acid. These types of acids involve anions from the periodic table. For " hydro" acids, perform the steps below:

1. Start the formula with a proton (H^+) and refer to the periodic table for the anion species.
2. Once charges from step #1 have been obtained, cross the charges down diagonally and remove signs (+/-)
3. Acid formulas will need to display the state of matter (aq) beside the chemical formula.

If the acid name does not begin with the prefix "hydro," then it is a polyatomic or ternary acid.

1. Start the fomula with a proton (H^+) and note the ending of the acid name. Acids that have "ic" endings will use the "ate" polyatomic ion. In contrast, acids that have "ous" endings will use the "ite" polyatomic ion.
2. Cross the proton and polyatomic charges down and remove signs (+/-).
3. Acid formulas will need to display the state of matter (aq) beside the chemical formula.

Table **4.12.1**: Common Acids

Acid Name	Formula	Real-World Applications
hydrochloric acid	HCl	Contained in stomach acid and liquid toilet bowl cleaner
nitric acid	HNO_3	Contained in chemical bombs and fertilizers.
sulfuric acid	H_2SO_4	Wet batter acid, chemical bombs, and fertilizers.
phosphoric acid	H_3PO_4	Preservative in dark-colored colas and fertilizer components.
acetic acid	CH_3COOH	Active ingredient of vinegar solution
hypochlorous acid	$HClO$	Acid is used to sanitize water.
carbonic acid	H_2CO_3	Acid contained in all carbonated beverages

A monoprotic acid is an acid that contains only one ionizable hydrogen. Hydrochloric acid and acetic acid are monoprotic acids. A polyprotic acid is an acid that contains multiple ionizable hydrogens. Most common polyprotic acids are either diprotic (such as H_2SO_4), or triprotic (such as H_3PO_4).

Bases Properties

Bases have properties that mostly contrast with those of acids.

1. Arrhenius bases that are soluble in water can conduct electricity.
2. Bases often have a bitter taste and are found in foods less frequently than acids. Many bases, like soaps, are slippery to the touch.
3. Bases also change the color of indicators. Red litmus turns blue in the presence of a base (see figure below), while phenolphthalein turns pink.
4. Some bases react with metals to produce hydrogen gas.
5. Acids (pH < 7.0) react with bases (pH > 7.0) to produce a salt and water. When equal moles of an acid and a base are combined, the acid is neutralized by the base. The resulting mixture will have a more neutral pH.

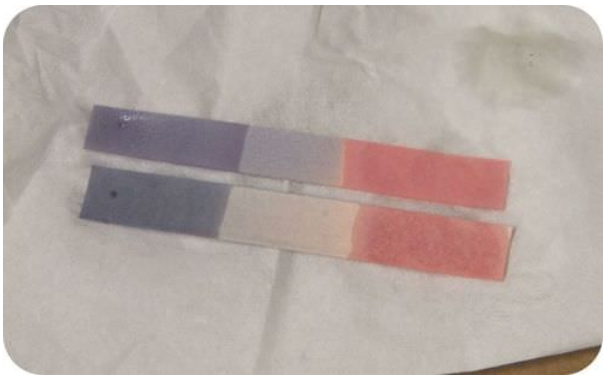


Figure 4.12.2: *Litmus paper has be treated with the plant dye called litmus. It turns red in the presence of an acid and blue in the presence of a base.*

Applications of Arrhenius Bases

Bases are ionic compounds which yield the hydroxide ion (OH^-) upon dissociating in water. The table below lists several of the more common bases.

Table 4.12.2: Common Bases

Base Name	Formula	Real-World Applications
Sodium hydroxide	$NaOH$	Drano and Lye
Potassium hydroxide	KOH	Oven cleaner
Magnesium hydroxide	$Mg(OH)_2$	Milk of Magnesia (laxative)
Calcium hydroxide	$Ca(OH)_2$	Chemical hair removal
Ammonium hydroxide	NH_4OH	ammonia (cleaner), do not mix with bleach

All of the bases listed in the table are solids at room temperature. Upon dissolving in water, each dissociates into a metal cation and the hydroxide ion.

$$NaOH\,(s) \overset{H_2O}{\rightarrow} Na^+\,(aq) + OH^-\,(aq)$$

Sodium hydroxide is a very caustic substance also known as lye. Lye is used as a rigorous cleaner and is an ingredient in the manufacture of soaps. Care must be taken with strong bases like sodium hydroxide, as exposure can lead to severe burns (see figure below).



Figure 4.12.4: This foot has severe burns due to prolonged contact with a solution of sodium hydroxide, also known as lye.

Brønsted-Lowry Acids and Bases

The Arrhenius definition of acids and bases is somewhat limited. There are some compounds whose properties suggest that they are either acidic or basic, but which do not qualify according to the Arrhenius definition. An example is ammonia (NH_3). An aqueous solution of ammonia turns litmus blue, reacts with acids, and displays various other properties that are common for bases. However, it does not contain the hydroxide ion. In 1923, a broader definition of acids and bases was independently proposed by the Danish chemist Johannes Brønsted (1879 - 1947) and the English chemist Thomas Lowry (1874 - 1936). A **Brønsted-Lowry acid** *is a molecule or ion that donates a hydrogen ion in a reaction.* A **Brønsted-Lowry base** *is a molecule or ion that accepts a hydrogen ion in a reaction.* Because the most common isotope of hydrogen consists of a single proton and a single electron, a hydrogen ion (in which the single electron has been removed) is commonly referred to as a proton. As a result, acids and bases are often called proton donors and proton acceptors, respectively, according to the Brønsted-Lowry definition. All substances that are categorized as acids and bases under the Arrhenius definition are also defined as such under the Brønsted-Lowry definition. The new definition, however, includes some substances that are left out according to the Arrhenius definition.

Acid-Base Neutralization Reactions

Recall the pH of both acids (below 7) and bases (above 7). If an acid and a base are mixed, the resulting mixture will have more of a neutral pH. The products of this reaction will be water and an ionic compound. In the laboratory, neutralization reactions are used before storage or disposal of acids and bases. For example, acids are neutralized by using ionic compounds that have base-like properties. One commonly used chemical to neutralize acids is sodium bicarbonate (baking soda). As for bases, acetic acid (common acid in vinegar) is used to neutralize the OH^- component. If a large amount of acid or base is spilled in the laboratory, it is neutralized and then absorbed into kitty litter before being properly disposed of.

Contributors and Attributions

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4.E: Valence Electrons and Bonding (Exercises)

Exercises

1: Identify whether each compound(s) is/are ionic.

1. NaI
2. Au_2CO_3
3. N_2O
4. SiO_2

Answer

Only answers (a) and (b) are ionic compounds. Both formulas begin with a metal (atom from the left side of the periodic table) ion.

2: Identify whether each compound(s) is/are covalent.

a. SiH_3
b. C_6H_5Cl
c. $KC_2H_3O_2$
d. $Ca(OH)_2$

Answer

Only answers (a) and (b) are covalent compounds. Both formulas begin with nonmetals and/or metalloids (atoms from the right side of the table)

3: Write the formula for each ionic compound.

a. magnesium sulfite
b. aluminum nitride
c. mercury II hydroxide
d. ammonium oxide

Answer

a. $MgSO_3$ b. AlN c) $Hg(OH)_2$ d) $(NH_4)_2O$

4: Write the formula for each covalent compound.

a. iodine trichloride
b. disulfur dibromide
c. arsenic trioxide
d. xenon hexafluoride

Answer

a. ICl_3 b. S_2Br_2 c. AsO_3 d. XeF_6

5: Which covalent species would be considered free radicals?

a. hydrogen monoxide
b. carbon dioxide
c. phosphorus disulfide
d. ammonia (NH_3)

Answer

a. silicon tetrafluoride

b. nitrogen dioxide
c. carbon disulfide
d. diphosphorus pentoxide

Answers

1.

2.

3.

4.

9. a. ICl_3
   b. S_2Br_2
   c. AsO_3
   d. XeF_6

11. H_2O and NH_3 (water and ammonia) (answers will vary)

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CHAPTER OVERVIEW

5: Basics of Nuclear Science

Nuclear physics is the field of physics that studies atomic nuclei and their constituents and interactions. Discoveries in nuclear physics have led to applications in many fields. This includes nuclear power, nuclear weapons, nuclear medicine and magnetic resonance imaging, industrial and agricultural isotopes, ion implantation in materials engineering, and radiocarbon dating in geology and archeology. Such applications are studied in the field of nuclear engineering.

5.1: The Discovery of Radiation
5.2: The Electromagnetic Spectrum
5.3: Types of Radiation
5.4: Ionizing Radiation and Non-ionizing Radiation
5.5: The Basics of Skin Cancer
5.6: Measuring Radiation
5.7: Calculating Half-Life
5.8: Using Nuclear Science to Diagnose Disease
5.9: Therapeutic Radiation
5.10: Non-medical Applications of Nuclear Science
5.E: Basics of Nuclear Science (Exercises)

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5.1: The Discovery of Radiation

Learning Objectives

- Understand the difference between induced and natural radioactivity
- Know which elements have unstable nuclei.
- Correlate the relationship between binding energy and stability.

From Section 3.3, we saw how J. J. Thomson discovered the electron by using cathode ray tubes (CRT). In November of 1895, a German physicist named Wilhelm Roentgen used this same technology to discover the X-ray. Roengten's ray originated from the CRT and reacted with a barium platinocyanide screen to fluoresce. After seeing this, Roentgen placed objects between this ray and the screen. He noted that the ray would still penetrate substances and leave an image on photographic film.

When naming this type of radiation, Roentgen reflected on his experiments. He could not confidently explain his observations. For this reason, he decided to call this new type of radiation the X-ray. Throughout his lifetime, he continued to explore this technology and even used his wife as a test subject (refer to Chapter 1 for her X-ray image). By never patenting this invention, Roengten freely shared the X-ray with other researchers and medical professionals. In 1901, he was awarded the Nobel Prize in Physics for his work with the x-ray.

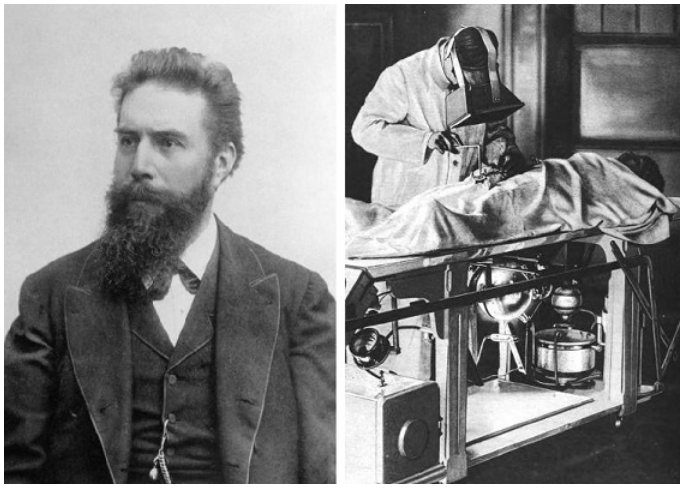


Figure **5.1.1**: (left) Photo of Wilhelm Conrad Roengten, the discoverer of x-rays. (right) Surgical operation during World War I using a fluoroscope that used x-rays to find embedded bullets

As with any new technology, people looked for ways to apply the x-ray to day to day life. Thomas Edison, the inventor of the light bulb, thought the average person should have an x-ray machine in their home. He designed x-ray machines to be smaller and portable. Unfortunately, many of his technicians died from radiation poisoning.

The Harmful Effects of X-rays

In November 1896, an article entitled "the harmful effects of X-rays" was published in Nature. The witness was an X-ray demonstrator during the summer in London. He therefore paid for himself throughout the summer at the rate of several hours per day of exposure. He testified: "In the first two or three weeks I felt no inconvenience, but after a while appeared on the fingers of my right hand many dark spots which pierced under the skin, and gradually they became very painful; the rest of the skin was red and strongly inflamed My hand was so bad that I was constantly forced to bathe it in very cold water An ointment momentarily calm the pain but the epidermis had dried up had become hard and yellow like parchment and completely insensible, so I was not surprised when my hand began to peel. "

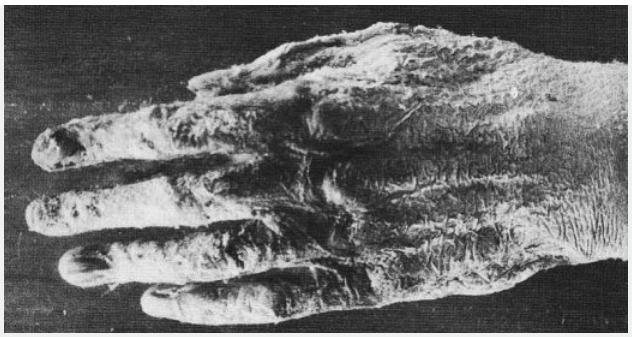


Figure **5.1.2**: Radiation poisoning due to over exposure of x-rays.

"Soon the skin and nails fall off and the fingers swelled, the pain remaining constant. I lost the skin of my right and left hands, and four of my nails have disappeared from the right hand and two left and three others were ready to fall off. During more than six weeks I was unable to hold anything in my right hand and I can not hold a pen since the loss of my nails …"

During Edison's time, people would host x-ray parties in their homes. The host of these gatherings would allow guests to x-ray different parts of their body. People would leave these events with their framed souvenirs. X-rays were even used to measure foot size. Devices like the fluoroscope were placed in shoe stores. Technicians, consumers, and observers could look in oculars while the foot was being x-rayed. Unnecessary exposure to radiation was not considered as a hazard during these times. In this era, most believed this was the most accurate way to measure the foot.



Video **5.1.1**: The shoe fitting fluoroscope was a common fixture in shoe stores during the 1930s, 1940s and 1950s. The first fluoroscopic device for x-raying feet may have been created during World War I to eliminating the need for patients to remove their boots, to speed up the processing of the large number of injured military personnel who were seeking help. After the war the device was modified the device for shoe-fitting and showed it for the first time at a shoe retailers convention in Boston in 1920.

Radioactivity

When Becquerel heard about Roentgen's discovery, he wondered if his fluorescent minerals would give the same x-rays. Becquerel placed some of his rock crystals on top of a well-covered photographic plate and sat them in the sunlight. The sunlight made the crystals glow with a bright fluorescent light, but when Becquerel developed the film he was very disappointed. He found that only one of his minerals, a uranium salt, had fogged the photographic plate. He decided to try again, and this time, to leave them out in the sun for a longer period of time. Fortunately, the weather did not cooperate and Becquerel had to leave the crystals and film stored in a drawer for several cloudy days. Before continuing his experiments, Becquerel decided to check one of the photographic plates to make sure the chemicals were still good. To his amazement, he found that the plate had been exposed in spots where it had been near the uranium containing rocks and some of these rocks had not been exposed to sunlight at all. In later experiments, Becquerel confirmed that the radiation from the uranium had no connection with light or fluorescence, but the amount of radiation was directly proportional to the concentration of uranium in the rock. Becquerel had discovered **radioactivity**.



Figure **5.1.3**: Image of Becquerel's photographic plate which has been fogged by exposure to radiation from a uranium salt. The shadow of a metal Maltese Cross placed between the plate and the uranium salt is clearly visible (Public Domain).

The Curies and Radium

One of Becquerel's assistants, a young Polish scientist named Maria Sklowdowska (to become Marie Curie after she married Pierre Curie), became interested in the phenomenon of radioactivity. With her husband, she decided to find out if chemicals other than uranium were radioactive. The Austrian government was happy to send the Curies a ton of pitchblende from the mining region of Joachimstahl because it was waste material that had to be disposed of anyway. The Curies wanted the pitchblende because it was the residue of uranium mining. From the ton of pitchblende, the Curies separated **0.10 g** of a previously unknown element, radium, in the form of the compound radium chloride. This radium was many times more radioactive than uranium.

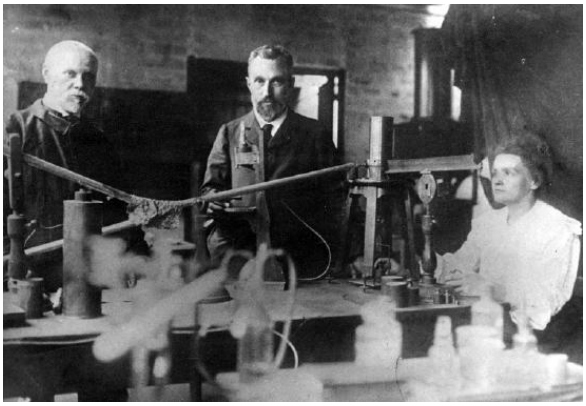


Figure **5.1.4**: Marie (right) and Pierre Curie (middle) with Henri Becquerel (left) shared the 1903 Nobel Prize

By 1902, the world was aware of a new phenomenon called radioactivity and of new elements that exhibited natural radioactivity. For this work, Becquerel and the Curies shared the 1903 Nobel Prize in Physics. These three researchers continued to work with hazardous radioactive materials. They experienced various ailments including burns and weakness by touching these substances. In 1906, Pierre Curie accidentally fell under a horse-drawn cart. He immediately died from his wounds and left Marie with two small children (Irene, 9 years old and Eve, 2 years old). After his death, Marie continued her research by identifying a new element, Polonium. In 1911, she was awarded the Nobel Prize in Chemistry for the discoveries of radium and polonium. As of today, Marie Curie is the only person ever to have received two Nobel Prizes in the sciences. To learn more about this famous female scientist, click on this link to watch a short video biography of her life.



Figure 5.1.2: Everyone knows that winning the Nobel Prize is a big deal, but why do we even have a Nobel Prize? And why does it matter?

Further experiments provided information about the characteristics of the penetrating emissions from radioactive substances. It was soon discovered that there were three common types of radioactive emissions. Some of the radiation could pass easily through aluminum foil while some of the radiation was stopped by the foil. Some of the radiation could even pass through foil up to a centimeter thick. The three basic types of radiation were named alpha, beta, and gamma radiation. The actual composition of the three types of radiation was still not known.

Eventually, scientists were able to demonstrate experimentally that the alpha particle, α, was a helium nucleus (a particle containing two protons and two neutrons), a beta particle, β, was a high speed electron, and gamma rays, γ, were a very high energy form of light (even higher energy than x-rays).

Unstable Nuclei May Disintegrate

A nucleus (with one exception, hydrogen-1) consists of some number of protons and neutrons pulled together in an extremely tiny volume. Since protons are positively charged and like charges repel, it is clear that protons cannot remain together in the nucleus unless there is a powerful force holding them there. The force which holds the nucleus together is generated by **nuclear binding energy**.

A nucleus with a large amount of binding energy per nucleon (proton or neutron) will be held together tightly and is referred to as stable. These nuclei do not break apart. When there is too little binding energy per nucleon, the nucleus will be less stable and may disintegrate (come apart). Such disintegrations are referred to as **natural radioactivity**. It is also possible for scientists to smash nuclear particles together and cause nuclear reactions between normally stable nuclei. These disintegrations are referred to as **artificial radioactivity**. None of the elements above #92 on the periodic table occur on earth naturally; they are all products of artificial radioactivity (man-made).

When nuclei come apart, they come apart violently accompanied by a tremendous release of energy in the form of heat, light, and radiation. This energy comes from some of the nuclear binding energy. In nuclear changes, the energy involved comes from the nuclear binding energy. However, in chemical reactions, the energy comes from electrons moving energy levels. A typical nuclear change (such as fission) may involve millions of times more energy per atom changing compared to a chemical change (such as burning)!

Need More Practice?

- Turn to Section 5.E of this OER and answer questions #5 and #7.

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5.2: The Electromagnetic Spectrum

Learning Objectives

- Understand the mathematical relationship between frequency and wavelength.
- Recall the metric system of conversion.
- Correlate frequency or wavelength to energy (qualitatively).
- Calculate frequency or wavelength of radiation.
- Know the order of the electromagnetic spectrum (names, not numbers)

Roentgen, Becquerel and the Curies experimented with radiation. Using machines, Roengten's focused on the production X-rays, which is a wave-type of radiation. Unlike Roengten, Henri Becquerel studied the natural radioactivity of elements. His uranium experiments yielded the production of alpha (particle-type) and gamma (ray-type) radiations. Becquerel's two graduate students, Marie and Pierre Curie, isolated two radioactive elements. Both radium and polonium emit alpha and beta particles upon decay. In this section, wave form radiation will be explored. This type of radiation has an extremely wide range of wavelengths, frequencies, and energies.

Properties of Waves

A wave is a periodic oscillation that transmits energy through space. Anyone who has visited a beach or dropped a stone into a puddle has observed waves traveling through water (Figure **5.2.1**). These waves are produced when wind, a stone, or some other disturbance, such as a passing boat, transfers energy to the water, causing the surface to oscillate up and down as the energy travels outward from its point of origin. As a wave passes a particular point on the surface of the water, anything floating there moves up and down.

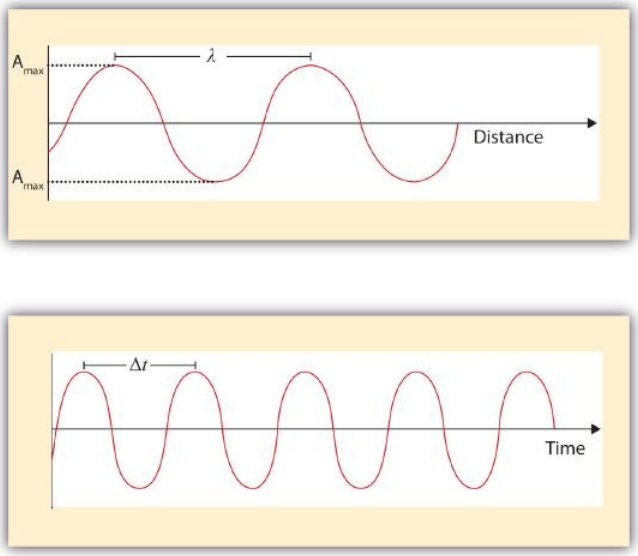


Figure **5.2.1**: Characteristics of Light Waves. Light acts as a wave and can be described by a wavelength λ and a frequency ν.

Waves have characteristic properties (Figure **5.2.1**). Waves are periodic, meaning, they repeat regularly in both space and time. The **distance** between two corresponding points in a wave—between the midpoints of two peaks, for example, or two troughs—is the **wavelength** (**λ**), distance between two corresponding pointsperiodween the midpoints of two peaks or two troughs. **λ** is the lowercase Greek lambda, and **ν** is the lowercase Greek nu. Wavelengths are described by a unit of distance, typically meters. The **frequency** (**ν**) **is the number of oscillations (i.e., of a wave) that pass a particular point in a given period of time**. The unit for frequency is per second (1/s = s^{-1}), which is equivalent to the SI unit of hertz (Hz). Amplitude, or vertical height of a wave, is defined as half the peak-to-trough. As the amplitude of a wave with a given frequency increases, so does its energy.

Electromagnetic Radiation

Energy that is transmitted, or radiated, through space in the form of periodic oscillations of electric and magnetic fields is known as electromagnetic radiation. (Figure **5.2.2**). Some forms of electromagnetic radiation are shown in Figure **5.2.4**. In a vacuum, all forms of electromagnetic radiation—whether microwaves, visible light, or gamma rays—travel at the speed of light (c), which is the speed with which all forms of electromagnetic radiation travel in a vacuum, a fundamental physical constant with a value of 2.99792458 × 10^8 m/s (which is about **3.00 ×10^8 m/s** or 1.86 × 10^5 mi/s). This is about a million times faster than the speed of sound.

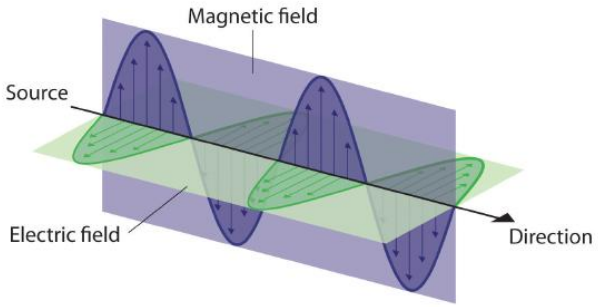


Figure **5.2.2**: The Nature of Electromagnetic Radiation. All forms of electromagnetic radiation consist of perpendicular oscillating electric and magnetic fields.

Because the various kinds of electromagnetic radiation all have the same speed (*c*), they differ in only wavelength and frequency. As shown in Figure **5.2.3** and Table **5.2.1**, the wavelengths of familiar electromagnetic radiation range from 10^1 m for radio waves to 10^{-12} m for gamma rays, which are emitted by nuclear reactions. Viewing the equation below, we can see how frequency of electromagnetic radiation is inversely proportional to its wavelength:

$$c = \lambda\nu$$
$$\nu = \frac{c}{\lambda} \tag{5.2.1}$$

For example, the frequency of radio waves is about 10^8 Hz, whereas the frequency of gamma rays is about 10^{20} Hz. Visible light, which is electromagnetic radiation that can be detected by the human eye, has wavelengths between about 7 × 10^{-7} m (700 nm, or 4.3 × 10^{14} Hz) and 4 × 10^{-7} m (400 nm, or 7.5 × 10^{14} Hz). Note that when frequency increases, wavelength decreases; c being a constant stays the same. Similarly when frequency decreases, the wavelength increases.

Please memorize equation 5.2.1 and the speed of light (with units). In addition, it is important to know which side of the electromagnetic spectrum is deadly.

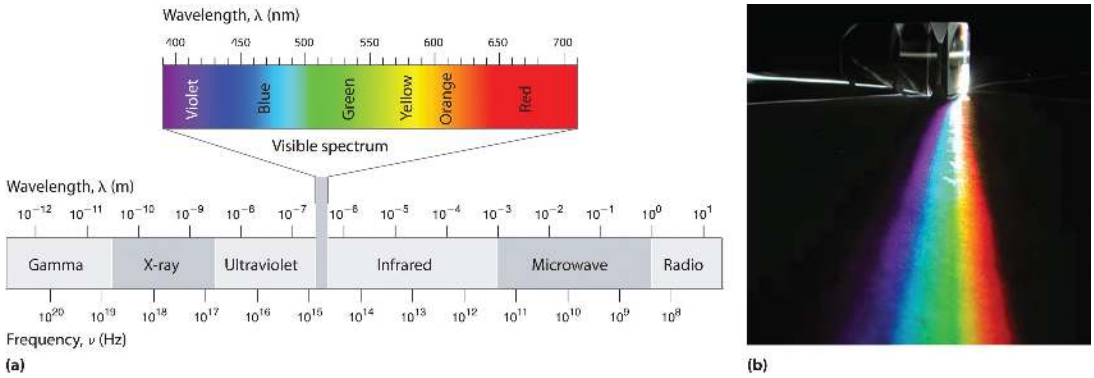


Figure **5.2.3**: The Electromagnetic Spectrum. (a) This diagram shows the wavelength and frequency ranges of electromagnetic radiation. The visible portion of the electromagnetic spectrum is the narrow region with wavelengths between about 400 and 700 nm. (b) When white light is passed through a prism, it is split into light of different wavelengths, whose colors correspond to the visible spectrum.

Table **5.2.1**: Common Wavelength Units for Electromagnetic Radiation

Unit	Symbol	Wavelength (m)	Type of Radiation
picometer	pm	10^{-12}	gamma ray
nanometer	nm	10^{-9}	x-ray
micrometer	μm	10^{-6}	infrared
millimeter	mm	10^{-3}	infrared
centimeter	cm	10^{-2}	microwave
meter	m	10^{0}	radio

Light also behaves like a package of energy. It turns out that for light, the energy of the "package" of energy is proportional to its frequency.

$$E \propto \nu \tag{5.2.2}$$

$$E \propto \frac{1}{\lambda} \tag{5.2.3}$$

Whereas visible light is essentially harmless to our skin, ultraviolet light, with wavelengths of ≤ 400 nm, has enough energy to cause severe damage to our skin in the form of sunburn. Because the ozone layer absorbs sunlight with wavelengths less than 350 nm, it protects us from the damaging effects of highly energetic ultraviolet radiation.

In this course, we will not do energy calculations. You should know the relationship between frequency and energy. Also, you show realize that short wavelength radiation is associated with a high energy.

> *The energy of electromagnetic radiation increases with increasing frequency and decreasing wavelength.*

Example 5.2.1

What is the frequency of light if its wavelength is 5.55×10^{-7} m?

Solution

We use the equation that relates the wavelength and frequency of light with its speed. We have

$$3.00 \times 10^{8} m/s = \left(5.55 \times 10^{-7} m\right) \nu$$

We divide both sides of the equation by 5.55×10^{-7} m and get

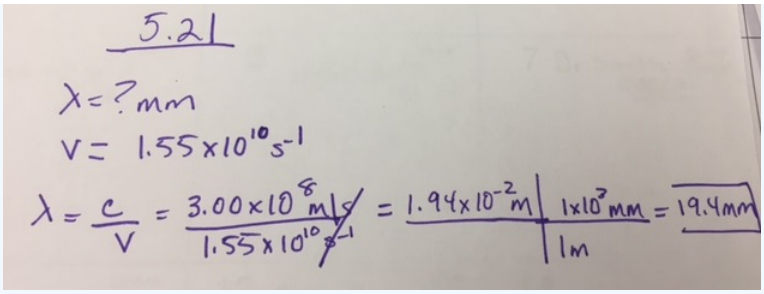
$$\nu = 5.41 \times 10^{14} s^{-1}$$

Note how the m units cancel, leaving s in the denominator. A unit in a denominator is indicated by a −1 power—s^{-1}—and read as "per second."

Exercise 5.2.1

What is the wavelength (in mm) of light if its frequency is 1.55×10^{10} s^{-1}?

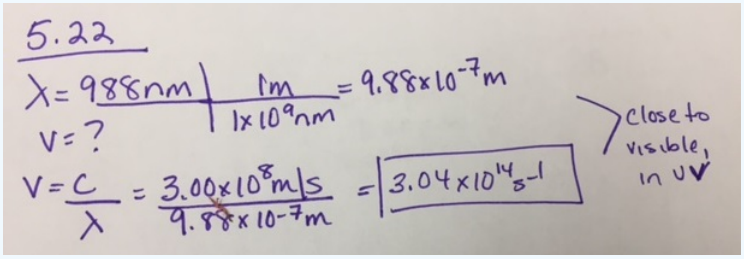
Answer



Example 5.2.2

Calculate the frequency of radiation if its wavelength is 988 nm. Where does this radiation appear in the electromagnetic spectrum?

Answer



Need More Practice?

- Refer to section 5.E of this OER and work problem #4. Refer to the electromagnetic spectrum to locate the type of radiation.

Contributors and Attributions

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5.3: Types of Radiation

Learning Objectives

- Become familiar with A/Z formats for alpha, beta, positron, neutron, gamma, and the three isotopes of hydrogen.
- Express the changes in the atomic number and mass number of radioactive nuclei when a particle or ray is emitted.
- Convert symbol-mass format of elements to A/Z format and then balance a nuclear reaction.
- Generate a decay reaction if provided with a symbol-mass format of an element.

Many nuclei are radioactive; that is, they decompose by emitting particles or rays and in doing so, become a different nucleus. In our studies up to this point, atoms of one element were unable to change into different elements. That is because in all other types of changes we have talked about only the electrons were changing. In these changes, the nucleus, which contains the protons that dictate which element an atom is, is changing. All nuclei with 84 or more protons are radioactive and elements with less than 84 protons have both stable and unstable isotopes. All of these elements can go through nuclear changes and turn into different elements.

In natural radioactive decay, three common emissions occur. When these emissions were originally observed, scientists were unable to identify them as some already known particles and so named them

- alpha particles (α),
- beta particles, (β), and
- gamma rays (γ)

using the first three letters of the Greek alphabet. At some later time, alpha particles were identified as helium-4 nuclei, beta particles were identified as electrons, and gamma rays as a form of electromagnetic radiation like x-rays except much higher in energy and even more dangerous to living systems.

Name	Symbol(s)	Representation	Description
Alpha particle	^4_2He or $^4_2\alpha$		(High-energy) helium nuclei consisting of two protons and two neutrons
Beta particle	$^0_{-1}\text{e}$ or $^0_{-1}\beta$		(High-energy) electrons
Positron	$^0_{+1}\text{e}$ or $^0_{+1}\beta$		Particles with the same mass as an electron but with 1 unit of positive charge
Proton	^1_1H or ^1_1p		Nuclei of hydrogen atoms
Neutron	^1_0n		Particles with a mass approximately equal to that of a proton but with no charge
Gamma ray	γ		Very high-energy electromagnetic radiation

Figure **5.3.1**: Although many species are encountered in nuclear reactions, this table summarizes the names, symbols, representations, and descriptions of the most common of these. **Please commit this chart to memory along with A/Z formats for the three Hydrogen Isotopes {H-2 = deuterium (d) and H-3 = tritium (t)}** (CC BY 4.0; OpenStax)

Alpha Decay

The nuclear disintegration process that emits alpha particles is called alpha decay. An example of a nucleus that undergoes alpha decay is uranium-238. The alpha decay of U-238 is

$$^{238}_{92}\text{U} \rightarrow {}^4_2\text{He} + {}^{234}_{90}\text{Th} \tag{5.3.1}$$

In this nuclear change, the uranium atom ($^{238}_{92}\text{U}$) transmuted into an atom of thorium ($^{234}_{90}\text{Th}$) and, in the process, gave off an alpha particle. Look at the symbol for the alpha particle: ^4_2He. Where does an alpha particle get this symbol? The bottom number in a nuclear symbol is the number of protons. That means that the alpha particle has two protons in it which were lost by the uranium

atom. The two protons also have a charge of $+2$. The top number, 4, is the mass number or the total of the protons and neutrons in the particle. Because it has 2 protons, and a total of 4 protons and neutrons, alpha particles must also have two neutrons. Alpha particles always have this same composition: two protons and two neutrons.

Another alpha particle producer is thorium-230.

$$^{230}_{90}\text{Th} \rightarrow {}^{4}_{2}\text{He} + {}^{226}_{88}\text{Ra} \tag{5.3.2}$$

Alpha decays occur with radioactive isotopes of radium, radon, uranium, and thorium.

Beta Decay

Another common decay process is beta particle emission, or beta decay. A beta particle is simply a high energy electron that is emitted from the nucleus. It may occur to you that we have a logically difficult situation here. Nuclei do not contain electrons and yet during beta decay, an electron is emitted from a nucleus. At the same time that the electron is being ejected from the nucleus, a neutron is becoming a proton. It is tempting to picture this as a neutron breaking into two pieces with the pieces being a proton and an electron. That would be convenient for simplicity, but unfortunately that is not what happens; more about this at the end of this section. For convenience sake, though, we will treat beta decay as a neutron splitting into a proton and an electron. The proton stays in the nucleus, increasing the atomic number of the atom by one. The electron is ejected from the nucleus and is the particle of radiation called beta.

To insert an electron into a nuclear equation and have the numbers add up properly, an atomic number and a mass number had to be assigned to an electron. The mass number assigned to an electron is zero (0) which is reasonable since the mass number is the number of protons plus neutrons and an electron contains no protons and no neutrons. The atomic number assigned to an electron is negative one (-1), because that allows a nuclear equation containing an electron to balance atomic numbers. Therefore, the nuclear symbol representing an electron (beta particle) is

$$^{0}_{-1}\text{e} \text{ or } {}^{0}_{-1}\beta$$

Thorium-234 is a nucleus that undergoes beta decay. Here is the nuclear equation for this beta decay.

$$^{234}_{90}\text{Th} \rightarrow {}^{0}_{-1}\text{e} + {}^{234}_{91}\text{Pa} \tag{5.3.3}$$

Beta decays are common with Sr-90, C-14, H-3 and S-35.

Gamma Radiation

Frequently, gamma ray production accompanies nuclear reactions of all types. In the alpha decay of U-238, two gamma rays of different energies are emitted in addition to the alpha particle.

$$^{238}_{92}\text{U} \rightarrow {}^{4}_{2}\text{He} + {}^{234}_{90}\text{Th} + 2{}^{0}_{0}\gamma$$

Virtually all of the nuclear reactions in this chapter also emit gamma rays, but for simplicity the gamma rays are generally not shown. Nuclear reactions produce a great deal more energy than chemical reactions. Chemical reactions release the difference between the chemical bond energy of the reactants and products, and the energies released have an order of magnitude of 1×10^{3} kJ/mol. Nuclear reactions release some of the binding energy and may convert tiny amounts of matter into energy. The energy released in a nuclear reaction has an order of magnitude of 1×10^{18} kJ/mol. That means that nuclear changes involve almost **a million times more energy** per atom than chemical changes!

Common gamma emitters would include I-131, Cs-137, Co-60, and Tc-99.

> Virtually all of the nuclear reactions in this chapter also emit gamma rays, but for simplicity the gamma rays are generally not shown.

The essential features of each reaction are shown in Figure 5.3.2.

Decay Type	Radiation Emitted	Generic Equation	Model
Alpha decay	$^{4}_{2}\alpha$	$^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}X' + {}^{4}_{2}\alpha$	Parent → Daughter + Alpha Particle
Beta decay	$^{0}_{-1}\beta$	$^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}X' + {}^{0}_{-1}\beta$	Parent → Daughter + Beta Particle
Gamma emission	$^{0}_{0}\gamma$	$^{A}_{Z}X^{*} \xrightarrow{\text{Relaxation}} {}^{A}_{Z}X' + {}^{0}_{0}\gamma$	Parent (excited nuclear state) → Daughter + Gamma ray

Figure **5.3.2**: Three most common modes of nuclear decay

"Nuclear Accounting"

When writing nuclear equations, there are some general rules that will help you:

- The sum of the mass numbers (top numbers) on the reactant side equal the sum of the mass numbers on the product side.
- The atomic numbers (bottom numbers) on the two sides of the reaction will also be equal.

In the alpha decay of ^{238}U (Equation 5.3.1), both atomic and mass numbers are conserved:

- mass number: $238 = 4 + 234$
- atomic number: $92 = 2 + 90$

Confirm that this equation is correctly balanced by adding up the reactants' and products' atomic and mass numbers. Also, note that because this was an alpha reaction, one of the products is the alpha particle, $^{4}_{2}\text{He}$.

Note that both the mass numbers and the atomic numbers add up properly for the beta decay of Thorium-234 (Equation 5.3.3):

- mass number: $234 = 0 + 234$
- atomic number: $90 = -1 + 91$

The mass numbers of the original nucleus and the new nucleus are the same because a neutron has been lost, but a proton has been gained and so the sum of protons plus neutrons remains the same. The atomic number in the process has been increased by one since the new nucleus has one more proton than the original nucleus. In this beta decay, a thorium-234 nucleus has one more proton than the original nucleus. In this beta decay, a thorium-234 nucleus has become a protactinium-234 nucleus. Protactinium-234 is also a beta emitter and produces uranium-234.

$$^{234}_{91}\text{Pa} \rightarrow {}^{0}_{-1}\text{e} + {}^{234}_{92}\text{U} \tag{5.3.4}$$

Once again, the atomic number increases by one and the mass number remains the same; confirm that the equation is correctly balanced. Before starting the problems, below preview this video of your instructor balancing nuclear reactions.

✔ Example 5.3.1

Complete the following nuclear reaction by filling in the missing particle.

$$^{210}_{86}\text{Rn} \longrightarrow {}^{4}_{2}\text{He} + ?$$

Solution

This reaction is an alpha decay. We can solve this problem one of two ways:

Solution 1: When an atom gives off an alpha particle, its atomic number drops by 2 and its mass number drops by 4 leaving: $^{206}_{84}\text{Po}$. We know the symbol is **Po**, for polonium, because this is the element with 84 protons on the periodic table.

Solution 2: Remember that the mass numbers on each side must total up to the same amount. The same is true of the atomic numbers.

- Mass numbers: $210 = 4 + ?$
- Atomic numbers: $86 = 2 + ?$

We are left with $^{206}_{84}\text{Po}$

Example 5.3.2

Write each of the following nuclear reactions.

a. Carbon-14, used in carbon dating, decays by beta emission.
b. Uranium-238 decays by alpha emission.

Solution

a) Beta particles have the symbol $^{0}_{-1}\text{e}$. Emitting a beta particle causes the atomic number to increase by 1 and the mass number to not change. We get atomic numbers and symbols for elements using our periodic table. We are left with the following reaction:

$$^{14}_{6}\text{C} \rightarrow {}^{0}_{-1}\text{e} + {}^{14}_{7}\text{N}$$

b) Alpha particles have the symbol $^{4}_{2}\text{He}$. Emitting an alpha particle causes the atomic number to decrease by 2 and the mass number to decrease by 4. We are left with:

$$^{238}_{92}\text{U} \rightarrow {}^{4}_{2}\text{He} + {}^{234}_{90}\text{Th}$$

Decay Series

The decay of a radioactive nucleus is a move toward becoming stable. Often, a radioactive nucleus cannot reach a stable state through a single decay. In such cases, a series of decays will occur until a stable nucleus is formed. The decay of **U**-238 is an example of this. The **U**-238 decay series starts with **U**-238 and goes through fourteen separate decays to finally reach a stable nucleus, **Pb**-206 (Figure **5.3.3**). There are similar decay series for **U**-235 and **Th**-232. The **U**-235 series ends with **Pb**-207 and the **Th**-232 series ends with **Pb**-208.

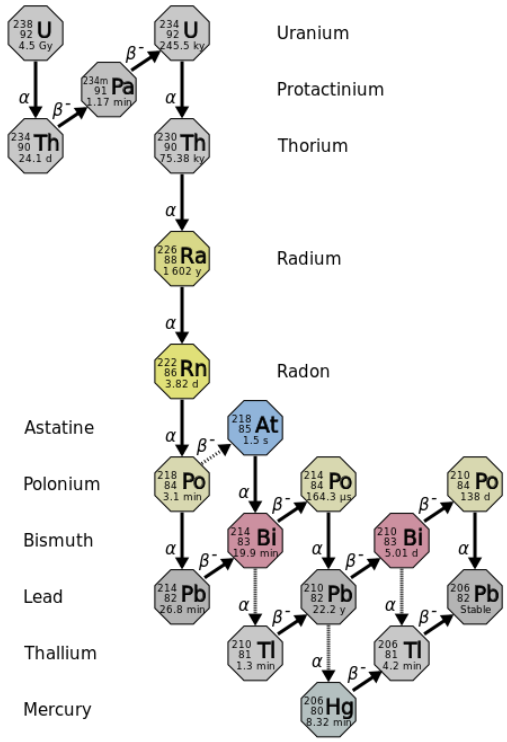


Figure **5.3.3**: Uranium-238 Decay chain. (CC-BY-3.0 Tosaka)

Several of the radioactive nuclei that are found in nature are present there because they are produced in one of the radioactive decay series. For example, there may have been radon on the earth at the time of its formation, but that original radon would have all decayed by this time. The radon that is present now is present because it was formed in a decay series (mostly by U-238).

Need More Practice?

- Turn to Section 5.E of this OER and work problems #1 and #2.

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5.4: Ionizing Radiation and Non-ionizing Radiation

Learning Objectives

- Qualitatively compare the ionizing and penetration power of alpha particles (α), beta particles (β), and gamma rays (γ).
- Describe the biological impact of ionizing radiation.
- Know the most common source of background radiation and how to minimize exposure to this source.

The Ionizing and Penetration Power of Radiation

The increased use of radioisotopes has led to increased concerns over the effects of these materials on biological systems (such as humans). All radioactive nuclides emit high-energy particles or electromagnetic waves. When this radiation encounters living cells, it can cause heating, break chemical bonds, or ionize molecules. The most serious biological damage results when these radioactive emissions fragment or ionize molecules. For example, alpha and beta particles emitted from nuclear decay reactions possess much higher energies than ordinary chemical bond energies. When these particles strike and penetrate matter, they produce ions and molecular fragments that are extremely reactive. The damage this does to biomolecules in living organisms can cause serious malfunctions in normal cell processes, taxing the organism's repair mechanisms and possibly causing illness or even death (Figure 5.4.1).

The ability of radiation to damage molecules is analyzed in terms of what is called **ionizing power**. When a radiation particle interacts with atoms, the interaction can cause the atom to lose electrons and thus become ionized. The greater the likelihood that damage will occur by an interaction is the ionizing power of the radiation. Ionizing radiation could affect either the whole body (somatic damage) and/or eggs and sperm (genetic damage).

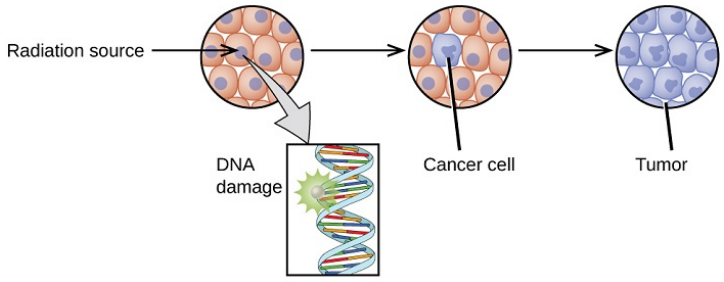


Figure 5.4.1: Radiation can harm biological systems by damaging the DNA of cells. If this damage is not properly repaired, the cells may divide in an uncontrolled manner and cause cancer.

Much of the threat from radiation is involved with the ease or difficulty of protecting oneself from the particles or the gamma ray. How thick of a wall do you need to hide behind to be safe? The ability of each type of radiation to pass through matter is expressed in terms of **penetration power.** The more material the radiation can pass through, the greater the penetration power and the more dangerous they are. In general, the greater mass present the greater the ionizing power and the lower the penetration power.

When comparing the most common forms of ionizing radiation (alpha, beta, and gamma), alpha particles have the greatest mass. Alpha particles have approximately four times the mass of a proton or neutron and approximately ~8,000 times the mass of a beta particle (Figure 5.4.1). Because of the large mass of the alpha particle, it has the highest ionizing power and the greatest ability to damage tissue. That same large size of alpha particles, however, makes them less able to penetrate matter. They collide with molecules very quickly when striking matter, add two electrons, and become a harmless helium atom. Alpha particles have the least penetration power and can be stopped by a thick sheet of paper or even a layer of clothes. They are also stopped by the outer layer of dead skin on people. This may seem to remove the threat from alpha particles but only from external sources. In a situation like a nuclear explosion or some sort of nuclear accident where radioactive emitters are spread around in the environment, the emitters can be inhaled or taken in with food or water and once the alpha emitter is inside you, you have no protection at all.

Figure 5.4.1: Properties of the three Primary Radiation Types

Particle	Symbol	Mass	Penetrating Power	Ionizing Power	Shielding
alpha	α	4 amu	Very Low	Very High	Paper and Skin
beta	β	1/1837 amu	Intermediate	Intermediate	Aluminum
gamma	γ	0 (energy only)	Very High	Very Low	2 inches lead

Beta particles are much smaller than alpha particles, and therefore,they have much less ionizing power (less ability to damage tissue), but their small size gives them much greater penetration power. Most resources say that beta particles can be stopped by a one-quarter inch thick sheet of aluminum. Once again, however, the greatest danger occurs when the beta emitting source gets inside of you.

Gamma rays are not particles but a high energy form of electromagnetic radiation (like x-rays except more powerful). Gamma rays are energy that has no mass or charge. Gamma rays have tremendous penetration power and require several inches of dense material (like lead) to shield them. Gamma rays may pass all the way through a human body without striking anything. They are considered to have the least ionizing power and the greatest penetration power.

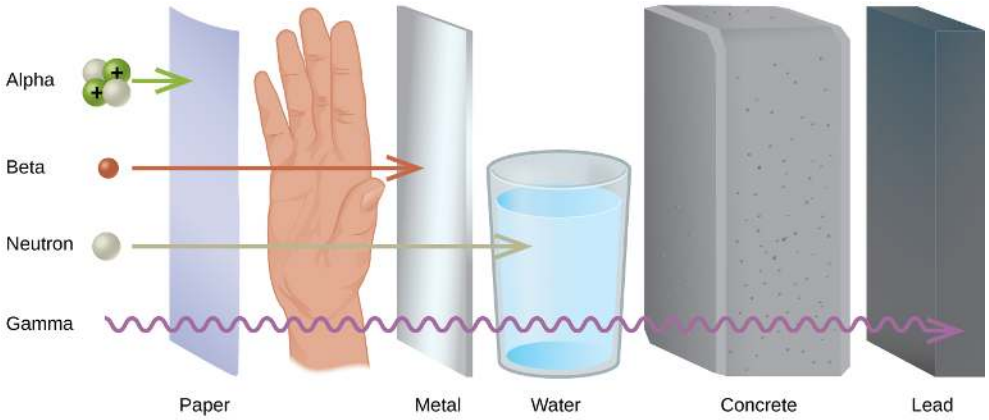


Figure **5.4.2**: The ability of different types of radiation to pass through material is shown. From least to most penetrating, they are alpha < beta < neutron < gamma. (CC BY-SA, OpenStax).

The safest amount of radiation to the human body is zero. It is not possible to be not exposed to ionizing radiation so the next best goal is to be exposed to as little as possible. The two best ways to minimize exposure is to limit time of exposure and to increase distance from the source. The image below summarizes the key concepts of ionization and penetration abilities of alpha, beta, and gamma radiation.

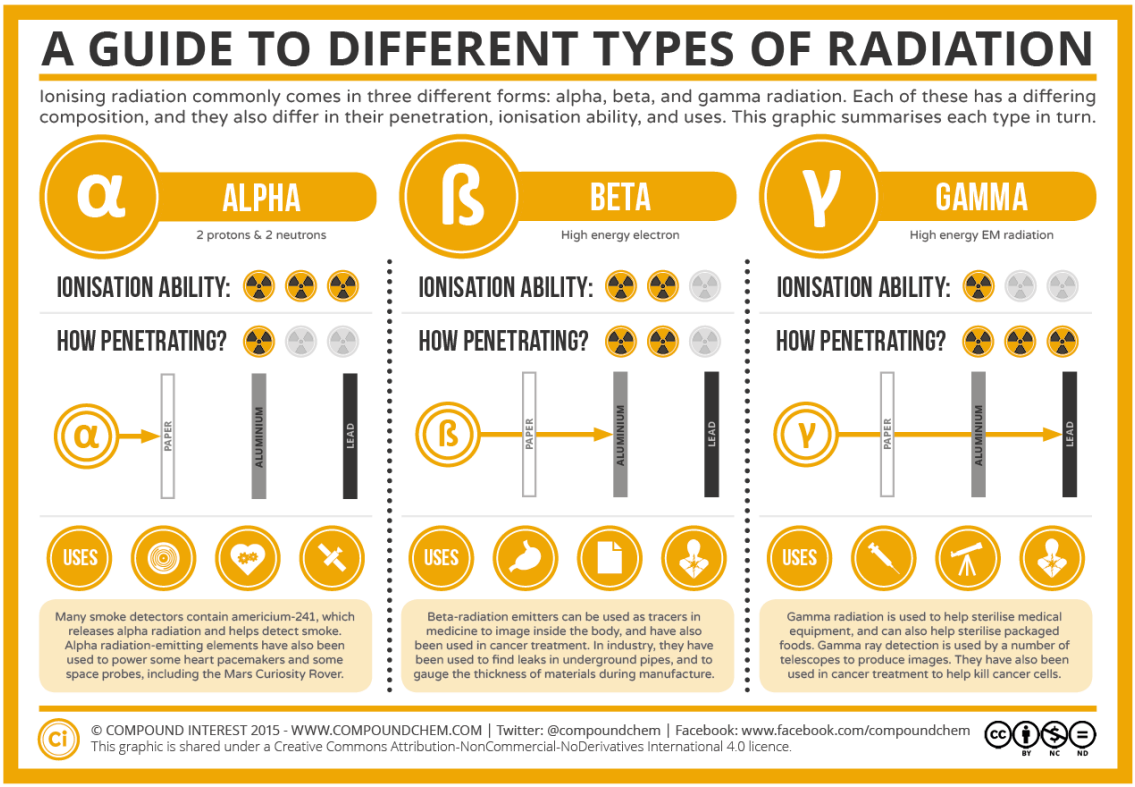


Figure 5.4.3: Ionization and penetrations abilities of alpha, beta, and gamma radiation. (CC BY-NC-ND, CompoundChem.com).

Nonionizing Radiation

There is a large difference in the magnitude of the biological effects of nonionizing radiation (for example, light and microwaves) and ionizing radiation, emissions energetic enough to knock electrons out of molecules, for example, α and β particles, γ rays, X-rays, and high-energy ultraviolet radiation (Figure 5.4.2).

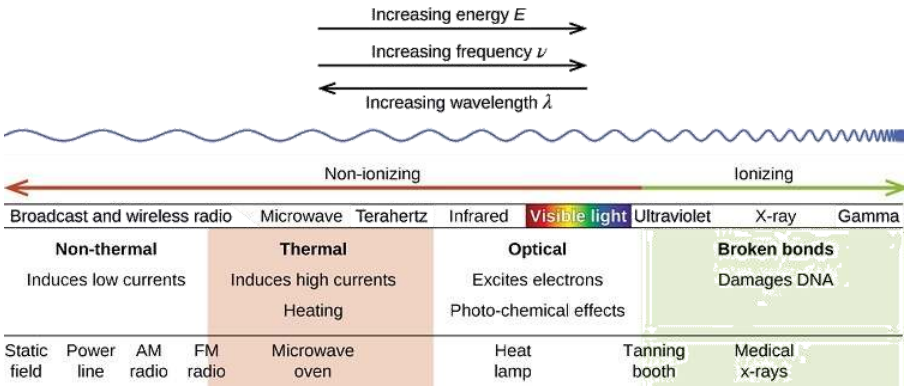


Figure 5.4.4: Lower frequency, lower-energy electromagnetic radiation is nonionizing, and higher frequency, higher-energy electromagnetic radiation is ionizing. (CC BY-SA, OpenStax).

Energy absorbed from nonionizing radiation speeds up the movement of atoms and molecules, which is equivalent to heating the sample. Although biological systems are sensitive to heat (as we might know from touching a hot stove or spending a day at the beach in the sun), a large amount of nonionizing radiation is necessary before dangerous levels are reached. Forms of nonionizing radiation include wave-like radiation shown on the left side of the image. This type of radiation would include the visible spectrum through radio waves.

Everyday Exposure to Radiation

Natural radiation provides the majority of exposure to the average person. Looking at the pie chart below, the largest sources of exposure to radiation is from radon gas (Rn-222). This isotope is an α emitter with a half–life of 3.82 days. Radon is produced through the radioactive decay of U-238, which is found in trace amounts in soil and rocks. In the environment, radon concentrations can vary depending upon a geographical location. Once the soil of a particular region is disturbed, this element can escape and cause serious health issues. Please be aware that radon, and not nuclear reactors, affect more people in the United States.

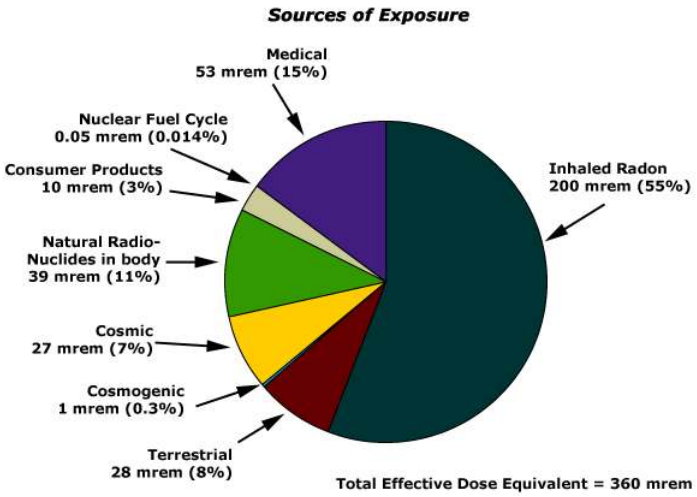


Figure 5.4.5: Sources of exposure to radiation. from Nuclear ScienceNationaln of Lawrence Berkeley Natioanl Lab and with CPEP (the Contemporary Physics Education Project).

Radon gas escapes from the ground and gradually seeps into homes and other structures above. Since it is about eight times more dense than air, radon gas accumulates in basements and lower floors and slowly diffuses throughout buildings (Figure 5.4.5). Once airborne, the radon enters the body through inhalation or ingestion. Through alpha emission, Rn-222 decays to produce large particles. These radioactive species travel to the respiratory tract where they will ionize lung tissue. Exposure to radon increases one's risk of getting cancer (especially lung cancer), and high radon levels can be as bad for health as smoking a carton of cigarettes a day. Radon is the number one cause of lung cancer in nonsmokers and the second leading cause of lung cancer overall. Radon exposure is believed to cause over 20,000 deaths in the US per year.

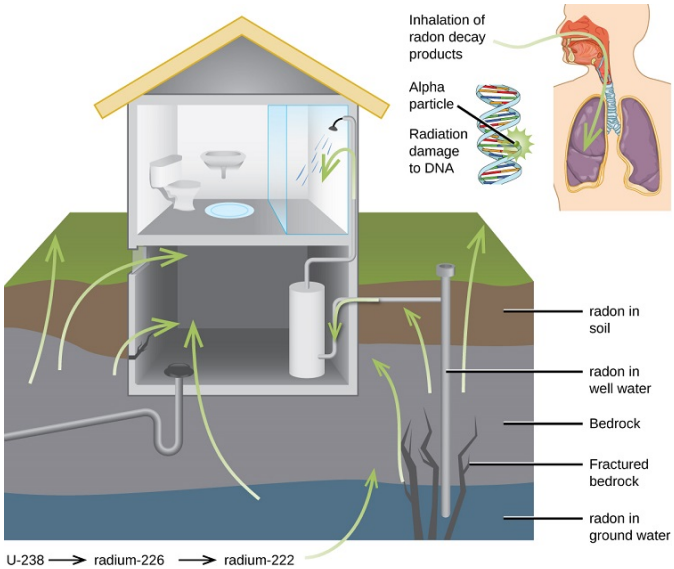


Figure 5.4.6: Radon-222 seeps into houses and other buildings from rocks that contain uranium-238, a radon emitter. The radon enters through cracks in concrete foundations and basement floors, stone or porous cinder block foundations, and openings for water and gas pipes.

Radon is found in buildings across the country, with amounts depending on where you live. The average concentration of radon inside houses in the US (1.25 pCi/L) is about three times the levels found in outside air, and about one in six houses have radon levels high enough that remediation efforts to reduce the radon concentration are recommended. The Environmental Protection Agency(EPA) tests homes throughout the United States. This agency classifies their test results into three different zones. Using color-coded keys, an individual can access their probability of being exposed to this deadly isotope. The EPA recommends an individual alter their home if the radon level exceeds 4 pCi/L. Click on this link to see your state and even county's radon level. Red-shaded areas of the EPA map indicate that tested radon levels exceed the 4 pCi/L concentration.

Radon tests can be purchased through the EPA or at most hardware stores. If you are a resident of South Carolina, you can request a free radon test kit through DHEC (Department of Health and Environmental Control). If a consumer finds excessive radon in their home, then alterations to the existing construction can be made. Some of these changes include installing barriers between the soil and the home and placing ventilation on the group floor to release radon outside. For more information regarding these types of alterations, click on this link.

Other sources of radiation in consumer products include smoke detectors, antique watches/clocks, and older ceramics/glass. Smoke detectors emit alpha particles of Am-241 (Americium). Antique watches and clocks use H-3 (tritium), Pm-147 (promethium), or Ra-226 (radium) as a fluorescent light source. Antique ceramics (dating before 1970) could contain U-238 if color is an orangey-red. If antique glassware is yellow or green in color, it could contain U-238 as well. Glassware with this isotope will glow under a black light.



Figure **5.4.7**: Vaseline glass contains natural or depleted uranium. Image courtesy of Elizabeth R. Gordon

Concrete, fertilizers, kitty litter, and even food (bananas and salt substitutes) can contain trace amounts of different types of radioactivity. K-40 (potassium) is present in all of these substances.

Need More Practice?

- Turn to Section 5.E of this OER and answer questions #3, #6, #9, and #10.

References

1. https://www.epa.gov/radon
2. https://www.orau.org/ptp/collection/consumer%20products/consumer.htm

Contributors and Attributions

- Paul Flowers (University of North Carolina - Pembroke), Klaus Theopold (University of Delaware) and Richard Langley (Stephen F. Austin State University) with contributing authors. Textbook content produced by OpenStax College is licensed under a Creative Commons Attribution License 4.0 license. Download for free at http://cnx.org/contents/85abf193-2bd...a7ac8df6@9.110).
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5.5: The Basics of Skin Cancer

Learning Objectives

- To distinguish between the different types of ultraviolet radiation.
- To interpret the ABCDE's of skin cancer.
- Compare the three types of skin cancer.
- Identify ADA-recommended skin care products (i.e.- SPF, Broad Spectrum terminology)
- Recall how often sun protection products should be applied.
- Explain the difference between water resistant and waterproof.
- Identify ADA-recommended UPF clothing.

Exposure to Ultraviolet Radiation

Of all the types of ionizing radiation, people come into more contact with ultraviolet radiation. Sources of this radiation would include the sun, ultraviolet lights, and tanning beds. The sun produces three different forms of ultraviolet rays (UVA, UVB, and UVC). Fortunately, the deadliest of these three rays (UVC) never reaches the earth's surface and is absorbed by the Earth's ozone layer. However, both UVA and UVB reach the Earth's surface to affect living systems.

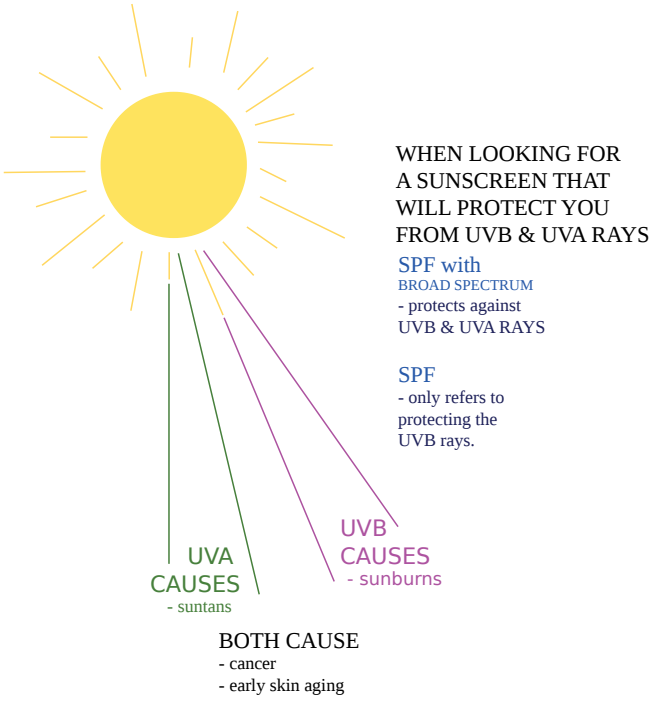


Figure 5.5.1: Effect of Light on skin

UVA is produced naturally by the sun and artificially by lamps and tanning beds. For years, sunbathers believed that UVA provided only a youthful glow. Now, the American Academy of Dermatologists has condemned the use of tanning beds. Scientific research has correlated certain types of skin cancers (mainly basal and squamous cell) with the use of these devices. Besides skin cancer, tanning beds cause premature aging and damage to your eyes. If a tanning bed is not properly sanitized between uses, skin diseases can be transmitted from one consumer to another.

Recognizing Suspicious Skin Changes

According to the American Academy of Dermatologists, skin cancer is the most common form of cancer. Exposure to ultraviolet rays or arsenic can cause skin diseases. Additionally, some individuals may be genetically predisposed to developing this illness (check out your family tree). Approximately 10,000 Americans a day will be diagnosed with one of the three different forms of skin

cancer. Millions of Americans have already been diagnosed with the most common form of skin cancer, basal cell carcinoma. This type of cancer grows very slowly and can spread to other parts of the body. Basal cell carcinoma frequently appears on the head and neck of a patient. Rarely, basal cell carcinoma can eventually affect other areas of the body like skin or bone.

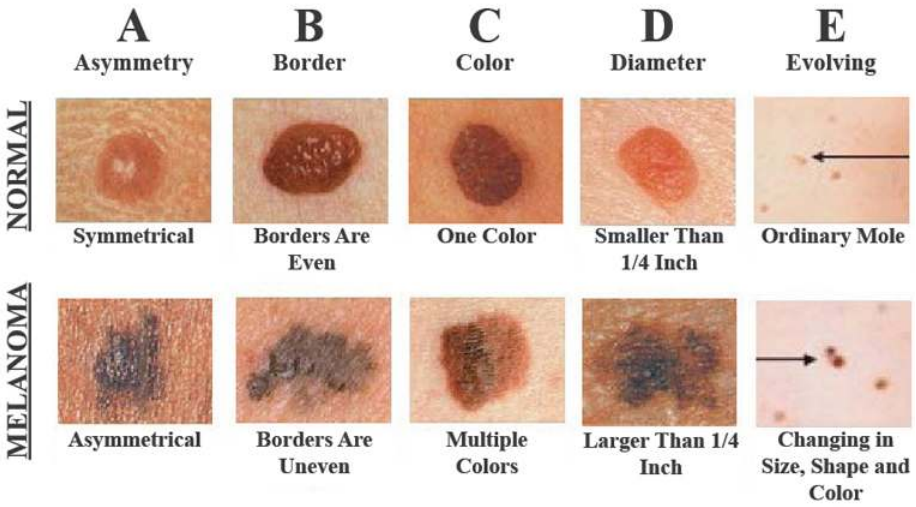


Figure 5.5.2: ABCDEs of Skin Cancer. A brown spot on the skin is likely to be a harmless mole, but it could be a sign of skin cancer. Unlike moles, skin cancers are generally asymmetrical, have irregular borders, may be very dark in color, and may have a relatively great diameter.

Squamous cell carcinoma appears more commonly on the face, neck, lips, and hands of the person. For females, squamous typically presents on the lower leg portion. This form of skin cancer is more likely to metastasize (spread) than basal cell carcinoma. If caught early and treated, patients can easily survive both basal and squamous cell carcinomas.

Melanoma, the most serious form of skin cancer, is the least common of all skin cancers. This type of cancer usually manifests on the trunks of males and the legs of females. It can spread easily to the brain, liver, bones, abdomen, or lymph nodes. If detected early, survival rates are good and life expectancy will be normal.

Figure 5.5.2 compares normal pigmentations to moles that have changed into melanoma. Monthly reviews of skin lesions and seeking medical advice is key to surviving this disease. Be sure to note these visual characteristics (the ABCDEs) of skin cancer for future evaluations (life and class).

Sunblocks and Sunscreens

UVB radiation in sunlight allows the skin to produce vitamin D. This vitamin prevents bone disorders like rickets and osteoporosis (brittle bone disease). The American Academy of Dermatology suggests vitamin D be obtained through foods or nutritional supplements. Excessive exposure to UV can be damaging and the pigment **melanin**, deposited in cells at the base of the epidermis, helps to protect the underlying layers of the skin from this damage. Melanin also colors the skin and variations in the amount of melanin produces colors from pale yellow to black. The darker the skin tone, the more melanin one has, and the less likely skin cancer will occur.



Figure 5.5.3: The author's great, great- grandmother was diagnosed with skin cancer on her nose during the 1950's.

Excess exposure to the sun can cause sunburn. This is common in humans, but light skinned animals like cats and pigs can also be sunburned, especially on the ears. Skin cancer can also result from excessive exposure to the sun. As holes in the ozone layer increase exposure to the sun's UV rays, so too does the rate of skin cancer in humans and animals.

Sunscreens and sunblocks are designed to protect skin from ultraviolet rays. *Sunblocks* contain inorganic ingredients like zinc oxide or titanium dioxide. These chemicals act as UV filters by reflecting the sun's UV rays. Sunblocks can have grainy textures due to the inorganic components. The thick nature of a sunblock can make it difficult to spread evenly on the skin. *Sunscreens* contain organic compounds like oxybenzone, avobenzone, homosalate, and octinoxate (Figure 5.5.4). By absorbing ultraviolet rays, these compounds decompose and give off heat. Sunscreens apply smoother than sunblocks. Often, manufacturers will combine sunscreen and sunblock ingredients to make their products.



Figure 5.5.4: Effect of Light on skin. Please note the infographic above uses sunblock and sunscreen interchangeably. Sunblocks are mineral (inorganic based) while sunscreens are organic compounds.

Sun protection factor (SPF) measures a product's protection from UVB rays. SPF does not quantify protection from UVA radiation. The American Academy of Dermatology recommends you select a sunscreen or sunblock with a minimum SPF factor of 30. This SPF value means a lotion can filter out 97% of UVB rays. Moving to a SPF of 50 will only filter out 1 more percentage of UVB rays. Increasing an SPF factor past 30 does very little in shielding skin from UVB radiation.

Products that protect skin from UVA must be labeled as being a broad spectrum. Sunblocks provide UVA and UVB protection, but sunscreens can vary on what they can screen. Every two hours, sunscreens/sunblocks should be reapplied to the skin. Sweating and swimming can remove sunscreen/sunblock products. No sun products are waterproof, but some are labeled as being water-resistant. Consumers are encouraged to reapply these products every two hours as well.

Clothing and Other Garments

Though most people are unaware, the clothing they wear every day serves as a barrier against harmful ultraviolet rays. The garment Ultraviolet Protection Factor (UPF) of a material is measured by how much UVA and UVB rays come in contact with the skin. Garments that receive a good rating by the Skin Cancer Foundation's Seal of Recommendation have a UPF rating of at least 30. Fabrics that receive excellent ratings have UPF values of 50 and can block 98% of the sun's rays, allowing only 2% to penetrate the skin.



Video 5.5.1: Labor Day skincare tips: UPF clothing. Whether you're heading to the UT football game or having a cookout by the pool, it's important to protect your skin from the sun, and sunscreen isn't the only way you can do that. Dr. Kellie Reed with Sanovseven specific factors maket UPF clothing.

Clothing does not protect equally and seven specific factors make clothing more effective: UPF, color, construction, content, fit, coverage, and activity. Contrary to lighter shades, darks, and bright colors absorb UV rays rather than letting them penetrate your skin. Densely woven clothing, like denim, wool, or synthetic fibers is more beneficial than tight clothing. If clothing becomes stretched, thinner, or wet, UV rays can seep through the fabric. Therefore, the thicker and looser the clothing, the more protection it will provide for the skin. Shiny polyester and lightweight silk fabrics are highly protective because they reflect radiation. Other fabrics like unbleached cotton and high-tech fabrics treated with chemical UV absorbers or dyes are also effective in shielding skin from UV exposure.

When spending large amounts of time outside, wearing long-sleeved shirts and pants offers more protection of skin. Topping off your outfit with a wide-brimmed hat maximizes protection from UV rays and helps prevent basal and squamous cancers that often appear on the head and neck and account for 90% of skin cancers. Lastly, select sunglasses that have been certified to protect your eyes from UV rays. A good pair of sunglasses will reduce your risk of developing cataracts later in life.

Contributors and Attributions

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5.6: Measuring Radiation

Learning Objectives

- Define units for measuring radiation exposure
- Explain the operation of common tools for detecting radioactivity
- List common sources of radiation exposure in the United States
- Calculate rem, Sv, mrem, and μSv and compare them to the reference standards.
- Remember average background of yearly radiation is 360 mrem.
- View the radiation video at bottom of the page and identify who receives the most ionizing radiation per year.

Several different devices are used to detect and measure radiation, including Geiger counters, scintillation counters (scintillators), and radiation dosimeters (Figure 5.6.1). Probably the best-known radiation instrument, the Geiger counter (also called the Geiger-Müller counter) detects and measures radiation. Radiation causes the ionization of the gas in a Geiger-Müller tube. The rate of ionization is proportional to the amount of radiation. These types of devices measure alpha and beta radiation quite well. If a Geiger counter is altered, it can detect gamma and x-rays. A scintillation counter contains a scintillator (a material that emits light (luminesces) when excited by ionizing radiation) and a sensor that converts the light into an electric signal. This instrument can effectively detect gamma, x-rays and, beta particles. Radiation dosimeters also measure ionizing radiation and are often used to determine personal radiation exposure. Commonly used types are electronic, film badge, thermoluminescent, and quartz fiber dosimeters.

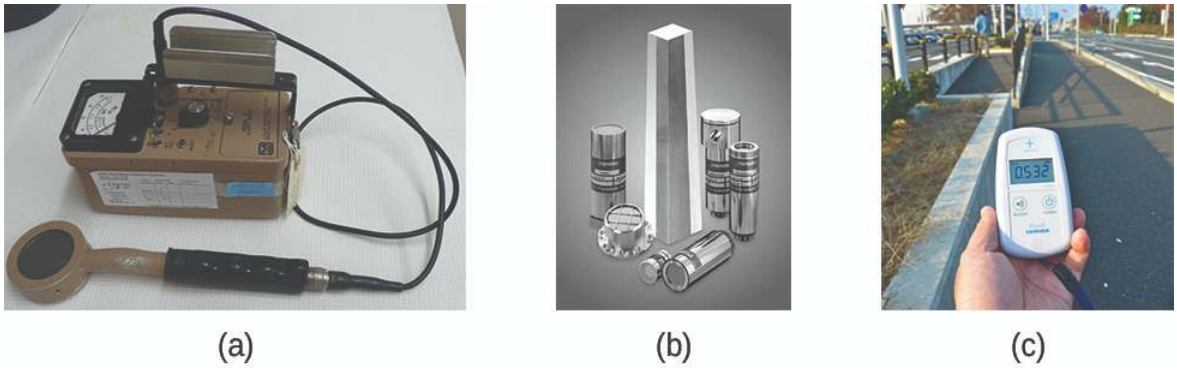


Figure 5.6.1: Devices such as (a) Geiger counters, (b) scintillators, and (c) dosimeters can be used to measure radiation. (credit c: modification of work by “osaMu”/Wikimedia commons).

A variety of units are used to measure different aspects of radiation (Table 5.6.1). The becquerel (Bq), and the curie (Ci) are used to describe rate of radioactive decay. Named in honor of Henri Becquerel and the the Curies, these units do not describe the damaging effects of radiation. Early medical applications used the units of of rad or gray (Gy) to indicate energy emitted onto an absorbing material. Today, most industries rely on the sievert (Sv) or rem. These two units measure tissue damage caused by radiation. **Looking at the chart below, please note the different units and what they describe. In CHM 101, it is not necessary for you to perform conversions (with the exception of rem/sV) with units that involve activities or absorbed doses.**

Table 5.6.1: Units Used for Measuring Radiation

Measurement Purpose	Unit	Quantity Measured	Description
activity of source	becquerel (Bq)	radioactive decays or emissions	amount of sample that undergoes 1 decay/second
	curie (Ci)		amount of sample that undergoes 3.7×10^{10} decays/second. The body normally contains .1μ Ci of C-14 radiation. 1 Ci is a huge amount of radiation.
absorbed dose	gray (Gy)	energy absorbed per kg of tissue	1 Gy = 1 J/kg tissue
	radiation absorbed dose (rad)		1 rad = 0.01 J/kg tissue Acute radiation sickness occurs before 100 rad.
biologically effective dose	sievert (Sv)	tissue damage	Sv = RBE × Gy
	roentgen equivalent for man (rem)		Rem = RBE × rad An average American is exposed to around 360 mrem of radiation/yr. Acute radiation poisoning can occur at levels as low as 25 rems. Chernobyl liquidators were exposed to between 7.5×10^5 and 1.3×10^6 mrems of radiation.

The roentgen equivalent for man (rem) is the unit for radiation damage that is used most frequently in medicine (100 rem = 1 Sv). For testing or therapy, radiation values will typically be given in mrem (millirem) or mSv (millisievert). Knowing how to convert these units will enable you to compare them to given standards. In addition, understanding the exposure limits in mrem, mSv, Sv, and uSv can give you an idea of the level of toxicity involved in nuclear reactor accidents or nuclear weapons.



Effects of Long-term Radiation Exposure on the Human Body

It is impossible to avoid some exposure to ionizing radiation. We are constantly exposed to background radiation from a variety of natural sources, including cosmic radiation, rocks, medical procedures, consumer products, and even our own atoms. We can minimize our exposure by blocking or shielding the radiation, moving farther from the source, and limiting the time of exposure.

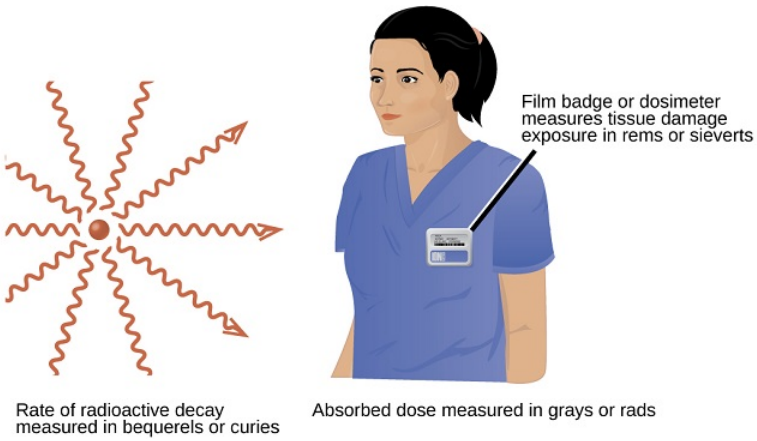


Figure **5.6.2**: Different units are used to measure the rate of emission from a radioactive source, the energy that is absorbed from the source, and the amount of damage the absorbed radiation does. (CC BY-SA 3.0; OpenStax).

As shown in Table **5.6.2**, the average person is exposed to background radiation from a variety of sources. Radon gas represents the greatest source of ionizing radiation. Indoor exposure to this alpha (α) emitter could increase the likelihood of developing lung cancer.

Table **5.6.2**: Average Annual Radiation Exposure (Approximate)

Source	Amount (mrem)
radon gas	200
medical sources	53
radioactive atoms in the body naturally	39
terrestrial sources (soil)	28
cosmic sources	28
consumer products	10
nuclear energy	0.05
Total	358

Radiation and Flying

Flying from New York City to San Francisco adds 5 mrem (or 0.005 rem) to your overall radiation exposure because the plane flies above much of the atmosphere, which protects us from most cosmic radiation.

The actual effects of radioactivity and radiation exposure on a person's health depend on the type of radioactivity, the length of exposure, and the tissues exposed. Table **5.6.3** lists the potential threats to health at various amounts of exposure over short periods of time (hours or days). An average person receives around 400 mrems of radiation each year. This amount is equivalent to 0.400 rems and 4 mSV. Table **5.6.3** shows the acute toxicity level of radiation in the unit rem. Comparing yearly radiation to this table, one can get an idea of how low daily exposure levels are. Additionally, one can understand the radioactive exposure of the victims of Hiroshima and Nagasaki. Studies involving these groups of people show once exposure limits exceed 100 rem, it is most likely a person will develop some form of cancer.

Table **5.6.3**: Effects of Short-Term Exposure to Radioactivity and Radiation

Exposure (rem)	Effect
1 (over a full year)	No detectable effect
~20	Increased risk of some cancers
~100	Damage to bone marrow and other tissues; possible internal bleeding; decrease in white blood cell count
200–300	Visible “burns” on skin, nausea, vomiting, and fatigue
>300	Loss of white blood cells; hair loss
~600	Death

Radiation Exposure

This 11 minute video shows how radiation can be measured. In addition, the scientists report their findings with various radiation units. While watching the video, answer the questions below to gain a better understanding of radiation around the world.



Table **5.6.4**: Who is the most radioactive?

Substance or Location	Amount of Radiation in µSv/hr
Banana	
Range of background radiation	
Hiroshima today (event: _____)	
Uranium mine	
Trinity Site (event: _____)	
Range of radiation while flying	
Chernobyl (event: _____)	
Walking in Fukushima (event: _____)	
Pripyat, Ukraine hospital maximum reading	
CT Scan	
Fukushima resident (lifetime exposure)	
Astronaut	
Smoker	

1.Does a Geiger counter measure nonionizing radiation?

2.At an acute level, how many Sieverts (Sv) of radiation will kill a person?

3. Fill in the missing information of the chart above (events and values):

4. What two places in Marie Curie's lab are still radioactive? What type of radiation is still lingering?
5. Why did the residents of Chernobyl and Fukushima have black bags on the sides of their highways?
6. In this video, what individuals are exposed to the most radiation in µSv?

References

1. 1 Source: US Environmental Protection Agency

Contributors

- Paul Flowers (University of North Carolina - Pembroke), Klaus Theopold (University of Delaware) and Richard Langley (Stephen F. Austin State University) with contributing authors. Textbook content produced by OpenStax College is licensed under a Creative Commons Attribution License 4.0 license. Download for free at http://cnx.org/contents/85abf193-2bd...a7ac8df6@9.110).
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5.7: Calculating Half-Life

Learning Objectives

- Describe what is meant by the term half-life and what factors affect half-life.
- Calculate the amount of radioactive material that will remain after an integral number of half-lives.
- Calculate the age of a material based upon its half-life.
- Describe how carbon-14 is used to determine the age of carbon containing objects.
- Give examples of other isotopes used in radioactive dating.
- Appreciate the half-life of isotopes involved in nuclear weapons and reactors.

Rate of Radioactive Decay

During natural radioactive decay, not all atoms of an element are instantaneously changed to atoms of another element. The decay process takes time and there is value in being able to express the rate at which a process occurs. A useful concept is **half-life (symbol is $t_{1/2}$)**, which is the time required for half of the starting material to change or decay. Half-lives can be calculated from measurements on the change in mass of a nuclide and the time it takes to occur. The only thing we know is that in the time of that substance's half-life, half of the original nuclei will disintegrate. Although chemical changes were sped up or slowed down by changing factors such as temperature, concentration, etc, these factors have no effect on half-life. Each radioactive isotope will have its own unique half-life that is independent of any of these factors.

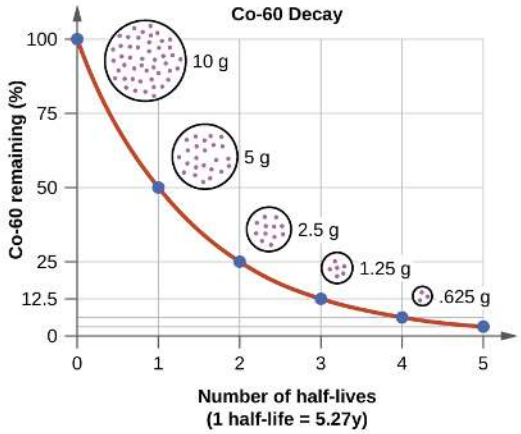


Figure 5.7.1: For cobalt-60, which has a half-life of 5.27 years, 50% remains after 5.27 years (one half-life), 25% remains after 10.54 years (two half-lives), 12.5% remains after 15.81 years (three half-lives), and so on. (CC-BY 4.0; OpenStax).

The half-lives of many radioactive isotopes have been determined and they have been found to range from extremely long half-lives of 10 billion years to extremely short half-lives of fractions of a second. The table below illustrates half-lives for selected elements. In addition, the final elemental product is listed after the decal process. Knowing how an element decays (alpha, beta, gamma) can allow a person to appropriately shield their body from excess radiation.

Table 5.7.1: Table of Selected Half-lives

Element	Mass Number (A)	Half-life	Element	Mass Number (A)	Half Life
Uranium	238	4.5 Billion years	Californium	251	800 years
Neptunium	240	1 hour	Nobelium	254	3 seconds
Plutonium	243	5 hours	Carbon	14	5730 years
Americium	245	25 minutes	Carbon	16	740 milliseconds

The quantity of radioactive nuclei at any given time will decrease to half as much in one half-life. For example, if there were **100 g** of **Cf**-251 in a sample at some time, after 800 years, there would be **50 g** of **Cf**-251 remaining. After another 800 years (1600 years

total), there would only be **25 g** remaining.

Remember, the half-life is the time it takes for half of your sample, no matter how much you have, to remain. Each half-life will follow the same general pattern as **Cf**-251. The only difference is the length of time it takes for half of a sample to decay.

Interactive Simulation: Visualizing Half-Life

Click on this interactive simulation to visualize what happens to a radioisotope when it decays. and learn about different types of radiometric dating, such as carbon dating. Understand how decay and half life work to enable radiometric dating. Play a game that tests your ability to match the percentage of the dating element that remains to the age of the object.

There are two types of half-life problems we will perform. One format involves calculating a mass amount of the original isotope. Using the equation below, we can determine how much of the original isotope remains after a certain interval of time.

$$\text{how much mass remains} = \frac{1}{2^n}(\text{original mass})$$

n is the number of half-lives.

Example 5.7.1

If there are 60 grams of **Np**-240 present, how much **Np**-240 will remain after 4 hours? (**Np**-240 has a half-life of 1 hour)

Solution

$$\text{how much mass remains} = \frac{1}{2^4}(60\,\text{grams})$$

After 4 hours, only **3.75 g** of our original **60 g** sample would remain the radioactive isotope **Np**-240.

Example 5.7.2

A sample of **Ac**-225 originally contained **8.0** ug. After 720 hours, how much of the original **Ac**-225 remains? The half-life of this isotope is 10 days.

Solution

To determine the number of half-lives (n), both time units must be the same.

$$720\,\cancel{hours} \times \frac{1\,day}{\cancel{24\,hours}} = 30\,days$$

$$n = 3 = \frac{30\,days}{10\,days}$$

$$\text{how much mass remains} = \frac{1}{2^3}(8.0\,ug)$$

After 720 hours, 1.0 ug of the material remains as **Ac**-225

Radioactive Dating

Radioactive dating *is a process by which the approximate age of an object is determined through the use of certain radioactive nuclides*. For example, carbon-14 has a half-life of 5,730 years and is used to measure the age of organic material. The ratio of carbon-14 to carbon-12 in living things remains constant while the organism is alive because fresh carbon-14 is entering the organism whenever it consumes nutrients. When the organism dies, this consumption stops, and no new carbon-14 is added to the organism. As time goes by, the ratio of carbon-14 to carbon-12 in the organism gradually declines, because carbon-14 radioactively decays while carbon-12 is stable. Analysis of this ratio allows archaeologists to estimate the age of organisms that were alive many thousands of years ago.

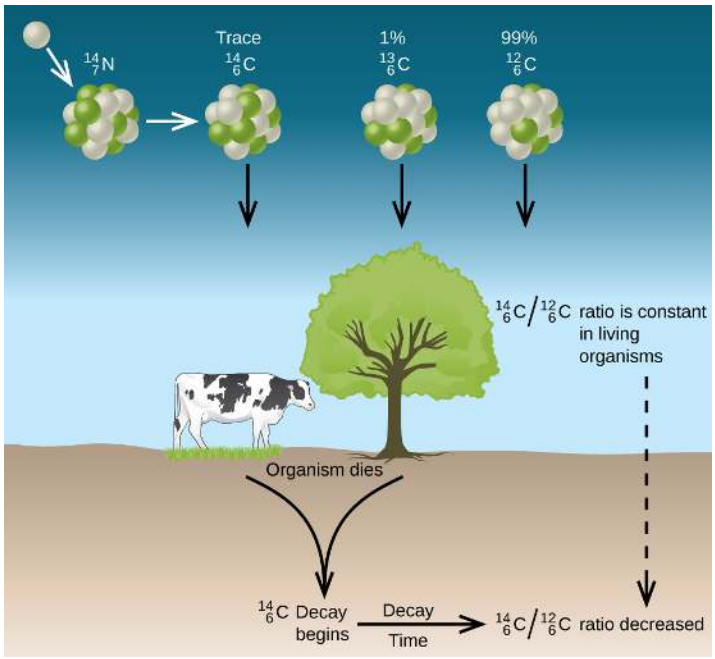


Figure **5.7.2**: Along with stable carbon-12, radioactive carbon-14 is taken in by plants and animals, and remains at a constant level within them while they are alive. After death, the C-14 decays and the C-14:C-12 ratio in the remains decreases. Comparing this ratio to the C-14:C-12 ratio in living organisms allows us to determine how long ago the organism lived (and died). (CC-BY 4.0; OpenStax).

C-14 dating does have limitations. For example, a sample can be C-14 dating if it is approximately 100 to 50,000 years old. Before or after this range, there is too little of the isotope to be detected. Substances must have obtained C-14 from the atmosphere. For this reason, aquatic samples cannot be effectively C-14 dated. Lastly, accuracy of C-14 dating has been affected by atmosphere nuclear weapons testing. Fission bombs ignite to produce more C-14 artificially. Samples tested during and after this period must be checked against another method of dating (isotopic or tree rings).



To calculate the age of a substance using isotopic dating, use the equation below:

$$\text{how old (time)} = n \times t_{1/2}$$

n is the number of half-lives and $t_{1/2}$ is the half-life (in time).

Example 5.7.3

How long will it take for 18.0 grams of Ra-226 to decay to leave a total of 2.25 grams? Ra-226 has a half-life of 1600 years.

Solution

18.0g ⇒ 9.0g ⇒ 4.5g ⇒ 2.25g, this is three half-lives

$$\text{how old (time)} = 3 \times 1600\,years$$

This decay process takes 4800 years to occur.

Radioactive Dating Using Nuclides Other than Carbon-14

Radioactive dating can also use other radioactive nuclides with longer half-lives to date older events. For example, uranium-238 (which decays in a series of steps into lead-206) can be used for establishing the age of rocks (and the approximate age of the oldest rocks on earth). Since U-238 has a half-life of 4.5 billion years, it takes that amount of time for half of the original U-238 to decay into Pb-206. In a sample of rock that does not contain appreciable amounts of Pb-208, the most abundant isotope of lead, we can assume that lead was not present when the rock was formed. Therefore, by measuring and analyzing the ratio of U-238:Pb-206, we can determine the age of the rock. This assumes that all of the lead-206 present came from the decay of uranium-238. If there is additional lead-206 present, which is indicated by the presence of other lead isotopes in the sample, it is necessary to make an adjustment.

Potassium-argon dating uses a similar method. K-40 decays by positron emission and electron capture to form Ar-40 with a half-life of 1.25 billion years. If a rock sample is crushed and the amount of Ar-40 gas that escapes is measured, determination of the Ar-40:K-40 ratio yields the age of the rock. Other methods, such as rubidium-strontium dating (Rb-87 decays into Sr-87 with a half-life of 48.8 billion years), operate on the same principle. To estimate the lower limit for the earth's age, scientists determine the age of various rocks and minerals, making the assumption that the earth is older than the oldest rocks and minerals in its crust. As of 2014, the oldest known rocks on earth are the Jack Hills zircons from Australia, found by uranium-lead dating to be almost 4.4 billion years old.

An ingenious application of half-life studies established a new science of determining ages of materials by half-life calculations. For geological dating, the decay of **U**-238 can be used. The half-life of **U**-238 is $\mathbf{4.5 \times 10^9}$ years. The end product of the decay of **U**-238 is **Pb**-206. After one half-life, a 1.00 gram sample of uranium will have decayed to 0.50 grams of **U**-238 and 0.43 grams of **Pb**-206. By comparing the amount of **U**-238 to the amount of **Pb**-206 in a sample of uranium mineral, the age of the mineral can be estimated. Present day estimates for the age of the Earth's crust from this method is at 4 billion years. This radioactivity approach can be used to detecting fake wine vintages too.

Isotopes with shorter half-lives are used to date more recent samples. For example, tritium ($t_{1/2}$ =12.3 years) can date samples within an age range of 1-100 years. Chemists and geologists use tritium dating to determine the age of water (ocean and fresh). In addition, tritium dating can be useful in determining the age of wines and brandies.

Need More Practice?

Turn to section 5.E and work problems 11 and 13.

Contributors and Attributions

-
- Emma Gibney (Furman University)

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5.8: Using Nuclear Science to Diagnose Disease

Learning Objectives

- Understand the difference between diagnostic and therapeutic radiation.
- Know what testing involve nuclear chemistry.
- Calculate dosages of radiation received with a nuclear test.
- Compare nuclear testing dosages to toxic concentrations.

Diagnostic medical applications involve testing for a disease or condition. In nuclear medicine, this could involve using x-rays, CT or PET scans, or isotopic studies. The radiation involved for each of these types of tools will vary in mrem or mSv amounts.

X-Ray Imaging

X-Ray imaging is one of the most basic and routine forms of imaging within modern medicine. Using electromagnetic radiation, scientists and doctors have the ability to visualize internal situations. X-Ray imaging takes advantage of the fact that dense structures (i.e., bone) absorb more x-rays than the softer tissues that surround it. By projecting radiation onto special film paper, the denser substance casts a shadow where less x-rays pass through the body, and a contrasting image is produced. The radiation emitted by an X-Ray is of the wavelength of 10 to 0.01 nanometers (nm). Because some parts of the body may be thicker than others, X-Rays are used in "soft" (10 to 0.10 nm) and "hard" (0.10 to 0.01 nm) dosages or radiation.

X-rays are produced by passing an electron beam through a tungsten anode in a vacuum. The electromagnetic waves that are released can be focused and adjusted according to what is imaged. X-Rays can image in very high definition at a low cost, but they provide poor contrast in soft tissues. Contrast agents can also be added to the body prior to imaging, which allows different tissues to absorb more radiation, creating a better contrasting image. This allows doctors and scientists to work with much more specific images within their diagnosis or research (i.e., the ability to determine different aspects of soft-tissue).

Projectional radioagraphy (Figure **5.8.1**) can be done standing or laying down. To obtain clearer images, a patient needs to be as still as possible. A technician may ask to take a big breath and hold it right before pushing the scan button. This allows the patient to keep their chest and abdomen in position and will allow a clearer image to be captured. Breathing will cause movement which will result in a blurred image.

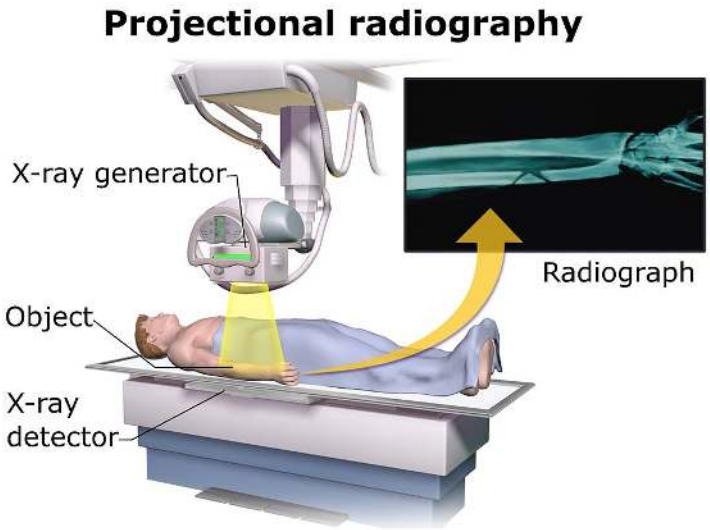


Figure **5.8.1**: Acquisition of projectional radiography, with an X-ray generator and a detector. (CC BY-SA 4.0; Blausen Medical).

Before having an x-ray or CT scan, patients should remove all metallic clothing or jewelry. Metals can distort x-ray images easily. Sometimes, lead aprons are provided to patients. The lead aprons shields a patient's reproductive organs from ionizing radiation. X-rays and CT scans can harm a developing embryo or fetus. For this reason, female patients are required to sign a liability wavier stating they are not pregnant at the time of testing. Other options like MRI or ultrasounds (nonionzing techniques) are available for these patients.

Diagnostic x-rays differ greatly in millisievert (mSV) dosages. Table **5.8.1** illustrates a few of these values. Using this table, you can calculate rem and mrem amounts and compare it to toxic values shown in Section 5.6.

Table **5.8.1**: Diagnostic x-rays levels

Type of X-ray Exam	Diagnostic Reference level (DRL) in mSv
Chest	0.96
Abdomen	7.10
C-spine	3.56
T-sping	8.00
L-Spline	12.0
Skull	6.00
Lumb	7.21
Hip	7.21

Source: Sonawane AU[1], Shirva VK, Pradhan AS., Radiat Prot Dosimetry. 2010 Feb;138(2):129-36. doi: 10.1093/rpd/ncp235.

Example 5.8.1: Chest X-ray

A chest x-ray yields a dosage of 6 mrems of radiation to a patient. Calculate this dosage in rems and millisieverts (mSv). Compare these values to your annual background dose (around 360 mrems) and cancer dose (100 rems).

Solution

For the first calculation, recall the metric prefix milli from Chapter 2.

$$\frac{6\ \cancel{mrem}}{1}\left|\frac{1\ rem}{1000\ \cancel{mrem}}\right. = 6 \times 10^{-3}\ rem$$

For the second calculation, you will need to insert the 100 rem = 1 Sv factor. Then, you will need to use your milli metric prefix again.

$$\frac{6 \times 10^{-3}\ \cancel{rem}}{1}\left|\frac{1\ \cancel{Sv}}{100\ \cancel{rem}}\right|\frac{1000\ mSv}{1\ \cancel{Sv}} = 6 \times 10^{-2}\ mSv$$

The dose of 6 mrem dose is significantly lower than the level of background radiation. In addition, the calculated $6 \times 10^{-3}\ rem$ value is well below the 100 rem dosage that is associated with development of cancer.

Example 5.8.2: Mammogram

Your grandmother/mother goes to get her yearly mammogram (x-ray image that helps detect breast cancer). The radiation level for this scan is .36mSv. Convert this value to mrem and rem. Compare calculated values to background and cancer causing levels (shown in previous problem).



Figure 5.8.2: Sharon Grubbs, 2d Medical Group mammography technologist, demonstrates the mammography machine. (Public Domain; U.S. Air Force photo by Staff Sgt. Mike Andriacco)

$$\frac{0.36\ \cancel{mSv} \mid 1\ \cancel{Sv} \mid 100\ rem}{1 \mid 1000\ \cancel{mSv} \mid 1\ \cancel{Sv}} = 3.6 \times 10^{-2}\ rem$$

$$\frac{3.6 \times 10^{-2}\ \cancel{rem} \mid 1000\ mrem}{1 \mid 1\ \cancel{rem}} = 36\ mrem$$

36 mrems is less than an average person's background radiation of 360 mrems. In addition, this value is 96.4 rems below the cancer level of 100 rems.

CT Scanning

Imagine a patient enters the hospital complaining of severe chest pain. After consulting the patient, the doctors decide that the source of the patient's problems is a constricted artery. However, the human body contains several long arteries. The doctors could use surgery to find the source of the clot, but this could take many hours and with no definite guarantee of success. This is exactly where radiation helps medical professionals bridge the gap that once existed. Computerized Axial Tomography (CT) scans use X-ray particles along with advanced computer technology in order to produce highly detailed cross sectional images of the body. Using these scans, medical professionals can accurately find clots and other other harmful medical conditions.

CT/CAT scans have the same fundamentals of x-rays, but they produce 3-D images using tomography. Using digital geometric processing, the CT scan creates a 3-D image compiling a large number of 2-D x-rays. These 2-D images are thin cross sections of the body taken from a single axis of rotation. A CT scanner consists of a table where the patient lies on, an x-ray device which rotates at high speed around the patient taking hundreds of cross sections of the body, and a computer with appropriate software to compile and render the 3-D image. The table in Figure 1 moves through the tube, allowing the machine to take hundreds of pictures from head to toe.



Figure 5.8.3: PET/CT-System with 16-slice CT; the ceiling mounted device is an injection pump for CT contrast agent. (Public Domain; Hg6996).

Similar to x-ray, contrast agents are typically added to the body before imaging occurs so that different tissues are more defined. Due to the fact that many more images are being taken in order to form a complete three dimensional image, the radiation dose is much higher. While a chest x-ray is around 0.10 mSv or radiation, a chest CAT scan subjects the patient to about 8 mSv of radiation; over twice the amount that the body would absorb from its environment in a year. For this reason, it is uncommon and unsafe to have multiple CAT scans taken unless completely necessary.

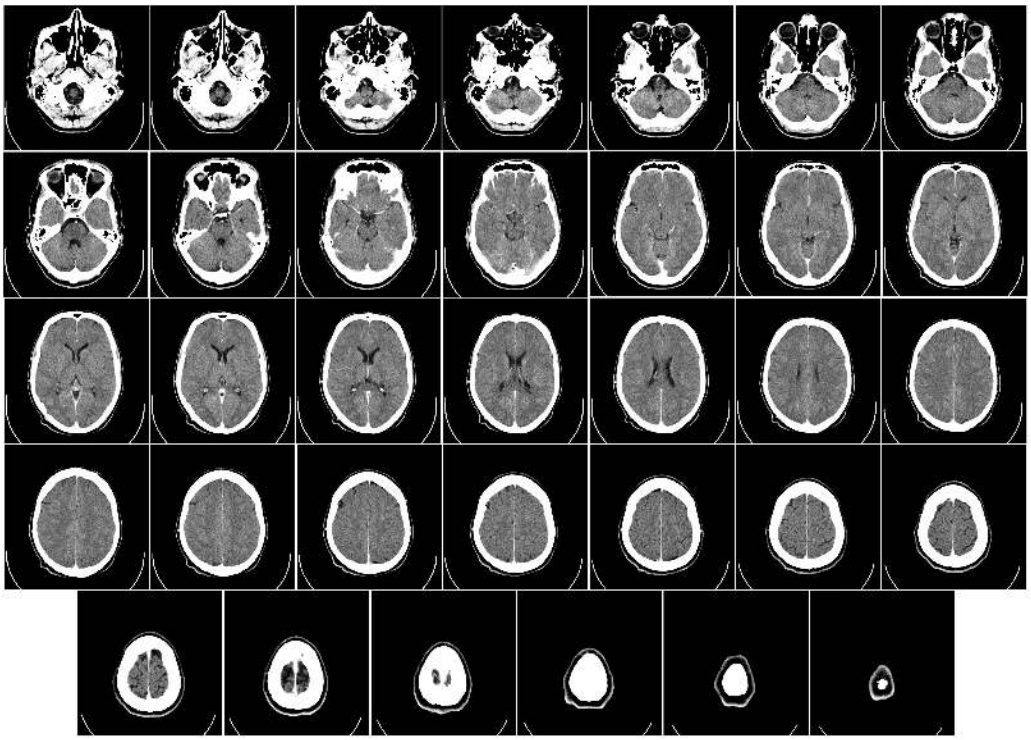


Figure 5.8.4: CT scan of the human brain. These images assist in diagnosing migraines, brain tumors, strokes, bleeding, and head injuries. upload.wikimedia.org/Wikipedia/commons/5/50/Computed_tomography_of_human_brain_-_large.png

Example 5.8.3: Body CT Scan

Your doctor suspects you have appendicitis and orders a CT scan. This type of evaluation exposes you to 12 msV of radiation. Convert the given mSv amount to rem and mrem. Lastly, compare this value to background and cancer mrem/rem values.

$$\frac{12\ \cancel{mSr}}{1} \left| \frac{1\ \cancel{Sr}}{1000\ \cancel{mSr}} \right| \frac{100\ rem}{1\ \cancel{Sr}} = 1.2\ rem$$

$$\frac{1.2\ \cancel{rem}}{1} \left| \frac{1000\ mrem}{1\ \cancel{rem}} \right. = 1200\ mrem$$

PET Scanning

Positron Emission Tomography or PET scan is a type of nuclear medicine imaging. Depending on the area of the body being imaged, a radioactive isotope is either injected into a vein, swallowed by mouth, or inhaled as a gas. When the radioisotope is collected in the appropriate area of the body, the gamma ray emissions are detected by a PET scanner (often called a gamma camera) which works together with a computer to generate special pictures, providing details on both the structure and function of various organs. Watch this informational video on how this technique works. PET scans are used to:

- Detect cancer
- Determine the amount of cancer spread
- Assess the effectiveness of treatment plans
- Determine blood flow to the heart muscle
- Determine the effects of a heart attack
- Evaluate brain abnormalities such as tumors and memory disorders
- Map brain and heart function

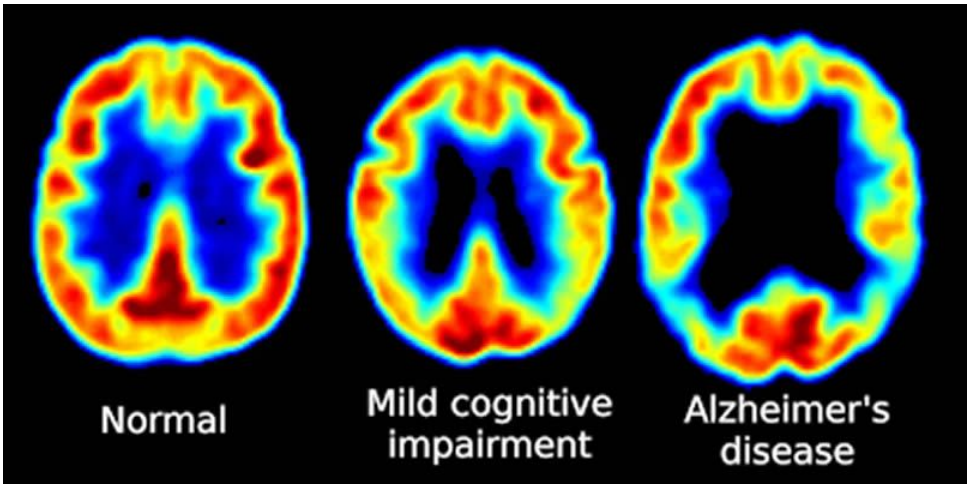


Figure 5.8.5: Mild cognitive impairment (MCI) is a state between normal ageing and dementia, where someone's mind is functioning less well than would be expected for their age. This image is for illustrative purposes only. (Public Domain; Center For Functional Imaging, Lawrence Berkeley National Laboratory. Alzheimer's Disease Neuroimaging Initiative (ADNI).

PET Scanning, is used to image the physiological aspects of the body rather than the anatomy. It images the function of the body rather than the form, such as where tagged molecules go and how they are used. For instance, if you were to image the brain of a deceased person, nothing would show up on a PET scan opposed to a CAT scan, as the brain is no longer functional. Pet Scanning is very useful in imaging tumors, which can be done when patients are injected with certain tracers. Often times PET scanners are used in collaboration with CAT scanners to create a composite image that shows both the function and form of the body. The animation below is a whole-body PET scan using the radioisotope of ^{18}F ($t_{1/2}$ = 110 min). Using this tracer, doctors can determine if cancer has metastasized by looking at the metabolic activity of glucose.

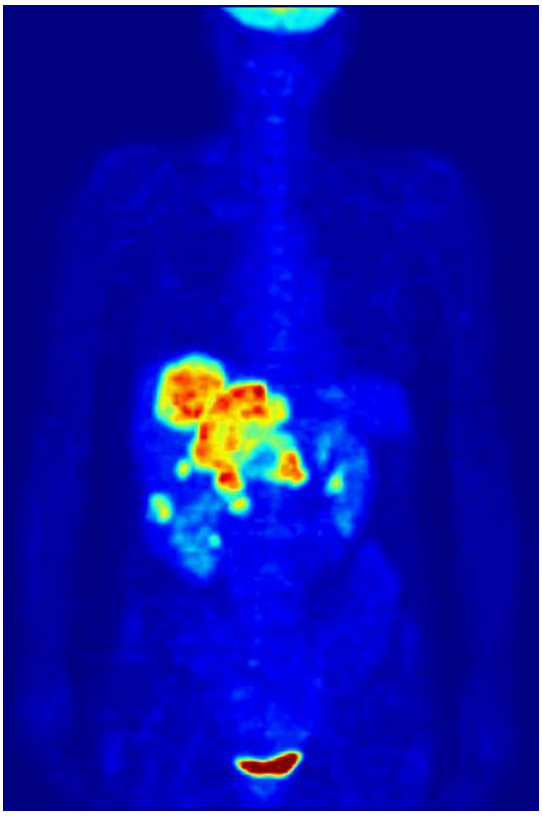


Figure 5.8.6: A whole body analysis by a PET scan. (Public Domain; Jens Maus, http://jens-maus.de/)

Other Isotopic Tests

Radioisotopes have revolutionized medical practice, where they are used extensively. More than 10 million nuclear medicine procedures and more than 100 million nuclear medicine tests are performed annually in the United States. Four typical examples of radioactive tracers used in medicine are technetium-99 ($^{99}_{43}\mathrm{Tc}$), thallium-201 ($^{201}_{81}\mathrm{Tl}$), iodine-131 ($^{131}_{53}\mathrm{I}$), and sodium-24 ($^{24}_{11}\mathrm{Na}$). Damaged tissues in the heart, liver, and lungs absorb certain compounds of technetium-99 preferentially. After it is injected, the location of the technetium compound, and hence the damaged tissue, can be determined by detecting the γ rays emitted by the Tc-99 isotope. Thallium-201 (Figure 5.8.1) becomes concentrated in healthy heart tissue, so the two isotopes, Tc-99 and Tl-201, are used together to study heart tissue. Iodine-131 concentrates in the thyroid gland, the liver, and some parts of the brain. It can therefore be used to monitor goiter and treat thyroid conditions, such as Grave's disease, as well as liver and brain tumors. Salt solutions containing compounds of sodium-24 are injected into the bloodstream to help locate obstructions to the flow of blood.

Small doses of I-131 (too small to kill cells) are used for purposes of imaging the thyroid. Once the iodine is concentrated in the thyroid, the patient lays down on a sheet of film and the radiation from the I-131 makes a picture of the thyroid on the film. The half-life of iodine-131 is approximately 8 days so after a few weeks, virtually all of the radioactive iodine is out of the patient's system. During that time, they are advised that they will set off radiation detectors in airports and will need to get special permission to fly on commercial flights.

Some isotopes that are used to diagnose diseases are shown in Table 5.8.2. **Be sure to memorize one symbol-mass format and application for the test on this unit**. All of these nuclear isotopes release one form of ionizing radiation (either/add particle or ray). In addition, each isotopic application would involve a specific amount of mrem/mSv radiation.

Table 5.8.2: Selected radioisotopes used in diagnostic nuclear medicine

Symbol-mass	Half-Life ($t_{1/2}$)	Application
Xe-133	5.27 days	Lung imaging
H-3	12.26 years	Analyzing total body water
Tl-201	73 hours	Stress tests for heart problems
Fe-59	44.5 days	Detection of anemia
Gd-153	242 days	Analyzing bone density
Cr-51	27.8 days	Determining blood volume
C-11	20.4 minutes	Brain scans
Tc-99m	6.0 hours	Heart, lung, kidney, bone marrow, brain, or bone marrow imaging
Pu-238	86 years	Powering pacemakers
I-131	8.0 days	Imaging Thyroid

Keep in mind that x-rays, CT scans, PET scans, and isotopic studies involve ionizing radiation. In contrast, MRI (magnetic resonance imaging) and ultrasounds do not utilize ionizing forms of radiation.

I like this picture-www.reddit.com/r/coolguides/comments/cv5mwx/brain_imaging/

Need more practice?

Refer to conversion worksheets on moodle.

Sources

1. http://cerncourier.com/cws/article/cern/66177 (radioisotope information)
2. en.Wikipedia.org/wiki/Nuclear_medicine (radioisotope information)

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5.9: Therapeutic Radiation

Learning Objectives

- Distinguish between diagnostic and therapeutic radiation.
- Know the types of cancer treatments available.
- Recall the A/Z formats of a proton (particle) and gamma (ray).
- Compare/contrast external beam therapy and brachytherapy.
- Know the differences between proton and photon radiation.
- Realize the side effects of radiation therapy and medications available.

There are many techniques used to treat cancer. Surgery can be used to remove cancerous tumors inside or on the body. With chemotherapy, ingested or injected chemicals are used to kill rapidly dividing cells (cancerous and noncancerous). For more information regarding chemotherapy, please access this link. Other cancer treatment methods include immunotherapy, stem cell replacement, hormone therapy, and targeted therapy.

Radiation therapy and Chemotherapy: Two different treatment procedures

Patients diagnosed with cancer might be required to do chemotherapy or radiation therapy. Sometimes, both of these methods are used for a patient. In this picture, a female patient is receiving chemotherapy through an IV. She is participating in cooling therapy while receiving her treatment. By placing her hands and feet in cooling devices, this will lower her chances of losing her finger and toenails. Cold cap therapy is also now available for chemotherapy patients. Wearing this type of device could enable a patient to keep his/her hair during chemotherapy.



Figure 5.9.1: (CC BY 2.0; Jenny Mealing).

Current therapeutic radiation applications involve the use of gamma, x-rays, or protons. Recently, some research facilities are investigating the use of alpha and beta tagged molecules to kill cancer cells. These radioisotopes will first locate a cancer related molecule on a tumor cell. Then, the alpha or beta tagged species will inject its radiation into the tumor. Sr-89 (beta emitter) and Ra-223 (alpha emitter) have been used in clinical research trials of certain types of bone cancers.

Radiation Therapy is used as a treatment to control malignant cells within cancer patients. Oncologists (specialists that deal with cancer) utilize radiation frequently to help slow or cure the spread of cancer within individuals. Radiation is specifically applied to malignant tumors in order to shrink them in size. Medical professionals, mainly radiation oncologists, administer a variety of dosages to patient, contingent to the patients current health, as well as other treatments such as chemotherapy, success of surgery, etc.

External Beam Therapy (Photon and Proton Therapy)

External Beam Therapy (EBT) is a method of delivering a high energy beam of radiation to the precise location of a patient's tumor. These beams can destroy cancer cells and with careful planning, NOT kill surrounding cells. The concept is to have several beams of radiation, each of which is sub-lethal, enter the body from different directions. The only place in the body where the beam would be lethal is at the point where all the beams intersect. Before the EBT process, the patient is three-dimensionally mapped using CT scans and x-rays. The patient receives small tattoos to allow the therapist to line up the beams exactly. Alignment lasers are used to precisely locate the target. The radiation beam is usually generated with a linear accelerator. The video below illustrates the basic preparation and administration of external beam therapy.



Targeting Cancer - Radiation Therapy Treatment Process

Photon EBT utilizes either x-ray or gamma rays. An x-ray source would require a linear accelerator to produce high energy electrons. In contrast, a gamma source incorporates a radioactive isotope (like Co-60). Keep in mind both of these technologies use ionizing radiation. As a result, cancer patients must be monitored throughout their life to ensure they do not develop other cancers, like leukemia. EBT is used to treat the following diseases as well as others:

- Breast cancer
- Colorectal cancer
- Head and neck cancer
- Lung cancer
- Prostate cancer

The majority of radiation patients receive photon EBT. The smaller size of this machine makes this therapy an option for all sizes of hospitals and cancer treatment centers. Photon EBT equipment costs approximately three million dollars. The size and the price of this technology enables smaller facilities to keep their patients closer to home during treatment

In the past ten years, another method of radiation treatment involving protons has become more available. This type of therapy requires a cyclotron to generate proton beams (recall, a proton is an ionized H-1 isotope). Unlike x-ray or gamma rays (photon therapy), protons are extremely heavy. Today's proton facilities occupy large plots of land to house (the size of a football field that is three stories high) the medical cyclotron. With a price tag of 150-200 million, these facilities are sporadically located in the United States.



Figure 5.9.2: Current Proton Therapy Centers in the US. The world's first hospital-based proton therapy center was a low energy cyclotron centre for ocular tumors at the Clatterbridge Centre for Oncology in the UK, opened in 1989, followed in 1990 at the Loma Linda University Medical Center in Loma Linda, California. Later, The Northeast Proton Therapy Center at Massachusetts General Hospital was brought online, and the HCL treatment program was transferred to it during 2001 and 2002. By 2010 these facilities were joined by an additional seven regional hospital-based proton therapy centers in the United States alone, and many more worldwide. See Wall Street Journal article for information on the details of opening up a center.

At this time, research facilities are working on miniaturizing proton generators. An ideal technology would reduce the cost from hundreds of millions of dollars to about twenty to thirty million per device. This would make proton therapy more available and convenient for patients.



Proton Therapy versus Photon Therapy

There are many advantages to choosing proton therapy over photon therapy. Unlike photon radiation, proton beams will only penetrate to the depth of the tumor and not pass through the entire body. This reduces the overall toxicity dose. In addition, fewer treatments are required for proton therapy patients than photon therapy.Unfortunately, proton therapy is more expensive than photon therapy and less common. Once approved by a facility and medical insurance, a patient may have to move temporarily to a larger city to receive treatment. Some forms of cancer have never been clinically treated with proton therapy (namely, breast cancer). Patients desiring proton therapy might not be able to receive type of therapy due to lack of research.

Brachytherapy

The Greek term brachy means to travel a short distance. This type of radiation involves placing ionizing pellets(seeds) or rods directly at the tumor. Photons (in the form of x-ray or gamma ray) are produced inside the body and will penetrate throughout this particular area localizing the radiation. Pellets are surgically implanted while rods can be temporarily inserted to produce radiation internally. With pellets/seeds, the patient will remain radioactive as long as these devices remain inside the body. People undergoing this type of radiotherapy need to be aware of their constant emission of radiation. Radiation that is administered through rods connected to a photon device will disperse energy immediately and not leave the patient radioactive.

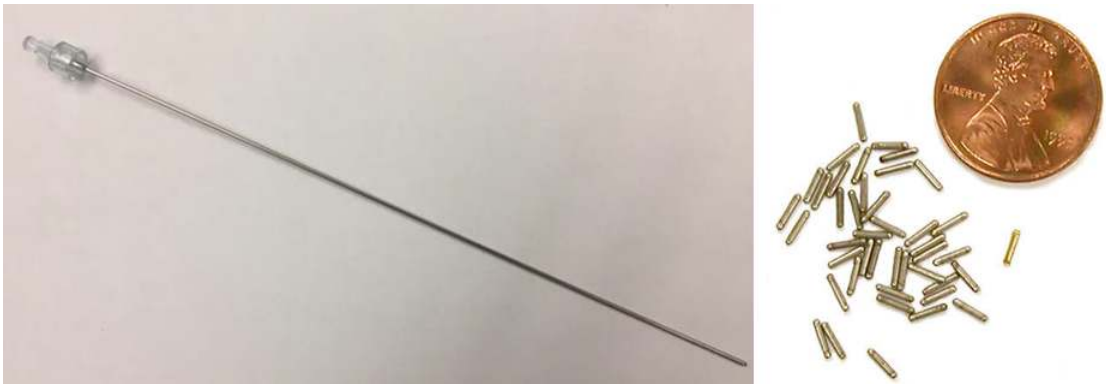


Figure **5.9.4**: The picture on the left shows a brachytherapy rod. This device would be connected to a gamma source and connected inside a human body. The second images shows radioactive pellets or seeds that can be surgically implanted near a tumor. Note how small the pellets are when compared to an American penny. Image taken from: https://c1.staticflickr.com/8/7254/7...74d83b7058.jpg

Brachytherapy is widely used in the treatment of cancers involving reproductive organs. Because the radiation is isolated internally, patients are less likely to experience side effects when receiving this type of treatment. Cancers that have been treated with brachytherapy are shown below:

- Prostate
- Breast
- Esophageal
- Lung
- Uterine
- Anal/Rectal
- Sarcomas
- Head and neck

Table **5.9.1**: Commonly used radiation sources (radionuclides) for brachytherapy.

Radionuclide	Type	Half-life
Cesium-131 (^{131}Cs)	Electron Capture, ε	9.7 days
Cesium-137 (^{137}Cs)	β^-- particles, γ-rays	30.17 years
Cobalt-60 (^{60}Co)	β^-- particles, γ-rays	5.26 years
Iridium-192 (^{192}Ir)	γ-rays	73.8 days
Iodine-125 (^{125}I)	Electron Capture, ε	59.6 days
Palladium-103 (^{103}Pd)	Electron Capture, ε	17.0 days
Ruthenium-106 (^{106}Ru)	β^-- particles	1.02 years
Radium-226 (^{226}Ra)	β^-- particles	1599 years

Side Effects of Radiation Therapy

Patients receiving radiation therapy can experience a variety of side effects. For example, sterility could occur if reproductive organs are irradiated. Skin that has been irradiated can appear dry and feel itchy. Some patients will loose sensation in the irradiated area. Radiation can affect the production of white and red blood cells. A reduction of white blood cells results in immunity disorders. Red blood cell lose causes anemia. Gastrointestinal issues such as diarrhea and nausea are common during radiation therapy. Some patients will lose hair as well. Lastly, dry mouth and tooth decay are prevalent during radiation treatments.

Medications are available to alleviate symptoms of radiation therapy. Narcotics can be prescribed to help alleviate intense pain. Prescription medications like zofran and phenergan can help with nausea. Special mouthwashes have been formulated to reduce dry mouth and cavities.

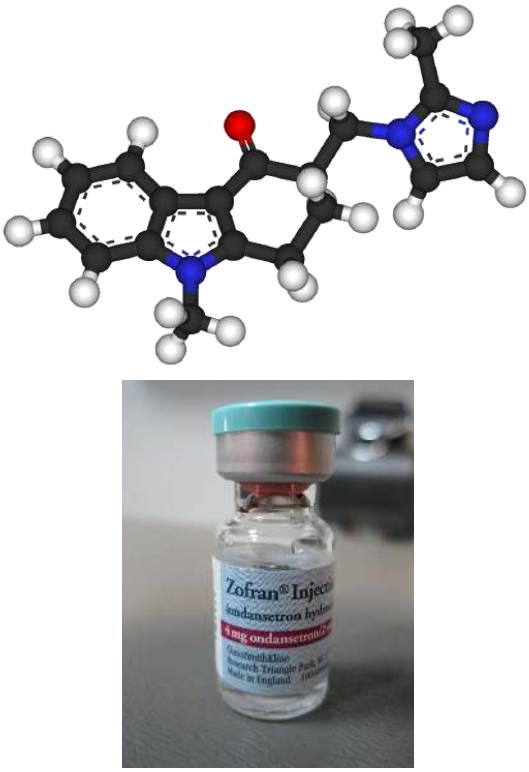


Figure **5.9.5**: (left) *Zofran is a medication used to prevent nausea and vomiting caused by cancer chemotherapy, radiation therapy, or surgery. (right) A vial of Zofran 4 mg containing ondansetron for intravenous injection. This medicine is a controlled substance and is used for nausea. Images used with permission (left: Public domain; Fvasconcellos and right: CC BY 3.0; Intropin)*

Hair loss is a side effect of radiation, but only locally

Radiation therapy can cause hair loss, but hair is only lost in the area being treated. For instance, radiation to your head may cause you to lose some or all the hair on your head (even eyebrows and lashes), but if you get treatment to your hip, you won't lose the hair on your head.

Access to Radiotherapy

For those countries who do not have access to nuclear technologies, the International Atomic Energy Agency (IAEA) provides support and technical assistance to its member countries. When nations chose to join the IAEA, then they will gain nuclear materials and technologies for energy, medical, industrial, and agriculture purposes. Once accepted into the IAEA, a country must allow weapons inspectors to monitor any equipment that could be used to make nuclear weapons. The IAEA does not allow countries that do not have nuclear weapons to obtain them.



IAEA video: Fighting Cervical Cancer: A Fair Chance for Every Woman Around the World

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- Emma Gibney (Furman University)

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5.10: Non-medical Applications of Nuclear Science

Learning Objectives

- Appreciate how radiation is used in agriculture and industry.
- Realize various isotopes and wave radiation are used as tracers and sanitizers.
- Distinguish between millimeter and back scatter technologies uses by the Transportation Security Administration (TSA).
- Know examples of foods that are irradiated in the United States.

Tracer Applications

Radioactive isotopes are effective tracers because their radioactivity is easy to detect. A **tracer** is a substance that can be used to follow the pathway of that substance through some structure. For instance, leaks in underground water pipes can be discovered by running some tritium-containing water through the pipes and then using a Geiger counter to locate any radioactive tritium subsequently present in the ground around the pipes. (Recall that tritium is a radioactive isotope of hydrogen.)

Tracers are used in diverse ways to study the mechanisms of chemical reactions in plants and animals. These include labeling fertilizers in studies of nutrient uptake by plants and crop growth, investigations of digestive and milk-producing processes in cows, and studies on the growth and metabolism of animals and plants.

For example, the radioisotope C-14 was used to elucidate the details of how photosynthesis occurs. The overall reaction is:

$$6\,CO_2(g) + 6\,H_2O(l) \longrightarrow C_6H_{12}O_6(s) + 6\,O_2(g),$$

The process is much more complex, proceeding through a series of steps in which various organic compounds are produced. In studies of the pathway of this reaction, plants were exposed to CO_2 containing a high concentration of $^{14}_{6}C$. At regular intervals, the plants were analyzed to determine which organic compounds contained carbon-14 and how much of each compound was present. From the time sequence in which the compounds appeared and the amount of each present at given time intervals, scientists learned more about the pathway of the reaction.

Airport Applications

Commercial airports use x-rays and CT imaging to items contained in luggage. An x-ray machine can produce images of hard and soft materials. Based upon relative densities, an x-ray image will display a different color for a different type of material. For example, foods and organic materials will appear orange on an x-ray scan. Harder materials like thicker plastics will appear green. Lastly, metals and extremely thick materials will produce a bluish color when scanned. Click on this video for how technology for scanning bags has changed in the last five years.



Figure 5.10.1: Photograph of a baggage screening x-ray display. (CC BY-SA; IDuke via Wikimedia).

Recently, the United States' Transportation Security Administration has installed new scanning devices at many commercial airports. Using CT analysis, TSA employees can view and manipulate three dimensional images of luggage. This new process does not require travelers to remove liquids or electronics from their bags which speeds up the security process. Click on this video below to see this technology.



to see this new technology.

American airports once used x-rays to scan human bodies for weapons. Up through 2013, back scatter technology was utilized to give very detailed body images. Due to the "naked body" pictures, this type of technology was banned in American airports and has now been replaced with millimeter wave generators. These machines produce cartoon like images and expose the body to high energy radio waves.

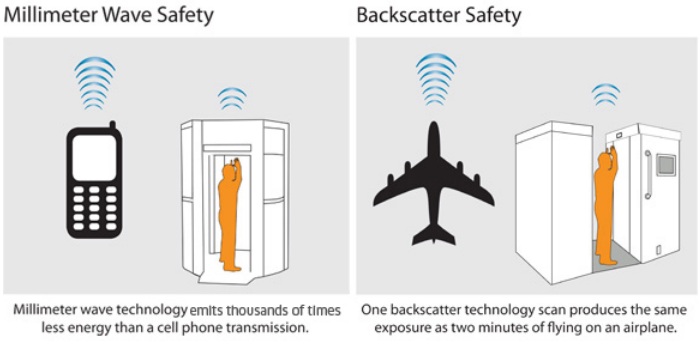


Figure 5.10.2: Different whole body scanning technologies have been used in airport security. (Public Domain; Transportation Security Administration via Wikipedia)

Irradiation of Food, Mail, and Water

Co-60 (gamma source) and x-rays are used to irradiate many foods in the United States. Ionizing radiation can be used to kill food-borne illnesses like salmonella and e coli. Irradiating food can also prolong shelf-life, delay ripening, and destroy insects. In addition, gamma/x-ray can sterilize foods making refrigeration unnecessary. Often, sterilized food is served to hospital patients who have impaired immune systems.



In the United States,irradiation of food is regulated by the FDA (Food and Drug Administration). Foods that have been irradiated must display the symbol called the Radura Figure **5.10.3** on their packaging. Some foods that could display this symbol are: meats (beef, pork, chicken), shrimp, lobster, fruits, vegetables, shellfish, and spices. Contrary to the belief of some people, irradiation of food *does not* make the food itself radioactive.



Figure **5.10.3** Radura- symbol that irradiation has been used to sanitize food. Iimage taken from: commons.wikimedia.org/wiki/F...ura-Symbol.svg

Ultraviolet (UVC) radiation has been used in the purification of drinking water. The peak wavelength for this process is around 222 nm. By using UVC, many viruses, bacteria, and other pathogens can be annihilated in air, water, and nonporous materials. UVC radiation is even powerful enough to destroy the protein coating of the SARS-Corona Virus. For more information on UVC and sanitation in water, click here.

In the fall of 2001, anthrax-laced letters were sent to various news agencies and two United States senators. Anthrax is an infectious disease caused by bacteria. It exists naturally in some soils and can be isolated in a laboratory. After September 11, 2011, this substance was used as a biochemical weapon. This particular incident killed five people and injured twenty-two, other individuals. Anthrax produces ulcers on the skin and causes severe breathing difficulties. Today, only members of the United States military receive vaccines for anthrax.

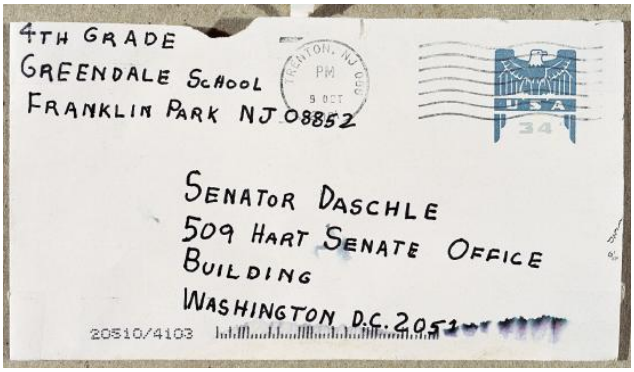


Figure **5.10.4**: Anthrax-laced letter that was sent to Senator Tom Daschle. (Public Domain; FBI via Wikipedia)

To combat this form of bioterrorism, the United States Postal Service (USPS) and the Federal Bureau of Investigation (FBI) installed x-ray generators to irradiate suspicious-looking mail sent to some governmental facilities. X-rays will kill the majority of these bacteria and some viruses as well. Once irradiated, mail (packages and letters) might change in color, texture, and smell. This ionizing radiation chemically alters the composition of the mail's paper component. The x-rays do not leave the mail radioactive.

Smoke Detectors

Americium-241, an α emitter with a half-life of 458 years, is used in tiny amounts in ionization-type smoke detectors (Figure 5.10.5). The α emissions from Am-241 ionize the air between two electrode plates in the ionizing chamber. A battery supplies a potential that causes movement of the ions, thus creating a small electric current. When smoke enters the chamber, the movement of the ions is impeded, reducing the conductivity of the air. This causes a marked drop in the current, triggering an alarm.

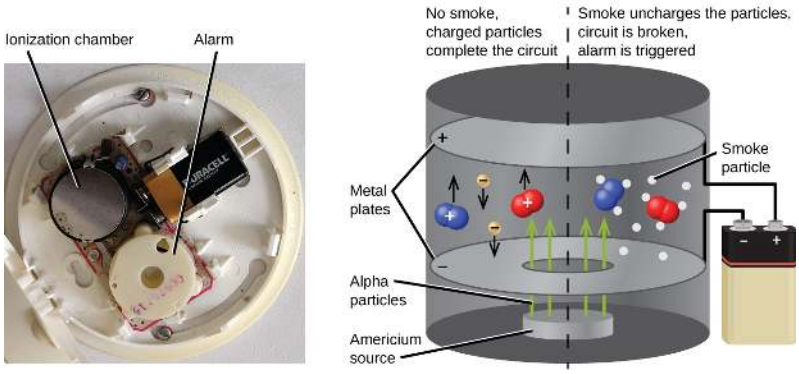


Figure 5.10.5: Inside a smoke detector, Am-241 emits α particles that ionize the air, creating a small electric current. During a fire, smoke particles impede the flow of ions, reducing the current and triggering an alarm. (credit a: modification of work by "Muffet"/Wikimedia Commons)

References

1. https://medlineplus.gov/anthrax.html
2. https://www3.epa.gov/radtown/mail-irradiation.html

References

- Elizabeth R. Gordon (Furman University)
- Emma Gibney (Furman University)

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5.E: Basics of Nuclear Science (Exercises)

1) Perform a beta emission of Rb-86.

2) What is the missing piece of this nuclear reaction: n → p + ?

3) Write a reaction for the decay of Rn-222. Review your ionizing section of your text book to determine the emission path. In addition, how could you shield yourself from the radiation released from this reaction?

4) You are exposed to radiation that has a wavelength of 50 µm. What is the frequency of this radiation? Where does this radiation appear? Is this radiation ionizing or nonionizing?

5) What is the difference between the radiation from Uranium and x-rays?

6) How can you alter a house that tests over the 4pCi level for radon?

7) Give one crazy application of x-ray science.

8) Which is the heaviest form of radiation: alpha, beta, or gamma?

9) Which is the least ionizing form of radiation: alpha, beta, or gamma?

10) Is your smoke detector radioactive?

11) Fatman (Nagasaki bomb) used approximately 6.4 kg of Pu-239. This artificially produced isotope ($t_{1/2}$ = 24,100 years) undergoes alpha decay. How many kg and pounds would remain after three decay processes?

12) Can one chemically change the half-life of a material?

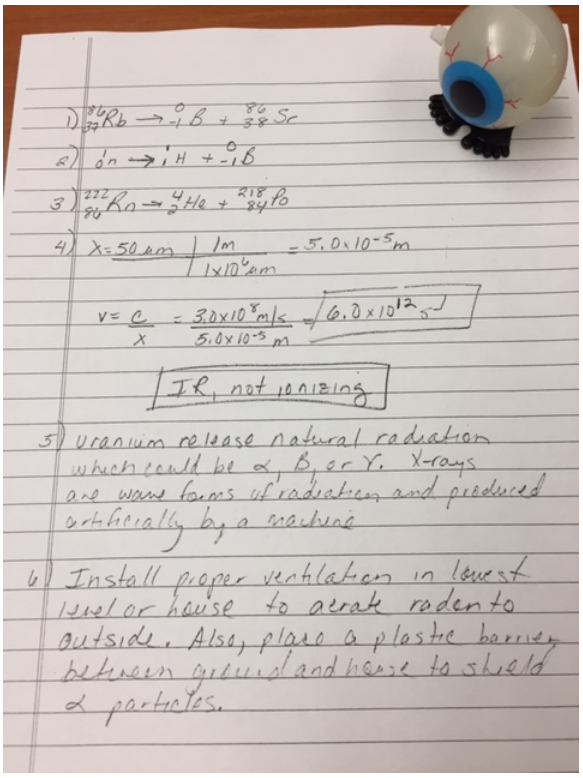
13) The $t_{1/2}$ of As-74 is 18 days, how much of a 160 mg sample remains after 2160 hours?

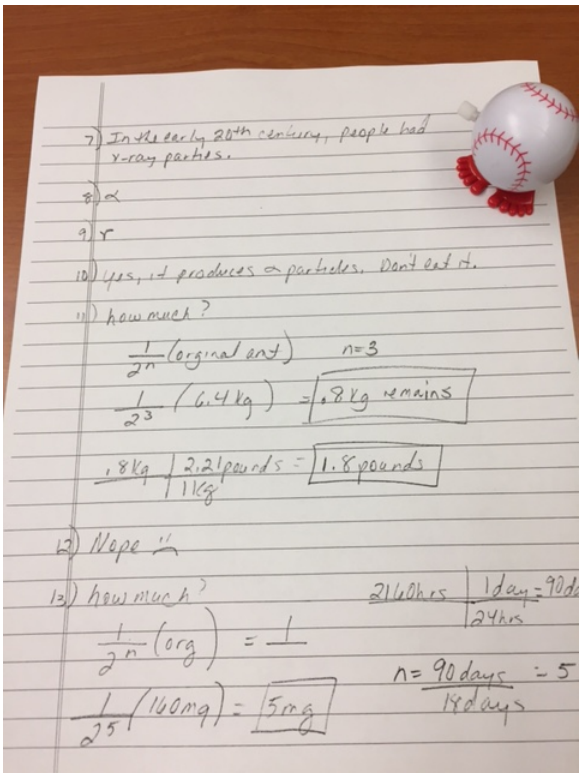
14) Write a balance reaction for the decay Ir-192. This isotope undergoes alpha and gamma emission at the same time.

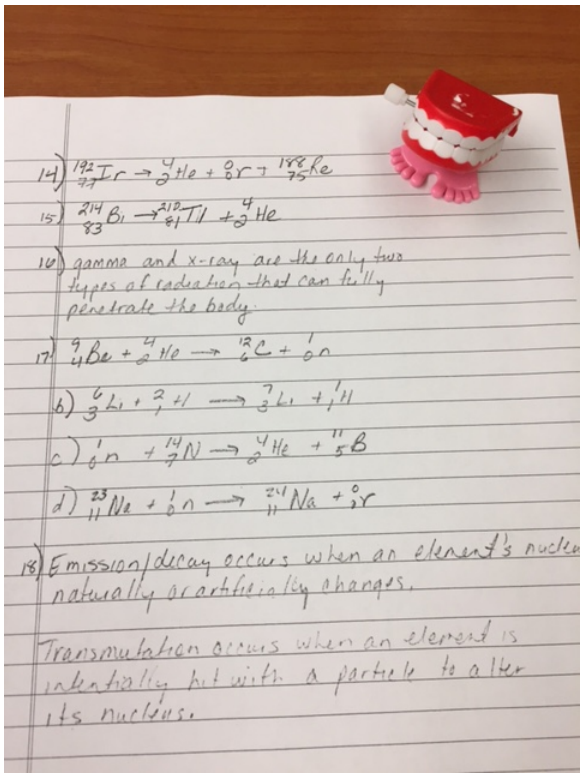
15) Bi-214 can decay to form Tl-210. Write balanced reaction for this emission process.

16) When focused from the outside of the body, which type(s) of radiation penetrate(s) the body completely? gamma, proton, x-ray, alpha, or beta

Solutions







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CHAPTER OVERVIEW

6: Nuclear Weapons- Fission and Fusion

A nuclear weapon is an explosive device that derives its destructive force from nuclear reactions, either fission (fission bomb) or from a combination of fission and fusion reactions (thermonuclear bomb). Both bomb types release large quantities of energy from relatively small amounts of matter.

6.1: The History and Basics of Fission
6.2: The Manhattan Project - Prewar
6.3: The Manhattan Project - Labs and Fuel
6.4: The Manhattan Project - Critical Mass and Bomb Construction
6.5: Hiroshima and Nagasaki
6.6: Aftermath of Bombings
6.7: Fusion
6.8: Fallout and Weapons Testing
6.9: Nuclear in the Media
6.E: Nuclear Weapons- Fission and Fusion (Exercises)

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6.1: The History and Basics of Fission

Learning Objectives

- When given a reaction, distinguish between decay/emission and artificial transmutation.
- Write and balance artificial transmutation reactions.
- Determine the origins of U-235 and Pu-239.
- Know the history of fission.
- Determine why only certain atoms can undergo fission or fusion.
- Explain the mechanism and applications of fission and fusion

Understanding the Neutron

In 1911, Ernest Rutherford applied a beam of alpha particle to a gold foil. This experiment helped him to determine the positive center of the atom, which he named the nucleus. Eight years later, this same scientist discovered the existence of proton by performing the following nuclear reaction:

$$^{14}_{7}\text{N} + ^{4}_{2}\text{He} \longrightarrow ^{17}_{8}\text{O} + ^{1}_{1}\text{H}$$

This reaction is an example of artificial transmutation. By taking a particle and hitting any existing nucleus, a new atom will be synthesized artificially. Note how this reaction differs from a decay/emission reaction. In the latter type of reaction, only one reactant will produce at least two products. Transmutations will illustrate a minimum of two reactants and various number of products.

Example 6.1.1: Artificial Transmutation or Decay Reactions?

Label each as being an artificial transmutation or a decay reaction.

a. $^{238}_{92}\text{U} \rightarrow ^{4}_{2}\text{He} + ^{234}_{90}\text{Th}$
b. $^{198}_{78}\text{Pt} + ^{1}_{0}\text{n} \rightarrow ^{199}_{78}\text{Pt} \rightarrow ^{199}_{79}\text{Au} + ^{0}_{-1}\beta$
c. $^{239}_{93}\text{Np} \rightarrow ^{239}_{94}\text{Pu} + ^{0}_{-1}\beta$
d. $^{11}_{6}\text{C} \rightarrow ^{11}_{5}\text{B} + ^{0}_{+1}\beta$
e. $^{27}_{13}\text{Al} + ^{4}_{2}\text{He} \longrightarrow ^{30}_{15}\text{P} + ^{1}_{0}\text{n}$

Answer

Only reactions b and e are artificial transmutations. The other reactions are examples of decays/emissions.

Throughout the 1930s, many scientists became focused on producing new radioactive elements. Before this time period, newly discovered elements were extracted from natural ores obtained from mining. Irene (daughter of Marie and Pierre Curie) and her husband Frederic Joliot-Curie bombarded existing elements with alpha particles. These experiments yielded new radioactive isotopes by an artificial process. For their efforts, Irene and Frederic were awarded the 1935 Noble Prize in chemistry. One of their key syntheses involve the bombardment of aluminum foil with alpha particles.

$$^{27}_{13}\text{Al} + ^{4}_{2}\text{He} \longrightarrow ^{30}_{15}\text{P} + ^{1}_{0}\text{n}$$

In their laboratory, the Joliet-Curies could not explain or identify the existence of the neutron. Their measurements showed that an additional, non-charged substance was produced in the aluminum foil reaction. They hypothesized that this unknown piece of the reaction must be a gamma-ray, which has a neutral charge.



Figure **6.1.1**: Irene and Frederic Joliot-Curie working in their lab to synthesize new isotopes by artificial transmutation. Image is taken from upload.wikimedia.org/wikiped...Curie_1935.jpg

The Significance of Artificial Transmutation

Unfortunately, the Joliot-Curies were incorrect in their analysis. Around the same time, a British scientist named James Chadwick bombarded beryllium with alpha particles to produce the species below:

$$^{9}_{4}\mathrm{Be} + {}^{4}_{2}\mathrm{He} \longrightarrow {}^{12}_{6}\mathrm{C} + {}^{1}_{0}\mathrm{n}$$

Using this reaction, he was able to characterize and explain the existence of this new atomic subatomic particle. He noted this atomic piece was the same mass as a proton but had no charge. In 1935, James Chadwick was awarded the Nobel Prize in physics for the discovery of the neutron.

Example 6.1.2

Translate the following reactions to A/Z symbols. Balance these artificial transmutations by finding the missing pieces.

a. sodium-23 is hit with an alpha particle to produce a proton and another isotope
b. fluorine-19 is bombarded a neutron to produce an alpha particle and another isotope
c. uranium-238 is hit with a neutron to produce an isotope and a beta particle

Solution

a. missing isotope piece = Mg-26
b. missing isotope piece = N-16
c. missing isotope piece = Np-239

Artificial transmutation has been utilized to make new elements. All elements with atomic numbers greater than 92 are produced synthetically. These elements are called transuranium elements and have been prepared by bombarding suitable target nuclei with smaller particles. The first of the transuranium elements to be made was neptunium (Z = 93), which was synthesized in 1940 by bombarding a ^{238}U target with neutrons. As shown below, this reaction occurs in two steps. Initially, a neutron combines with a ^{238}U nucleus to form ^{239}U, which is unstable and undergoes beta decay to produce ^{239}Np:

$$^{238}_{92}\mathrm{U} + {}_{0}{}^{1}\,\mathrm{n} \rightarrow {}^{239}_{92}\mathrm{U}$$

$$^{239}_{92}\mathrm{U} \rightarrow {}^{239}_{93}\,\mathrm{Np} + {}^{0}_{-1}\beta \qquad (6.1.1)$$

Subsequent beta decay of ^{239}Np produces the second transuranium element, plutonium (Z = 94):

$$^{239}_{93}\mathrm{Np} \rightarrow {}^{239}_{94}\mathrm{Pu} + {}^{0}_{-1}\beta \qquad (6.1.2)$$

Bombarding the target with more massive nuclei creates elements that have atomic numbers significantly greater than that of the target nucleus (Table **6.1.1**). Such techniques have resulted in the creation of the superheavy elements 114 and 116, both of which lie in or near the “island of stability." As of this writing, 22 transuranium elements have been produced and officially recognized by IUPAC; several other elements have formation claims that are waiting for approval.

Table **6.1.1**: Preparation of Some of the Transuranium Elements

Name	Symbol	Atomic Number	Reaction
americium	Am	95	$^{239}_{94}\text{Pu} + {}^{1}_{0}\text{n} \longrightarrow {}^{240}_{95}\text{Am} + {}^{0}_{-1}\text{e}$
curium	Cm	96	$^{239}_{94}\text{Pu} + {}^{4}_{2}\text{He} \longrightarrow {}^{242}_{96}\text{Cm} + {}^{1}_{0}\text{n}$
californium	Cf	98	$^{242}_{96}\text{Cm} + {}^{4}_{2}\text{He} \longrightarrow {}^{243}_{97}\text{Bk} + 2{}^{1}_{0}\text{n}$
einsteinium	Es	99	$^{238}_{92}\text{U} + 15{}^{1}_{0}\text{n} \longrightarrow {}^{253}_{99}\text{Es} + 7{}^{0}_{-1}\text{e}$
mendelevium	Md	101	$^{253}_{99}\text{Es} + {}^{4}_{2}\text{He} \longrightarrow {}^{256}_{101}\text{Md} + {}^{1}_{0}\text{n}$
nobelium	No	102	$^{246}_{96}\text{Cm} + {}^{12}_{6}\text{C} \longrightarrow {}^{254}_{102}\text{No} + 4{}^{1}_{0}\text{n}$
rutherfordium	Rf	104	$^{249}_{98}\text{Cf} + {}^{12}_{6}\text{C} \longrightarrow {}^{257}_{104}\text{Rf} + 4{}^{1}_{0}\text{n}$
seaborgium	Sg	106	$^{206}_{82}\text{Pb} + {}^{54}_{24}\text{Cr} \longrightarrow {}^{257}_{106}\text{Sg} + 3{}^{1}_{0}\text{n}$ $^{249}_{98}\text{Cf} + {}^{18}_{8}\text{O} \longrightarrow {}^{263}_{106}\text{Sg} + 4{}^{1}_{0}\text{n}$
meitnerium	Mt	107	$^{209}_{83}\text{Bi} + {}^{58}_{26}\text{Fe} \longrightarrow {}^{266}_{109}\text{Mt} + {}^{1}_{0}\text{n}$

Particle Accelerators: Artificial Transmutators

To perform artificial transmutation reactions, there are two large machines that can be utilized. A device called a **particle accelerator** can accelerate positively charged particles to the speeds needed to overcome the electrostatic repulsions between them and then target nuclei by using electrical and magnetic fields. Operationally, the simplest particle accelerator is the linear accelerator (Figure **6.1.2**), in which a beam of particles is injected at one end of a long evacuated tube. A modern linear accelerator such as the Stanford Linear Accelerator (SLAC) at Stanford University is about 2 miles long.

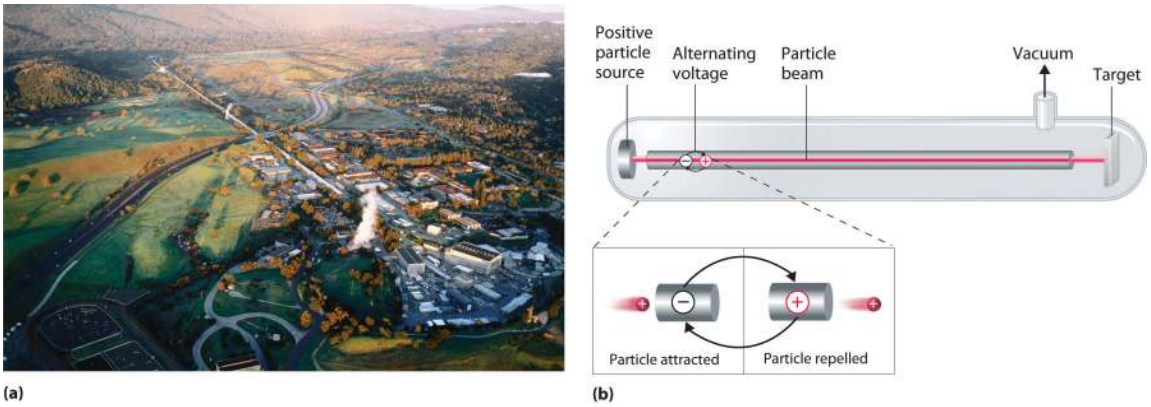


Figure **6.1.2**: A Linear Particle Accelerator. (a) An aerial view of the SLAC, the longest linear particle accelerator in the world; the overall length of the tunnel is 2 miles. (b) Rapidly reversing the polarity of the electrodes in the tube causes the charged particles to be alternately attracted as they enter one section of the tube and repelled as they leave that section. As a result, the particles are continuously accelerated along the length of the tube. (CC BY-SA-NC; anonymous)

To achieve the same outcome in less space, a particle accelerator called a **cyclotron** forces the charged particles to travel in a circular path rather than a linear one. The particles are injected into the center of a ring and accelerated by rapidly alternating the polarity of two large D-shaped electrodes above and below the ring, which accelerates the particles outward along a spiral path toward the target.

Fission and Fusion: Selecting the Isotopes

Fission is the splitting of an atomic nucleus. In nuclear weapons and reactors, neutrons hit unstable nuclei to form smaller atoms. Nuclei that are larger than Fe-56 may undergo fission. Of these elements, fission requires heavy, unstable nuclei. This means selected atoms would have low binding energies and would have large atomic masses. Figure four shows the relative binding energies for various isotopes. According to figure 4, uranium-238 and uranium-235 both have lower binding energies with heavy masses. These two isotopes would be suitable for splitting based on these requirements. Of these two isotopes, only uranium-235 is readily fissionable. This is due to the odd neutron count contributing to additional instability. Another fissionable isotope not shown

in figure 4, is plutonium-239. This is a synthetic isotope produced by transmutation and decay reactions. Like uranium-235, it has low binding energy, high mass, and an odd number of neutrons. U-235 and Pu-239 are used in atomic bombs (fission based) and nuclear reactors.

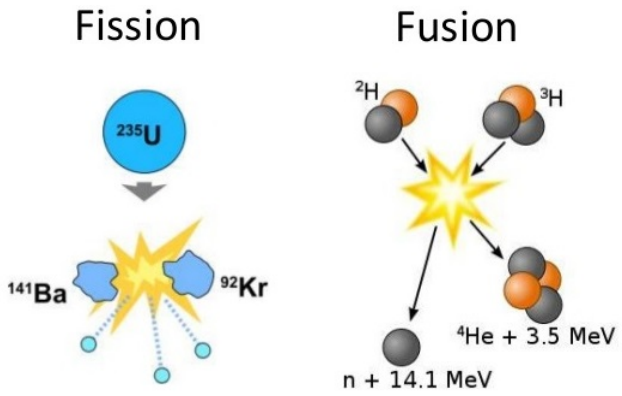


Figure **6.1.3**: (left) Nuclear fission occurs with one large nuclear is split into two or more smaller nuclei. (right) Nuclear fusion happens when two small nuclei combine to make a larger nucleus.

Fusion is the bringing together of two atomic nuclei to form a larger atom. Positively charged centers of atoms make this type of reaction extremely difficult. For this reason, smaller atoms are suitable for fusion reactions. In addition, these particular isotopes need to have low binding energies in order to undergo fusion. Atoms that possess these two qualities are H-2 and H-3. For fusion to occur, extreme temperatures are required to fuse the deuterium and tritium together.

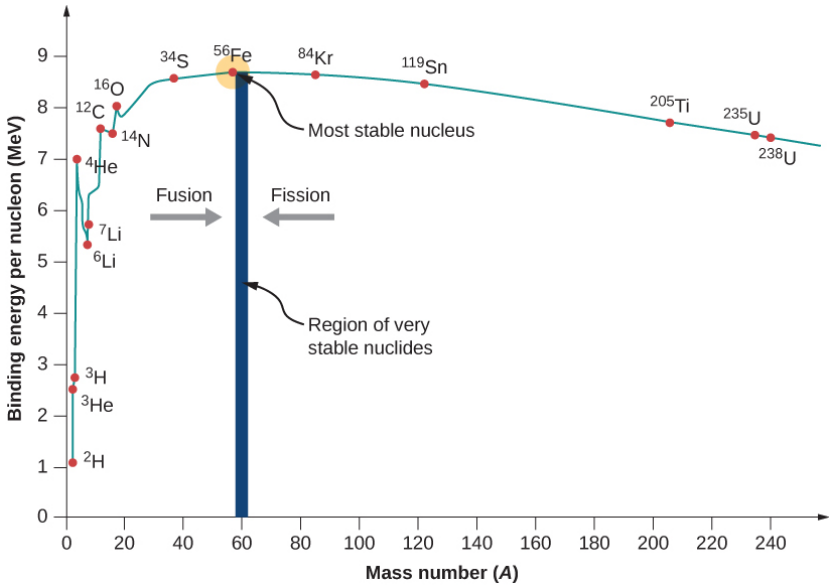


Figure **6.1.4**: In this graph of binding energy per nucleon for stable nuclei, the BEN is greatest for nuclei with a mass near ^{56}Fe. Therefore, fusion of nuclei with mass numbers much less than that of Fe, and fission of nuclei with mass numbers greater than that of Fe, are exothermic processes. (CC BY 4.0; OpenStax).

Fission and Chain Reactions

In both fission and fusion, large amounts of energy are given off in the form of heat, light, and gamma radiation. Italian physicist, Enrico Fermi, performed the first fission reaction in 1934. He was unaware that he had split a uranium atom into two smaller nuclei. Four years later, two German scientists, Otto Hahn and Fritz Strassman repeated Fermi's uranium reaction. While performing this experiment, two other scientists, Lise Meitner and Otto Frisch analyzed the data. Meitner, an Austrian physicist, noted that the uranium atom had split into two smaller pieces. She used the term "fission" to describe her observations.



Figure 6.1.5: Austrian physicist, Lise Meitner who coined the term "fission" to explain the neutron bombardment of U-238. I. (Public Domain; via Wikipedia)

The nuclear equation illustrating this fission reaction is shown below:

$$ {}^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}_{56}{}^{141}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}\mathrm{n} $$

The products shown are only one of many sets of products from the disintegration of a U-235 nucleus. Over 35 different elements have been observed in the fission products of U-235. Fission has been used in nuclear weapons and powers all nuclear reactors. Approximately fifty-five countries worldwide possess fission technology in the form of research or energy reactors. Less than ten of these countries have fission weapons.

On the other hand, fusion technology is not as accessible. Only five countries (five permanent members of the United Nations Security Council) have knowledge and scientific capability of constructing fusion weapons. Unlike fission reactors. there are no commercial fusion reactors. Fusing nuclei is quite difficult to perform in a safe and controlled environment. For more insight as to the differences between fission and fusion, click on the informational video below.



Energy of Reactions

Although Albert Einstein was not directly involved in the construction of nuclear weapons, he did devise a theory to explain the amount of energy released during a nuclear reaction (fission or fusion).

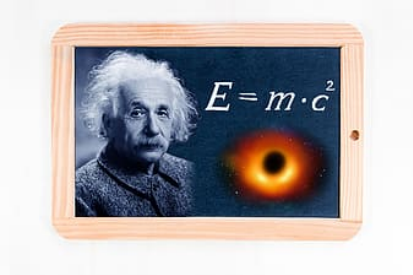


Figure 6.1.6: Albert Einstein and his famous equation. Image courtesy of Royalty free HD einstein formula photos | Pikrepo

This theory is known as special relativity as is shown below:

$$ E = mc^2 \tag{6.1.3} $$

Here, the mass can be converted to significant amounts of energy in nuclear reactions. Understanding the speed of light to be $3.0x10^8$ m/s can give you an appreciation for how much energy can be produced per unit of matter. Nuclear reactions require very small amounts of fissionable material to produce large amounts of energy (as in a nuclear reactor) or destruction (as in a bomb).

Sources

1. https://www.aps.org/publications/aps...icshistory.cfm

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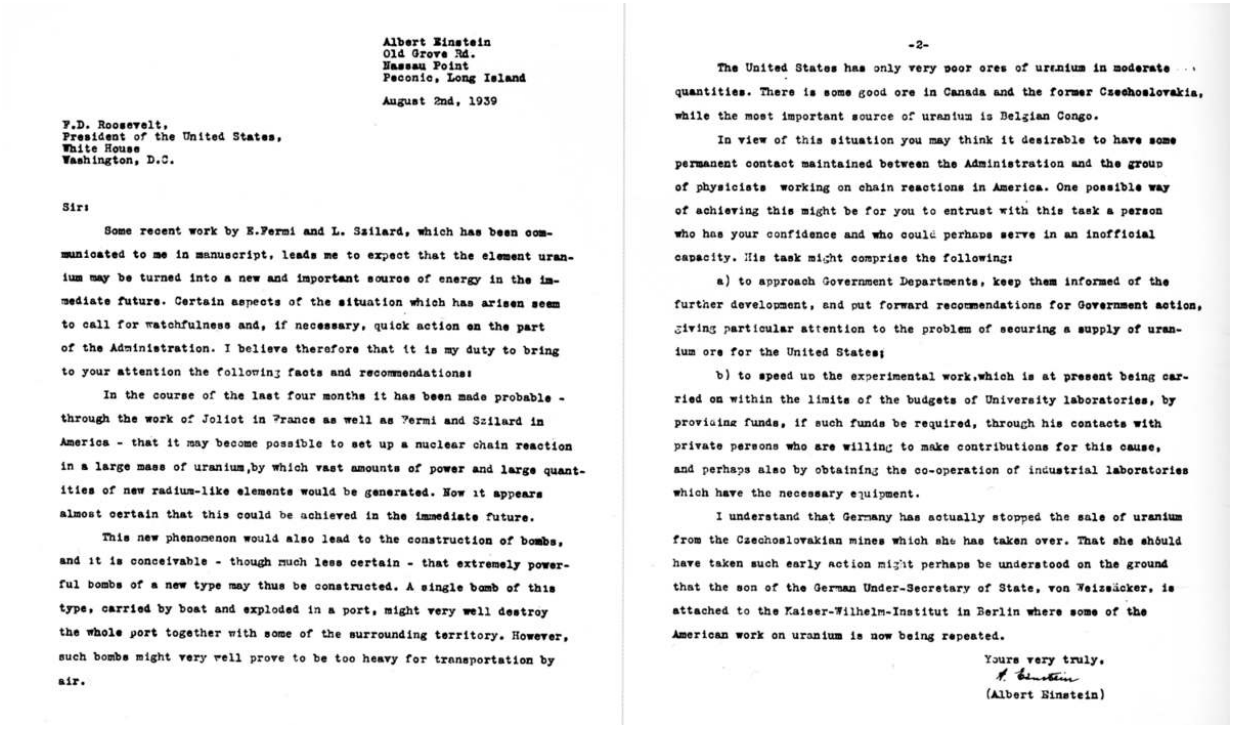
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6.2: The Manhattan Project - Prewar

Learning Objectives

- Explore the early beginnings of the Manhattan Project.
- Record the military and scientific leaders of the Manhattan Project.
- Review all the embedded videos and answer questions related.

In October of 1939, the United States became concerned about the fission research efforts occurring in Nazi Germany. To express their concerns, two recent immigrant scientists, Albert Einstein and Leo Szilard drafted a letter to President Franklin Delano Roosevelt. Within a month's time, President Roosevelt established the Advisory Committee on Uranium. This research group was provided a limited budget of approximately $150,000. Projects were to only include uranium isotopic separation. Two physicists from the University of Columbia were assigned to accomplish this task. With a very limited budget, Enrico Fermi and Leo Szilard were expected to surpass any uranium efforts that Nazi Germany had already accomplished. Click on this link to visualize how these scientists felt about this project.



Albert Einstein
Old Grove Rd.
Nassau Point
Peconic, Long Island

August 2nd, 1939

F.D. Roosevelt,
President of the United States,
White House
Washington, D.C.

Sir:

Some recent work by E.Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations:

In the course of the last four months it has been made probable - through the work of Joliot in France as well as Fermi and Szilard in America - that it may become possible to set up a nuclear chain reaction in a large mass of uranium,by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.

This new phenomenon would also lead to the construction of bombs, and it is conceivable - though much less certain - that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.

-2-

The United States has only very poor ores of uranium in moderate quantities. There is some good ore in Canada and the former Czechoslovakia, while the most important source of uranium is Belgian Congo.

In view of this situation you may think it desirable to have some permanent contact maintained between the Administration and the group of physicists working on chain reactions in America. One possible way of achieving this might be for you to entrust with this task a person who has your confidence and who could perhaps serve in an inofficial capacity. His task might comprise the following:

a) to approach Government Departments, keep them informed of the further development, and put forward recommendations for Government action, giving particular attention to the problem of securing a supply of uranium ore for the United States;

b) to speed up the experimental work,which is at present being carried on within the limits of the budgets of University laboratories, by providing funds, if such funds be required, through his contacts with private persons who are willing to make contributions for this cause, and perhaps also by obtaining the co-operation of industrial laboratories which have the necessary equipment.

I understand that Germany has actually stopped the sale of uranium from the Czechoslovakian mines which she has taken over. That she should have taken such early action might perhaps be understood on the ground that the son of the German Under-Secretary of State, von Weizsäcker, is attached to the Kaiser-Wilhelm-Institut in Berlin where some of the American work on uranium is now being repeated.

Yours very truly,
A. Einstein
(Albert Einstein)

Figure 6.2.1: The letter written by Einstein and Szilard to President Franklin D. Roosevelt.

At this time, President Roosevelt attempted to pacify these nuclear scientists by allocating this amount of research funding. Feeling fearful, this group of researchers continually pleaded for more money and facilities where they could expand their projects. President Roosevelt denied their requests until Pearl Harbor was bombed in December of 1941. After this, Roosevelt established the Manhattan Project, which was to focus on research and construction of an atomic bomb. He placed Leslie R. Groves, head of the U.S. Army Corps of Engineers, to organize and lead this undertaking.



Figure **6.2.2**: General Leslie R. Groves and J. Robert Oppenheimer.

General Groves assigned J. Robert Oppenheimer to lead the top-secret laboratory that would construct the first atomic bomb. At the time, Oppenheimer was a theoretical physicist employed at the University of California, Berkeley. Both Groves and Oppenheimer would work together for over four years to complete this project.

Example 6.2.1

Watch the first installment of the History Channel's Modern Marvel Series (total time: 10:59) and answer the questions below:



1. How much money was spent on the making of the atomic bomb (1940's and today's estimates)?
2. Why did Teller, Einstein, Szilard, and Bethe flee Europe?
3. What country discovered fission and which element was investigated to prove this?
4. How did Enrico Fermi escape Italy?
5. How did FDR first get introduced to the idea of atomic fission? What event encouraged him to allocate more funds to this research project?
6. Which isotope is more useful for the construction of nuclear weapons: U-235 or U-238?
7. What two processes were used for uranium enrichment? Where would these processes be done?

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6.3: The Manhattan Project - Labs and Fuel

Learning Objectives

- List the four main labs and chief scientists at each Manhattan Project site.
- Explain the science of the four main Manhattan Project labs.
- Determine which lab had the most expensive project.
- Compare and contrast how U-235 and Pu-239 were obtained during the Manhattan Project.
- Watch the embedded video and record answers to corresponding questions.

Designated Areas for Laboratories

For security purposes, the Manhattan Project selected several different geographical locations for laboratory research areas. Most employees at a research facility were not aware of the ultimate goal of this endeavor. Only selected scientists and engineers were informed of the existence of other working laboratories that would contribute to the construction of the first atomic bomb. The Manhattan Project employed over 130,000 people at a cost of 2 billion dollars at the time (today's estimate would be over 20 billion).



Figure **6.3.1**: Shift-change at the Y-12 plant in Oak Ridge, Tennessee.

Different laboratory sites employed all types of workers. Engineers and scientists focused on different mechanisms of the atomic bomb. Construction workers built barracks, laboratories, schools, and community buildings. Medical personnel assisted residents with health care concerns and needs. Educators were hired for newly constructed schools. In addition, factory workers were employed to man different stations of each research facility. Figure **6.3.2** shows the integral laboratories of the Manhattan Project. For a sample of what is was like to work at one of these settings, click on this link and watch a part of the entire interview of a female scientist who worked at Los Alamos National Laboratory.

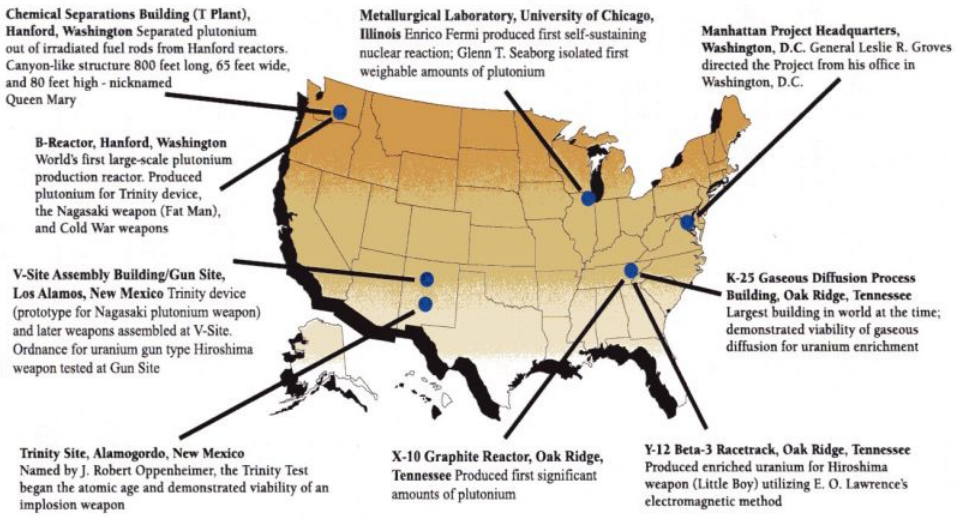


Figure **6.3.2**:Various lab locations during the Manhattan Project. Image taken from: https://www.osti.gov/opennet/manhatt...esMapLarge.jpg

Four Major Projects

From December of 1941 to August 1945, the labs showed in Figure **6.3.2** focused on four major problems in the construction of the first nuclear weapon. In this section of the text, we will analyze two of these issues. It is important for you to grasp the basic chemistry/physics incorporated to solve the problem. In addition, please correlate the lab responsible for solving each problem with its lead scientists. The four major obstacles that plagued Manhattan Project Scientists/ Engineers were:

1. **Obtaining and purifying U-235 to use as weapon fuel (Oak Ridge, TN by Ernest Lawrence)**
2. **Synthesizing Pu-239 to be used as an alternate weapon fuel (Hanford, WA by Glen Seaborg)**
3. **Calculating the critical mass of nuclear fuel to ensure a chain reaction (the University of Chicago, IL by Enrico Fermi and Leo Szilard)**
4. **Assembling and then testing nuclear device (Los Alamos, NM by J. Robert Oppenheimer)**

Project 1: Obtaining and purifying U-235

Mining Uranium

Significant amounts of uranium can be found the western part of the United States, Australia,Canada, and Kazakhstan. When located in the earth, uranium exists as an oxide (UO_2). This compound is part of an ore that contains other minerals. The most common of these uranium containing ores is called pitchblende or Uraninite.



Figure **6.3.3**: (left) Uranium Ore. Collected by Verl Allman, November 1965, from Shinkolobwe, Belgian Congo. Mineral collection of Brigham Young University Department of Geology, Provo, Utah. Photograph by Andrew Silver. No BYU index, U. (right) A photo of yellowcake uranium, a solid form of uranium oxide produced from uranium ore. Yellowcake must be processed further before it is made into nuclear fuel. Courtesy of Energy Fuels Inc.

Once harvested, pitchblende is crushed and treated with acid to isolate UO_2. Typically, a ton of pitchblende mined will yield only 2 to 4 pounds of UO_2. The purified form of UO_2 is dried to form a cake- like solid. From here, uranium yellowcake is combined with fluorine to form gaseous uranium hexafluoride (UF_6). This product will be enriched in order to meet the nuclear requirements of a country (nuclear reactors use 2-5% enriched fuel while nuclear bombs utilize 90 % enriched material).



Natural uranium contains 0.7205% U-235, the fissile isotope of uranium. The remaining mass includes 99.274% U-238 and a small amount of U-234 (0.0055%). Uranium-238 does not contribute to slow neutron fission; however, it can react with neutrons to form a fissile isotope of plutonium, Pu-239. Thus U-238 is known as a fertile material, i.e., one that can produce fissile materials. Although U-235 and U-238 are chemically identical, they differ slightly in their physical properties, most importantly mass. This small mass difference allows the isotopes to be separated and makes it possible to increase (enrich) the percentage of U-235 in uranium.

In producing U-235 for the first atomic bomb, Manhattan Project scientists considered four physical processes for uranium enrichment:

- gaseous diffusion (effusion),
- electromagnetic separation,
- liquid thermal diffusion, and
- centrifugation.

This text will focus only on the first two mentioned methods of isotopic separation. During the project, the electromagnetic separation, gaseous diffusion, and liquid thermal diffusion were employed at Oak Ridge, Tennessee. The combination of these processes formulated the fuel for the Hiroshima bomb (Little Boy). Centrifugation was abandoned because the technology and materials required to spin corrosive uranium hexafluoride with a rotator at high speeds were not practical for industrial, large-scale separations. However, advances in technology and materials make centrifugation the preferred method of enrichment today.

Gaseous Diffusion

Gaseous diffusion has been used to produce enriched uranium for use in nuclear power plants and weapons. Nuclear reactors require fuel that is 2–5% ^{235}U, and nuclear bombs need around 90% U-235 concentrations. In a gaseous diffusion enrichment plant, uranium hexafluoride (UF_6, the only uranium compound that is volatile enough to work) is slowly pumped through large cylindrical vessels called diffusers, which contain porous barriers with microscopic openings. The process is one of diffusion because the other side of the barrier is not evacuated. The $^{235}UF_6$ molecules have a higher average speed and diffuse through the barrier a little faster than the heavier $^{238}UF_6$ molecules. The gas that has passed through the barrier is slightly enriched in $^{235}UF_6$ and the residual gas is slightly depleted. The small difference in molecular weights between $^{235}UF_6$ and $^{238}UF_6$ only about 0.4% enrichment, is achieved in one diffuser (Figure **6.3.4**). But by connecting many diffusers in a sequence of stages (called a cascade), the desired level of enrichment can be attained.

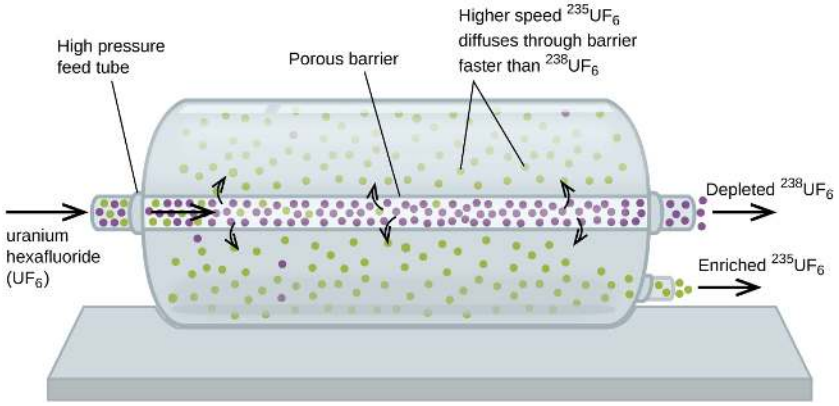


Figure **6.3.4**: In a diffuser, gaseous UF_6 is pumped through a porous barrier, which partially separates $^{235}UF_6$ from $^{238}UF_6$ The UF_6 must pass through many large diffuser units to achieve sufficient enrichment in ^{235}U.

The gaseous diffusion method of isotopic separation presented many problems. First, a non-corrosive material (nickel and aluminum oxide) would need to be selected to serve as a barrier. The holes in the barrier needed to be microscopic (approximately one-millionth of an inch in diameter) and uniform in size. Gaseous diffusion plants require very large amounts of energy to alter pressurized areas in the diffuser cascades. In addition, the entire system must be leak-free; no air can be allowed in and no uranium hexafluoride (extremely corrosive gas) can escape.



Figure **6.3.5**: The K25 Gaseous Diffusion Plant at Oak Ridge, Tennessee. Courtesy of Atomic Archive

The laboratory facility that would handle the large-scale separation of gaseous $^{235}UF_6$ from $^{238}UF_6$ was constructed at Oak Ridge, Tennessee. This plant, built during World War II, was half a mile long, six stories high, and covered 43 acres.

Electromagnetic Separation

The electromagnetic isotope separation (EMIS) process is based on the principle of a simple mass spectrometer, which states that a charged particle will follow a circular path when passing through a uniform magnetic field. Thus, uranium tetrachloride chloride ions containing U-235 and those containing U-238 with the same charge and kinetic energy (energy-related to movement) will have slightly different paths when moving through a magnetic field. The radius of the path traversed by the heavier U-238 ions will be larger than the radius of the path of the lighter U-235 ions. This allows for the separation and collection of the isotopes in receivers (Figure **6.3.4**).



Figure **6.3.6**: J. Robert Oppenheimer (father of the atomic bomb), Enrico Fermi (the scientist who invented fission), and Ernest Lawrence (the engineer who designed calutrons) discussing U-235 enrichment. Photograph of the calutron in the Y-12 facility. *Images were taken from upload.wikimedia.org/wikiped..._Lawrence.jpeg and upload.wikimedia.org/wikiped...lpha_Track.jpg*

EMIS units, known as "calutrons", were operated in the Y-12 area of Oak Ridge. EMIS is a batch process, with each unit requiring a long time to produce small amounts of U-235, many units were used to produce the first fissionable uranium. Uranium ions for the EMIS are generated by heating solid uranium tetrachloride, UCl_4, to produce a vapor that is then bombarded with electrons to produce positively charged ions. There was a major problem with this process: less than half of the original U-235 was collected in the receivers. The rest was scattered throughout the calutron and was difficult to recover. At Oak Ridge, two groups of calutrons were used to produce weapons-grade uranium. The first group, or alpha calutrons, enriched uranium (7.0% U-235) from the gaseous diffusion plant to between 12 and 20% U-235. The second group, or beta calutrons, took the alpha product and enriched it to approximately 90% U-235 (weapons-grade uranium). As difficulties with the gaseous diffusion process were overcome, the EMIS process was phased out.

Use of enriched U-235

By the spring of 1945, Oak Ridge had shipped approximately 132 lbs. of enriched uranium (90% U-235) to Los Alamos, New Mexico; it had been produced using thermal diffusion, gaseous diffusion, and electromagnetic separation (Figure **6.3.7**). This enriched uranium was used in "Little Boy", the bomb dropped on Hiroshima on August 6, 1945. With the discontinuation of thermal diffusion and electromagnetic separation after the war, gaseous diffusion became the primary method for enriching uranium in the United States. Today, most nuclear weapons use plutonium as the fissionable component.

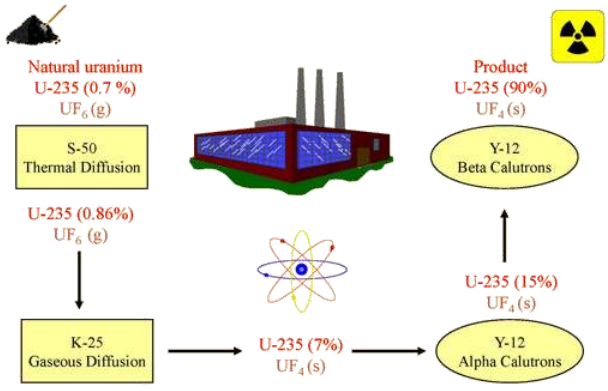


Figure **6.3.8**: Methods Used to Produce Enriched Uranium for the First Atomic Bomb(Frank Settle)

Project 2: Synthesizing Pu-239

In the winter of 1940, a group of chemists (Glenn Seaborg, Edwin McMillan, Joseph Kennedy, and Arthur Wahl) bombarded U-238 with deuterons (H-2) in the University of California (Berkeley) cyclotron. They identified a new isotope of Np, which decayed by beta emission and produced a new element, plutonium.

$$^{238}_{92}U_{92} + {}^{2}_{1}H \rightarrow {}^{238}_{93}Np + 2\,{}^{1}n_0$$

$$^{238}_{93}Np \xrightarrow{\tau_{1/2}=2.12 days} {}^{238}_{94}Pu + \beta^-$$

$$^{238}_{94}Pu \xrightarrow{\tau_{1/2}=90 year} \alpha^{2+} + {}^{236}_{92}U$$



Figure 6.3.8: Glen Seaborg, the discoverer of Pu-239, standing in his laboratory. (Public Domain; United States Department of Energy).

The new plutonium atom was chemically different from U, Np, and other reaction products. At this time, Seaborg and Wahl could not identify which Pu isotope produced the alpha activity. It was later identified as Pu-238. In the spring of 1941, another more important isotope of plutonium, Pu-239, was produced using neutrons from the Berkeley cyclotron to target a uranium compound surrounded by paraffin. This new Pu isotope, an alpha emitter with a half-life of about 24,000 years, was separated from other reaction products using the same chemistry as that used to isolate Pu-238. However, the longer half-life of Pu-239 reduced its activity, making it more difficult to detect than Pu-238.

$$^{238}_{92}U + {}^{1}n_0 \rightarrow {}^{239}_{92}U + \gamma$$

$$^{239}_{92}U \xrightarrow{\tau_{1/2}=23.5\ min} {}^{239}_{93}Np + \beta^-$$

$$^{239}_{93}Np \xrightarrow{\tau_{1/2}=2.35\ days} {}^{239}_{94}Pu + \beta^-$$

$$^{239}_{93}Pu \xrightarrow{\tau_{1/2}=24{,}110\ yrs} {}^{235}_{92}U + \alpha$$

In March 1941, Seaborg's group irradiated a sample estimated to contain 0.25 mg of Pu-239 surrounded by paraffin with neutrons produced in the cyclotron. Under these conditions, this isotope appeared to undergo fission. When the Pu was replaced with a sample containing approximately 0.5 mg U-235, the other known fissionable material, neutron-induced fission was also observed, but at a rate approximately half that of Pu-239. This discovery raised the possibility of using a controlled chain reaction to produce quantities of Pu-239 sufficient for nuclear weapons. The product Pu-239 would have to be separated from the unreacted uranium and fission products by chemical means. It now became important to investigate the chemistry of plutonium to develop large-scale separation procedures.

However, in the summer of 1942, the cyclotron was the only means of producing plutonium, and the amounts produced were so small that they could not be seen or weighed with existing balances. Calculations showed that long periods of neutron bombardment of uranium in the cyclotron would produce only a few micrograms of Pu-239, much less than that normally required to determine the physical and chemical properties of a new element. The preparation and measurement of such small quantities of plutonium required the development of "ultramicrochemical" techniques and equipment.

At the University of Chicago's Metallurgical Lab (referred to as the Met Lab), the first weighing of a plutonium compound occurred in the fall of 1942. Only 2.77 micrograms of PuO_2 were isolated and measured with a balance especially designed for small masses. In November 1943, the first pure plutonium metal was chemically prepared at a temperature of 1,400º C. The plutonium metal appeared as silvery globules weighing about 3 micrograms each.



Figure **6.3.9**: Twenty micrograms of plutonium hydroxide in a capillary tube, September 1942 (Courtesy of the University of California, Berkeley)

Although the Pu-239 isotope had the potential to be fissionable material for bombs or power generation, the realization of this potential required larger amounts of this isotope. Large-scale production of Pu-239 required a controlled nuclear chain reaction of uranium, a feat that would soon be achieved by Enrico Fermi and Leo Szilard in Chicago. A facility to mass-produce Pu-239 was built in Hanford, Washington. Glenn Seaborg was assigned to direct this particular laboratory. The resulting fuel would be used in the Trinity test bomb, the Nagasaki bomb, and two reserve weapons.

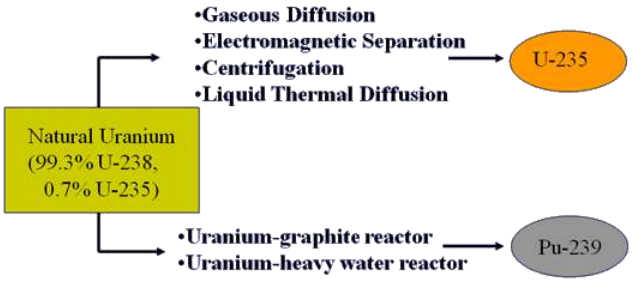


Figure **6.3.11**: Routes to Fissionable Materials for Atomic Bombs

Example 6.3.1

Watch from the 11-minute mark of this video to the 23:20 mark. Then, answer the questions below.



1. What region of the country was selected to be the bomb design site?
2. Who did General Groves select to be the lead scientist? Briefly describe his personality.
3. How much U-235 was enriched during the Manhattan Project? What amount of U-235 was used in the construction of Little Boy?
4. What was special about the construction of Y-12? Where was this facility and what did it provide for the Manhattan Project?
5. How did Groves convince construction workers to come to Y-12?
6. Did the calutrons work perfectly when the alpha one racetrack was started?
7. What was the Gadget? What type of fuel would it use and how would it explode?
8. What element was made in 1941? What area of the country would produce this isotope in large amounts?
9. Is Pu-239 more or less likely to undergo fission than U-235?
10. What is K-25 and where is it located? What would K-25 produce?

Sources

1. http://www.history.com/topics/the-manhattan-project
2. https://www.osti.gov/opennet/manhatt...m_research.htm

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6.4: The Manhattan Project - Critical Mass and Bomb Construction

Learning Objectives

- Explain the concept of critical mass for a fission reaction.
- Know the bomb mechanisms of Little Boy and Fat Man.
- Watch the embedded videos and record answers to any corresponding questions.
- Compare and contrast Little Boy and Fatman (size, fuel, targets, and casualities)

Determining Critical Mass

Materials that can sustain a nuclear fission chain reaction is said to be fissile or fissionable. This reaction becomes self-sustaining when the number of neutrons produced by fission equals or exceeds the number of neutrons absorbed by splitting nuclei plus the number that escape into the surroundings. The amount of a fissionable material that will support a self-sustaining chain reaction is a **critical mass**.



In order to determine critical mass required for a nuclear chain reaction, Enrico Fermi and Leo Szilard constructed the world's first controlled fission experiment. At the University of Chicago, the physicists piled 40,000 graphite (carbon based pencil material) blocks in a 24 square foot formation (see below). Fermi and Szilard embedded the graphite with 19,000 pieces of uranium. In a squash court (similar to a racketball court) on December 2, 1942, slow neutrons bombarded the pile to produce a sustained, nuclear chain reaction. The fission reaction was detectable by using a Geiger Counter. This mini reactor did not explode or injure any scientists due to its design. From these experiments, Fermi, Szilard and their colleagues determined the critical mass of U-235 to be approximately 50 kg. In addition, they concluded that critical mass was dependent upon the type of fuel (U-235 or Pu-239), shape of fuel (round reduces amount), temperature of the reaction (higher increased neutron collisions), and density of material. Other experiments and calculations lead to the critical mass determination of Pu-239. Unlike U-235, only 10 kg of Pu-239 was required to sustain a nuclear chain reaction.

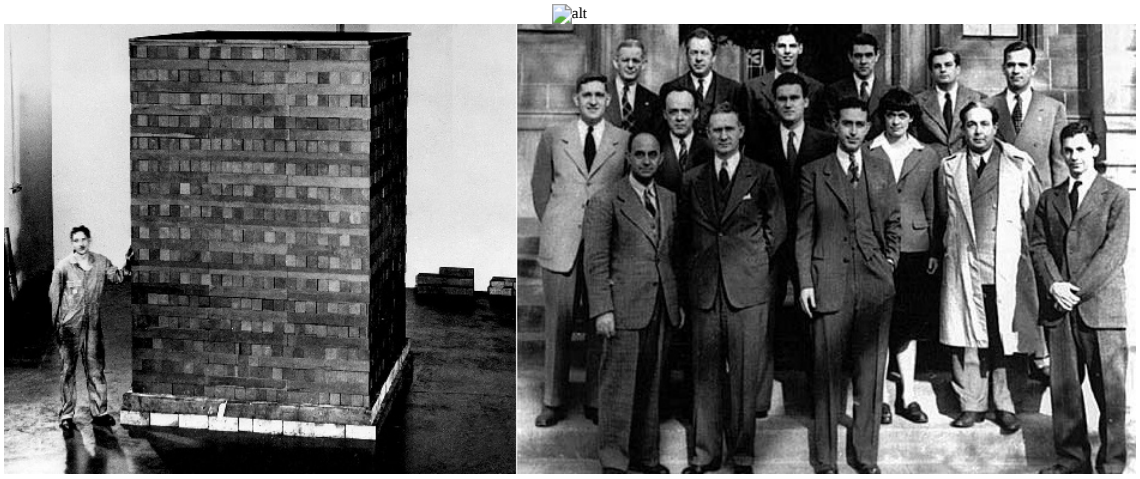
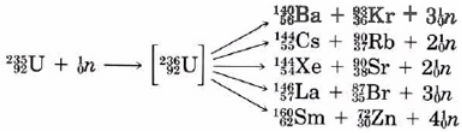


Figure **6.4.1**: Chicago Pile-1 reactor built to produced sustainable nuclear fission. Chicago Pile-1 scientists standing together. Enrico Fermi is standing on bottom row, far-left. Leo Szilard is positioned to the right of the only female scientist (Leona Woods) in this particular research group. Images taken from: upload.wikimedia.org/wikiped...2803096%29.jpg and upload.wikimedia.org/wikiped...goPileTeam.png

The fission of uranium produces more neutrons than it consumes. As can be seen from Eqs. (1), for every neutron captured by a U-235 nucleus, between two and four neutrons are produced. As soon as a stray neutron bombards a U-235 nucleus, fission will take place and three neutrons will be produced. These in turn will fission three more U-235 nuclei, producing a total of nine neutrons. A third repetition will produce 27 neutrons. a fourth 81. and so on. This process (which is called a *chain reaction*) escalates very rapidly. Within a few microseconds a very large number of nuclei fission, with the release of a tremendous amount of energy, and an atomic explosion results.



There are two reasons why a normal sample of uranium metal does not spontaneously explode in this way. Natural uranium consists mainly of the isotope U-238 while the fissionable isotope U-235 comprises only 0.7 percent of the total. Most of the neutrons produced in a given fission process are captured by U-238 nuclei without any further production of neutrons. The escalation of the fission process thus becomes impossible. However, even a sample of pure U-235 will not always explode spontaneously. If it is sufficiently small, many of the neutrons will escape into the surroundings without causing further fission. The sample must exceed a **critical mass** before an explosion results. In an atomic bomb several pieces of fissionable material, all of which are below the critical mass, are held sufficiently far apart for no chain reaction to occur. When these fragments are suddenly brought together, an atomic explosion results immediately.

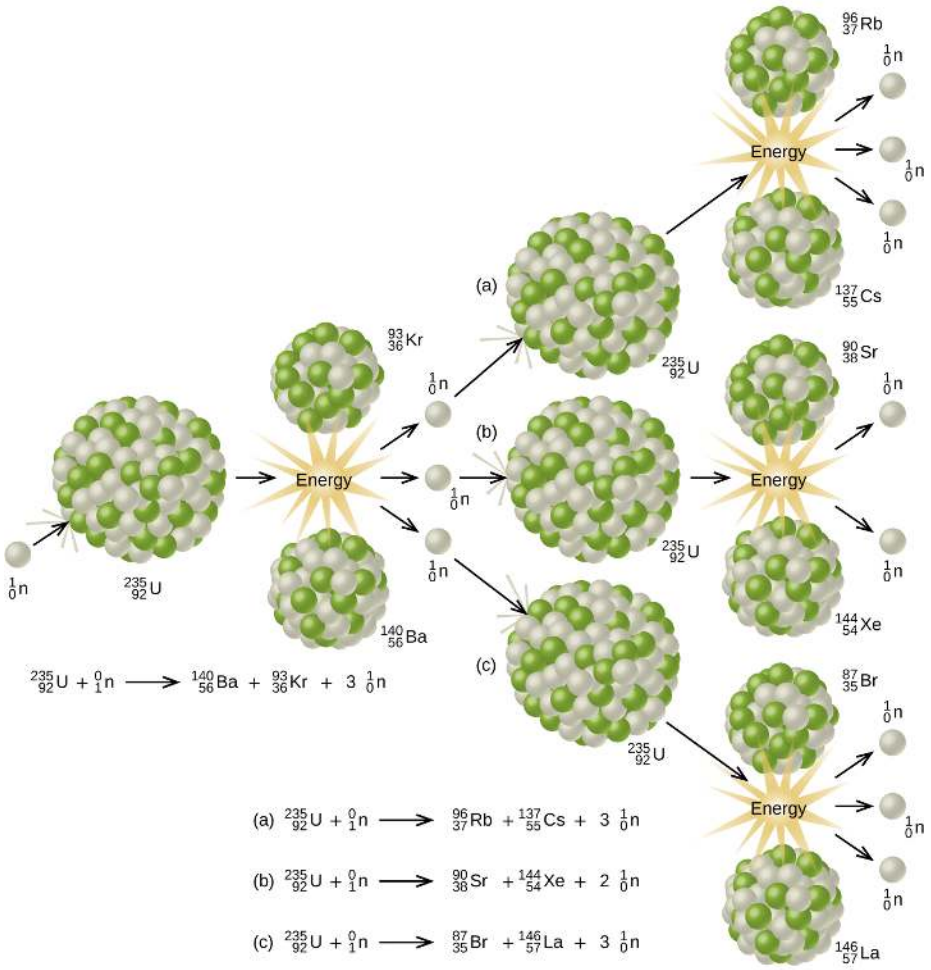


Figure **6.4.2**: The fission of a large nucleus, such as U-235, produces two or three neutrons, each of which is capable of causing fission of another nucleus by the reactions shown. If this process continues, a nuclear chain reaction occurs.

Bomb Construction

At Los Alamos, New Mexico, J. Robert Oppenheimer, and his research group were given the task of assembling and testing the fission bomb. Both types of fuel that were manufactured (U-235 and Pu-239) would be placed separately into two different bomb designs. The smaller of the two bombs would contain U-235 and was code-named "Little Boy." The larger bomb, which housed Pu-239, was named "Fat Man." Of the two, only the Pu-239 bomb would be tested before it was dropped in wartime.

The basic design of the U-235 bomb is shown in the figure below. To prevent the spontaneous detonation of an atomic bomb, the fissile U-235 is kept in a subcritical configuration. It is then rapidly assembled into a supercritical mass using conventional explosives. Once the bomb has achieved this mass, any neutron introduced into it will be likely to initiate a chain reaction. The mechanism for "Little Boy" was a gun that fired one subcritical piece of U-235 into another to form a supercritical mass (Figure **6.4.3**). The pieces had to be assembled within a time less than the average time between appearances of spontaneous neutrons from either U-235 or cosmic radiation. A conventional explosive in an artillery barrel could fire the U-235 mass at speeds of a few millimeters per second, fast enough to prevent a fizzle caused by a spontaneous neutron setting off a premature chain reaction.

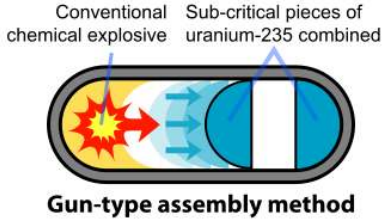


Figure **6.4.3**: Little Boy: Gun-Type Device. (Public Domain).

Originally, the gun-type mechanism was planned for both the U-235 and Pu-239 weapons. However, a problem arose with the Pu-239 bomb that required a different assembly mechanism because of the small amount of Pu-240 that is produced with the Pu-239 in the reactor. Pu-240 emits large numbers of neutrons spontaneously: 1,030 neutrons per gram per second compared with 0.0004 neutrons per gram per second for U-235. Even at a concentration of 1% Pu-240 in the fissile Pu-239, the required mass of Pu emits 52,000 neutrons per second or one neutron every 20 microseconds. Thus, it is very probable that a neutron from Pu-240 will initiate a premature chain reaction during the critical last 100 microseconds of the critical mass in a gun-type assembly. This problem was discovered in mid-1944, well after the start of the construction of the massive Hanford plutonium production facilities.

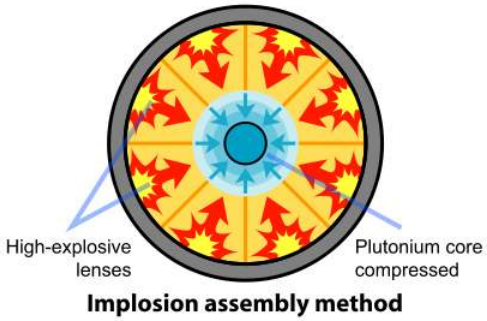


Figure **6.4.4**: Fat Man: Implosion-type bomb. (Public Domain).

The removal of the Pu-240 was impractical. So the scientists and engineers looked for a faster method of assembling the plutonium. A mechanism based on implosion provided the solution to this problem. In this design, the fissile material is shaped into a single sphere with a mass slightly less than critical (Figure **6.4.4**). Layers of carefully shaped high explosives surround the sphere. When the explosives are detonated, the force of the shock wave compresses the fissile material into a smaller volume, forming a supercritical mass. This method of assembly is much faster than the gun-type mechanism and thus eliminates the problems resulting from spontaneous neutron emission of Pu-240. The spherical mass resulted in a pumpkin-shaped weapon called "Fat Man".

Example 6.4.1

Watch the from the 23-minute mark through the 28-minute mark of the third installment of the History Channel's Manhattan Project and answer the questions below.



1. What were the problems with the two different types of fuel that were to be used in the fission weapons?
2. What was the configuration or set-up of the Pu-239 bomb?
3. The combination of electromagnetic separation and gaseous diffusion enriched enough U-235 to produce how many bombs?
4. Why was the U-235 bomb never tested?
5. When was the construction of the U-235 completed?
6. How much did Truman know about the nuclear bombs when FDR was alive?
7. Who was selected to pilot the plane for the nuclear weapons?

8. What island would serve as a base to house the nuclear bombs before delivering them to their targets?

In July 1945, the United States had enough fissile material for one uranium and two plutonium weapons. The scientists and engineers felt confident that the gun-type assembly mechanism for Little Boy would function properly. Besides, they did not have the material for a test device. They were less confident about the implosion mechanism on the plutonium weapon and felt that a test was necessary. On July 16, 1945, the first nuclear device, known as "The Gadget", was placed on a 100-foot tower and successfully detonated in the Alamogordo Desert, 200 miles south of Los Alamos (Figure **6.4.5**).

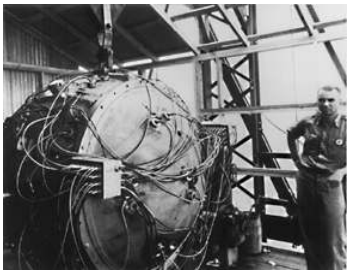


Figure **6.4.5**: The Gadget at the Trinity Test Site, 1945. Courtesy of the U.S. Department of Defense

As the war with Japan continued and a costly allied invasion loomed as a real possibility, President Truman approved the use of nuclear weapons against selected Japanese targets. The U.S. Army Air Force received orders to use these weapons anytime after August 3, 1945. On August 6, "Little Boy" was dropped on Hiroshima (Figure **6.4.6**).



Figure **6.4.6**: Little Boy - The only U-235 weapons constructed during WWII. Courtesy of the U.S. Department of Defense

Little Boy was a uranium weapon containing 141.4 pounds of fissionable material containing 82.7% U-235. Only about two pounds fissioned, releasing an energy equivalent to 15-16,000 tons of TNT. The immediate effects of the blast killed an estimated 70,000 people, and by the end of 1945 an additional 20,000 to 70,000 deaths occurred, many due to lack of adequate medical resources.

Three days later, "Fat Man" destroyed a large part of Nagasaki (Figure **6.4.7**). Fat Man contained 13.6 pounds of Pu-239, of which only 2 pounds underwent fission. The explosive yield was equivalent to about 22,000 tons of TNT. Fat man resulted in 35,000 immediate deaths. By the end of 1945, at least 70,000 people perished in this event.

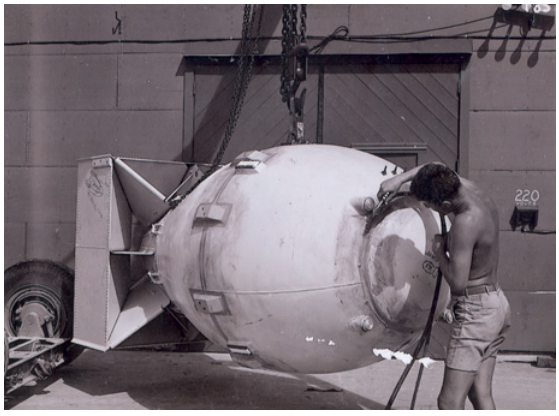


Figure* 6.4.7*: *Fat Man – One of many Pu-239 nuclear weapons constructed during WWII. Courtesy of the U.S. Department of Defense*

Example 6.4.2

Start the video below at the 28:00 mark and stop it at the 32-minute setting. Then, answer the questions below:



9. When and where was the first nuclear bomb tested?
10. Was the bomb placed on the ground?
11. What were scientists afraid the first nuclear bomb would do?
12. What did Edward Teller (father of the fusion bomb) apply to his skin before the bomb was ignited? Why did he do this?
13. What did the bomb do to the tower and the surrounding sand?
14. In the photograph, where did General Grove focus his attention?

Need More Practice?

In section 6E, work problem 6.

Sources

1. https://www.uchicago.edu/features/ho...anged_science/

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6.5: Hiroshima and Nagasaki

Learning Objectives

- Determine why the United States selected specific Japanese citys for nuclear bomb targets.
- Recall the names of the pilots, planes, and cities that were destroyed by Little Boy and Fat Man.
- Relate the types of radiation nuclear bombs release to chapter 5 concepts.
- Watch and answer all questions to embedded videos contained in this section.

Target Cities

On May 10th and 11th, a Target Committee meet at Los Alamos National Laboratory to determine possible targets for the atomic bomb. Military personnel and selected Manhattan Project scientists discussed the preparations required for the dropping of Little Boy. They mentioned the height of detonation, weather and radar data, and rehearsals for the mission. Cities selected needed to be urban areas of more than three miles in diameter. In addition, bombing targets would need to be effectively damaged by a blast and they would not be damaged before being subject to nuclear warfare. The shortlist of targets can be seen below in order of selection:

1. Kyoto (former capital and industrial center with a population of over 1 million)
2. Hiroshima (army depot and port)
3. Yokohama (untouched industrial center)
4. Kokura (one of the largest arsenals in Japan)
5. Niigata (untouched port area, industrial center, housed oil refineries)

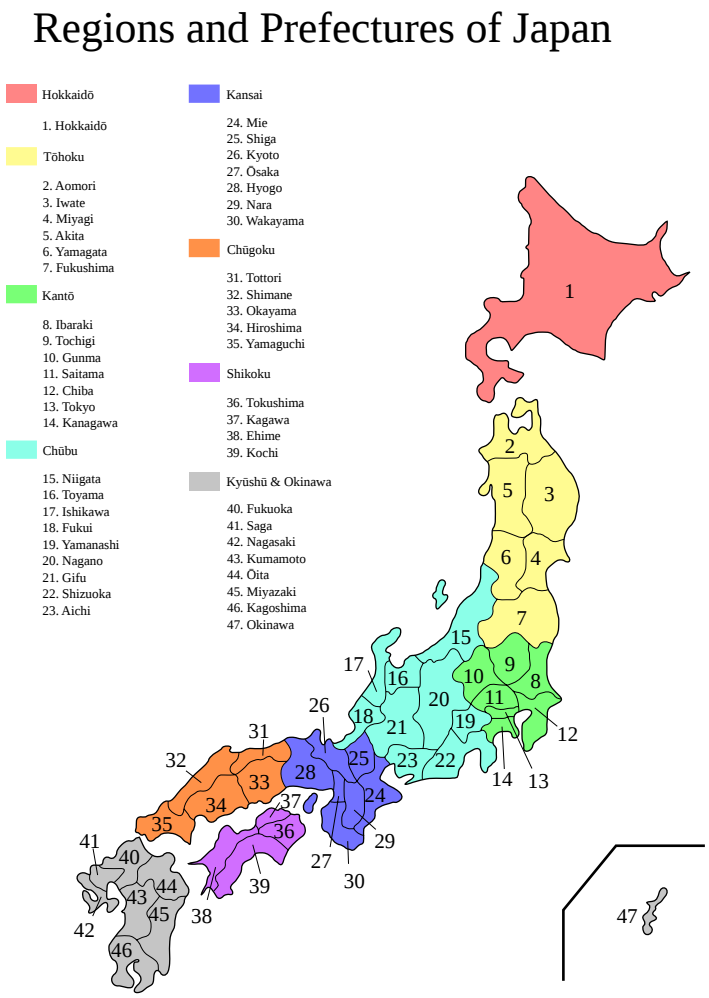


Figure **6.5.1**: Map of Japan. (Public Domain; TheOtherJesse via Wikipedia)

Immediately, Kyoto was removed from this list. The United States Secretary of War, Henry Stimson, had honeymooned there previously and recognized the cultural significance of this area. Kyoto contained beautiful gardens, 17 World Heritage Sites, and over 2,000 Buddhist Temples and Shinto Shrines. Many committee members argued that dropping the bomb on Kyoto would have a more emotional impact on the Japanese than dropping it on another city. Regardless, Kyoto was removed from the list of target sites and the bomb would be diverted to Hiroshima.

Hiroshima (August 6, 1945)

On August 6, 1945, Colonel Paul Tibbets and his 11 membered crew flew the Enola Gay from Tinian Island to Hiroshima, Japan. Previously that morning, other American weather planes had surveyed the visibility for this target. On August 6, 1945, Little Boy was dropped around 8:15 a.m. It fell for over 44 seconds and then exploded at approximately 2000 feet (epicenter) above the city of Hiroshima. During this time, two other American planes recorded scientific data (The Great Artiste) and visual images (The Necessary Evil). The bomb packed a power equivalent to 12-15 kilotons of TNT.





Figure **6.5.2**: (left) Crew members of the Enola Gay (Public Domain; US Dept. of Defense). (right) Plane routes for the atomic bomb missions (Public Domain Mr.98 via Wikipedia)

Before the bombing of Hiroshima, the population of the city was estimated to be around 255,000. This city was relatively flat and was densely populated. Many buildings were constructed with reinforced concrete in order to withstand earthquake damage. Hiroshima housed a military base that served as a communications center, storage point, and assembly area for the Japanese army.



"All the News That's Fit to Print"

The New York Times.

LATE CITY EDITION
Partly cloudy, less humid today. Cloudy and warm tomorrow.

Copyright, 1945, by The New York Times Company.

VOL. XCIV..No. 31,972. NEW YORK, TUESDAY, AUGUST 7, 1945. THREE CENTS

FIRST ATOMIC BOMB DROPPED ON JAPAN; MISSILE IS EQUAL TO 20,000 TONS OF TNT; TRUMAN WARNS FOE OF A 'RAIN OF RUIN'

HIRAM W. JOHNSON, REPUBLICAN DEAN IN THE SENATE, DIES

Isolationist Helped Prevent U. S. Entry Into League—Opposed World Charter

CALIFORNIA EX-GOVERNOR

Ran for Vice President With Theodore Roosevelt in '12—In Washington Since '17

Jet Plane Explosion Kills Major Bong, Top U. S. Ace

Flier Who Downed 40 Japanese Craft, Sent Home to Be 'Safe,' Was Flying New 'Shooting Star' as a Test Pilot

KYUSHU CITY RAZED

Kenney's Planes Blast Tarumizu in Record Blow From Okinawa

ROCKET SITE IS SEEN

125 B-29's Hit Japan's Toyokawa Naval Arsenal in Demolition Strike

REPORT BY BRITAIN

'By God's Mercy' We Beat Nazis to Bomb, Churchill Says

ROOSEVELT AID CITED

Raiders Wrecked Norse Laboratory in Race for Key to Victory

Steel Tower 'Vaporized' In Trial of Mighty Bomb

Scientists Awe-Struck as Blinding Flash Lighted New Mexico Desert and Great Cloud Bore 40,000 Feet Into Sky

NEW AGE USHERED

Day of Atomic Energy Hailed by President, Revealing Weapon

HIROSHIMA IS TARGET

'Impenetrable' Cloud of Dust Hides City After Single Bomb Strikes

Figure **6.5.3**: Front page of New York Times after Hiroshima bomb explosion. See interactive NYTimes Story. (Fair use)

At around 8:00 a.m. that morning, a Japanese radar operator detected three planes flying near Hiroshima. These planes were American weather planes noting visibility for the bombing that would occur. Due to the small number of planes, Hiroshima citizens were encouraged but not required to seek shelter. At 8:15 a.m., Little Boy detonated producing a blinding flash and a booming sound.

Due to crosswinds, the Enola Gay missed the original target of the Aioi Bridge and directly hit the Shima Surgical Clinic. Total destruction occurred within one mile of the epicenter (ground beneath = hypocenter). All buildings, with the exception of reinforced concrete, were completely leveled. Extending to 5700 feet from the epicenter, most steel-framed buildings showed extensive damage. At approximately 6600 feet from the epicenter, multi-storied brick buildings had some degree of wreckage. In

the city, over 69 % of the buildings were destroyed from the blast. Overhead electrical installations (power lines) were destroyed at a distance of over 5500 feet from the epicenter.

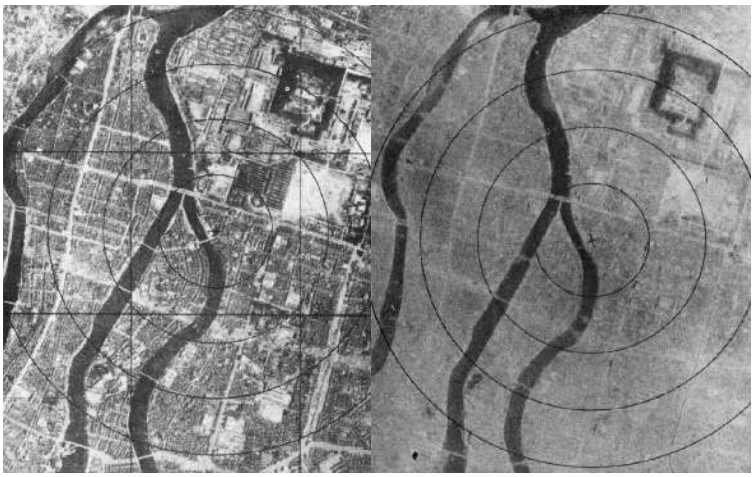


Figure **6.5.4**: Hiroshima before bombing. Area around ground zero. 1,000 foot circles.Hiroshima after the bombing and firestorm

Within a few microseconds of detonation, gamma, ultraviolet, and visible radiation were emitted to the surrounding areas. Shortly thereafter, a large ball (several hundred feet in diameter) was produced. Intense temperatures((in excess of a million degrees Celsius) and changes in pressures (19 tons per square meter) ultimately produced a growing shockwave. With the formation of a mushroom could, particle (mainly alpha and neutron) and wave (gamma, ultraviolet, and visible) are emitted a second time.

93% of residents who were up to 1000 feet of the epicenter died immediately. Deaths were attributed to thermal burns (from wave radiation), vaporization, flying debris, and extreme radiation exposure. Residents who were about 5,000 feet (almost a mile) from the epicenter had a 49% mortality rate. A distance of 10,000 feet (almost two miles) from the epicenter ensured safety. Individuals who were inside a structure were more likely to survive the detonation. Obviously, reinforced concrete structures provided more protection than wooden or bricked facilities. At Hiroshima, around 60% of the mortalities were attributed to severe burns. Falling debris killed around 30% of deaths. Lastly, pressure changes and radiation exposure killed the remaining 10%. In total, 60,000 - 70,000 people died immediately after the detonation of Little Boy. Within three months of this date, the total would increase to over 130,000 people.

Nagasaki (August 9, 1945)

Three days after the bombing of Hiroshima, the Bockscar with its crew flew towards Kokura. Piloted by Charles Sweeney, this plane carried the plutonium weapon, Fat Man. As with the Enola Gay, the Great Artiste accompanied the overloaded B-29. On that morning, the Bockscar passed over Kokura three times attempting to drop its nuclear bomb. Cloudy weather prevented the crew from arming the weapon and the target was abandoned. Determined to still use the plutonium weapon, the Bockscar flew towards Nagasaki. At 11:02 a.m., Fat Man detonated 1700 feet above the city. Releasing over 20 kilotons of energy, the bomb exploded between Mitsubishi Steel and Arms (weapons facility) and Mitsibushi-Urakami Works (Torpedo factory). The plane immediately rerouted to Iwo Jima due to a fuel shortage. Hours later, the Bockscar returned to Tinian Island. Like the Enola Gay, both sets of crews were not harmed on either mission.

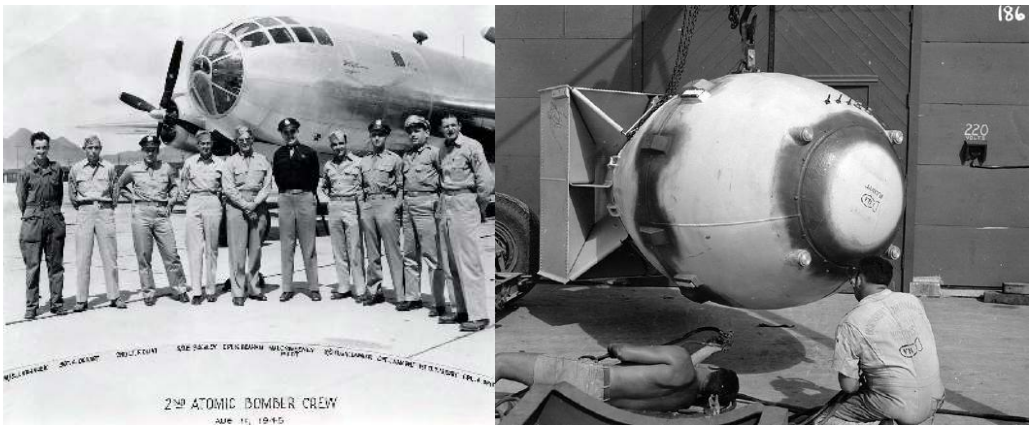


Figure 6.5.5: (left) Crew of the Bockscar (Public Domain; US Air Force). (right) Bomb Technicians adjusting Fat Man on Tinian Island before being loaded into the Bockscar (Public Domain; United States Navy).

The pre-bomb population of Nagasaki was approximately 195,000 people. Nestled between mountains, this city was contained in a valley. Differences in topography and population densities resulted in fewer casualties than the Hiroshima bomb. The larger plutonium weapon instantly killed between 35,000 to 39,000 residents. Within a year's time, a total of 65,000 people would perish.

Being a larger weapon, Fat Man had a larger destruction radius when compared to Little Boy. Over 30% of Nagasaki was completely destroyed. Steel framed buildings were severely damaged within 6000 feet of the epicenter. Multi-stored buildings sustained significant destruction 6500 feet from the epicenter. At Nagasaki, damage of Japanese homes extended to over 10,500 feet from the epicenter (compared to the distance of 8000 feet at Hiroshima). Nagasaki had fewer buildings constructed with reinforced concrete. Wood-framed buildings provided little to no protection for this city's residents.

95% of the deaths at Nagasaki were due to burns (gamma and ultraviolet). The remaining percent could be attributed to falling debris, glass, and radiation illnesses. Within 4900 feet of the epicenter, approximately 67% of the residents died. The epicenter distance of 6500-9900 feet (1.2-1.9 miles) resulted in an approximately 14% casualty rate. Differences in population density and topography of area resulted in fewer deaths in Nagasaki than Hiroshima.

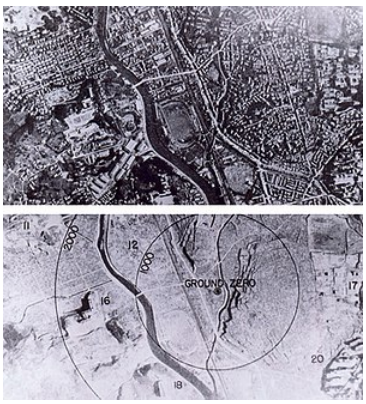


Figure 6.5.7: Pre and post bombing pictures of Nagasaki. (Public Domain; U.S. National Archives : RG 77-MDH)

On August 15, 1945, Emperor Hirohito publicly announced the surrender of Imperial Japan. Aboard the USS Missouri battleship, members of the Japanese government signed the Japanese Instrument of Surrender on September 2, 1945.

Example 6.5.1

Watch from the 32 minute mark to the end of the History Channel's Manhattan Project and answer the questions below.

1. How powerful was the plutonium test bomb (in tons)? Which bomb would be dropped first?
2. What was the purpose of the petition at Oak Ridge? Did the other labs (Los Alamos, Hanford, and Chicago) get to see the petition?
3. Give some reasons as to why America still chose to drop the bombs.

4. Why were certain cities in Japan not bombed during 1945?
5. When and where was Little Boy dropped? Give the time of day as well. How powerful (TNT) was it.
6. How did Paul Tibbets' describe Hiroshima?
7. What was the death toll at Hiroshima?
8. Where was Fat Man dropped?
9. When did Japan surrender?
10. When did Russia detonate their first nuclear weapon?
11. What did Edward Teller design?
12. What was Oppenheimer's attitude toward furthering nuclear bomb research?



Need more practice?

In section 6E, answer questions 6-8.

References

1. http://avalon.law.yale.edu/subject_menus/mpmenu.asp

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6.6: Aftermath of Bombings

Learning Objectives

- Survey the destruction of Little Boy and Fat Man by listening to witness testimonies.
- Virtually tour memorials dedicated to the victims of Hiroshima and Nagasaki.
- Watch all embedded videos and answer corresponding questions.

Hiroshima

Sixteen hours after Little Boy was dropped, President Harry S. Truman announced publicly that a nuclear weapon had been used against Japan. Up until that time, Japanese scientists were unsure as to what had happened to their community. There was so discussion as to whether chemical or biological warfare had occurred. Fear spread that disease could be spread by being in contact with a resident of Hiroshima. Healthcare professionals were warned to not enter this area due to fear of contraction of an infectious disease.



Figure **6.6.1**: Arial view of Hiroshima shown at the Hiroshima Peace Museum. Photo Courtesy of Shane Patel (Furman University, Class of 2016).

Individuals working at the Shima Hospital noted how all of the x-ray films had mysteriously been exposed. From this observation, resident healthcare workers dismissed this weapon to be chemical or biological in nature. Knowing this, the Japanese had to determine how to combat the effects of this new weapon. Fires burned upon Hiroshima for long periods of time. Water was scarce and contaminated. Families were separated and locating individuals was near to impossible. Communication had been severed from neighboring communities. Moreover, there were no medications designed to fight radiation sickness.

Exploring 24 hours after Hiroshima Video



Note: Please be aware of graphic images shown in times 16:30 -16:50 , 18:26-18:55 , and 27:00 - 27:30 of this video.

Watch the **through the 30-minute mark of this** video and answer the questions below:

1. What distance (in feet) from the epicenter resulted in almost 100% mortality for the residents of Hiroshima?
2. What are the atomic shadows? How did scientists use these images to assist in understanding the atomic bomb detonation?
3. Richard Rhodes (atomic bomb book author) describes the melting of what types of materials at 3200ºF?
4. Describe the lunch box that was found 1/3 mile from ground zero. Did the owner of this object survive the bombing?
5. How long does it take for the shock wave to flatten Hiroshima? What was the approximate number of buildings destroyed by shock waves?
6. When the shock wave occurred, how far away were the crew of the Enola Gay?
7. What was the radius of heavy damage from the shockwave?
8. Did any people survive from being inside the A-bomb dome? This is the building that survived the atomic blast at Hiroshima.
9. Where was Takashi (the schoolboy) when the atomic blast occurred? How did he survive?
10. How long did the fires burn after the bomb was dropped? How many square miles of the city were burned?

Typically, individuals who were outside and close (within 0.2 miles) to the epicenter were vaporized or severely burned. Some survivors as close as .4 miles lived if there were inside a concrete based building. Other types of structures offered little to no protection. In many cases, people inside of a structure were crushed to death. People outside during the explosion were exposed to flying debris and extreme pressure changes.

Remembering this event, it is important to people of all backgrounds and cultures. By viewing artifacts and listening to survivor testimonies, one can gain a small amount of insight as to what the residents experienced on August 6, 1945. In addition, listening to Threnody to the Victims of Hiroshima by Penderecki can provide an auditory experience of the sheer terror of nuclear warfare.



Figure **6.6.2**: Kunishige Masahiro, a survivor of the Hiroshima bombing, shares his story with students (photo courtesy of Grace Cohen, Furman University, Class of 2016).

Today, Hiroshima has many museums and monuments dedicated to the survivors of Little Boy. One of the most notable sites is the A-bomb dome. This structure was approximately 600 meters from the hypocenter (ground zero) and 160 meters from the epicenter (air detonation). Unfortunately, none of the individuals inside this structure survived due to their close proximity to the explosion.



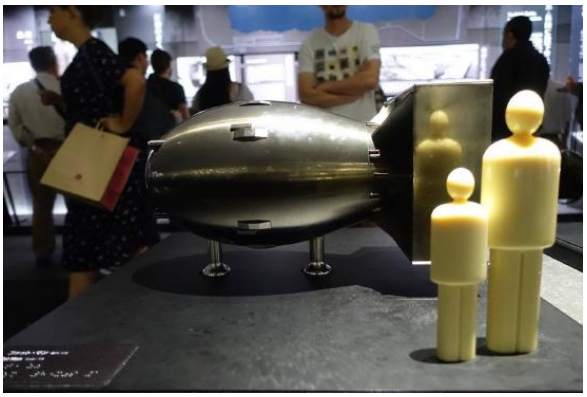


Figure \(\PageIndex{3}\): Picture of A-Bomb Dome in 2016.

Figure \(\PageIndex{4}\): Picture of Little Boy at the Hiroshima Peace Museum. Both images courtesy of Shane Patel (Furman University, Class of 2016).

Over the years, the A-bomb Dome has undergone many restorations. Other monuments have been constructed and dedicated as well. Click here to see a comprehensive link to these sites. For people who cannot travel to Hiroshima, The Hiroshima Peace Museum offers a virtual tour. Clicking on this link, one can access testimonies, images of Hiroshima and its inhabitants, and messages of peace.

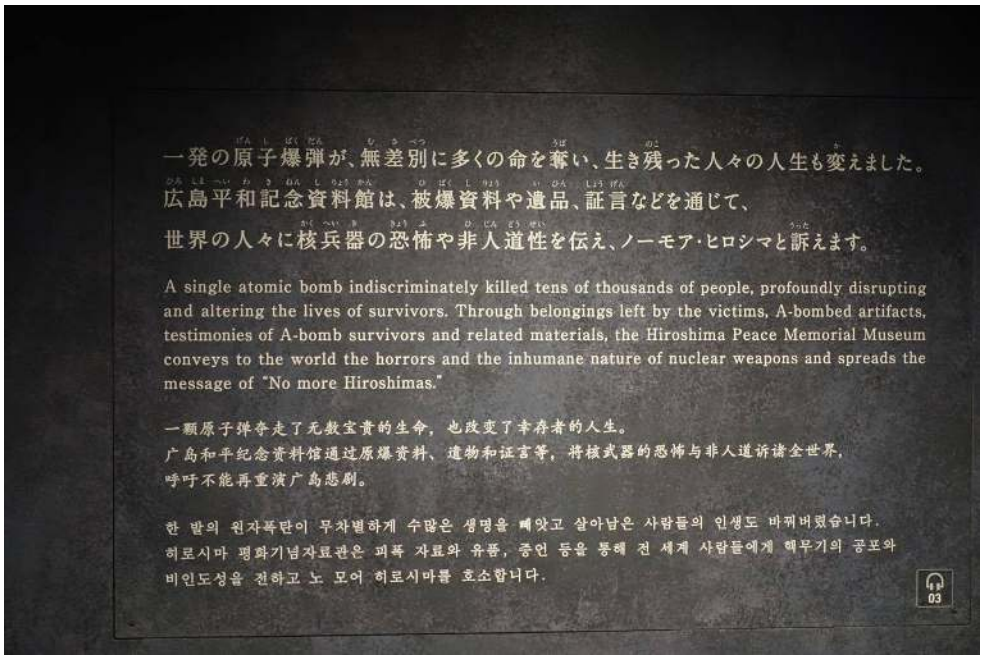


Figure **6.6.5**: Plaque at the Hiroshima Peace Museum. Photo courtesy of Shane Patel (Furman University, Class of 2016).

Nagasaki

Unlike the flat terrain of Hiroshima, Nagasaki was located in a valley between mountains. The 20 kiloton blast was contained in this region affecting a shipbuilding center and two Mitsubishi industrial parks. The population of this city was more dispersed than that of Hiroshima. Residents of Nagasaki lived in the valley as well in mountainous regions of this area. Unlike Hiroshima, most of the buildings were composed of wood and not concrete or brick. This material did not adequately protect residents and collapsed easily. Moreover, wooden structures became deadly projectiles of shrapnel during the detonation of Fat Man.

The most famous structure that survived the bombing of Nagasaki is the one-legged entrance to the Sanno Shrine. This building was approximately 800 meters from the bomb's hypocenter. Today, it has been incorporated into the newly constructed buildings of the city.





Figure **6.6.6**: Image of the Sanno Shrine immediately after the bombing of Nagasaki. .**Figure 6.6.7:** A 2007 picture of the same shrine.

Like Hiroshima, Nagasaki has numerous statues and a peace museum memorializing August 9, 1945. A tall tower has been erected at the hypocenter distance of 500 meters. At the base of this tower, a black stone describes the nuclear bombing and its effects. Each year, a memorial service is held at this site to celebrate survivors, remember victims, and promote peace. Just down from this tower, a large bronze statue (9.7 meters in height and 30 tons in weight) sits with its arms outstretched to the sky. Designed by a local sculptor, Seibo Kitamura, this Peace Statue symbolizes different aspects of nuclear weapons and the bombing of Nagasaki. The vertically raised arm represents the threat of nuclear bombing. The left hand with palm-held flat symbolizes peace for all the world's inhabitants. The crossed leg illustrates quiet meditation while the left leg shows an intense readiness to rescue and provide assistance to those affected by the destruction. Lastly, the face is not limited to one culture with eyes closed to offer prayers for those who perished.





Figure **6.6.7**: The hypocenter of Fat Man and **Figure 6.6.8:** the Nagasaki Peace Statue. Both images courtesy of Shane Patel (Furman University, Class of 2016)

For a quick overview of some of the memorials, click on the video underneath this paragraph. The videographer provides interesting footage of the inside of the Nagasaki Peace Museum. You will see preserved artifacts and a three-dimensional image of the blast radius. Once outside, he shows the hypocenter tower, Peace Statue, gardens, and various other memorials. For an explanation to the other memorials shown in his video, click on this link.



Figure \(\
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{1}\): Paste Caption Here

Sources

1. https://www.atomicheritage.org/histo...-nagasaki-1945

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6.7: Fusion

Learning Objectives

- Compare and contrast devices with deliverable weapons.
- Determine the requirements for fusion weapons.
- Appreciate the tonnage of destruction of fusion devices/weapons.
- Recall all the countries that possess fusion technology.
- Know the Father of the fusion bomb and the three names associated with fusion weapons.
- Explain the difference between a tactical and strategic nuclear weapon.
- Define what an ICBM is and know who has the longest reaching ICBM nuclear warheads.
- Classify a nuclear weapon as being fission or fusion based on tonnage and metric unites.
- Know the name of the largest deliverable nuclear weapon and what country dropped it.
- Explain basic nuclear espionage that enabled the USSR to obtain nuclear weapon blueprints.
- List which countries have only fission weapons.
- List which countries have both fission and fusion weapons.
- Contrast a nuclear weapon to a dirty bomb.
- Determine which weapon requires less engineering (Fat Man or Little Boy).
- Explain the overall goal of the START treaty.

Mike - The First Fusion Device

The first fusion device was tested by the United States on November 1, 1952. On Elugelab Island located in the Marshall Islands, this non-deliverable weapon measured 20 feet in height and weighed over 140,000 pounds. During the eighth round of United States nuclear testing (named Operation Ivy), Mike (fusion weapon) vaporized the entire island where it was detonated. The 10.4 megaton blast was 500 times more powerful than the Nagasaki weapon and left a crater in the ocean that was 6,240 feet wide and 164 feet deep.

Example 6.7.1

From video and classroom discussion, answer the questions below:



Video **6.7.1**: A scene from our PBS documentary "Dr. Teller's Very Large Bomb" (with perhaps a bit too much information on how to build your own hydrogen bomb.) (Complete hour-long documentary available at www.foolishearthling.com)

1. Could the United States transported Mike by airplane? Was this bomb deliverable or non-deliverable?
2. What nuclear isotopes did this device contain?
3. What two types of nuclear reactions were used in Mike?
4. Is fission or fusion more technologically complex?
5. What was Teller's response after Mike exploded?

6. How far away were the observers of Mike?

Edward Teller, one of the Manhattan Project scientists, is credited with designing the fusion bomb. Unlike J. Robert Oppenheimer, Teller felt it was important and necessary for the United States to pursue new nuclear weapons. After the dropping of Little Boy and Fat Man, Edward Teller testified against Oppenheimer in order to get his security clearance revoked at Los Alamos National Laboratory. He was successful in his testimony and Oppenheimer left Los Alamos for Princeton University. In 1963, Oppenheimer was presented with the Enrico Fermi Award. This accolade recognized international achievement in the field of energy. Only three years later, Oppenheimer died of throat cancer in Princeton, New Jersey.



Figure **6.7.1**: Edward Teller, the physicist, who invented the fusion bomb. Image is taken from upload.wikimedia.org/wikiped...NL-cropped.png

Teller was not present for the testing of Mike. For personal and professional reasons, he left the South Pacific and head back to Berkley, California. At the university, he waited for Mike to affect the university's seismograph machine. This instrument detects earthquake activity due to natural or artificial causes. Before the bomb detonation, Teller had calculated the exact time the vibration would reach the University of California, Berkley.

The Mechanics of Fusion

The process of converting very light nuclei into heavier nuclei is also accompanied by the conversion of mass into large amounts of energy, a process called fusion. The principal source of energy in the sun is a net fusion reaction in which four hydrogen nuclei fuse and produce one helium nucleus and two positrons. This is a net reaction of a more complicated series of events:

$$4\,{}^{1}_{1}\mathrm{H} \longrightarrow {}^{4}_{2}\mathrm{He} + 2\,{}^{1}_{0}\mathrm{n}$$

A helium nucleus has a mass that is 0.7% less than that of four hydrogen nuclei; this lost mass is converted into energy during the fusion. This reaction produces about 3.6×10^{11} kJ of energy per mole of ${}^{4}_{2}\mathrm{He}$ produced. This is somewhat larger than the energy produced by the nuclear fission of one mole of U-235 (1.8×10^{10} kJ), and over 3 million times larger than the energy produced by the (chemical) combustion of one mole of octane (5471 kJ).

It has been determined that the nuclei of the heavy isotopes of hydrogen, a deuteron, ${}^{2}_{1}H$ and a triton, ${}^{3}_{1}H$, undergo fusion at extremely high temperatures (thermonuclear fusion). They form a helium nucleus and a neutron:

$${}^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \longrightarrow {}^{4}_{2}\mathrm{He} + 2\,{}^{1}_{0}\mathrm{n}$$

This change proceeds with a mass loss of 0.0188 amu, corresponding to the release of 1.69×10^{9} kilojoules per mole of ${}^{4}_{2}\mathrm{He}$ formed. The very high temperature is necessary to give the nuclei enough kinetic energy to overcome the very strong repulsive forces resulting from the positive charges on their nuclei so they can collide.

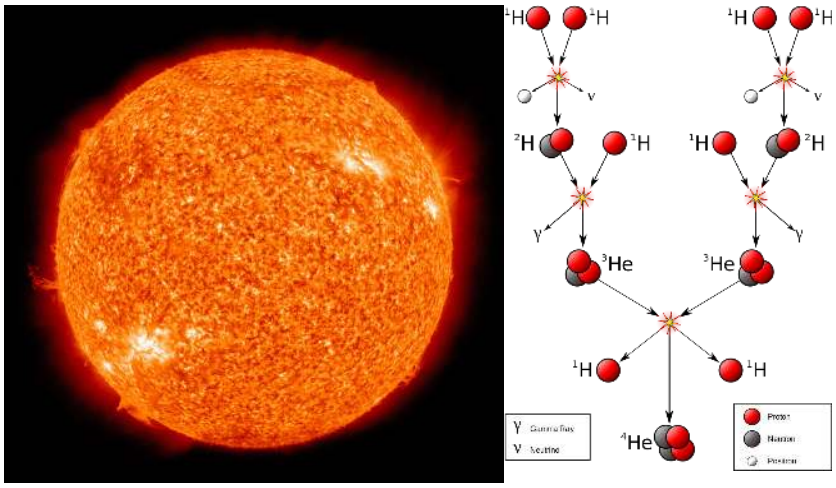


Figure **6.7.2**: (left) The Sun is a main-sequence star, and thus generates its energy by nuclear fusion of hydrogen nuclei into helium. In its core, the Sun fuses 620 million metric tons of hydrogen each second. (right) The proton-proton chain dominates in stars the size of the Sun or smaller.

The most important fusion process in nature is the one that powers stars. In the 20th century, it was realized that the energy released from nuclear fusion reactions accounted for the longevity of the Sun and other stars as a source of heat and light. The fusion of nuclei in a star, starting from its initial hydrogen and helium abundance, provides that energy and synthesizes new nuclei as a byproduct of that fusion process. The prime energy producer in the Sun is the fusion of hydrogen to form helium, which occurs at a solar-core temperature of 14 million Kelvin. The net result is the fusion of four protons into one alpha particle, with the release of two positrons, two neutrinos (which changes two of the protons into neutrons), and energy (Figure **6.7.2**).

Overview of Ivy Mike's Mechanism

Fusion requires extreme temperatures. In order to achieve this, all fusion weapons contain a primary fission component. U-235 or Pu-239 are detonated first and the resulting heat fuses the deuterium and tritium components of a thermonuclear weapon.

Initially, the fission reaction of the primary releases gamma and x-ray, neutrons, and heat to produce the high temperatures required for following the fusion reactions. The fuel for the fusion is lithium deuteride, $^{6}_{3}\mathrm{Li}^{2}_{1}\mathrm{H}$. The neutrons react with lithium to produce tritium, $^{3}_{1}\mathrm{H}$, and alpha radiation.

$$^{6}_{3}\mathrm{Li} + ^{1}_{0}\mathrm{n} \rightarrow ^{3}_{1}\mathrm{H} + ^{4}_{2}\mathrm{He}$$

At the high temperature created by the fission of the primary, the tritium then undergoes fusion with the deuterium in the lithium deuteride fuel.

$$^{3}_{1}\mathrm{H} + ^{2}_{1}\mathrm{H} \longrightarrow ^{4}_{2}\mathrm{He} + ^{1}_{0}\mathrm{n} + \mathrm{energy}$$

The fusion reaction liberates a huge amount of energy and creates large numbers of high energy neutrons, which causes the additional fission of the uranium surrounding the secondary.

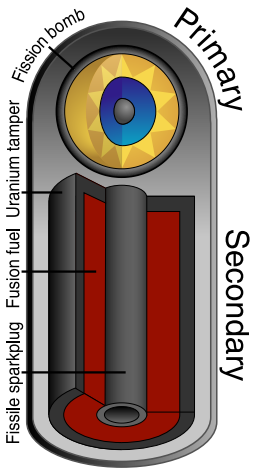


Figure **6.7.3**: A Thermonuclear Weapon. The basics of the Teller–Ulam design for a thermonuclear weapon. Radiation from a primary fission bomb compresses a secondary section containing both fission and fusion fuel. The compressed secondary is heated from within by a second fission explosion. (Public Domain; Fastfission via Wikipedia).

More recent fusion weapons utilize different mechanisms. Today's, warheads use a series of fission-fusion-fission chain reactions to produce yields several orders of magnitude greater than Little Boy or Fat Man. At this time, fusion weapons still require:

1. knowledge and construction of fission
2. isolation of H-2 and H-3 isotopes, and
3. extreme temperatures.

The five permanent members of the United Nations Security Council all possess the knowledge and the technology of fusion. These countries with their fusion device detonation dates are United States (1952), the former Soviet Union (1953), the United Kingdom (1957), China (1967), and France (1968). Note that these dates refer to device detonations and not deliverable nuclear weapons. As of November 2017, it is still unclear if North Korea has detonated a fusion device.

In March of 1953, the United States dropped its largest fusion bomb over the Bikini Atoll in the Marshall Islands. Castle Bravo produced a punch equivalent to 15 megatons of TNT. The fallout isotopes affected over 11,000 square kilometers of area. Unfortunately, winds carried the lingering radiation to neighboring islands that were inhabited. Only 145 kilometers away from the epicenter, a Japanese fishing vessel (Lucky Dragon #5) was fishing with a crew of 24 people. Castle Bravo killed one person on the Lucky Dragon #5 and exposed the other crew members to extremely high dosages of radioactive isotopes (fallout).



Figure **6.7.4**: (left) The explosion of Castle Bravo in 1954. (right) The family of Kuboyama Aikichi, the Japanese fisherman who perished after Castle Bravo, processing to his funeral. (Public Domain; via Wikipedia) and Flickr.

Tsar Bomba - The Largest Nuclear Weapon

The former Soviet Union is credited with dropping the largest fusion bomb in history. On October 30, 1961, a fifty megaton three staged fusion bomb was dropped over the Arctic Circle. This weapon was calculated to be 1570 times more powerful than Little Boy and Fat Man combined. Tsar Bomba weighed 27 metric tons and was 26 feet long with a 7-foot diameter. The resulting fireball

reached a maximum height of 1000 km (620 miles). The mushroom cloud produced was 64 km (40 miles) in height with a maximum width of 95 km (59 miles). Lastly, the flash from the fireball could be seen from 270 km (170 miles) away and burns were experienced up to 100 km (62 miles) from epicenter.



Video **6.7.2**: Discovery Channel - Ultimates - Explosions - Tsar bomb segment.

The Development of Nuclear Weapons after World War II

The use of nuclear weapons by the United States to hasten the end of the war initiated a nuclear arms race between the United States and the Soviet Union that lasted until the end of the Cold War in 1992. During this period, scientists in both countries developed powerful thermonuclear fusion weapons (hydrogen bombs) and more efficient fission bombs. Table **6.7.1** compares the explosive power of current nuclear warheads. A nuclear weapon includes the warhead encased in a bomb or missile. For a given tonnage, it is important to convert values to either kilotons or megatons. Then, the weapon can be properly classified. Look to your Learning Management System (Moodle for Furman students) to view an example of your instructor working a tonnage conversion problem.

Table **6.7.1**: Yields (Equivalent Tons of TNT) of Nuclear Warheads

Terrorist weapon (improvised nuclear device)	< 3 kilotons
Bunker buster or tactical nuclear weapon	3 to 5 kilotons
Fission weapon (Pu-239 or U-235)	15 to 50 kilotons
Boosted fission weapon	100 to 500 kilotons
Thermonuclear weapon	1 to 57 megatons

Improvised nuclear devices (IND) are low yield weapons that might be assembled by non-state groups or “rogue” nations for a terrorist attack. The most likely scenario would be the acquisition of a critical mass of HEU and the construction of a simple gun-type assembly mechanism.

Tactical nuclear warheads are placed in a variety of delivery systems such as artillery shells, torpedoes, cruise missiles, and bombs. These weapons may be defined by their range and types of targets. Tactical nuclear weapons are short-range weapons that are to be used on a battlefield or a military target. On the other hand, strategic nuclear weapons are longer-range weapons that would disrupt the infrastructure of a country or a nation. Bunker busters are designed to deliver nuclear warheads to hardened, underground targets.

Nuclear weapons with yields greater than 5 kilotons of TNT are known as strategic weapons. They are designed to be used on targets such as missile launch sites, command and control centers, large cities, or industrial sites. The two types of early fission weapons have been discussed previously. Boosted warheads contain a small amount of deuterium and tritium (isotopes of hydrogen) gases, which undergo fusion with the initiation of the fission reaction.

$$ {}^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \longrightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} + \text{energy} $$

The fusion releases an intense burst of high energy neutrons which amplifies the fission chain reaction, along with a small amount of energy This boosting allows increased yields from smaller, lighter warheads. Most current fission weapons contain boosted warheads. The 12-year half-life of tritium requires that these warheads be replenished at regular intervals.

Thermonuclear warheads, developed during the Cold War, used a series of fission-fusion-fission reactions to produce yields several orders of magnitude greater than those of fission devices. Weapons designers have also reduced the size of thermonuclear warheads so that multiple warheads could be carried by a single missile. Today, a ballistic missile submarine can carry 24 missiles each with 6 thermonuclear warheads.

A nuclear weapon can be modified from being tactical to strategic. In 1968, Los Alamos National Laboratory build the B61 thermonuclear bomb. This weapon was only twelve feet long and thirteen inches wide. The power range could be easily adjusted from .3 to 340 kilotons. B61 was a two-stage thermonuclear weapon and over 3100 were constructed in the United States.



Figure **6.7.6**: Technicians assembling a B61 nuclear weapon. Image take from upload.wikimedia.org/wikiped...sGulf_B-61.jpg

Some countries possess ICBMs which are intercontinental ballistic missiles. These weapons can travel a minimum of 3400 miles (5500 kilometers). ICBMs can contain chemical or nuclear weapons. Noted countries that have or have had ICBMs are Russia, United States, India, China, Israel, France, and North Korea. In 2025 Russia presented the longest reaching ICBM to the world. This weapon can reach a destination of over 8000 miles.

World Arsenals

According to the Arms Control Association October 2017's report, the countries contained in the table below possess nuclear warheads. This type of weapon would have a fission or fusion portion fastened to the front of a guided missile, rocket, or torpedo. In the world, there are approximately 15,000 nuclear warheads. Of this number, ninety percent are in military service while the remaining percent await dismantlement.

Table **6.7.2**: Stats for countries that possess nuclear weapons.

Country	Amount of Nuclear Warheads
Russia	7000
United States	6800
France	300
China	270
United Kingdom	215
Pakistan	140
India	130
Israel	80
North Korea	10

At one time, former Soviet Union countries like Belarus, Kazakhstan, and Ukraine stored nuclear weapons. Now, they do not possess any nuclear warheads. South Africa, Brazil, Iraq, Libya, Argentina, South Korea, and Taiwan have abandoned their nuclear weapon programs as well.

In August of 1949, the American monopoly on nuclear weapons technology ended. The USSR ignited a 20 kiloton Pu-239 weapon that they named First Lightning. American nuclear scientists code-named this detonation to be Joe-1. The weapon was a duplicate of the Trinity device that was tested by the Manhattan Project scientists in July of 1945. A spy ring of scientists and civilians passed implosion mechanics and hydrogen bomb technology to KGB agents. The most notable of these people were Klaus Fuchs, Julius, and Ethel Rosenberg. During the Manhattan Project, Fuchs worked at the gaseous diffusion facility (University of Columbia) and the Pu-239 implosion laboratory (Los Alamos). In addition, Fuchs assisted Edward Teller with hydrogen bomb research. Fuchs passed the knowledge of implosion and fusion directly to KGB agents and through civilians, Ethel and Julius Rosenberg.



Figure **6.7.7**: (left) Ethel and Julius Rosenberg and (left) Klaus Fuchs. Images taken from: upload.wikimedia.org/wikiped...A_-_278757.jpg and upload.wikimedia.org/wikiped...berg_NYWTS.jpg

The USSR had started fission research in the mid to late 1930s. They primarily focused on uranium enrichment and determination of critical mass. After the bombings of Hiroshima and Nagasaki, Stalin pushed USSR scientists harder to obtain nuclear weapons technology. During the Manhattan Project, Stalin was aware that the United States was pursuing the development of fission weapons. Espionage provided USSR scientists with blueprints of the Trinity device and information regarding fusion. This data expedited the USSR to detonate its first fission device in 1949. Less than a year after the American testing of Mike (first fusion device), USSR exploded a 400 kiloton, H-bomb device named Joe-4. Hans Bethe, an American Manhattan Project scientists, debated the nature of this explosion. Fragments and resulting isotopes did not indicate that a fusion device had exploded. In 1955, the USSR dropped their first fusion weapon which yielded energy within the megaton range.

Individuals who participated in the espionage of nuclear bomb secrets received different types of punishments. Fuchs, a British citizen who had immigrated from Nazi Germany, served nine years in prison and then was released to East Germany. The Rosenbergs were executed at Sing Sing Prison in New York State. Ethel Rosenberg's brother, David Greenglass, had testified against the couple in order to save his own wife from prison. Greenglass, an army sergeant at Los Alamos, had obtained bomb secrets and had his wife type documents for couriers. For his participation, Greenglass served a decade in prison. His wife was not tried or punished for her involvement. To read more about this fascinating event in history, click on this link.

Since the late 1960s, the United States and the former Soviet Union/Russia have signed several treaties to downside their nuclear arsenals. The START (Strategic Nuclear Arms Control Agreements) program has greatly reduced the number of nuclear weapons for both countries. For more information regarding START, click on this link.

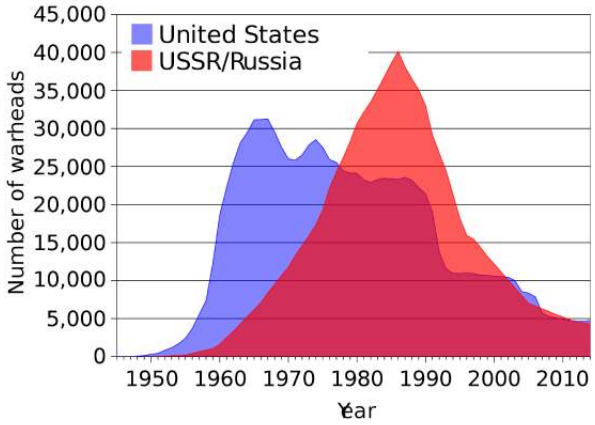


Figure **6.7.8**: Nuclear Arsenals of the United States and USSR/Russia over the past sixty years. Image is taken from upload.wikimedia.org/wikiped...kpiles.svg.png

Requirements for Producing Nuclear Weapons

A nation seeking to produce nuclear weapons must complete the following basic steps:

- Develop a weapon design or obtain one from an external source.
- Produce highly enriched uranium or plutonium for the core of the device or obtain this material from an external source.
- Fabricate this material into the fissile component of the weapon.
- Fabricate or obtain from external sources the non-nuclear components of the weapon. These include high explosives and a triggering mechanism to detonate the nuclear core.
- Verify the reliability of all components individually and as a system.
- Assemble the components into a deliverable weapon.
- For fusion weapons, a thorough knowledge of fission is required. A fusion bomb must contain a fission counterpart.

Nuclear Terrorism

Most recently, attention has centered on the possibility of “rogue” nations or terrorist groups obtaining a fission device. Two possibilities exist: the acquisition of an intact weapon or the construction of an improvised nuclear device (IND) device from components either stolen or acquired illegally from a rogue state. In the first case, an organized group must obtain the financial resources to initiate this act of extreme violence. The group must then acquire an intact weapon through purchase, theft, diversion, or as a gift. It then has to ascertain how to bypass or disable safeguards incorporated in the weapon to prevent its unauthorized use. Lastly, the weapon must be transported to a high-value target and detonated. The challenges involved with the successful completion of each step are formidable.

The second case would also involve sizeable obstacles. As in the first case, an organization and funding would be required. The group would have to acquire sufficient fissile material, fabricate it into a fissile component, and assemble an IND. This would require significant technical expertise. A device similar to a uranium gun-type bomb (Figure **6.7.2**) would be easier to build than a plutonium implosion weapon. Transport and detonation of an IND would involve greater risks than those associated with the intact weapon.

The lack of complete control of fissile materials and the economic conditions in the former Soviet Union have increased the possibility that HEU and plutonium from weapons programs might be available on the international black market. Several instances involving plutonium and enriched uranium smuggled from the former Soviet Union have been observed since 1994. The United States and Russia have had a “blend down” agreement since 1993 that renders excess HEU incapable of being fabricated into nuclear weapons. Under the terms of this agreement, the United States purchases from Russia uranium of which the concentration of U-235 has been reduced by mixing it with U-238 to that suitable for fueling nuclear power reactors.

Other nations also have quantities of HEU and plutonium from their weapon programs and the production of civilian nuclear power. Figures **6.7.9** and **6.7.10** show the global disposition and current status of HEU and plutonium.

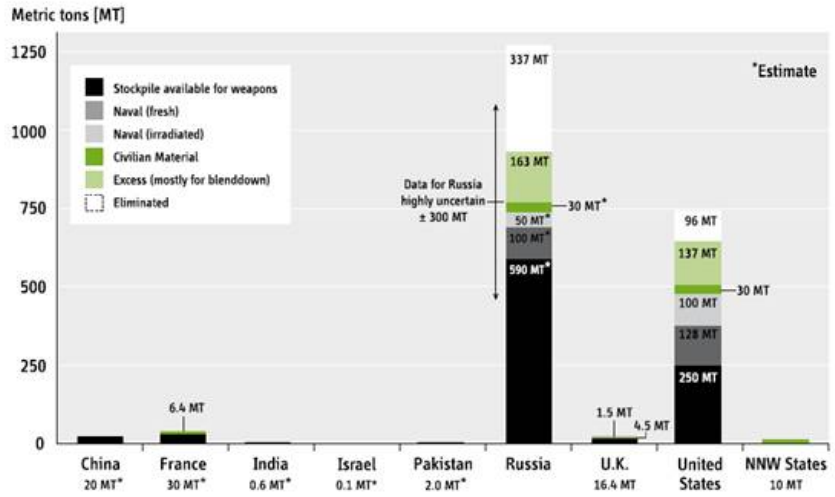


Figure **6.7.9**: - Global Stockpiles of HEU in 2008. From the Global Fissile Material Report 2008, p. 11

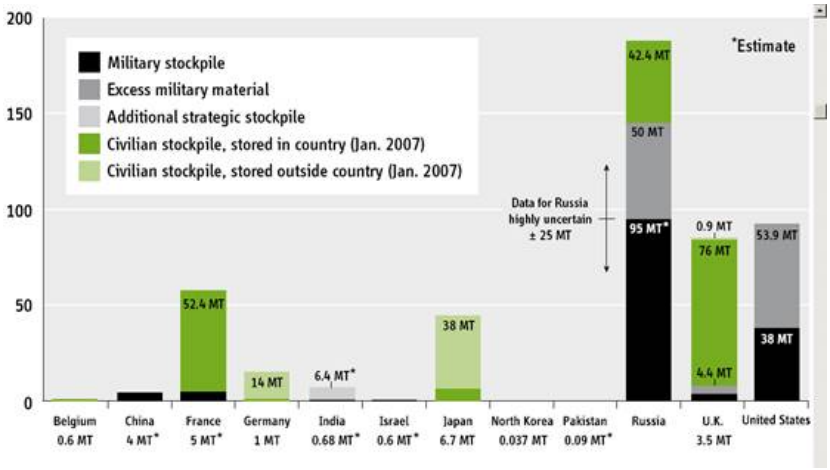


Figure **6.7.10**: - Global Stockpiles of Plutonium in 2007. From the Global Fissile Material Report 2008, p. 16

Need more practice?

In section 6E, answer questions 11-20. Also, Furman students should access chapter 6 moodle documents to view tonnage conversion problem.

References

1. http://www.atomicarchive.com/History.../page_13.shtml
2. https://www.ctbto.org/specials/testi...-castle-bravo/
3. www.armscontrol.org/factshee...ponswhohaswhat

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6.8: Fallout and Weapons Testing

Learning Objectives

- Compare and contrast fallout amounts for fission and fusion bombs.
- Choose a fission fallout isotope, relate isotope to health problem, and research an antidote.
- Recall the various treaties mentioned in this section.
- Understand why supplies of HEU and Pu-239 should be monitored.
- Identify countries who have never signed or withdrawn from treaties mentioned.
- Watch all embedded videos and record answers.

Operation Crossroads

Near the end of World War II, the United States acquired many islands in the South Pacific. Here, numerous nuclear gadgets and bombs were tested in various scenarios. The first round of testing was performed in the summer of 1946 on the Bikini Atoll located in the Marshall Islands. This event was code-named "Operation Crossroads" and it included the testing of two different fission bombs which each yielded approximately 23 kilotons of power. The Able device was dropped on July 1, 1946, by airplane over water containing a variety of warships. On July 25, 1946, the Baker device was detonated 90 feet underwater. Both tests were done to understand how nuclear weapons affect seafaring vessels.



Figure **6.8.1**: Baker Nuclear Test over the Bikini Atoll.

In 1976, filmmaker Bruce Connor along with composers Patrick Gleeson and Terry Riley produced a 36-minute film entitled, "Operation Crossroads." In this short movie, viewers can see the immense power of the Baker Test. Both the Museum of Modern Art and the Whitney Museum in New York City have shown Operation Crossroads in their exhibits.

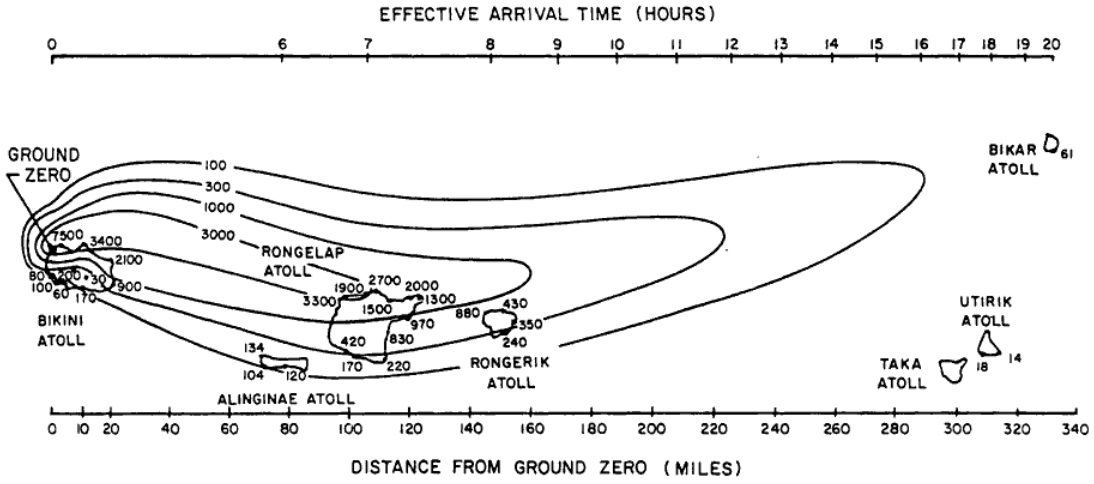


Video **6.8.1**: Crossroads is a 1976 short film directed by Bruce Conner. It features 36 minutes of extreme slow-motion replays of the July 25, 1946 Operation Crossroads Baker underwater nuclear test at Bikini Atoll in the Pacific. You can see an excerpt of this work by viewing the time between **1:40 and 2:16** of this video.

On July 26, 2016, the American National Security Archives released extensive footage of nuclear bomb testing at the Bikini Atoll. Click this link to access any of these 15 declassified film clips.

Fallout

Fallout refers to the radioactive material that "falls out" of the atmosphere after a nuclear explosion (reactor or bomb). It consists of dust and radioactive particles that can contaminate an area with radioactivity and pose a huge health hazard to biological organisms. It can contaminate the animal food chain which can have drastic effects on the affected region. The weather has a huge impact on the fallout, wind currents can spread radioactive fallout either over a large area, such as in the case of *Castle Bravo*, or not.



alt

Figure **6.8.2**: The 450 km (280 mi) fallout plume from 15 Mt shot Castle Bravo, 1954. (Pubic Domain; United States Department of Energy via Wikipedia)

alt In regards to nuclear reactions, fission produces more fallout products than fusion. The intense heat of the latter type of reactions reduces the amount and type of radioisotopes produced. Although more powerful, fusion is a "cleaner" type of nuclear reaction. By increasing the fission component of a fusion weapon, bombs can be designed to generate more fallout products. Of the different types of isotopes that fission produces, the most worrisome are **Sr-90**, **Cs-137**, and **I-131**. The first of these isotopes has a half-life of 28.8 years and decays by gamma and beta emission. Once ingested or inhaled, Sr-90 deposits in teeth, bone, and bone marrow. Sr-90 exposure can lead to bone cancer and/or leukemia. Cs-137 ($t_{1/2}$ = 30.17 years) emits beta and gamma radiation. This ionizing radiation deposits in soft tissues of the body. In addition, this particular radioisotope is water-soluble and can easily

contaminant food and water supplies. I-131 had a half-life over 8.1 days and undergoes gamma/beta decay. Once this fallout product enters the body, it attacks the thyroid gland. Extensive damage could affect heart rate, blood pressure, body temperature, and childhood growth. In addition, I-131 exposure could result in thyroid cancer.

Example 6.8.1:

Watch the fallout video and then answer the questions below:



1. Describe the physical appearance of fallout.
2. How does fallout spread?
3. What was the baby tooth study?
4. What particular isotopes does the speaker mention in this video?
5. What is the 7-10 rule?
6. What mistake does the speaker say when he is discussing different isotopes?
7. Why do Americans who lived in the country from 1945-1963 have more I-131 in their bodies?

Antidotes

Today, there are medications that can be dispensed to help with fallout exposure. On the (Center for Disease Control)'s link, there are four different substances described. Research one of these substances by evaluating how they protect the body and what particular isotope the antidote can counteract. In addition, be aware of one group of individuals who cannot take this medication. **This information is the required information for your next test.**



Figure **6.8.3**: Dutch Artist, Vincent Van Gogh (1853-1890), used Prussian Blue as one of the signature blues in his Starry Night (1889). Prussian Blue is also used as an antidote for radioactive thallium and cesium. (Publci Domain; Vincent van Gogh via Wikipedia)

Limiting Nuclear Weapon Testing

On August 5, 1963, the leaders of the United States (President John F. Kennedy), the Soviet Union, and the United Kingdom signed the Partial Nuclear Test Ban Treaty. This document would limit where nuclear bombs/devices could be tested. These three countries would no longer perform nuclear trials underwater, in the atmosphere, or in outer space. This treaty would allow countries to remain testing underground with certain limits. Also, these countries would attempt to move towards disarmament. Reducing nuclear weapons and testing would allow the environment to recover from decades of contamination.



Figure **6.8.3**: President John F. Kennedy signing the Partial Nuclear Test Ban Treaty in 1963. Image is taken from upload.wikimedia.org/wikiped...tober_1963.jpg

During the early nineties, President George H.W. Bush announced that the United States would no longer perform full-scale nuclear tests. Four years later, the United Nations General Assembly adopted the Comprehensive Test Ban Treaty. This agreement (known as the CTBT) would halt nuclear bomb/device testing entirely. To go in effect, the United Nations required forty-four of the current nuclear states (those with nuclear capabilities) to sign and ratify the CTBT. In 1996, the United States (President Bill Clinton) quickly signed the CTBT. However, the United States Senate refused to provide support and the United States has not ratified it. There are several countries that have not signed and refused to ratify the CTBT. These countries include North Korea, India, and Pakistan. Others have signed but not ratified the treaty: China, Israel, Iran, Egypt, and the United States. For a comprehensive list of countries, click on this link.

From 1945 to 1992, the United States has tested approximately 1,054 nuclear bombs and devices. Of this amount, 216 of these tests were performed in the atmosphere, underwater, and in outer space. The majority of these tests detonated in the Nevada Test Site, New Mexico Test Site, and the Marshall Islands (South Pacific).

Other countries have done significant nuclear testing as well. Looking at the figure below once can visualize how many nuclear bombs/devices have been detonated over a fifty-year period. This link shows all (not just the United States') nuclear test sites.

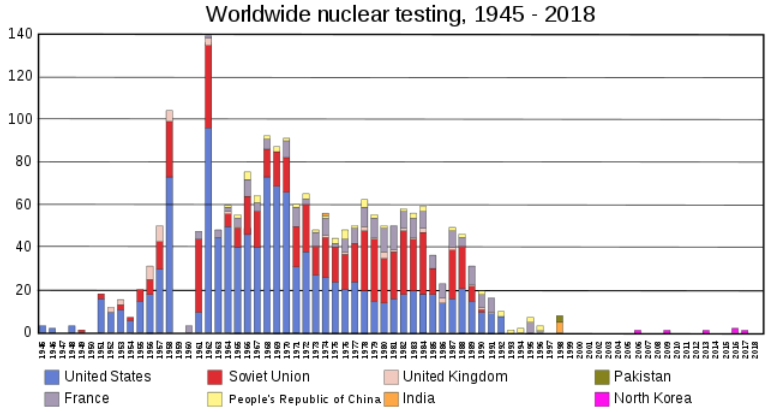


Figure **6.8.4**: Image taken from: upload.wikimedia.org/wikiped...esting.svg.png

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- Complete Bibliography on Radiation from the Aslos Digital Library for Nuclear Issues

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6.9: Nuclear in the Media

Learning Objectives

- Appreciate nuclear culture through books, music, and videos.
- Recognize the symbolic meaning of Godzilla.
- Determine if Duck and Cover really protects you.
- Analyze Billy Joel's song, "We didn't start the fire" and extract two nuclear references.

Books

Pulitzer Prize winner, Richard Rhodes, has written many nonfiction accounts of the development of nuclear weapons. Rhodes, an American journalist, and historian published *The Making of the Atomic Bomb* (1986) and *Dark Sun* (1996). The first of these books describes accounts of Manhattan Project employees, technical aspects of Little Boy and Fat Man, testing of the Trinity device, and the dropping of the weapons over Japan. He goes into great detail in regard to the construction of atomic weapons. In his second installment, Rhodes chronicles the development of Edward Teller's fusion bomb. He discusses the trial of J. Robert Oppenheimer, who opposed the construction of new nuclear weapons. With court testimony and images, Rhodes shows how Teller and Oppenheimer verbally opposed one another. Lastly, Dark Sun provides evidence as to the USSR espionage during the Manhattan Project. Stolen data and schematics provided information for a Soviet Union Pu-239 fission bomb (1949) and Hydrogen device (1953).

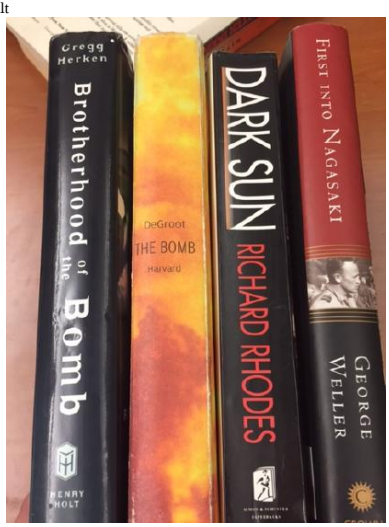


Figure **6.9.1** (left) Richard Rhodes. (right) Technical based books describing the Manhattan or fusion Projects. Image is taken from upload.wikimedia.org/wikiped...ard_Rhodes.jpg and the author's private library.

Other authors have recorded the atomic bomb history. Greg Herken's *Brotherhood of the Bomb* focuses on the men of the Manhattan Project. The personal and academic lives of these individuals are explored. Candid and serious pictures of Oppenheimer, Lawrence, Fermi, and even Teller are displayed in the pages of this book. In addition, Herken includes the blueprints of Little Boy and Fat Man.

The Bomb by Degroot is a less technical read that starts with the Manhattan Project and extends throughout the Cold War. There are several interesting songs, poems, pictures, and accounts by scientists and people who lived during this era. Degroot goes on to include the Cold War and how nuclear weapons have affected a person's day to day living.

George Weller's *First into Nagasaki* is one of the few accounts of individuals who witnessed what happened after Fat Man was dropped. Weller was an American novelist, playwright, and war correspondent who illegally entered Nagasaki after the bomb was dropped. While in Nagasaki, Weller was able to meet and interview several members of Japanese POW camps. He was able to record their experiences and stories of survival. Weller never published his work while he was alive. Upon his death, his son

discovered these written chapters. Weller's son edited and add a third section to this book. *First Into Nagasaki* was finally published in 2006.

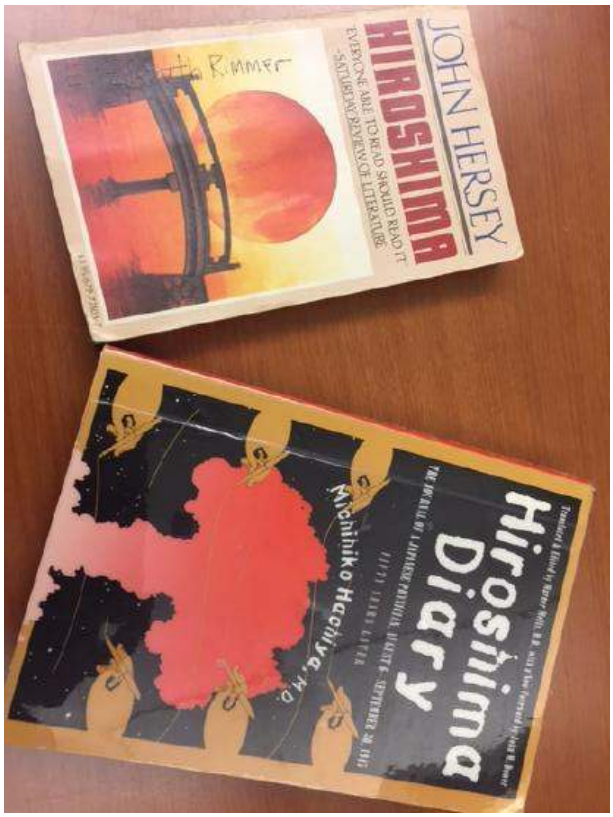


Figure **6.9.2**: Diaries accounting the dropping of Little Boy

Two books that read more like diaries are shown above. Hershey's Pulitizer Prize-winning account follows the lives of six Hiroshima residents before and up to one year after the dropping of Little Boy. Unlike Weller, Hershey was allowed to publish his experiences as a World War II war correspondent. Michihiko Hachiya, a Japanese medical practitioner, recorded his observations of Hiroshima from August 6th through September 30, 1945. He explains the state of chaos involved in managing a nonfunctioning hospital. With humor and grace, Dr. Hachiya describes his circumstances of surviving f nuclear bomb detonation and fallout

A brief overview of the German atomic bomb efforts is described in "Hitler's Scientists." Although the Germans first explained fission, they focused money and research effort on rockets. After the German surrender in May 1945, their scientists were contained and monitored in a farmhouse. Allied forces had hoped to learn the secrets of their atomic bomb efforts and capture their reactions to the American bombings of Japan. This investigation was part of the Aslos Project that led allied forces to determine the Germans had not gotten very far with their nuclear endeavors

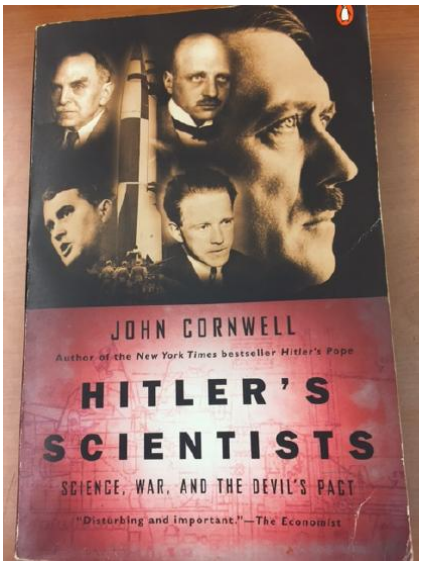


Figure **6.9.3**: German Bomb Effort

Several individuals aboard the Enola Gay and Bocks Car have written eyewitness accounts of the dropping of Little Boy or Fat Man. Both the pilot and the navigator of the Enola Gay have published books about these days. Charles Sweeney, pilot of the Bocks car, and Abe Spitzer, radioman on the Great Artiste, also have their recollections published as well.

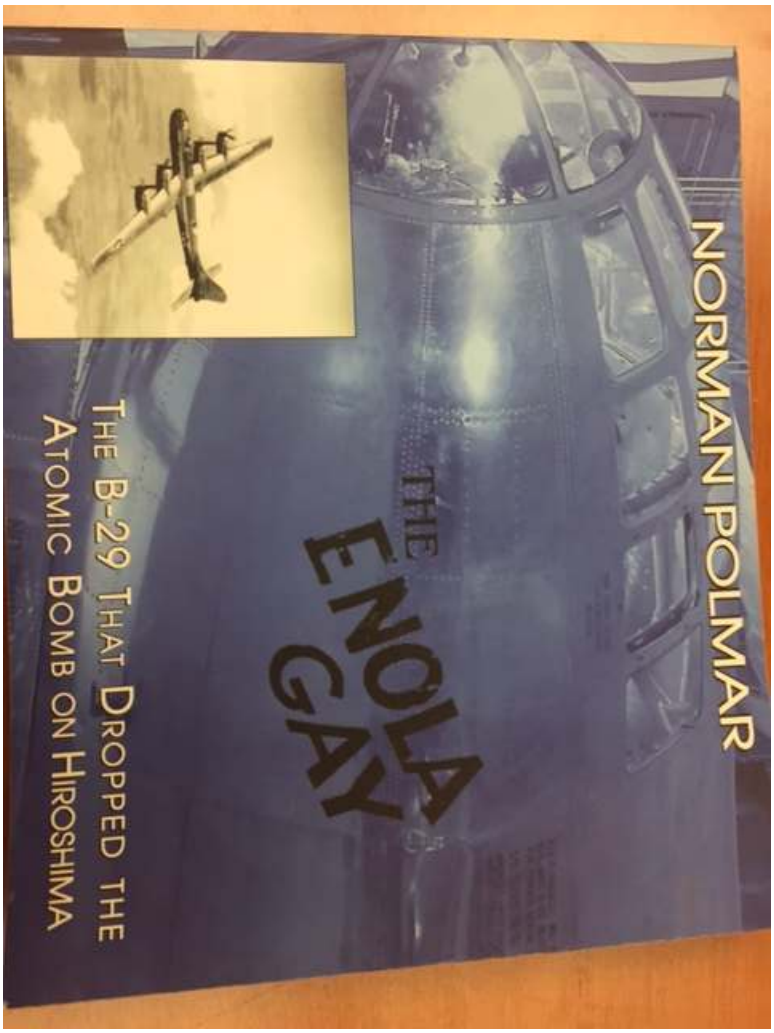


Figure **6.9.5**: Enola Gay

The planes that carried Little Boy and Fat Man have been preserved are on permanent display. Enola Gay is housed at the Smithsonian National Air and Space Museum in Chantilly, Virginia. The Bockscar is located at the National Museum of the Air Force in Dayton, Ohio. The other planes that flew on both missions were scrapped for their metal and are no longer in existence.

Movies

Example 6.9.1: godzilla



Watch the first three minutes of this video to get an idea of the origin of Godzilla.

1. What year was the first Godzilla movie produced?
2. What country is created the Godzilla character?
3. What American character rivals Godzilla?
4. What two types of animals/creatures compose Godzilla?
5. What does Godzilla represent to the Japanese people? Describe some of his powers.

By the late 1940s, the USSR had constructed a detonated its first nuclear device. In response to this event, the United States Civil Defense Ministry recorded the Duck and Cover. This 1951 film was to be shown in the American classroom in order to prepare school children on how to respond to a nuclear attack. It provided kids and adults with "tips" on how to avoid immediate radiation and lingering fallout after an attack.



Over the years, the movie industry has included nuclear weapons in quite a few of their action films. For example, many of the James Bond or 007 movies incorporate the stealing of nuclear material or weapons. Movies made during the Cold War usually involved nuclear espionage or accidental detonations. Nuclear exposure has also been used to explain why zombies exist. Several horror movies focus on survivors of nuclear fallout that morph into altered beings due to radiation.



Atomic Music

Songs have been written to highlight atomic themes as well. Many of these became popular during the Cold War. Click on a few of these to determine the atomic component.

- Threnody to the Victims of Hiroshima (Penderecki): https://www.youtube.com/watch?v=Pu371CDZ0ws
- Radioactive (Imagine Dragons) https://www.youtube.com/watch?v=ktvTqknDobU
- Political Science (Randy Newman) https://www.youtube.com/watch?v=Kg_LDeUEiWY
- Russians (Sting) https://www.youtube.com/watch?v=wHylQRVN2Qs
- Ninety Nine Red Balloons (Nena): https://video.search.yahoo.com/yhs/s...b9&action=view
- Manhattan Project (Rush): https://www.youtube.com/watch?v=ktvTqknDobU
- Melt With You (Modern English): https://www.youtube.com/watch?v=LuN6gs0AJls
- We Didn't Start the Fire (Billy Joel): we didn't start the fire - YouTube, (warning: there are graphic images in the background of the video, turn on closed captioning for lyrics)
- Breathe (Kate Bush):
- Two Minutes to Midnight (Iron Maiden):
- Red Rain (Peter Gabriel):
- Enola Gay (OMD):
- Two Minutes to Midnight (Iron Maiden)

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6.E: Nuclear Weapons- Fission and Fusion (Exercises)

1) Translate the following artificial transmutation reactions into nuclear symbols and balance:

a. Be-9 is hit with an alpha particle to produce C-12 and ?
b. Li-6 is bombarded with deuterium to form ? and Li-7
c. A neutron hits N-14 to produce an alpha particle and ?
d. Na-23 combines a neutron to form Na-24 and ?

2) What is the difference between emission/decay and transmutation?

3) Which of the following instruments can artificially transmute elements: cyclotron, electromagnetic separation, gaseous diffusion, and/or linear accelerator?

4) Which country split the atom first?

5) What is the significance of $E = mc^2$?

6) Review the Manhattan questions from the Modern Marvel movie.

7) Compare/contrast the bombings of Hiroshima and Nagasaki.

8) Did the same plane drop both of the bombs over Japan? Did the crew of the airplane(s) perish during the bombing?

9) Review basic bomb drawings illustrated on 6.4.3

10) Review questions from video in section 6.6.1 (Exploring 24 hours after Hiroshima).

11) Who was the father of the atomic bomb? Who was the father of the H-bomb?

12) What are the basic materials that are used in a fusion weapon? Who dropped the largest H-bomb? Was this bomb a gadget/device?

13) What is the destruction tonnage range of a fission bomb versus a thermonuclear bomb?

14) What is the difference between a tactical and strategic nuclear weapon? Was the Trinity bomb a strategic or tactical weapon?

15) What is an ICBM? Do all ICBM's contain a nuclear component?

16) Name the countries that have fusion technology.

17) At this time, which country has the most nuclear warheads? Does Japan and Germany possess any nuclear weapons?

18) What types of nuclear secrets were passed by the Rosenbergs and Fuchs?

19) What is START and who does this treaty involve?

20) How does a blend down of HEU reduce the chances of a rogue nation producting IND?

21) Which type of weapon produces more fallout: fission bomb or a H-bomb?

22) Name the three fallout isotopes and how they impact the human body.

23) Review the questions regarding the fallout video in section 6.8.

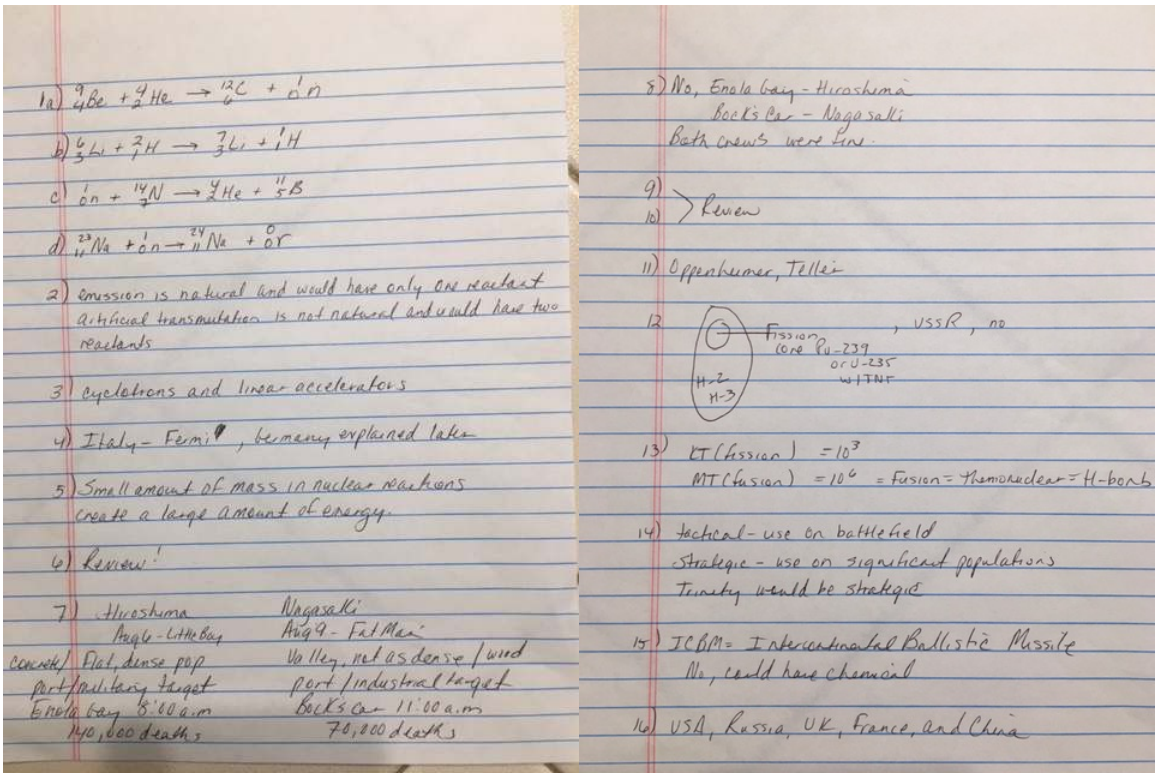
24) Know one antidote to radiation poisoning (see highlighted region in 6.8)

25) What is the difference between the Nuclear Test Ban Treaty (1963) and Comprehensive Test Ban Treaty (1996).

26) Name some of the countries that have not ratified the CTBT. Why do you think they have not done this?

27) Does Duck and Cover help to protect you in any way from nuclear annihilation?

28) What does Godzilla represent in Japanese culture?



1a) $^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}C + ^{1}_{0}n$

b) $^{6}_{3}Li + ^{2}_{1}H \rightarrow ^{7}_{3}Li + ^{1}_{1}H$

c) $^{1}_{0}n + ^{14}_{7}N \rightarrow ^{4}_{2}He + ^{11}_{5}B$

d) $^{23}_{11}Na + ^{1}_{0}n \rightarrow ^{24}_{11}Na + ^{0}_{0}\gamma$

2) Emission is natural and would have only one reactant
Artificial transmutation is not natural and would have two reactants

3) cyclotrons and linear accelerators

4) Italy - Fermi, Germany explained later

5) Small amount of mass in nuclear reactions create a large amount of energy.

6) Review!

7)

	Hiroshima	Nagasaki
	Aug 6 - Little Boy	Aug 9 - Fat Man
concrete	Flat, dense pop	Valley, not as dense / wind
	port / military target	port / industrial target
	Enola Gay 8:00 a.m	Bock's car 11:00 a.m
	140,000 deaths	70,000 deaths

8) No, Enola Gay - Hiroshima
Bock's Car - Nagasaki
Both crews were fine.

9)
10) > Review

11) Oppenheimer, Teller

12) Fission core Pu-239 or U-235 w/ TNT, USSR, no
H-2
H-3

13) KT (fission) $= 10^{3}$
MT (fusion) $= 10^{6}$ = Fusion = Thermonuclear = H-bomb

14) tactical - use on battlefield
Strategic - use on significant populations
Trinity would be strategic

15) ICBM = Intercontinental Ballistic Missile
No, could have chemical

16) USA, Russia, UK, France, and China

17) Russia, no

18) Fat Man blueprints + H-bomb information

19) START
Strategic Nuclear Arms Control Treaty
Russia / U.S.A

20) Making it less pure - not 90%, won't be fissionable due to low critical mass
IND = improvised nuclear device (small nuke to scare people, not kill large amounts of individuals)

21) Fission, Fusion produces mostly Sr.

22) Sr-90, bone cancer, blood
Cs-137, gastro (stomach)
I-131, thyroid

23) Review

24) Look up on CDC site

25) Nuclear Test Ban - no testing in H_2O, air, space
CTBT - no testing at all

26) Not Ratified - U.S.A, China, Iran, Israel, and Egypt
Not Signed - North Korea, India, and Pakistan

27) Nope

28) Godzilla = atomic bomb. Radioactive breath, stomps buildings, land animal

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CHAPTER OVERVIEW

7: Nuclear Energy

Even before the atomic bomb had been produced, scientists and engineers had begun to think about the possibility of using the energy released by the fission process for the production of electrical energy. In the United States, only 19.7 percent of the electrical energy in 2016 was produced by this nuclear energy. The proportion is higher in some other countries, notably France and Slovakia. Unfortunately, producing power from atomic fission has turned out to be much more expensive than was previously expected. Even in these days of high prices for fossil fuels, it is still only barely competitive.

7.1: Sharing and Monitoring Nuclear Technology
7.2: Generating Electricity
7.3: Powering the United States
7.4: Generating Electricity by Using Fission
7.5: United States Commercial Nuclear Power Reactors
7.6: Funding and Licensing for United States Commercial Nuclear Reactors
7.7: South Carolina Energy
7.8: Three Mile Island Nuclear Accident
7.9: Chernobyl Nuclear Disaster
7.10: Fukushima Nuclear Disaster
7.11: Transporting and Storage of Nuclear Waste
7.12: Decommissioning and Dismantling Nuclear Reactors
7.13: Additional Types of Nuclear Reactors
7.E: Nuclear Energy (Exercises)

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7.1: Sharing and Monitoring Nuclear Technology

Atoms For Peace Speech

On December 8, 1953, President Dwight D. Eisenhower addressed the United Nations with a twenty-minute speech entitled, " Atoms for Peace." In this event, Eisenhower attempted to diminish the nuclear arms race between the United States and the Soviet Union. Eisenhower believed that peaceful uses of nuclear technology should be available to all countries. Moreover, he encouraged non-nuclear states (countries) to obtain information regarding advances in nuclear medicine and nuclear reactors. The United States and the Soviet Union would no longer have a monopoly on nuclear applications. President Eisenhower wanted a central agency that would collect, store, and distribute radioactive materials to all countries. This "uranium bank" would allow non-nuclear states to obtain fissionable material for medicine and energy. Watch the video below to gain more insight into the "Atoms for Peace" speech.



IAEA

In response to Eisenhower's speech, the United Nations established the IAEA (International Atomic Energy Agency) in 1957. This group serves as the world's nuclear watchdog and has three goals to oversee:

- Assist all member countries with peaceful uses of nuclear technology
- Inspect nuclear facilities to ensure weapons are not being constructed
- Provide information regarding the safety of nuclear materials.

The IAEA is housed in Vienna, Austria. It has two regional offices in Toronto, Canada, and Tokyo, Japan. There are liaison offices for this organization in New York City and Geneva, Switzerland. Research facilities for the IAEA are located in Austria and Monaco. As of March 2022, there were 175 member countries of the IAEA. A listing of these countries with their dates of membership can be found by clicking on this link. On this list, North Korea has been removed from membership. This can be attributed to their lack of cooperation regarding reactor inspections.



Image is taken from upload.wikimedia.org/wikiped...AEA_emblem.jpg

NPT

The IAEA has also been charged with enforcing the NPT (Nuclear **Non**-Proliferation Treaty). Entered into force in March of 1970, this involves nuclear and non-nuclear states. Nuclear states are the five countries that exploded a nuclear device before 1967. This group includes the United States, Russia, United Kingdom, France, and China. All other countries besides these are labeled as

being non-nuclear states. The five nuclear states and the IAEA are responsible for enforcing the NPT. This treaty expects the following to occur:

- States that do not have nuclear weapons will not build or buy them.
- States that possess nuclear weapons will work towards disarmament.
- All states will be provided information regarding peaceful applications of nuclear technology.

As ofNovember 2022 , there were 191 countries that had signed the NPT. This link shows countries and their NPT statues. Many countries have ratified or consent to abide by this document. Others have assessed the treaty which means they have accepted NPT terms after the treaty has been entered into force. Lastly, some countries have succeeded or revoked membership from the NPT. For a basic overview of the NPT, click on the video below.



Strategic Arms Reduction Treaty (START)

On July 31, 1991, the United States and the Russian Federation signed the Strategic Arms Reduction Treaty (START). Since the Soviet Union dissolved in December 1991, the enforcement date of this treaty was postponed to December of 1994. This treaty limits number of Intercontinental Ballistic Missiles (ICBM) and nuclear warheads that both of these countries possess. Both Russia and the United States agreed to inspections and reductions of their strategic nuclear stockpiles.

https://media.nti.org/documents/start_1_treaty.pdf

References

- https://www.chemheritage.org/distill...nuclear-gambit
- https://www.iaea.org/about/overview/history

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- Caralyn Zehnder et al. at Georgia College and State University

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7.2: Generating Electricity

Learning Objectives

- Know the basic governmental agencies that have and now regulate the United State's nuclear facilities and materials.
- Understand the basics of how electrical energy is produced and transmitted.
- Learn the purpose of transformers and substations in electrical energy.
- Calculate the cost of running an appliance for a period of time (typically for a month).
- Have knowledge of "vampire" devices.

AEC/NRC History

During the Manhattan Project, Enrico Fermi and Leo Szliard constructed the world's first nuclear reactor in the basement of the University of Chicago. It consisted of layers of graphite (carbon) embedded with pieces of uranium. The sustained chain reaction was measured via a Geiger counter. After World War II, Manhattan Project scientists knew that fission could be used for power as well. In 1946, Harry S. Truman signed the McMahon/Atomic Energy Act. This transferred atomic energy control from the military to civilian power. The Atomic Energy Commission (AEC) was established to develop nuclear energy for peaceful purposes. This group would study how fission could be used to power homes, industries, submarines, and battleships. In addition, the AEC would investigate how nuclear isotopes could be used in the fields of medicine and agriculture.



Figure **7.2.1**: U.S. Government (Public Domain; chris 論 via Wikipedia)

The AEC constructed the first experimental breeder nuclear {this type of equipment uses LEU (majority of mass would be U-238) to produce weapons- grade plutonium} reactor in Arco, Idaho. On December 20, 1951, the reactor went online and produced enough energy to power four light bulbs. In 1957, the first full-scale American commercial nuclear reactor was completed in Shippingport, Pennsylvania. Unit One reactor was operated by Duquesne Light Company and cost approximately 73 million dollars. The electrical power this reactor produced varied from 60 to 100 MW. Over its twenty-five year lifetime, this reactor produced over 7.4 billion kilowatt hours of energy. In 1989, Shippingport Reactor 1 was shut down and decommissioned due to the cost of running and maintaining this aged reactor.

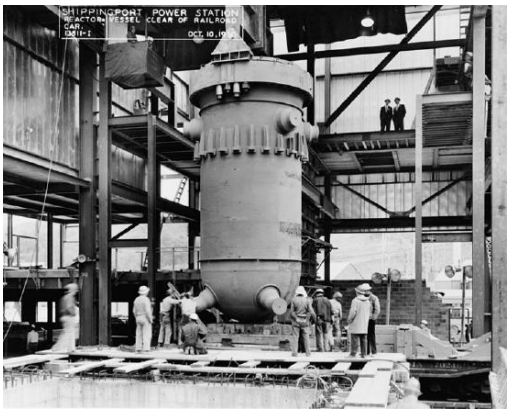


Figure **7.2.2**: Installation of Shippingport Reactor 1 in Pennsylvania. (Public Domain; U.S. Department of Energy, Naval Reactors Program via Wikipedia)

From its conception, the AEC appeared to take a greater interest in nuclear weapons security than nuclear reactor safety. For this reason, Congress dismantled the AEC in 1974. The existing Department of Energy (DOE) would focus on nuclear security (weapons and materials) and nonproliferation (stopping the construction of nuclear weapons). The newly formed Nuclear Regulatory Commission (NRC) would concentrate on ensuring the safe use of radioactive materials. In other words, radioisotopes used in medical, agricultural, and industrial applications would be watched to minimize the contamination of people and the environment. Additionally, NRC would regulate all commercial reactors. These energy sources would be licensed and inspected for safety purposes. If a reactor failed inspection, then the NRC has the power to enforce fines and penalties on that particular reactor.

What is Electricity?

Electricity is a form of energy resulting from the flow of electrons. When magnetic fields are applied to a wire containing electrons, a continuous current (rate of electron flow) is produced. This type of current is a direct current (DC) and can be used to power battery supplies. Direct currents are not capable of transmitting electricity long distances. Electrons in a direct current encounter significant resistance which limits the flow of energy. A high current corresponds with a large loss of electrical energy transfer or otherwise known as electrical power. When keeping electrical power constant, current and voltage (pressure that pushes electrical current) are inversely related. Thus, it is optimal to run an electrical grid at a high voltage.

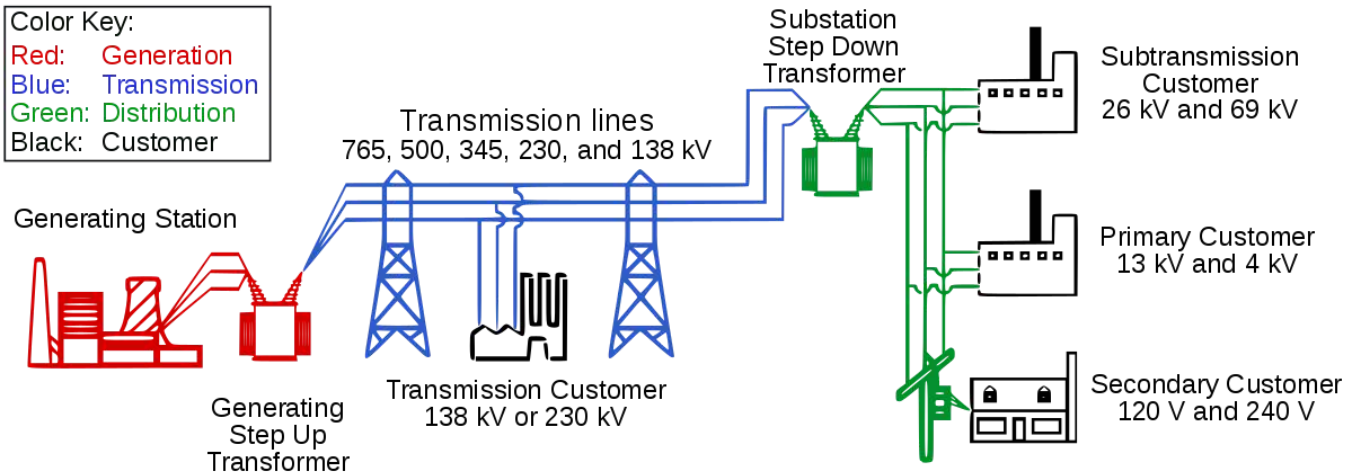


Figure **7.2.2**: Simple diagram of electricity grids in North America.. (Copyright; https://en.Wikipedia.org/wiki/United...ment_of_Energy via https://www.ferc.gov/industries/elec...kout/ch1-3.pdf)

To make electricity transmission more efficient, alternating currents are utilized. Here, the electrons fluctuate in various directions. A transformer increases the voltage to decrease the current. Again, this step is needed to reduce energy loss and optimize power. When the electricity is transmitted to the customer, then a substation reduces the voltage for safety and economical reasons.



General Energy Production

The great majority of all electrical generating systems (whether coal-burning power plants, hydroelectric plants, or nuclear power plants) all follow a reasonably simple design. The electricity is produced by spinning a coil of wire inside a magnetic field. When a fluid (air, steam, water) is forced through the pipe, it spins the fan blades which in turn spin the axle. To generate electricity, the axle of a turbine is attached to the loop of wire in a generator. When a fluid is forced through the turbine, the fan blades turn, the turbine axle turns, and the loop of wire inside the generator turns, thus producing electricity.

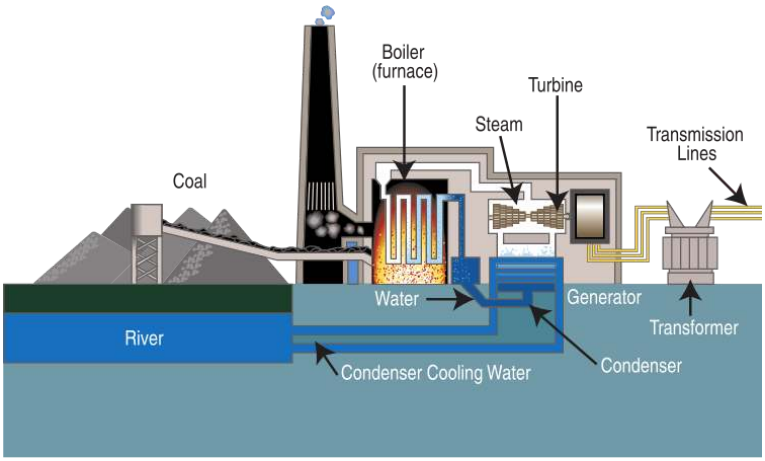


Figure **7.2.3**: Coal-fired plant. Coal burned in the boiler heats water to produce steam. The steam spins the turbine, which drives the generator.(Public Domain; Tennessee Valley Authority via Wikipedia)

The essential difference in various kinds of electrical generating systems is the method used to spin the turbine. For a wind generator, the turbine is a windmill. In a geothermal generator, steam from a geyser is forced through the turbine. In hydroelectric generating plants, water falling over a dam passes through the turbine and spins it. In fossil fuel (coal, oil, natural gas) generating plants, the fossil fuel is burned and the heat is used to boil water into steam and then the steam passes through the turbine and makes it spin. In a fission reactor generating plant, a fission reaction is used to boil the water into steam and the steam passes through the turbine to make it spin.



Basic Energy Units

When understanding electrical energy consumption, the kilowatt (kW) is the most commonly used unit in the United States. This unit is a measure of power. A more specific unit, the kilowatt-hour (kWh) is utilized to denote how much fuel is used to generate electrical energy over a specific amount of time. Power meters are installed in consumer and industrial facilities to measure kilowatt-hour usage. Power companies charge various rates around the country for electrical consumption. The pictures below show a traditional power meter and a typical residential power bill. Watch this video to get an understanding of the kilowatt-hour and how different appliances use different amounts of kilowatts.

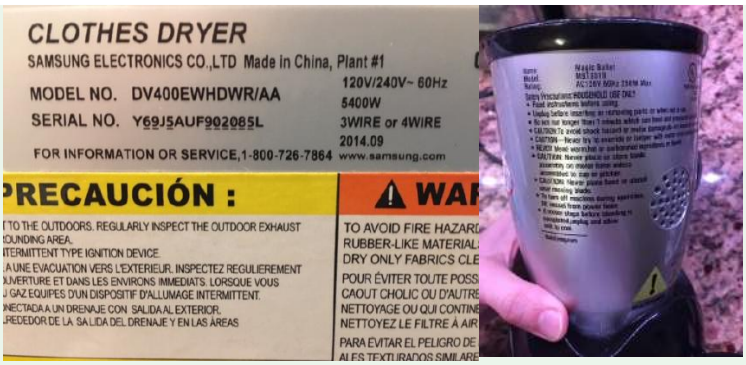


Figure **7.2.4**: Meter image is taken from https://c1.staticflickr.com/7/6013/5...116c6fa6_b.jpg and (right) A power bill showing kilowatt-hours.

Wattages for common household appliances can be obtained by looking at labels or using the manufacturer's website. Typically, power units for these devices are listed in watts. Calculating a price for the monthly use can be done by following the rules listed in the text box. Be aware of "vampire" devices. Even when these items are turned off, they still drain energy from your home. Conserve energy by unplugging these apparatuses. Examples of these include desktop computers/displays, faxes, printers, TVs, microwaves, garage door openers, video game consoles, coffee makers, electric toothbrushes, cable boxes, and device charges. If a consumer is unwilling to unplug these devices, then they should invest in power cords with surge protection. Turning off power strips after use will allow the consumer to still conserve energy.

Calculating Appliance Energy Usage

When purchasing appliances for the home or business, be sure to note the wattage of each product. Energy-efficient devices will save money a consumer money on their monthly electric bill.



To calculate the monthly electrical bill for an appliance, use the following steps listed below:

1. Locate the running wattage on a given appliance. For a running wattage, convert this value to kilowatts using dimensional analysis (recall 1000 watts = 1 kW)
2. Multiply the calculated kW by the hours of operation for a month.
3. Research the energy value your power company charges per month (Furman U uses Duke Energy and current values can be located using this link. The December value for the first 1000 Kw use is 11.8¢ per kilowatt hour. If you exceed 1000 Kw for your home, you will pay a higher rate for the extra power.
4. Multiply the kWh by the monthly rate. The final answer will be a cent value. Divide this number by 100 to obtain the dollar amount.

Sources

- Paul Flowers (University of North Carolina - Pembroke), Klaus Theopold (University of Delaware) and Richard Langley (Stephen F. Austin State University) with contributing authors. Textbook content produced by OpenStax College is licensed under a Creative Commons Attribution License 4.0 license. Download for free at http://cnx.org/contents/85abf193-2bd...a7ac8df6@9.110).

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7.3: Powering the United States

Learning Objectives

- Determine if an energy source is renewable or nonrenewable.
- Realize what sources provide the most power for the United States.
- Compare and contrast the different types of energy sources.
- Understand the environmental impacts of energy sources.
- Compare and calculate the amounts of energy produced from each source (using Kilo, Mega, and Giga units)

Source of Energy

Production of electricity can involve either one of two primary energy sources. For example, a country employs nonrenewable sources like natural gas, petroleum, coal, or nuclear energy to supply power to homes and industry. In addition, an area might choose to incorporate renewable energy sources to meet its consumers' needs. Examples of these would include biomass, hydropower, geothermal, wind, and solar energies.

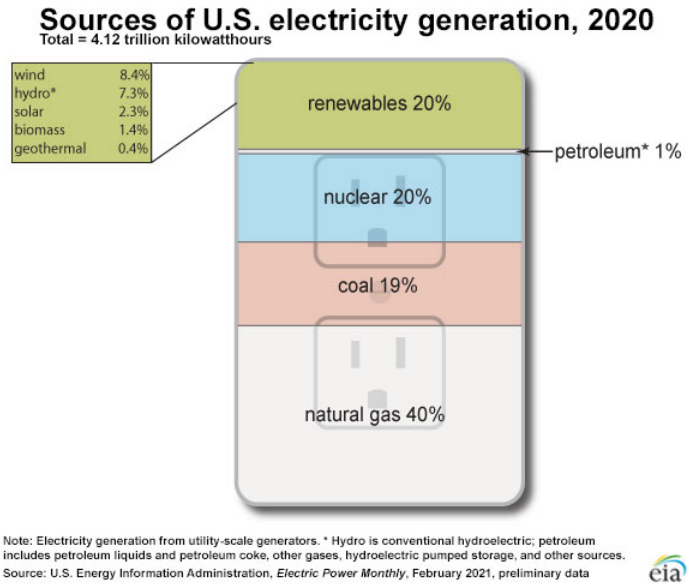


Figure 7.3.5: Chart illustrating electrical power generation in the United States. Image is taken from Electricity in the U.S. - U.S. Energy Information Administration (EIA)

As of 2020, the current United States population is approximately 331 million people. Supplying electricity to a population of this size requires many different types of sources. At this time, the majority of electrical output is the result of fossil fuel combustion. Click on this link to see how energy sources used in the United States have changed over the years.

Energy Units

The SI unit for heat is the Joule. Heat can also be measured using the unit calories. One calorie (this unit is not equivalent to the calorie seen in foods) is equivalent to 4.184 Joules. The table below illustrates the amount ot heat that can be produced from the burning of a specific material. Capital M is representative of the metric unit, mega. The one gas in the table below is measured using the volumetric term of meters cubed (m^3). Lastly, the other substance amounts correlate per kilogram of material burned.

Table 7.3.2: Energy Conversion: Typical Heat Values of Various Fuels (units are Megajoule/kilogram)

Firewood (dry)	16 MJ/kg
Brown coal (lignite)	10 MJ/kg
Black coal (low quality)	13-23 MJ/kg
Black coal (hard)	24-30 MJ/kg
Natural Gas	38 MJ/m^3
Crude Oil	45-46 MJ/kg
Uranium - in a typical reactor	500,000 MJ/kg (of natural U)

Coal

In the United States, coal is the cheapest option as an electrical source. The coal industry estimates that there are approximately 260 billion tons of coal yet to be mined in this country. Assuming the daily rate of coal consumption remained constant, the United States should have enough coal reserves to last over 230 years. Annually, The United States produces over one billion tons of coal. This value equates to approximately 12% of the world's supply.

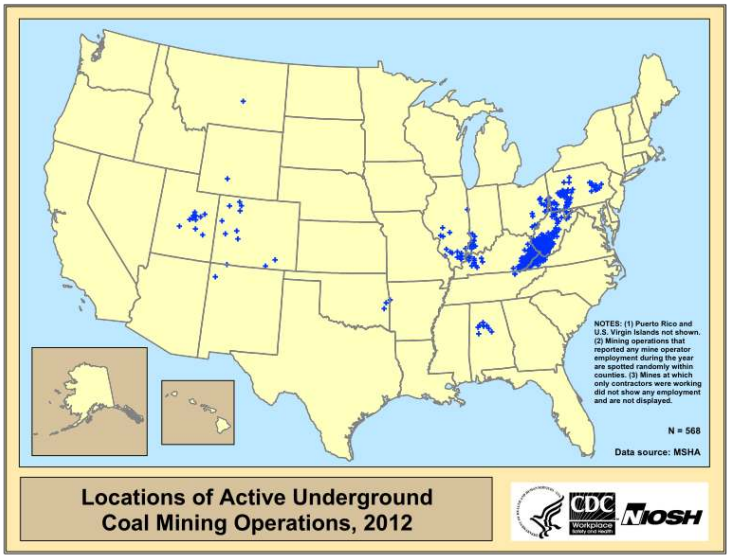


Figure 7.3.6: Locations of underground coal mines in the US. (Public Domain; US Dept of Health, Center for Disease Control via Wikipedia)

Heavy equipment is utilized to extract coal from the surface of the earth. Surface mining can lead to residual chemicals from the coal entering the water supply and surrounding soils. Many states, namely West Virginia and Pennsylvania, still use coal miners to dig coal from underground reserves. Although regulated, this occupation can be particularly risky with exposure to particulate chemicals that can affect the lung and hearts of workers. In addition, gaseous chemicals inside the mine can combust easily if a spark is present. This could result in trapped workers and fatalities at the site.



There are 600 coal-burning electric plants in the US delivering 44.9% of American electricity and producing 2 billion tons of CO_2 annually, accounting for 40% of U.S. CO_2 emissions and 10% of global emissions. Coal-burning facilities also produce 64% of the sulfur dioxide emissions, 26% of the nitrous oxide emissions, and 33% of mercury emissions. Sulfur dioxide and nitrous oxide combustion are precursors to acid rain and industrial and photochemical smog. Mercury, a heavy metal toxin, affects the neurological system and can cause behavior and intellectual disorders. Incomplete combustion of carbon can produce particulate matter. These carbon-based solids gather in the atmosphere and make visibility difficult. For more information about combustion of any type of fossil fuel, click on this link.

Trace amounts of radionuclides can be detected in coal. Uranium and thorium isotopes that are present will eventually decay to other species. When burned, these substances become airborne and release their decay products. All chemicals and matter resulting from the combustion process can cause heart, lung, and immunity disorders. In addition, high combustion areas can affect the average lifespan of individuals and species living in these areas.



Figure 7.3.7: Two pictures of Beijing in 2005. The picture on the left shows the city after two days of rain. The picture on the right shows smog gathering in the atmosphere.

Coal can be cleaned to remove some impurities (like sulfur-based species), but there is no such thing as "clean" coal. Industries that burn coal can install scrubbers in their smokestacks to grab many pollutants before they enter the atmosphere. In the United States, the Environmental Protection Agency (EPA) regulates all pollutants resulting from the combustion process except for carbon dioxide.

Natural Gas

Natural gas combustion does not produce as many types of byproducts. It is a much cleaner fuel to burn and there would be fewer environmental and health problems related to this fuel choice. Greenhouse gases are still produced when this fuel is burned. Unfortunately, natural gas exists deep within the ground and can be difficult to extract.

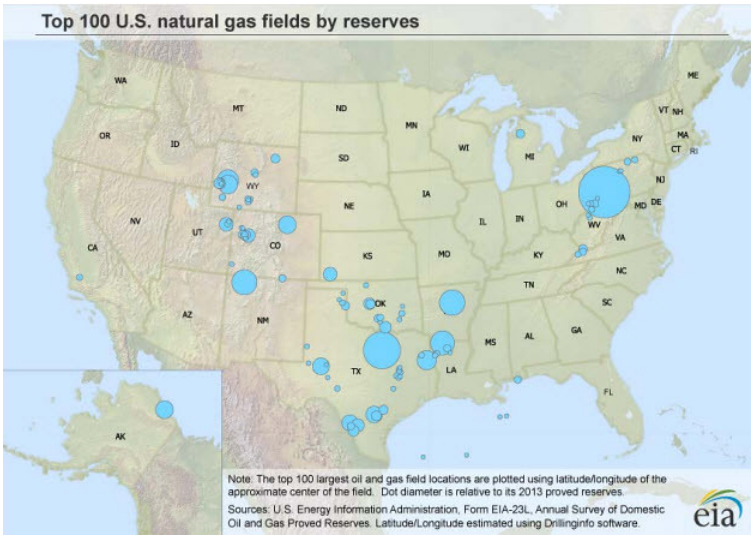


Figure **7.3.8**: Natural gas reserves in the United States. Image is taken from https://c1.staticflickr.com/9/8743/1...08652510_z.jpg



Hydroelectric

Hydroelectric sources provide almost 7% of the United State's electricity. To use this type of energy, a large body of water needs to be present within the area. A river is intentionally dammed to create a large water supply. With monitored releases, the dammed water is allowed to fall to a lower altitude. This motion will turn a turbine which will produce energy. Unlike fossil fuel combustion, hydroelectric sources do not release toxins into the atmosphere. As a result, this method of energy production does not contribute to global warming, acid rain, or smog production. Some disadvantages of hydroelectric power include the disruption of aquatic ecosystems. Construction of hydroelectric facilities requires large areas of land that could involve uprooting and affecting human and animal populations. Lastly, altering land geology can cause severe flooding.

The largest hydroelectric facility in the United State is located in Washington State along the Columbia River. Grand Coulee Dam produces over 6800 Megawatts of electrical energy for this region of the country. At this time, there are over 1600 hydroelectric plants in the United States.



Figure 7.3.9: Arial view of Grand Coulee Dam. The image is taken from upload.wikimedia.org/wikiped...Dam_aerial.jpg

Solar and Wind Power

In recent years, the use of wind and solar sources has increased in this country. Both of these types of energy require large plots of land for their structures. In addition, both the sun and wind need to be present to generate energy. Wind and solar energy can be stored for days in which the climate does not produce adequate amounts of either. With wind energy, there is some concern about how the structures appear and affect wildlife. These devices can also be very noisy. At this time, Texas leads the country in the production of wind energy.

Research has focused on making components of solar panels less toxic and more affordable for the average consumer. Many utility companies offer incentives for residents to install solar panels. In addition, some utility companies will buy back excess solar wattage from their own consumers. The state of California leads the country in the production of solar energy. The Ivanpah Solar Farm in the Mohave Desert generates over **390 megawatts** of energy per year.



Figure 7.3.10: Ivanpah is the largest solar farm in the United States in California. The image is taken from upload.wikimedia.org/wikiped...ity_Online.jpg

Recently, Furman University installed its own solar farm. Click on this link to read more about how this university is using renewable energy to cut down on carbon emissions.

Nuclear Reactors

There are over thirty countries that use nuclear power to generate electricity. Commercial nuclear reactors can be found in North and South America, Europe, Africa, and Asia. The United States has the most reactors of any other country. There are around ninety-nine reactors in the United States that provide around twenty percent of the electrical energy in the United States. Other countries, like France, employ around sixty nuclear reactors to produce 80% of their electrical power.

Table 7.3.1: Nuclear Share of Electricity Generation in 2016. Data from the International Atomic Energy Agency

Country	Number of Operated Reactors	Total Net Electrical Capacity	[MW]Nuclear Electricity Supplied	[GW.h]Nuclear Share
FRANCE	58	63130	386452.88	72.3
SLOVAKIA	4	1814	13733.35	54.1
UKRAINE	15	13107	76077.79	52.3
BELGIUM	7	5913	41430.45	51.7
HUNGARY	4	1889	15183.01	51.3
SWEDEN	10	9740	60647.40	40.0
SLOVENIA	1	688	5431.27	35.2
BULGARIA	2	1926	15083.45	35.0
SWITZERLAND	5	3333	20303.12	34.4
FINLAND	4	2764	22280.10	33.7
ARMENIA	1	375	2194.85	31.4
KOREA, REPUBLIC OF	25	23077	154306.65	30.3
CZECH REPUBLIC	6	3930	22729.87	29.4
SPAIN	7	7121	56102.44	21.4
UNITED KINGDOM	15	8918	65148.98	20.4
UNITED STATES OF AMERICA	100	100351	804872.94	19.7
ROMANIA	2	1300	10388.20	17.1
RUSSIA	36	26496	184054.09	17.1
CANADA	19	13554	95650.19	15.6
GERMANY	8	10799	80069.61	13.1
SOUTH AFRICA	2	1860	15209.47	6.6
MEXICO	2	1552	10272.29	6.2
ARGENTINA	3	1632	7677.36	5.6
PAKISTAN	4	1005	5438.90	4.4
CHINA	36	31384	197829.04	3.6
INDIA	22	6240	35006.83	3.4
NETHERLANDS	1	482	3749.81	3.4
BRAZIL	2	1884	14970.46	2.9
JAPAN	43	40290	17537.14	2.2
IRAN	1	915	5923.97	2.1

Today's nuclear power plants use fission reactions to generate energy for electrical production. One kilogram of U-235 can supply over 2.4 x 10^7 kilowatt-hours (kWh) of energy. In contrast, one kilogram of coal can only produce 8 kilowatt-hours of energy. Also, nuclear does not contribute to the problems of acid rain, smog, or greenhouse gas production.

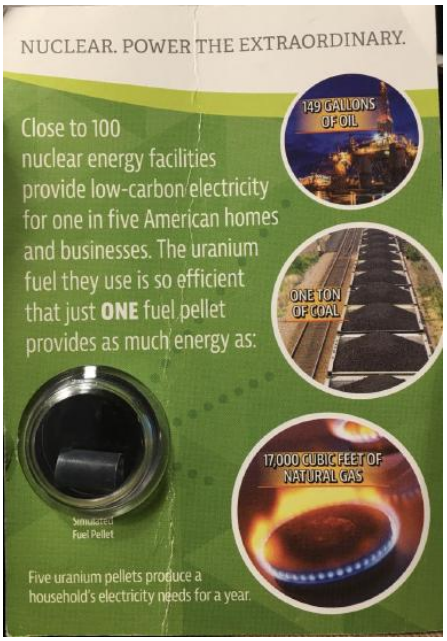


Figure **7.3.11**: Nuclear power fuel pellet (Copyright; Southern Nuclear Company)

Nuclear and coal power plants can appear similar to most people. Both of these types of facilities have large cooling towers that release excess steam energy into the atmosphere. Nuclear power plants will have small, round, and dome-like structures to house the nuclear reactors. In contrast, coal-fired plants will have slender chimney stacks that tower above or at the rounder cooling towers.



Figure **7.3.12**: (left) View of Vogtle Nuclear Power Plant (Units 1 and 2) in Augusta, Georgia produces approximately 2.3 gigawatts of power a year. (right) The *Bruce Mansfield Coal Fire Plant in Shipping Port, Pennsylvania produces 2.4 gigawatts of energy a year. Images* are taken from en.Wikipedia.org/wiki/Vogtle...Vogtle_NPP.jpg and https://3.bp.blogspot.com/-WycgHj-jt...eMansfield.jpg

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- Paul Flowers (University of North Carolina - Pembroke), Klaus Theopold (University of Delaware) and Richard Langley (Stephen F. Austin State University) with contributing authors. Textbook content produced by OpenStax College is licensed under a Creative Commons Attribution License 4.0 license. Download for free at http://cnx.org/contents/85abf193-2bd...a7ac8df6@9.110).

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7.4: Generating Electricity by Using Fission

How a Nuclear Reactor Works

Electrical Power can be generated by using a variety of methods



Video **7.4.1**: Nuclear Energy Explained: Risk or Opportunity. Anything with the word nuclear next to it usually comes with a fair bit of misunderstanding. Hopefully, this video demystifies the process of how nuclear fuels are turned into electricity and how we can use them in combination with renewables to reduce greenhouse gas emissions, and the effects on the climate that comes with high levels of them.

Components of a Reactor

Chain reactions of fissionable materials can be controlled and sustained without an explosion in a nuclear reactor. Any nuclear reactor that produces power via the fission of uranium (U-235) or plutonium (Pu-239) by bombardment with neutrons must have at least five components: nuclear fuel consisting of fissionable material, a nuclear moderator, reactor coolant, control rods, and a shield/containment system.

alt The reactor works by separating the fissionable nuclear material such that a critical mass cannot be formed, controlling both the flux and absorption of neutrons to allow shutting down the fission reactions. In a nuclear reactor used for the production of electricity, the energy released by fission reactions is trapped as thermal energy and used to boil water and produce steam. The steam is used to turn a turbine, which powers a generator for the production of electricity.

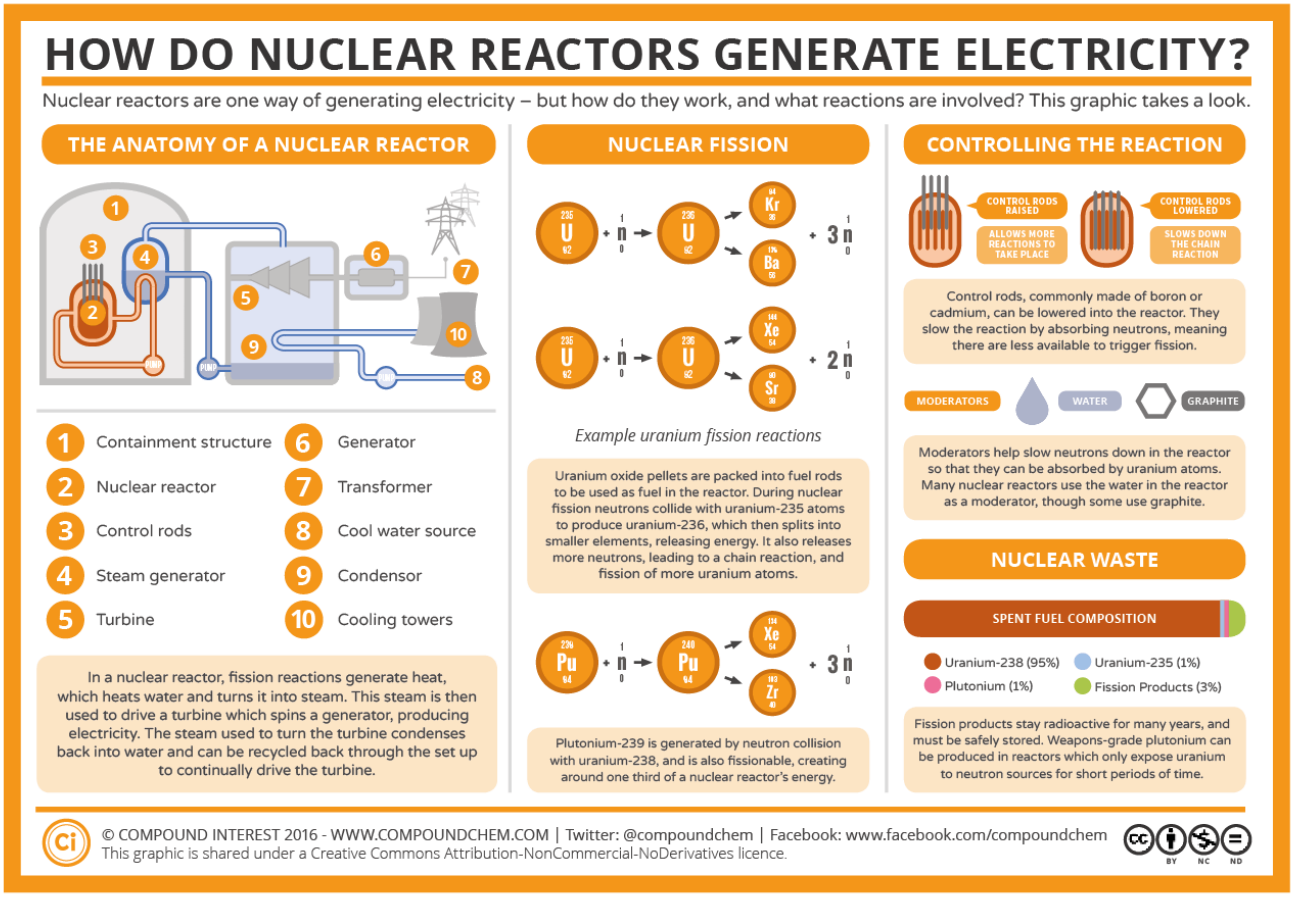


Figure **7.4.1**: Andy Brunning's Nuclear Reactor.

ıre **7.4.2**: A Light-Water Nuclear Fission Reactor for the Production of Electric Power. The fuel rods are made of a corrosion-stant alloy that encases the partially enriched uranium fuel; controlled fission of ^{235}U in the fuel produces heat. Water surrounds fuel rods and moderates the kinetic energy of the neutrons, slowing them to increase the probability that they will induce on. Control rods that contain elements such as boron, cadmium, or hafnium, which are very effective at absorbing neutrons, are l to control the rate of the fission reaction. A heat exchanger is used to boil water in a secondary cooling system, creating steam rive the turbine and produce electricity. The sizeable hyperbolic cooling tower, which is the most visible portion of the facility, denses the steam in the secondary cooling circuit; it is often located at some distance from the actual reactor. (CC BY-NC-SA anonymous)

Nuclear Fuels

Naturally occurring uranium is composed almost totally of two uranium isotopes. It contains more than 99% uranium-238 and less than 1% uranium-235. It is uranium-235. However, that is **fissionable** (will undergo fission). For uranium to be used as fuel in a fission reactor, the percentage of uranium-235 must be increased, usually to about 3%. (Uranium in which the U-235 content is more than 1% is called **enriched uranium**.)The enriched UF_6 gas is collected, cooled until it solidifies, and then taken to a fabrication facility where it is made into fuel assemblies. Each fuel assembly consists of fuel rods that contain many thimble-sized, ceramic-encased, enriched uranium (usually UO_2) fuel pellets. Modern nuclear reactors may contain as many as 10 million fuel pellets. The amount of energy in each of these pellets is equal to that in almost a ton of coal or 150 gallons of oil. Once the supply of U-235 is acquired, it is placed in a series of long cylindrical tubes called fuel rods. These fuel cylinders are bundled together with **control rods** made of neutron-absorbing material. The amount of U-235 in all the fuel rods taken together is adequate to carry on a chain reaction but is less than the critical mass.

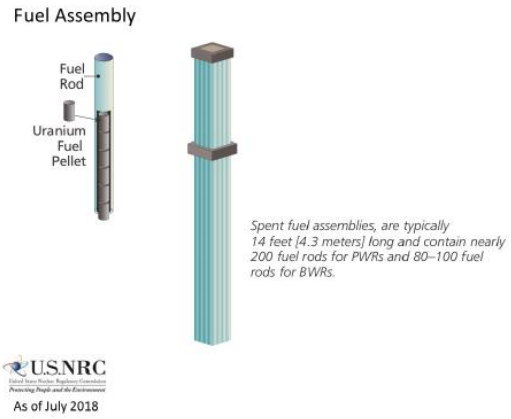


Figure **7.4.3**: Fuel rod assembly in US commercial nuclear power plants. (Copyright; author via source)

Nuclear Moderators

Neutrons produced by nuclear reactions move too fast to cause fission (Figure **7.4.4**). For efficient collisions to occur, a moderator must be used to slow the speeds of the neutrons. Moderators can be composed of many different types of chemical substances. The first experimental nuclear reactors used high-purity graphite (or carbon) as a moderator. Today, many countries use light water (LW) as moderators. Otherwise known as H_2O, this substance needs to in large supply. Most LW reactors are built near lakes or other freshwater sources. Depending on the type of fuel, a country would select a corresponding moderator for determining wattage output. Other types of moderators that are used today include heavy water (HW which is D_2O), carbon dioxide, beryllium, or graphite.

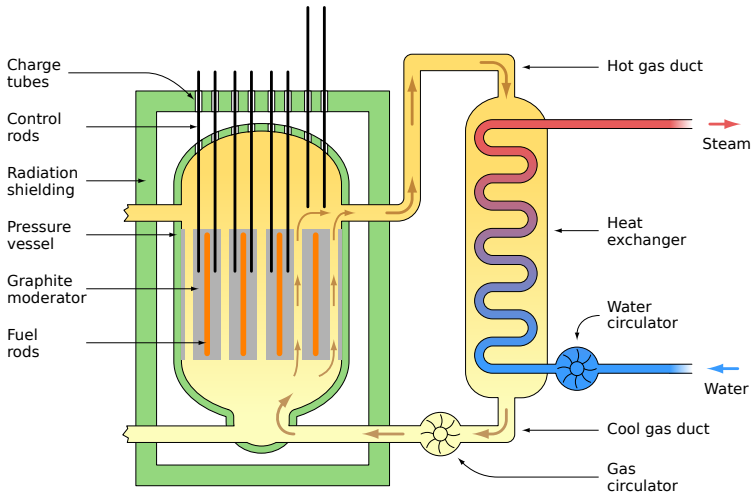


Figure **7.4.4**: The Magnox reactor is utilized by Russia and the United Kingdom. (CC BY-SA 3.0; Emoscopes via Wikipedia)

Reactor Coolants

A nuclear reactor coolant is used to carry the heat produced by the fission reaction to an external boiler and turbine, where it is transformed into electricity. Two overlapping coolant loops are often used; this counteracts the transfer of radioactivity from the reactor to the primary coolant loop. All nuclear power plants in the US use light water as a coolant. Other coolants include molten sodium, lead, a lead-bismuth mixture, or molten salts.

Click on the video below and watch from the 1-minute mark until the end to learn about Liquid Metal Fast Breeder Reactors.



Video**7.4.1**: Liquid Metal Fast Breeder Reactors (LMFBR)

1) Provide the symbol-mass formats for the isotopes that are used in this particular nuclear reactor.

2) What is this reactor breeding?

3) List the advantages of a country employing an LFMBR.

4) List the disadvantages of a country employing an LFMBR.

5) Do you think the United States uses this type of reactor commercially? Why or why not?

Control Rods

Nuclear reactors use control rods (Figure **7.4.5**) to control the fission rate of the nuclear fuel by adjusting the number of slow neutrons present to keep the rate of the chain reaction at a safe level. Control rods are made of boron, cadmium, hafnium, or other elements that are able to absorb neutrons. Boron-10, for example, absorbs neutrons by a reaction that produces lithium-7 and alpha particles:

$$^{10}_{5}\mathrm{B} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{7}_{3}\mathrm{Li} + {}^{4}_{2}\mathrm{He}$$

When control rod assemblies are inserted into the fuel element in the reactor core, they absorb a larger fraction of the slow neutrons, thereby slowing the rate of the fission reaction and decreasing the power produced. Conversely, if the control rods are removed, fewer neutrons are absorbed, and the fission rate and energy production increase. In an emergency, the chain reaction can be shut down by fully inserting all of the control rods into the nuclear core between the fuel rods.

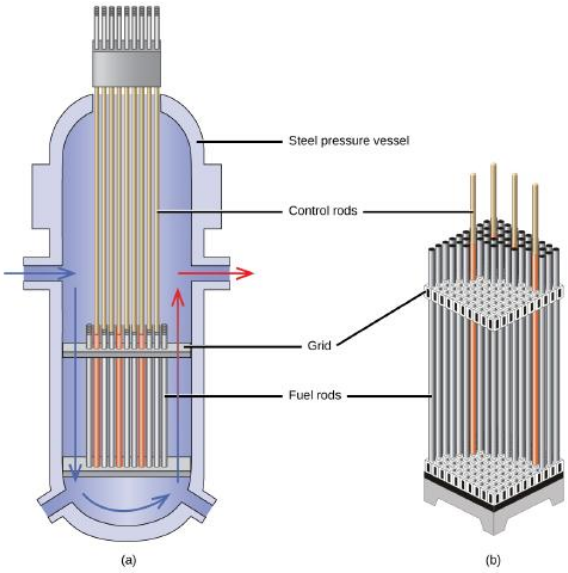


Figure **7.4.5**: The nuclear reactor core shown in (a) contains the fuel and control rod assembly shown in (b). (credit: modification of work by E. Generalic, glossary.periodni.com/glossar...en=control+rod)

Shield and Containment System

During its operation, a nuclear reactor produces neutrons and other types of radiation. Even when shut down, the decay products remain radioactive. In addition, an operating reactor is thermally very hot, and high pressures result from the circulation of water or another coolant through it. Thus, a reactor must withstand high temperatures and pressures and must protect operating personnel from the radiation. Reactors are equipped with a containment system (or shield) that consists of three parts:

1. The reactor vessel, a steel shell that is 3–20-centimeters thick and, with the moderator, absorbs much of the radiation produced by the reactor
2. The main shield of 1–3 meters of high-density concrete
3. A personnel shield of lighter materials that protects operators from γ rays and X-rays

In addition, reactors are often covered with a steel or concrete dome that is designed to contain any radioactive materials that might be released by a reactor accident.



Figure **7.4.6**: The containment structure of the Millstone Nuclear Power Plant. (CC BY-SA 2.0; Eric Lewis via Flickr)

Nuclear power plants are designed in such a way that they cannot form a supercritical mass of fissionable material and therefore cannot create a nuclear explosion. But as history has shown, failures of systems and safeguards can cause catastrophic accidents, including chemical explosions and nuclear meltdowns (damage to the reactor core from overheating).

Reviewing Reactor components

Read over this particular section of the OER and then watch both embedded videos. Test your knowledge of nuclear reactors by answering the questions below.



1. What particle bombards U-235 to produce fission?
2. How does the fission reaction in a nuclear weapon differ from that of a reactor?
3. What is the purpose of a control rod in a nuclear reactor?
4. In moving the control rods, must electricity always be applied?
5. What is the purpose of the moderator? What is the chemical formula of the moderator described in this video?
6. What is the purpose of a coolant? What is the chemical formula of the coolant described in this video?
7. If coolant leaks out of the reactor, then what could happen?
8. If a nuclear reactor experiences a meltdown, how has this affected the structure of the nuclear reactor?

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7.5: United States Commercial Nuclear Power Reactors

Location of United States Commercial Reactors

In 2020, there are ninety-five commercial working nuclear reactors in the United States. The majority of these reactors are on the eastern side of the country. Each reactor site houses between one and three reactors. The average age of these nuclear reactors is approximately thirty-six years. Each year, reactor units are rigorously inspected for safety. Also, reactors that cannot meet safety measures or are not able to be upgraded will be placed on shut-down. These reactors will eventually be closed forever or decommissioned.

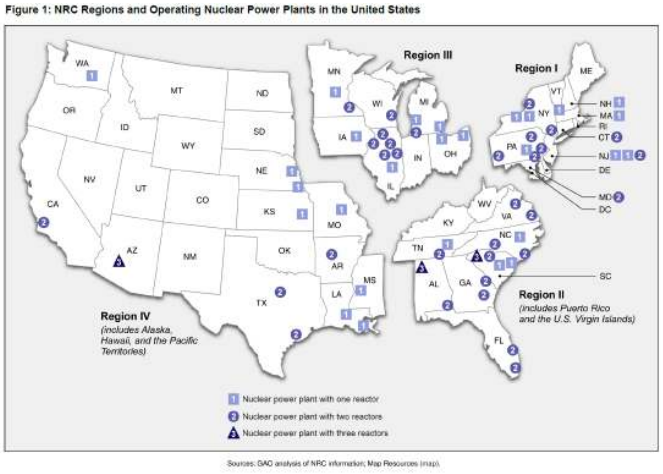


Figure 7.5.1: Nuclear Power: Analysis of Regional Differences and Improved Access to Information Could Strengthen NRC Oversight (U.S. Government Accountability Offic)

Two Types of United States Commercial Reactors

In the United States, commercial reactors can be one of two types. Sixty-four reactors are pressurized water reactors (or PWRs). This type of reactor uses light water as a moderator and a coolant. The water in the reactor is kept under high pressure. This type of configuration does not allow water to boil. The water inside the reactor transfers its heat to the water in a steam generator. Then, steam is produced to aid in the production of electrical energy.

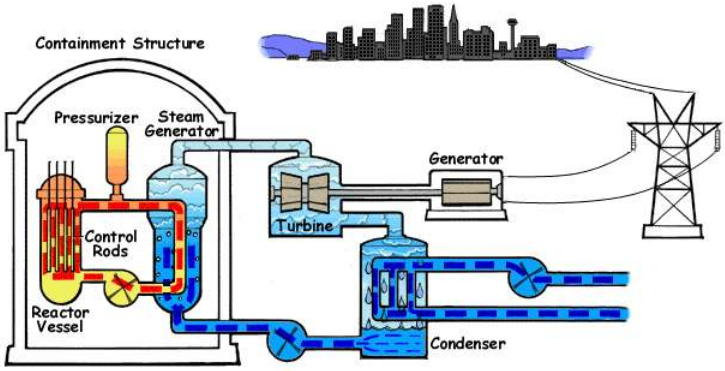


Figure 7.5.1: Pressurized Water Reactor. (Public Domain; Nuclear Regulatory Commission via Wikipedia)

The other thirty-two commercial reactors are of the boiling water reactors (BWRs) variety. These reactors also use light water as their moderator and coolant. Here, the water in the reactor is allowed to boil. This heated water goes directly to the turbine house which is separated from a generator. The radioactive water that goes through the turbine is contained inside the nuclear facility. Cooling this water with a condenser allows it to be returned into the reactor and used for coolant once again.

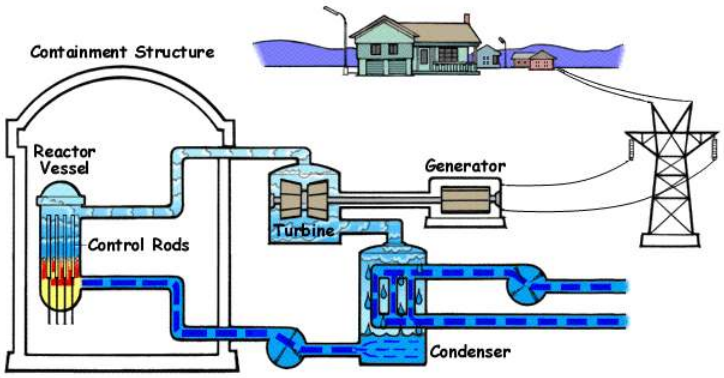


Figure 7.5.2: Boiling Water Reactor. (Public Domain; Nuclear Regulatory Commission via Wikipedia)

NRC Classification of Nuclear Reactors

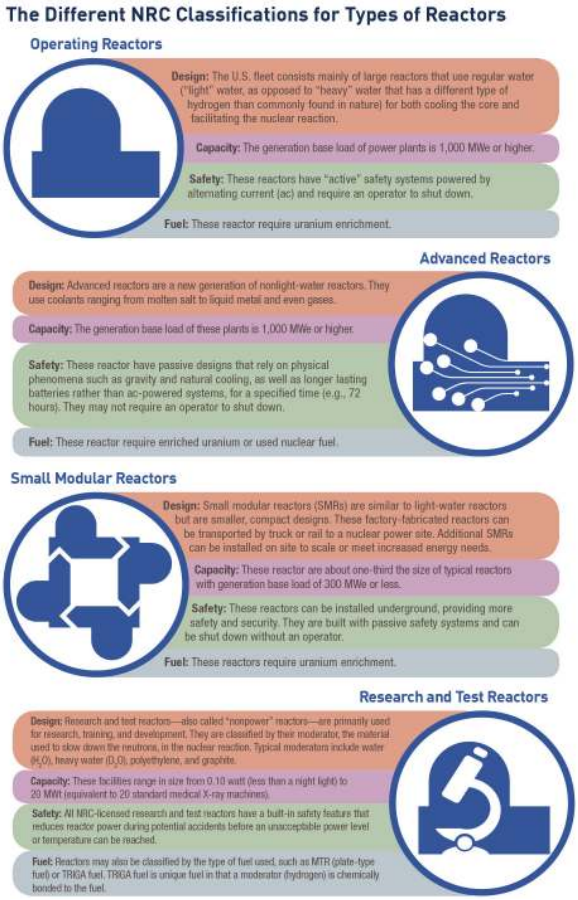


Figure 7.5.2: Infographics of the NRC different classifications for types of reactors from the 2017-2018 Information Digest, NUREG 1350, Volume 29. Published in August 2017. (Nuclear Regulatory Commission)

Decommissioning Nuclear Reactors

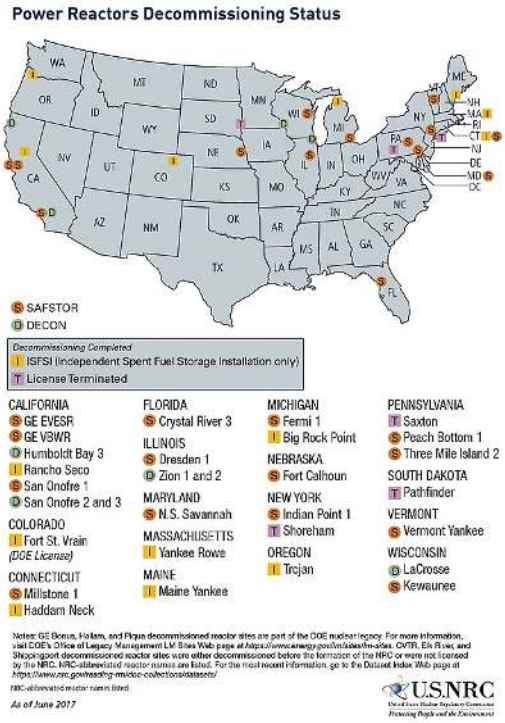


Figure **7.5.3**: Infographics of the Map of Power Reactors Decommissioning status from the 2017-2018 Information Digest, NUREG 1350, Volume 29. Published in August 2017. (Nuclear Regulatory Commission)

New Construction in the United States

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7.6: Funding and Licensing for United States Commercial Nuclear Reactors

Funding and Licensing - An Introduction:

While nuclear reactors are an incredible source of carbon-free energy, it is important to note the various costs and licensing that are needed to successfully complete such a large-scale infrastructure project from start to finish. The largest hurdle in financing nuclear projects derives from the upfront construction costs required to assemble these infrastructure projects. All upfront costs fall under the responsibility of the project owner, which can be a massive undertaking. Before owners with sufficient capital can begin construction, however, they must go through a complicated and extensive licensing process.

Licensing:

The first step towards constructing a commercial nuclear power plant in the United States involves obtaining an official license from the Nuclear Regulatory Commission (NRC). In order to begin construction, overseers of this project must obtain two interrelated licenses: (1) a construction permit and (2) an operating license as underlined in Title 10 of the Code of Federal Regulations (10 CFR), Part 50.

The NRC conducts an incredibly thorough application process for licensure, stipulating that project managers go through several careful reviews, including NRC safety, environmental, and antitrust reviews. Interested applicants first prepare and submit a Safety Analysis Report that meticulously lists the design blueprints, local data pertaining to the prospective site, and security and/or safety features integrated into the plant's design and construction that mitigates any future risks, accidents, or emergencies. Upon submission of this safety review, an applicant would then need to submit an environmental impact statement for the plant as well as an antitrust review to determine whether the participating company's mergers and acquisitions are competitive and fair to their consumers, avoiding violations of federal antitrust laws. For those seeking a slightly simpler process of gaining a combined license, a similar process can be found below:

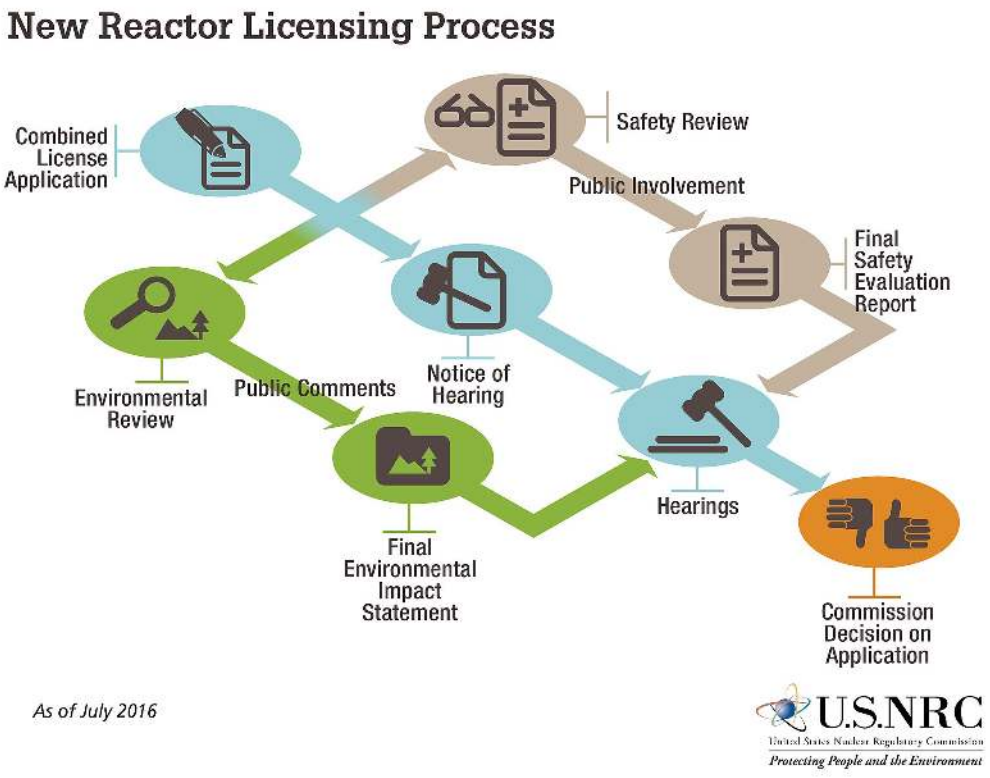


Image is the intellectual property of the U.S. NRC and is taken from https://commons.wikimedia.org/wiki/F...275046722).jpg

Once an organization has submitted an application, the NRC carefully weighs each portion of the application and decides whether the party can move forward. After hosting a publicly advertised meeting to educate the public on the details of the potential plant, NRC staff will examine the application itself to ensure that the plant's blueprint meets the required regulations, including:

- The site's surrounding population, seismology, meteorology, geology, and hydrology
- The design of the plant itself
- "Technical qualifications" and experience of the applicant related to running the plant
- Plant emissions into the surrounding environment
- Failsafe/emergency plans

Acting in tandem with the NRC, The Advisory Committee on Reactor Safeguards – an independent body that delivers an additional separate opinion regarding nuclear plants' safety – will also examine the application and eventually contact the NRC with its own recommendation.

Lastly, the applicant, incorporating all prior reviews and suggestions throughout the licensing process, must complete a Final Safety Analysis Report to obtain an operating license. This final report should reiterate the applicant's request for an operating license by articulating the power plant's final design, operative policies, and precautionary measures. While an applicant for a construction permit is required by law to undergo an additional public hearing managed by an Atomic Safety and Licensing Board, that same applicant is not necessarily required to experience a similar public hearing to acquire an operating license.

Up-Front Financing I: Government and Private Ownership

The sponsor of nuclear power plant projects normally fits into two broad categories – public ownership by a country's government or private ownership by corporations – or a combination of both. Through debt and equity financing, the project owner and manager can rely on bank loans and investors that both allow them to gain ownership in the project. The construction of a nuclear power plant carries with it a potential for financial risk initiated by a plethora of complications ranging from construction and scheduling delays to exchange and interest rate risks. While it is possible for multiple private corporate stakeholders to entirely finance a nuclear expansion project, government involvement as a partner in a project can provide financial stability, preventing this infrastructure project that takes, on average, half a decade to complete from suddenly going under. Above all, having multiple, financially independent stakeholders investing in a singular project is the best guarantee of its long-term success.

Up-Front Financing II: Capital Costs – Construction, Manpower, and Financing

Upon establishing their respective stakes in a nuclear project, investors must first address the capital costs – the sheer manpower, raw resources, component parts, and electrical systems necessary for the construction project's completion. Project managers usually hire between 500-3500 nuclear power plant workers and are tasked with acquiring massive amounts of steel and concrete.

Additionally, they need to plan for **Engineering, Procurement, and Construction (EPC) costs** as well as **owners' costs**. **EPC costs** are defined legally as any construction costs for which the owner can be held liable to cover. These costs most commonly include any monetary penalties or fees the owner of a project is lawfully bound to pay due to the termination of a construction contract. **Owners' Costs** simply refer to the price of testing the plants' systems and training its staff.

Lastly, **Financing costs** arise throughout the period of construction as a result of fluctuating interest rates based on the debt assumed by the plant project's owner. The general rule for assessing these costs is that the longer the construction period is, the higher the financing cost will be.

Financing III: Overhead / Operating Costs

Nuclear Power Plant Operation costs refer to fuel costs, including the fuel itself such as Uranium, management of the fuel, and nuclear waste disposal. Project owners only shift to worrying about these costs when a commercial reactor is built and fully operational. Although the costs to provide up-front financing for a reactor are astronomically high, nuclear power plants compensate with fuel costs that are significantly lower than that of a coal-fired power plant. The World Nuclear Association (WNA) reports that on average the total fuel costs of a nuclear power plant in an Organization for Economic Co-Operation and Development (OCED) country like the United States are around a third to a half of those for a coal-fired plant. Plant owners save on these costs mainly because their plant's source of energy, Uranium, is highly concentrated, cheap, and more accessible than coal. WNA cites that one kilogram of natural uranium yields about 20,000 times as much energy as one kilogram of coal.

Financing IV: Consumer Costs

Once a nuclear project is underway with an enormous amount of capital behind it, the project manager and relevant stakeholders offset these massive costs by ensuring its economic viability – i.e., its ability to generate a steady revenue stream greater than operating costs once fully operational. This revenue is largely generated through a fraction of the utility bills of local residents who will rely or continue to rely on the electricity generated by the commercial nuclear power plant in the future. It is often common that future customers financially contribute to a nuclear power plant through the entirety of its construction and that electricity bills will exponentially increase as a result of major project delays.

Total Estimated Costs

Since 2008, the total estimated costs required to fund a nuclear power plant's construction have been $7-9 billion dollars for each new unit, which has continued to rise. These rapidly ballooning costs have prompted experts to examine the question of why these projects turn out to be so expensive for all involved parties. A recent MIT study focused on the frequent result that the projected cost of a plant frequently does not come close to matching the actual cost once construction begins. These researchers identified multiple key reasons why these costs often greatly exceed projections such as:

- Tightening safety regulations
- Declining labor productivity, which is disproportionately higher in the case of nuclear power plant construction
- Rising costs of engineering services, on-site job supervision, and construction facilities
- Rising costs of reactor component parts, particularly the steam supply system, turbine generator, and reactor containment building (more than doubled between 1976 and 2017)
- The assumption by field experts that costs will decrease as new plant designs become more familiar when they continue to increase

MIT researchers present that a lethal combination of the factors above has contributed to heightened plant costs since the mid-1970s. Before deciding to undergo a massive nuclear power plant project, interested parties must over-estimate the up-front costs necessary to complete construction in order to succeed.

Managing Risk

Risk is the final factor to consider when deciding to finance a commercial reactor's construction. The assumption of financial risk by the government of a particular country significantly improves its chances of success through loan guarantee, asset ownership, or equity share. However, oftentimes private commercial investors proceed without the government to fund these 'capital intensive' projects, as defined by the International Atomic Energy Agency (IAEA), that are exceptionally susceptible to the fluctuation in interest rates, inflation, and unforeseen delays in project construction. In 2005, Congress passed the Energy Policy Act that established a production tax credit – 1.8 cents per kWh of electricity for each tax credit – that project owners could qualify for up until the first eight years of the plant's operation. While the federal support is helpful in stabilizing costs at the front end, companies cannot retain these tax credits after experiencing multiple long project delays that expand beyond the eight-year period and will therefore have to rely on their own funds.

Case Study: VC Summer, Tax Credits, and Risk

The long duration of these projects coupled with their financial unpredictability makes project owners particularly vulnerable to civil litigation. The VC Summer Expansion project serves as a cautionary lesson for those interested in financing a nuclear power plant that lacks up-front capital, a fiscally stable contracting company, and governmental support. After the newly bankrupted contractor pulled out of the expansion project for Units 2 and 3 and the plant experienced continuous delays, project owners Santee Cooper and the SCANA Corporation failed to qualify for a much-needed tax credit from the federal government and were subject to multiple lawsuits. For more on the details of this failed nuclear expansion project, see **Section 7.7** on **South Carolina Energy**.

Contributors:

Andrew Allen (Furman University)

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7.7: South Carolina Energy

Energy Sources

According to the Department of Energy, the state of South Carolina generates 96.8Twh (terawatt hours= 10^{12} watt-hours) of electrical energy a year. This accounts for only 2% of the country's electrical power. The sources of South Carolina energy production are shown in the table below.

Source	Twh (Terawatt Hours of Energy)	Percentage of Electrical Power
Coal	28.4	29%
Petroleum	0.1	<1%
Natural Gas	14.3	15%
Nuclear	51.1	53%
Hydroelectric	0.5	<1%
Other Renewable	0	<1%

Nuclear Power in South Carolina

Oconee Nuclear Power Plant is located in Seneca, South Carolina. This facility is owned and operated by Duke Energy. The three pressurized water reactors (PWR) were constructed and then commissioned in the early 1970s. The approximate cost for the building of these three units was 1.96 billion dollars (2007). Each of the three units produces 846 megawatts (10^6 watts) of energy per year. In total, Oconee Nuclear Station has a maximum output capacity of 2500 megawatts of energy per year. In terms of hours, Oconee Nuclear provides 20,565 Gigawatt (10^9 watts) hours of power.

Like all US commercial reactors, Oconee Nuclear Station uses light water as a moderator and coolant. PWR contains 150-200 fuel rod assemblies. Both BWRs and PWR plants in the United States use low enriched uranium (LEU) embedded in each fuel rod as an energy source.



Figure **7.7.1**: Oconee Nuclear Power Plant. (Copyright; author via source)

For backup power, Oconee units 1-3 rely on hydroelectric sources provided by Lake Keowee. If this system were to fail, a nearby combustion facility will provide energy to cool the core uncase of emergencies.

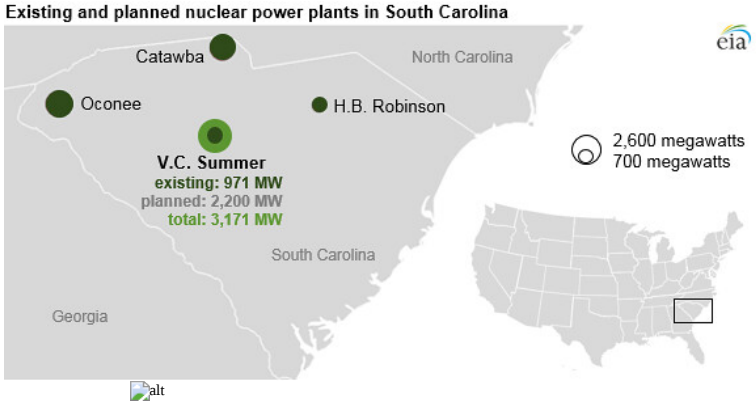


Figure **7.7.2**: Oconee reactor image taken from: upload.wikimedia.org/wikiped...arolina%29.JPG **Figure 7.7.3:**Nuclear power plants in South Carolina. Image taken from:https://c1.staticflickr.com/5/4410/3...258ed1cd_z.jpg

The Virgil C. (VC) Summer Nuclear Station is a Nuclear Power Plant located in Jenkinsville, South Carolina, that consists of one operating unit licensed since 1982. Westinghouse Electric Company LLC (Westinghouse), a U.S.-based nuclear power company later acquired by Toshiba, designed VC Summer's first unit as a three-loop, pressurized water reactor with a license to generate around 2,900 MWt of power for South Carolina, as seen below:



"Virgil C. Summer Nuclear Station, Unit 1" by NRCgov is licensed with CC BY-NC-ND 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by-nc-nd/2.0/ or CC BY-NC-ND 2.0.

After over 20 years of Unit 1's success, VC Summer's owners – SCANA Corporation, its subsidiary South Carolina Electric & Gas Company (SCE&G), and Santee Cooper – launched a massive expansion project of the plant in 2008 entailing the installment of two new reactors, Units 2 and 3. A state-owned utility company providing electricity and water to South Carolina residents since the 1930s, Santee Cooper (the South Carolina Public Service Authority) held smaller ownership in the project at around 45%, whereas SCANA, along with SCE&G, took a "majority ownership stake" of 55% and therefore handled the day-to-day operations of the project.

After SCANA entered an Engineering, Procurement, and Construction contract with Westinghouse and encountered a small planning delay in 2011, construction on the new units started in March 2013 and was immediately met with more delays. Despite the expected total cost of $9.8 billion dollars and completion dates of 2017 and 2018 for Units 2 and 3 respectively, SCANA announced the VC Summer expansion project would be delayed for at least one year and its units would cost an additional $1.2 billion. Upon reaching an important construction milestone on Unit 2 in installing a 'super module' in 2015, SCANA pushed back the completion of the reactor units back even further to 2019 and 2020.

SCANA's repeated reassurance to the community that its partner remained committed to finishing the project in February 2017 proved futile when Westinghouse filed for Chapter 11 bankruptcy in March 2017. Without adequate financial backing to complete the nuclear units, SCANA and Santee Cooper abandoned the VC Summer project in July 2017, citing inflated costs and another delayed completion date estimated at least 2024. The failed, incomplete nuclear project not only led to Dominion Energy's acquisition of SCANA but also resulted in a plethora of class action lawsuits by affected paying customers against the project's company owners and the prosecution of SCANA senior executives for fraud by both the Securities and Exchange Commission and South Carolina's U.S. Attorney's Office, followed by expensive settlements and plea agreements, explored below.

VC Summer Legal Controversies I: Class Action Lawsuits

Due to VC Summer's stakeholders' heavy financial reliance on revenue from customer utility bills to fund Unit 2 and 3's construction, both the SCANA corporation (now known as Dominion Energy) and Santee Cooper have settled several class-action lawsuits against them. A class- action lawsuit involves a plaintiff – the initiator of the lawsuit that has suffered an injury as a result of a defendant – that represents a large group of plaintiffs that have suffered the same or similar injury. Because a notable percentage of local South Carolinians' utility bills directly contributed to construction costs, many felt they were entitled to compensation once the VC Summer project was abandoned after years of collecting funds from the public. SCANA and Santee Cooper's extensive hold over the state drove many aggrieved customers to introduce several lawsuits, resulting in millions (and sometimes billions) of dollars in settlement agreements.

Richard Lightsey et al. v. SCE&G and SCANA, settled in the Court of Common Pleas in 2017 in Hampton County, South Carolina, resulted in the total settlement of up to two billion dollars in total for all affected SCE&G customers. A regularly updated ratepayer settlement website tracks the dates the settlement checks were released and summarizes the legal rights all SCE&G customers have in relation to the settlement; checks were mailed in August 2019.

The *Cook v. Santee Cooper* (2019) class action lawsuit also resulted in settlement checks for affected residents, all of whom directly or indirectly contributed to VC Summer's unfinished Unit 2 and 3's construction costs through utility bills. While Santee Cooper and SCE&G adamantly denied the allegation that it 'improperly charged' its customers in their electric bills, the company eventually agreed to settle for $520 million. SCE&G, now Dominion Energy, is required to cover $320 million of the settlement by placing the money into a Common Benefit Fund, while Santee Cooper covers the remaining $200 million in annual installment amounts beginning in 2020 of $65 million, $65 million, and $70 million, respectively. A webpage mirroring that of *Lightsey v. SCANA*'s settlement outlines additional specific details designed to advise all customers of their rights. Involved individuals received settlement checks in mid-November of 2020.



"Santee Cooper Bill" by TheDigitel Myrtle Beach is licensed under CC BY 2.0

SCANA Securities Litigation is a pending class-action lawsuit and settlement introduced by past SCANA investors. These groups alleged that SCANA's senior executive team mislead them through 'false and misleading statements,' violating federal securities laws. They are scheduled to receive $192,500,000 from the former SCANA Corporation – $160 million in cash and $32.5 million in cash or shares of Dominion Energy common stock. While checks have yet to be released to the affected stakeholders, the SCANA Securities Litigation website states that the first distribution will occur sometime in August 2021.

VC Summer Legal Controversies II: Criminal Indictments

Recently revealed criminal activity within the SCANA Corporation further compounded VC Summer's financial woes. On July 23, 2020, South Carolina's U.S. Attorney General's Office (SC USAO) announced that the former Executive Vice President of the SCANA Corporation, Stephen Byrne, had plead guilty to conspiracy to commit mail and wire fraud. The outcome of *SEC v. SCANA et al*, a South Carolina district court case, marked the conclusion of a joint investigation over several years by the U.S. Attorney's Office, the FBI, the U.S. Securities and Exchange Commission (SEC), the SC USAO, and the South Carolina Law Enforcement Division (SLED). Upon entering into a plea agreement with law enforcement, Byrne was required to work with state investigators to provide information into the network of SCANA executives that continuously lied about the progress of VC Summer's additional nuclear power stations to increase customer rates and qualify for production tax credits.

This case – referred to as a 'conspiracy to defraud SCANA customers' by the FBI – garnered attention from the USAO when they learned SCANA was charging its utility customers for additional commercial units that were not even built or operating yet. In *SEC v. SCANA et al*, the United States Securities Exchange Commission (SEC) alleged that Byrne, along with SCANA's CEO Kevin Marsh and its senior executive team, engaged in securities fraud by intentionally and repeatedly deceiving their investors and the general public about VC Summer's progress. Byrne carried out this fraud through issuing materially false and misleading statements as well as omissions to South Carolinians and South Carolina's Public Service Commission and the Office of Regulatory Staff. While he privately knew that construction on the plant was far behind schedule back in June of 2016, Byrne is said to have publicly informed all involved parties that construction would be completed on time to continue increasing customer utility bills and comfortably qualify for production tax credits.

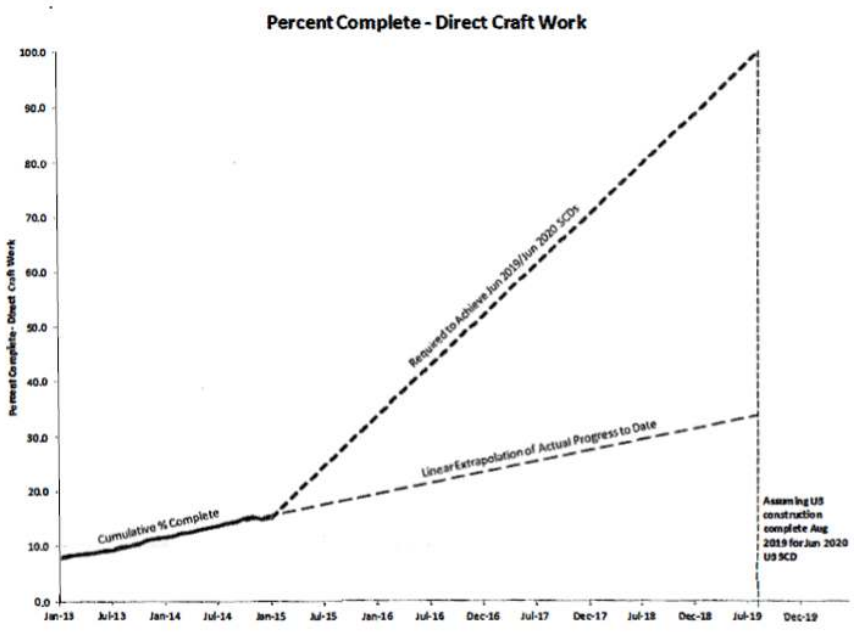


Image taken from https://www.sec.gov/litigation/compl...int-022720.pdf, the official complaint made against SCANA by the SEC on its official government website. The official litigation release can be viewed at https://www.sec.gov/litigation/litre...20/lr24976.htm.

The following year in February 2021, Kevin Marsh, the former CEO of the SCANA Corporation, also pleaded guilty to commit mail and wire fraud for his involvement in the abandoned nuclear reactor expansion project. Marsh admitted that he intentionally defrauded rate-payers in order for his company to "obtain and retain rate increases imposed on SCANA's customers and qualify for up to $2.2 billion in tax credits," as stated by the U.S. Attorney's Office. As CEO of a former Fortune 500 company, Marsh was charged for committing equally serious criminal offenses to that of Stephen Byrne. Furthermore, on June 10, 2021, the former Westinghouse VP Carl Dean Churchman plead guilty to making a false statement to the FBI as they were in the process of conducting the VC Summer investigation. A recent press release from the SC USAO's office indicated that the joint investigation by law enforcement and the FBI is ongoing, potentially signaling that more indictments are coming in the next few months.

Byrne and Marsh's indictments, plea deals, and sentencing to a maximum penalty of five years in prison with massive fines serve an important lesson for corporations looking to finance nuclear power plants while simultaneously defrauding the federal government and the public – **it's just not worth it.** When stakeholders deviate from the proper procedures necessary to license and fund nuclear power plants, criminal misconduct, including purposefully lying to investors and utility customers for financial gain, becomes second nature. However, if a mix of private and public governmental stakeholders follow the steps outlined in the previous section, timely, fully legal construction of commercial nuclear reactors in the United States is a real possibility, given that you have sufficient funds.

Contributors:

Andrew Allen (Furman University)

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For a brief introduction to VC Summer's Legal Drama, see here and here for the civil settlements and here for more on the criminal aspects of the case.

Affected investors serving as plaintiffs in *SCANA Securities Litigation* (2021) include West Virginia Investment Management Board, Stichting Blue Sky Global Equity's Active Low Volatility Fund, and Stichting Blue Sky Active Large Cap Equity USA Fund.

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7.8: Three Mile Island Nuclear Accident

The importance of cooling and containment are amply illustrated by three major accidents that occurred with the nuclear reactors at nuclear power generating stations in the United States (Three Mile Island), the former Soviet Union (Chernobyl), and Japan (Fukushima). Other nuclear incidents have occurred around the world that have involved the storage or transportation of nuclear materials.

Three Mile Island (Harrisburg, Pennsylvania, March 28, 1979)

The two reactors housed at this facility are located in Middletown, Pennsylvania. This site is approximately 10 miles southeast of Harrisburg, Pennsylvania. Both units are PWRs (pressurized water reactors) are were commissioned in the mid to late 1970s. Before the accident, each of the Three Mile Island (TMI) reactors generated around 800 MW of electrical power. The smaller cylindrical buildings in the photograph below are units 1 and 2 reactors at this facility. The four larger structures in this picture are the cooling towers that allow excess heat to be transferred to the atmosphere.



Figure **7.8.1**: Color photograph of the Three Mile Island nuclear- generating station, which suffered a partial meltdown in 1979. The reactors are in the smaller domes with rounded tops (the large smokestacks are just cooling towers). (United States Department of Energy)

On March 28, 1979, Three Mile Island's Unit Two reactor lost cooling water in the secondary loop (note blue loop in the figure below). This event occurred around 4:00 a.m. and alarms sounded in the control room immediately. Within one minute, the reactor automatically shut down. Meanwhile, water in the primary loop (yellow tube) overheated and the pressure of the reactor increased. To relieve this excess pressure inside the reactor, the pressure relief valve (top yellow/red tube) opened up. Backup pumps restarted the water in the secondary loop to assist cooling efforts.

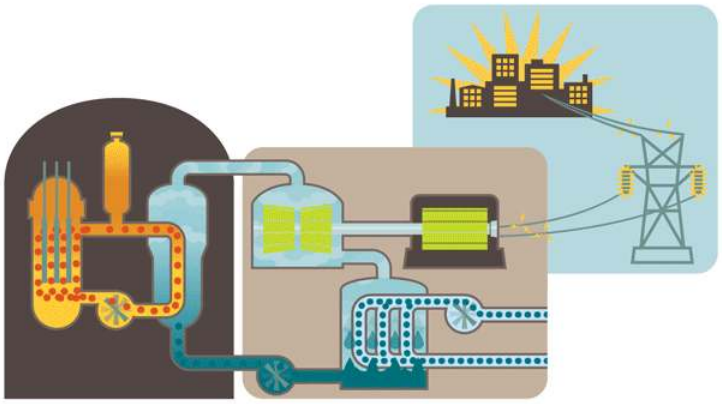


Figure **7.8.2**: The following animated diagram graphically depicts the sequence of events associated with the accident at TMI-2. (United States Nuclear Regulatory Commission; Public Domain).

In the control room, operators noted the decrease in pressure of the reactor and a reduction of cooling water in the primary loop. Within fifteen minutes of the original malfunction, approximately 3000 gallons of cooling water had escaped the reactor but remained in the containment building. The reactor components (fuel and control rods) became exposed to a lack of water. These

materials were melted to various degrees. Back in the control room, instrumentation noted that the pressure valve remained closed. Operators attempted to cool down the control and fuel rods by pumping more water into the primary loop of the reactor. Unfortunately, the pressure value was still open and most of the water converted to steam. This made temperatures increase greatly in the reactor core.



Figure **7.8.3**: President Jimmy Carter leaving Three Mile Island for Middletown, Pennsylvania., 04/01/1979. (https://catalog.archives.gov/id/540021)

By 6:22 a.m., the operators closed a valve before the pressure release valve. This allowed water to remain in the primary loop. Unfortunately, most of the water in the core was in the form of steam and did not circulate efficiently throughout the core. In addition, the steam reacted with metals in the control and fuel rods. These reactions produced combustible hydrogen gas which rose to the top of the reactor core. By 7:50 a.m., all cooling water was restored to the core successively, but a large hydrogen bubble hovered over the top of the reactor. At this time, operators were fearful the bubble might ignite and then explode the core to the outside environment. To prevent this explosion from happening, operators and engineers vented the hydrogen gas outside the nuclear reactor into the atmosphere. This venting occurred from March 30 until April 1, 1978.



Figure **7.8.4**: A sign in Middletown, Pennsylvania dedicated in 1999 describing the Three Mile Island accident, the evacuation of the residents in the area, and the impacts to the nuclear power industry. (Wikipedia Commons)

Residents in nearby communities were informed of a nuclear issue around 7:24 a.m. on March 28, 1979. Radio and television broadcasts started within the next hour. By 12:45 p.m., representatives of the Department of Energy (DOE) arrived to evaluate the current status of the reactor. DOE agents put together a plan of action to keep the reactor under control. Numerous state governmental officials met with the DOE and devised safety protocols (remain indoors) and emergency evacuation plans if the hydrogen bubble were to burst. To see a comprehensive timeline of these events, please click here.

In the venting process, a minimal amount of radioisotopes were released to the areas surrounding the TMI nuclear power station. Several independent research facilities have quantified the radiation that was released during the accident These studies state that residents within 10 miles of TMI were exposed to radiation within the range of 0.08 mSv to 1 mSv. Referring back to Section 5.8, this level of radiation is comparable to having a chest x-ray exam (Table **7.8.2**).

Table **7.8.1***: Fission products vented to the atmosphere from TMI 2*

Isotope	Emits	Half-life ($t_{1/2}$)
Kr-85	beta particles, gamma rays	10.8 years
Cs-137	beta particles, gamma rays	30.2 years
I-131	beta particles, gamma rays	8.0 days
Xe-133	beta particles, gamma rays	5.3 days

In 1984, nuclear scientists were able to survey the destruction of the reactor core. They concluded that approximately 1/3 of the fuel rods melted inside the reactor. This accident was labeled a partial meltdown (full meltdown would indicate the majority of fuel rods were melted). The contaminant structure remained intact and protected the citizens of the area.

The clean-up process for TMI unit 2 started in August of 1979. It was a twelve-year project that employed over 1000 people. All radioactive fuel and water were shipped to existing nuclear waste storage facilities in the United States (Washington State and Idaho). The containment building for this reactor still remains and houses waste for the TMI unit 1. The approximate clean-up price for this accident was 973 million dollars.

The accident at Three Mile Island halted all construction of new nuclear power plants in the United States. Many citizens became fearful of nuclear power in general and became supportive of other types of energy sources. Films like the China Syndrome catalyzed this feeling for decades after this catastrophe.



Video **7.8.1**: Description of TMI Unit 2 partial meltdown.

At the time of the partial meltdown of TMI Unit 2, reactor 1 was shut down for refueling. Despite much opposition, Unit 1 was restarted in the fall of 1985 has been providing power to the residents of this area until September 2019. Funding could not be secured in order to keep this unit running due to the relatively low cost of fossil fuels.

Example 7.8.1

The average radiation exposure due to the TMI Unit 2 accident was between .08mSv and 1 mSv. Calculate this dosage in rem and mrem. Compare these values to average background radiation (360 mrem) and Acute Radiation Syndrome (ARS, 25 rem). To refresh your memory, click on this link and view example 5.8.1

Solution

For the first calculation, recall the metric prefix milli from Chapter 2.

$$\frac{.08\ \cancel{mSv}}{1}\left|\frac{1\ rem}{1000\ \cancel{mSv}}\right. = 8 \times 10^{-5}\ rem$$

For the second calculation, you will need to insert the 100 rem = 1 Sv factor. Then, you will need to use the milli metric prefix again.

$$\frac{8 \times 10^{-5}\ \cancel{rem}}{1} \left| \frac{1\ \cancel{Sv}}{100\ \cancel{rem}} \right| \frac{1000\,mSv}{1\ \cancel{Sv}} = 8 \times 10^{-4}\,mSv$$

Comparing the calculated mrem level to background radiation, one can see that this is a small concentration of radiation. As for the ARS level, the first calculated rem value is significantly lower than 25 rems.

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7.9: Chernobyl Nuclear Disaster

Chernobyl (Pripyat, Ukraine, April 26, 1986)

Another major nuclear accident involving a reactor occurred in April 1986, at the Chernobyl Nuclear Power Plant in Ukraine, which was still a part of the former Soviet Union. While operating at low power during an unauthorized experiment with some of its safety devices shut off, one of the reactors at the plant became unstable. Its chain reaction became uncontrollable and increased to a level far beyond what the reactor was designed for. The steam pressure in the reactor rose to between 100 and 500 times the full power pressure and ruptured the reactor. Because the reactor was not enclosed in a containment building, a large amount of radioactive material spewed out, and additional fission products were released, as the graphite (carbon) moderator of the core ignited and burned.

Inside Look



Video 7.9.1: High detail 3D animations and explanations of the inner workings of Chernobyl nuclear power station. Showing why it was so vulnerable to blowing itself up and how it was different from western reactors.

Watch the video above (8:42 in length) and answer the questions below:

1. How many working reactors were at the Chernobyl Power Plant site? How many more were under construction?
2. Which unit experienced a full meltdown?
3. What type of fuel and moderator did Chernobyl use?
4. Describe the positive void coefficient? Are Western reactors designed to experience positive void coefficients?
5. Compare the basic core size of Fukushima to Chernobyl.
6. Compare the basic containment layers of Fukushima to Chernobyl.
7. What is the purpose of leaving the top of an RBMK reactor open? Do Western reactors have this design?
8. What events led to the explosion of Chernobyl? Was this a chemical or a nuclear explosion?
9. Name the two countries that were most affected by the Chernobyl meltdown.
10. Did the people who cleaned up Chernobyl have special training in radiation? What is the nickname of these individuals?
11. How fast did the USSR construct the first sarcophagus? Why did it need to be replaced?
12. Look below to the section of Today's Chernobyl. The EU constructed this massive structure. How much did this cost and how long did it take to build?
13. Does Russia still use RBMKs?
14. Describe the ghost town of Pripyat today. Just before the accident, an amusement park was constructed to celebrate May Day. Did the people of Pripyat get to enjoy the Ferris Wheel? Would you have gotten on that Ferris Wheel during that time (assuming you were on this planet)?

Basics of the Disaster

On April 26, 1986, a test was scheduled at the Chernobyl Nuclear Power Plant to evaluate residual cooling capacity in the event of a power grid failure. At the time of the accident, the Chernobyl facility used four RBMK (Reaktor Bolshoy Moshchnosty Kanalny or high power channel) reactors to produce a total of 4000 MW of energy. Two more reactors were being constructed to produce additional wattage. RBMKs not only produce a large amount of energy but also produce weapons-grade Pu-239. The excessive power, design, and materials of these reactors have discouraged many countries (the United States) from building them.



Video **7.9.2**: Video from the 2019 HBO miniseries " Chernobyl."

Components of the Chernobyl RMBK reactors.

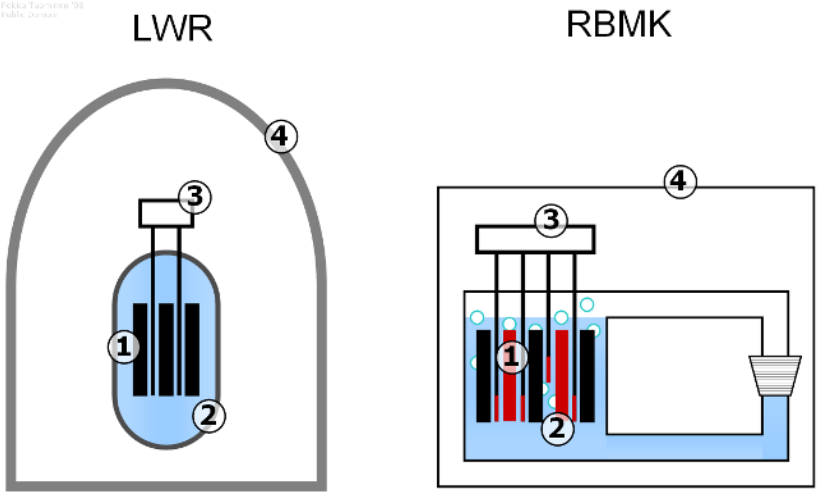


Figure **7.9.1**: The critical differences in the RBMK reactor compared to a LWR (Light Water Reactor) that directly contributed to the Chernobyl disaster. 1. The flammable graphite moderator in the reactor core that burned in the fire, 2. The positive void coefficient in the water made possible the power peak that blew the reactor vessel, 3. The control rods were very slow, they took 18-20 seconds to be inserted into the reactor. Moreover they had graphite tips that actually intensified the fission chain reaction in the beginning of the insertion. 4. No containment building at all, data from IAEA: *INSAG-7 The Chernobyl Accident: Updating of INSAG-1*. Vienna, 1992; NEA:*Chernobyl - Assessment of Radiological and Health Impacts*. Pariisi, 2002; Nakao, M.: *Chernobyl Accident*. University of Tokyo, 2006.

Unlike light water reactors, RBMK reactors use graphite moderators to slow the neutrons of the fission process. This type of material can combust easily. The less enriched U-235 fuel of this reactor produces Pu-239 to be produced. Unfortunately, the Chernobyl reactor technicians felt that removing the new Pu-239 fuel would be too difficult with a full containment covering of unit 4. The new Pu-239 material would be extracted while the reactor continued to produce energy. The high power wattage, combustible moderator, and open containment convinced many other countries to steer clear of building RBMKs.When comparing the differences of RBMK reactors to those typically used in most other countries, view the table below:

Table **7.9.1**: Types of Nuclear Reactor

Type of Reactor	Containment	Fuel	Coolant	Moderator
PWR	repetitive layers of lead/ concrete and top is closed inside the reactor building	slightly enriched U-235 (2-4%)	LW = light water	LW = light water
BWR	repetitive layers of lead/ concrete and top is closed inside the reactor core building	slightly enriched U-235 (2-4%l	LW = light water	LW = light water
RBMK	layers of lead/concrete and top is open inside the reactor core building to allow extraction of rods while the reactor is producing energy	low enriched U-235 (<2%)	LW = light water	Graphite (carbon)

Before the accident

Nuclear reactors require active cooling in order to remove the heat generated by radioactive decay. Even when not generating power, reactors still generate some heat, which must be removed in order to prevent damage to the reactor core. Cooling is usually accomplished through fluid flow, water in Chernobyl's case.

The problem at the Chernobyl plant was that following an emergency shutdown of all power, diesel generators were needed to run the cooling pumps. These generators took about a minute to attain full speed, which was deemed an unacceptably long time for the reactor to be without cooling. It was suggested that the rotational momentum of the winding down steam turbine be used to power the pumps in the time between shutdown and the generators being ready. A test was devised to test this method in 1982, but the turbine did not prove to be successful in providing the required voltage as it spooled down. Two more tests would be conducted in the following years, but would also be unsuccessful. The fourth test was scheduled to be run on April 25, 1986.



Figure 7.9.2: Interior view of the control room of Chernobyl Nuclear Power Plant unit 3. Over 3,000 people continue to work at Chernobyl to monitor nuclear fuel and carry out the decommissioning of the facility. (www.iaea.org/NewsCenter/Multi...bank/index.js

The experiment was devised in such a way that if it had gone as planned, the disruption and danger to the plant would be very minimal. First, the reactors would be brought down to low power, between 700 and 800 megawatts. Then the steam turbine would be run up to full speed and then turned off. The power generated by the winding down generators would then be measured to determine if it was sufficient to power the cooling pumps in the time before the diesel generators got up to full speed.

By 1986, the plant had been running for two years without the implementation of a method to keep the cooling pumps running continuously following an emergency shutdown. This was an important safety measure that the plant was lacking, which presumably gave the plant managers a considerable amount of urgency in completing another test.

Preparing for the test

The experiment was scheduled to run during the day shift of 1985, while the night shift would only have to maintain cooling of the radioactive decay in the shut-down plant. However, another power generator nearby unexpectedly shut down, necessitating the need for the Chernobyl plant to delay the test and continue producing power. The experiment would be resumed at 11:04 PM, by which time the day shift had departed and the evening shift was about to leave. This meant that the experiment would be conducted in the middle of two shifts, leaving very little time for the night shift employees to be briefed about the experiment and told what to do.

The power reduction of reactor 4 to 700 MW was accomplished at 00:05 AM on the 26th of April. However, the natural production of a neutrino absorber, Xenon-135, led to a further decrease in power. When the power dropped to about 500 MW, the night shift operator committed an error and inserted the reactor control rods too far. This caused the reactor to go into a near-shutdown state, dropping power output to around 30 MW.

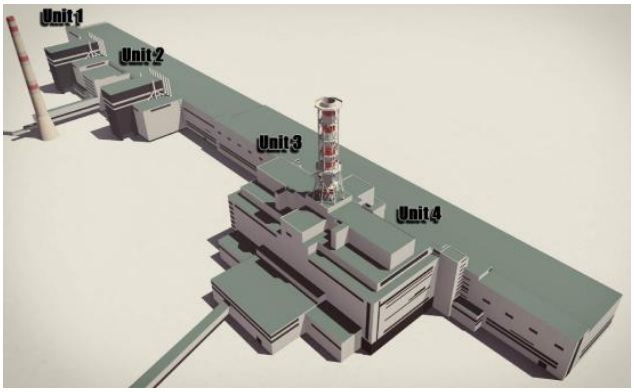


Figure **7.9.3**: Layout of four working RBMK reactors at the Chernobyl Nuclear Power plant. (Copyright; By Tadpolefarm - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/inde...curid=81169789)

Since this was too low for the test, it was decided to restore power by extracting the control rods. Power would eventually rise and stabilize at around 200 MW.

The operation of the reactor at such a low power level would lead to unstable temperature and flow. Numerous alarms and warnings were recorded regarding emergency measures taken to keep the reactor stable. In the time between 12:35 and 12:45 AM, alarm signals regarding thermal-hydraulic parameters were ignored in order to preserve the reactor's power level.

The test continued, and at 1:05 AM extra water pumps were activated in order to increase the water flow. The increased coolant flow rate led to an increase in the coolant temperature in the core, reducing the safety margin. The extra water flow also led to a decrease in the core's temperature and increased the neutron absorption rate, decreasing the reactor's power output. Operators removed the manual control rods in order to maintain power.

All these actions led to the reactor being in an unstable state that was clearly outside safe operation protocol. Almost all the control rods had been removed, which reduced the effectiveness of inserting safety rods in an emergency shutdown. The water was very close to boiling, which meant that any power increase would cause it to boil. If it started boiling, it would be less effective at absorbing neutrons, further increasing the reactor's power output.

Conducting the test

The experiment was started at 1:23:04 AM. The steam to the turbines was shut off, causing the turbines to start spooling down. Four of the eight cooling pumps were also shut down. The diesel generator was started and began powering the cooling pumps after at 1:23:43. Between this time, the four pumps were powered by the slowing steam turbines. As the turbines slowed down, their power output decreased, slowing the cooling pumps. This leads to the increased formation of steam voids in the core, reducing the ability of the cooling water to absorb neutrons. This increased the power output of the reactor, which caused more water to boil into steam, further increasing the reactor's power. However, during this time the automatic control system was successful in limiting power increase through the insertion of control rods.



Video 7.9.3: Chernobyl nuclear accident why happened? Animated Demonstration

At 1:23:40, a button was pressed that initiated the emergency shutdown of the reactor and the insertion of all control rods. It is believed that this was done as a routine method to shut down the reactor to conclude the experiment and not as an emergency measure.

The process of inserting the control rods was initiated, but it took about 20 seconds for the rods to be completely inserted. A flawed design in the graphite-tip control rod meant that coolant was displaced before the neutron absorbing material could be fully inserted and slow down the reaction. This meant that the process of inserting the control rods actually increased the reaction rate in the lower half of the core.



Video 7.9.2: Trailer video from the 2019 HBO miniseries " Chernobyl."

A massive power spike occurred, causing the core to overheat. Some of the fuel rods fractured, causing the control rods to become stuck before they were fully inserted. Within three seconds the core's power output rose to above 500 MW. According to the simulation, it is estimated that power output then rose to 30 GW, ten times the normal power output. This was caused by the rising power output causing massive steam buildup, which destroyed fuel elements and ruptured their channels.

It is not possible to know precisely what sequence of events led to the destruction of the reactor. It is believed that the steam buildup entered the reactor's inner structure and lifted the 2000 ton upper plate. This steam explosion further ruptured fuel channels, resulting in more coolant turning into steam and leaving the reactor core. This loss of coolant further increased the reactor's power. A nuclear excursion (an increasing nuclear chain reaction) caused a second, even more, powerful explosion.

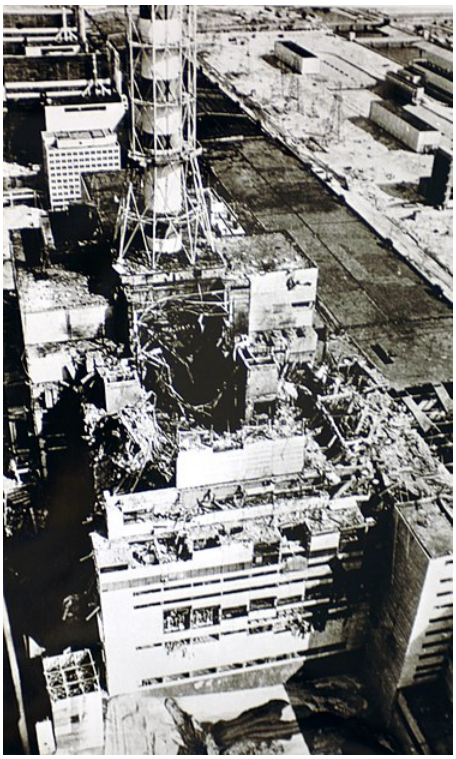


Figure 7.9.4: A new reckoning of time began on 26 April 1986 At 1:23:45 AM. This photo was taken from a helicopter on the day following the explosion of the Chernobyl #4 reactor. IAEA Imagebank - 02790015

The explosion destroyed the core and scattered its contents in the surrounding area, igniting the red-hot graphite blocks. Against safety regulations, a flammable material, bitumen, had been used in the roof of the reactor. When this was ignited and scattered into the surrounding area, it started several fires on reactor 3. Those working there were not aware of the damage that had been done and continued running the reactor until it was shut down at 5:00 AM.

Radiation Levels and Fallout

In the worst-hit parts of the reactor building, radiation levels were high enough to cause fatal doses in a matter of minutes. However, all dosimeters available to the workers did not have the ability to read radiation levels so high and thus read "off-scale." Thus, the crew did not know exactly how much radiation they were being exposed to. It was assumed that radiation levels were much lower than they actually were, leading the reactor crew chief to believe that the reactor was still intact. He and his crew would try to pump water into the reactor for several hours, causing most of them to receive fatal doses of radiation.

Since containment failed at Unit 4 Reactor, particle and wave radiation emerged from the burning power plant. Winds carried the fallout to various places in the European continent. Click on this previous OER page for a review of radioactive fallout.



Figure **7.9.5**:Figure **7.9.5**: Chernobyl radiation map from CIA handbook. (http://www.lib.utexas.edu/maps/commonwealth/chornobyl_radiation96.jpg and File:Tchernobyl_radiation_1996.svg for the vector version)

Concentration of Radiation around Unit 4

Radiation is measured with a variety of units. In order to understand biological damage, click on this previous OER page and read about Sieverts (Sv) and Rem. (rem). Also, refer to your learning management (LMS) for problems involving rem and Sv conversions.

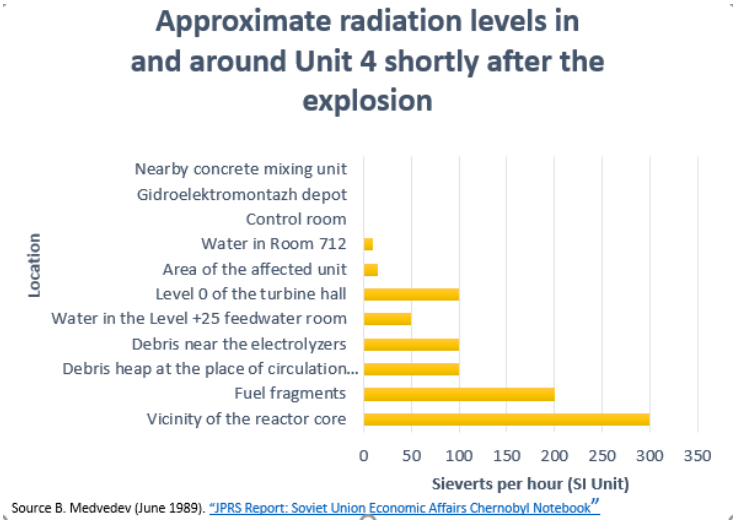


Figure **7.9.6**: **Čeština:** Přibližné stupně radiace krátce po explozi 4. reaktoru v černobylské jaderné elektrárně.https://commons.wikimedia.org/w/index.php?title=User:Sandra_K%C5%99%C3%AD%C5%BEov%C3%A1&action=edit&redlink=1

Evacuation of Pripyat

Pripyat, a city nearby the power plant, was not immediately evacuated. At first, the government denied that the reactor had exploded and insisted that it was only a small accident. By April 27, though, investigators were forced to acknowledge that the reactor had exploded and ordered Pripyat to be immediately evacuated. The process of moving over 40,000 people from this area was started around 2 p.m. following the nuclear explosion. Over 1200 buses from Kyiv, transported this city's inhabitants beyond the exclusion zone.



Video **7.9.3**: Message of evacuation the city of Pripyat (1986)

On April 28, Sweden's Forsmark Nuclear Power plant detected the presence of I-131 of their radiation detectors. Late into that night, Moscow news reported that an accident had occurred at the Chernobyl Nuclear Power plant. Within an hour of this announcement, Denmark had also detected isotopes that result only from nuclear fission.

Fatalities and Health Effects

At the time of the accident, around 600 people were employed at the Chernobyl Nuclear Power Plant. When the explosion occurred, two workers immediately died. Two decades of radiological health studies performed by the World Health Organization (WHO) have determined that approximately 134 Chernobyl employees were exposed to high-dose radiation (.8-1.6 Gray). These workers would be diagnosed with having Acute Radiation Sickness (ARS). Of the 134 ARS victims, 28 of these individuals passed within the next three months.



Figure **7.9.7**: Erected near the Chernobyl site is a monument to the "liquidators", an estimated quarter of a million soldiers and citizens enlisted as the 1986 accident's "first responders". (Chernobyl, Ukraine, 1991) (Petr Pavlicek/IAEA)

In the 2011 report entitled, "Health effects due to radiation from the Chernobyl accident," the United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR), states that 530,000 of the reactor's recovery workers were exposed to ionizing radiation dosages between 20-500 mSv. This test group was initially studied from April 1986 through 1990. Currently, health monitoring of these individual continues. Studies have determined that workers who were exposed to over 200mSv were more likely to develop leukemia. Radiation Induced cataracts were also noted in workers that were exposed at levels lower than 200 mSv.

Over 115,000 people who lived in the Ukraine and Belarus evacuated after the meltdown of Unit 4. Radiation levels reported for this particular group were around 30 mSv. As for other parts of Europe, radiation exposure from the Chernobyl meltdown was considered to be less than yearly background radiation (1 mSv).

UNSCEAR reports that there is a significant increase in diagnoses of thyroid cancer that can be attributed to I-131. Over 6,000 people (with less than 1% mortality rate) in Belarus and the Ukraine have developed this cancer during the study. Exposure to this radioactive isotope could have been due to direct fallout exposure or indirect means (drinking milk from cows who ingested I-131 or eating foods grown in radioactive soil).

There seems to be little or no affect in regards to fertility impairment with any of the evacuees. As for birth defects, residents of Belarus and the Ukraine have reported more birth defects since the accident occurred. UNSCEAR has stated that this increase could be that individuals are more likely to report any type of birth defect now than any before the meltdown occurred. Due to the nature of the accident and evacuation effort, many citizens of Belarus and Ukraine have reported an increase in mental health conditions.

Temporary Containment

Later the reactor was encapsulated in steel and concrete, a now-decaying structure known as the sarcophagus. The construction of this covering occurred in May of 1986 and was completed by November of that same year. Not long after construction, the protective covering was cracked and released more radiation.



Figure **7.9.8**: The Chernobyl reactor #4 building as of 2006, including the later-built sarcophagus and elements of the maximum-security perimeter.(https://www.flickr.com/photos/83713082@N00/535916329; Carl Montgomery)

Today's Pripyat

Today, radiation levels are still higher than normal in the areas surrounding the plant but have dropped considerably from the levels that they were at twenty years ago. It is now considered safe to visit the areas immediately surrounding the plant for short periods of time. However, it is estimated that it will take 20,000 years for reactor 4's core to be completely safe.



Figure **7.9.9**: Montage of Pripyat(Copyright; Wikiwind (montage); (WT-en) RealLeo at English Wikivoyage (Pripyat CentralSquare.jpg); Jorge Franganillo from Barcelona, Spain (Pripyat (38307778522).jpg, Pripyat welcome sign (38071252145).jpg, Pripyat (38338630751).jpg); Alexander Blecher, blecher.info (Chernobyl Exclusion Zone (2015) 68.JPG); Shanomag (The Abandoned Sports Hall in Pripyat - Chernobyl.jpg).)

Today's Chernobyl

Previous issues - Unit 1- meltdown (immediate shutdown, restarted, and finally shut down in 1996). 1986-full meltdown of Unit 4. 1992- Unit 2, fire in turbine room, shut down due to Unit 4 publicity and Unit 3 ran until 2000.

The cake plate moved over reactor 4 in November 2016.

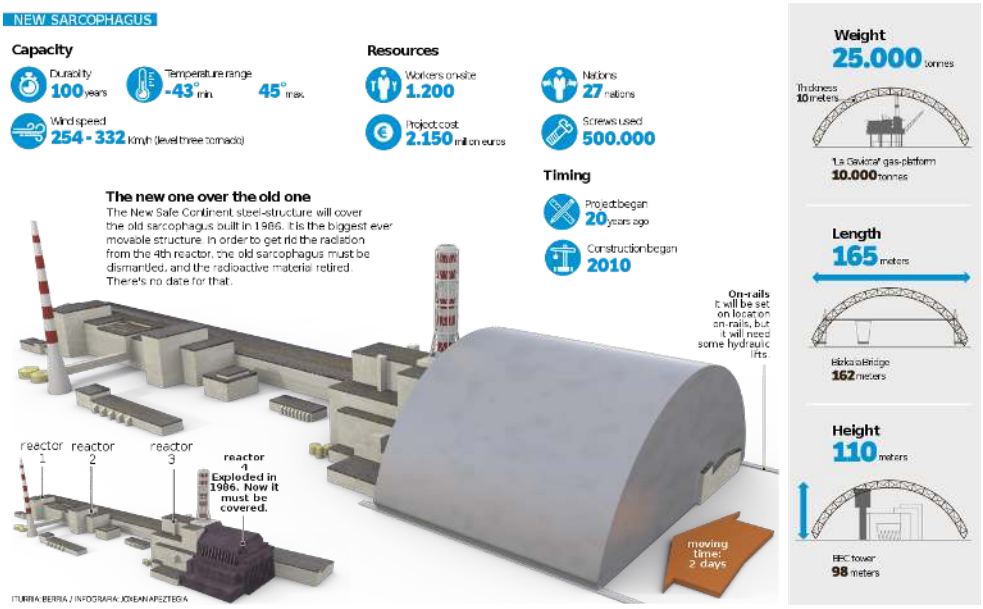


Figure 7.9.10: This image covers the construction of the Chernobyl New Sarcophagus. (File:1121-Txernobylgo zentral nuklearrerako arkofago berria.svg;)

Nuclear Tourism



For tour info: https://www.chernobyl-tour.com/english/

Resources

- http://www.nucleartourist.com/events/chernobl.htm
- en.Wikipedia.org/wiki/Chernobyl_disaster
- Microsoft Word - WHO Report on Chernobyl Health Effects corrected July 5 06.doc
- Mitigating health consequences of Chernobyl (who.int)

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7.10: Fukushima Nuclear Disaster

Learning Objectives

- Explore the components of a Fukushima nuclear reactor.
- Compare and Contrast Fukushima reactors to United States reactors.
- Determine how partial meltdown occurred at Units 1 and 2 at the Fukushima Nuclear Power Plant.
- Determine if a partial meltdown at Fukushima could have been avoided.
- Note the timeliness of evacuation efforts and compare them to the Chernobyl Nuclear accident.
- Compare radiation dosages and fatalities at Fukushima to those at Chernobyl and Three-Mile Island
- Review the safety of building nuclear reactors at geographical spots around the globe.

Nuclear Power Plants in Japan

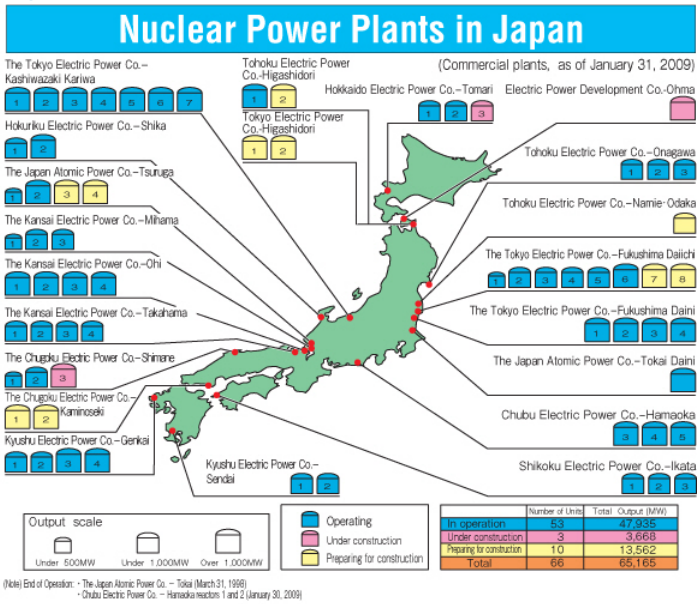


Figure 7.10.1: Copy and Paste Caption here. (Copyright;))

Background of Fukushima Dai-ichi nuclear facility

Fukushima Dai-ichi nuclear station was commissioned in March 1971. Six boiling water reactors (BWR) were designed to produce a net energy output of 2719MW. General Electric designed Units 1 (460 MW), 2(784 MW), and 6(1100 MW). Toshiba constructed Units 3 (784 MW) and 5 (784 MW). Lastly, Hitachi devised Unit 4 (784 MW). All six reactors were managed and maintained by the Tokyo Electric Power Electric Company (TEPCO).

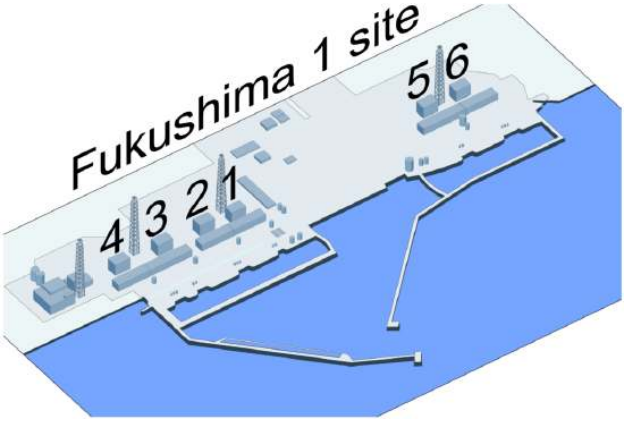


Figure **7.10.2**: Fukushima I Nuclear Powerplant site close-up without text. (Copyright; https://commons.wikimedia.org/w/inde...edit&redlink=1)

These six units all employed light water as a coolant and a moderator. All but unit 3 utilized low enriched uranium (LEU) for fissionable fuel. Unit 3 produced energy from mixed oxide fuel (M.O.X) which is composed of LEU oxides and fissionable Pu-239 oxides. Units 1-5 had a Mark 1 containment system while Unit 6 had upgraded to a Mark 2 containment model.

Previous observations of facility

Sea wall

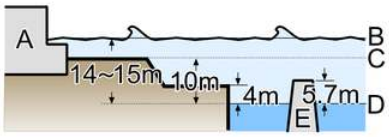


Figure **7.10.3**: The height of the tsunami that struck the station approximately 50 minutes after the earthquake. A: Power station buildings B: Peak height of tsunami C: Ground level of site D: Average sea level E: Seawall to block waves. (Copyright, https://commons.wikimedia.org/w/inde...edit&redlink=1)

Storage of spent fuel rods

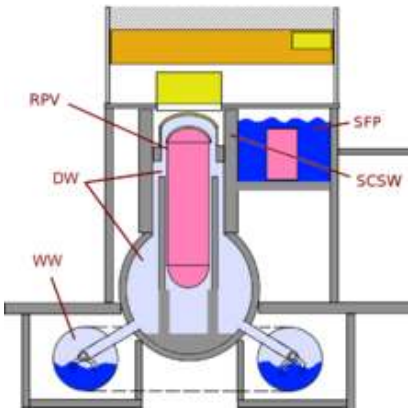


Figure **7.10.4**: Cross-section of a typical BWR Mark I containment as used in units 1 to 5. **RPV**: reactor pressure vessel **DW**: dry well enclosing reactor pressure vessel. **WW**: wet welll – torus-shaped all around the base enclosing steam suppression pool. Excess steam from the drywell enters the wet well water pool via downcomer pipes. **SFP**: spent fuel pool area **SCSW**: secondary concrete shield wall (Copyright; Sketched in Paint.net using 826 x 852 canvas inspired by Page 15 (pdf: 40), Containment Integrity Research at Sandia National Laboratories - An Overview, Manuscript completed: March 2006, Published: July 2006, id: NUREG/CR-6906 and SAND2006-2274P [1] - Prepared by Sandia National Laboratories for the U.S. Nuclear Regulatory Commission, Job Code Y6757. The two diagrams on the same page are labeled: *Figure 5 Typical BWR Mark I Concrete Containment with Steel Torus.*

Back up power sources

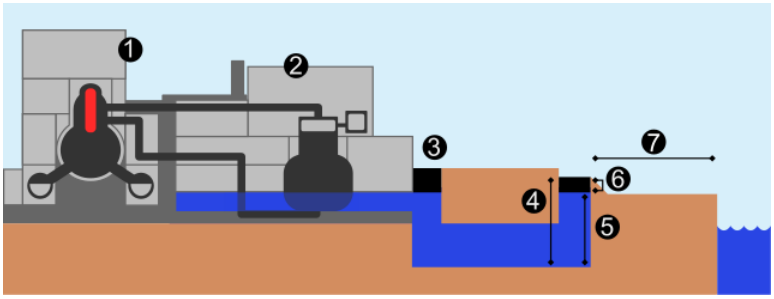


Figure \(\PageIndex{5\): The diagram is labeled simply with numbers to be language neutral. Hope this helps! Key: 1 Reactor building; 2 Turbine generator and associated condenser; 3,4,5,6 and 7: various trenches and pipe tunnels (Copyright;https://commons.wikimedia.org/wiki/User:Nesnad)

After the Tsunami

On March 11, 2011, the Fukushima Daiichi Nuclear Power Plant in Japan was badly damaged by a 9.0-magnitude earthquake and resulting tsunami. At the time, Units 4,5, and 6 were shut down for refueling and maintenance. Once the earthquake arrived at 2:46 p.m., the control rods of units 1, 2, and 4 were immediately submerged completely in their corresponding reactor vessels. Automatically, emergency generators came online to power electronics and coolant systems. However, the tsunami quickly flooded the emergency generators and cut power to the pumps that circulated coolant water through the reactors. High-temperature steam in the reactors reacted with zirconium alloy to produce hydrogen gas. The gas escaped into the containment building, and the mixture of hydrogen and air exploded. Radioactive material was released from the containment vessels as the result of deliberate venting to reduce the hydrogen pressure, deliberate discharge of coolant water into the sea, and accidental or uncontrolled events.



Watch the video above (13:01 minutes) and answer the questions below. **This video is quite technical. Please focus on the questions and don't become overwhelmed with the comprehensive explanation of the reactor design.**

1) What two natural disasters occurred prior to the Fukushima nuclear disaster? How many people lost their lives due to these natural disasters?

2) How many reactors were producing energy before the explosion? How many reactors were unloading fuel? Lastly, how many reactors were shutdown?

3) What type of reactors were used at this site (RBMK, PWR, BWR, or AP1000)? Does the United States use this type of reactor?

4) Where was the spent fuel stored in the reactor? Note: The United States does not store spent fuel in this location of the reactor.

5) When the earthquake hit, did the control rods work?

6) If a reactor site loses power, they need a backup power supply to keep the reactor core cool. Did Fukushima eventually lose back-up power? What did this do to reactors 1-3?

7) Several times, the NRC and IAEA told Fukushima that their sea walls were too low. How did this contribute to the loss of back-up power?

8) Not having enough coolant, led to the production of hydrogen gas. What is the danger of having this gas inside the reactor core?

9) To reduce the pressure of the core, workers at Fukushima vented the radioactive gas into the atmosphere (similar to Three-Mile Island situation). How else did this radiation affect the planet?

10) Workers at Fukushima used seawater to cool the core. What is the problem with using this substance?

11) Did the containment of the reactors hold?

12) What is a cold shutdown? Has this been achieved yet?

13) Do Japan force its citizens to man and then clean-up Fukushima? Do you think the people involved understood the hazards of radiation (unlike Chernobyl)?

14) At Fukushima, there were two deaths at the reactor site due to the natural disaster. There have been no reported deaths due to the meltdowns. How does this differ from Chernobyl?

Explosions and Meltdown

Immediately after the earthquake, the six external power supplies shut-down. Loss of external power could result in overheating in the reactor cores. Of the six diesel back-up generators, only one remained functional to provide cooling water. This generator cooled units 5 and 6 until it lost power. The five other diesel generators were flooded when the Tsunami hit. As a last resort, Fukushima accessed their 125 volt DC back-up batteries. One of these energy sources was able to keep unit 3 cool for 30 hours until it failed to produce any more power.

Unfortunately, hydrogen gas was produced in units 1-4. Explosions of this gas occurred in units 1,3 and 4. On March 14, hydrogen gas explosions blew to the rooftops off of Units 1 and 3. There was no damage to the 20 cm thick steel containment structure.



Evacuation of the area surrounding Fukushima Dai-chi

Around 3:40 p.m., back-up sources for the reactors lost power. Evacuation of a 2 km radial zone began at 7:03 p.m. Two hours, later the radius of evacuation was increased to 3 km. The Japanese government announced the following morning that the evacuation zone would increase to 10 km. Later that day, the final evacuation zone of 20 km was publicized. An estimated 200,000 people were evacuated from this area.

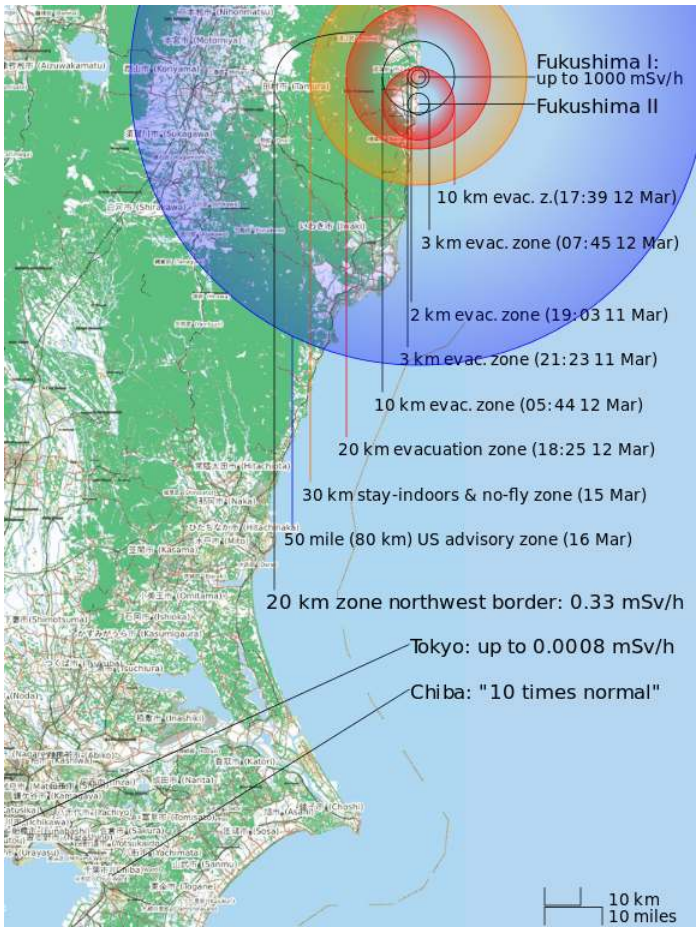


Figure **7.10.6**: Fukushima I and II Nuclear Accidents Overview Map showing evacuation and other zone progression and selected radiation levels as of March 15. (Copyright;CMG Lee and OpenStreetMap contributors)

Radiation Levels

On March 16, radiation dosages inside the nuclear power station were 400 mSv per hour. Outside the facility, dosimeters measure 1.9 mSv per hour. The average TEPCO worker was exposed to 50-100 mSv per hour while on-site at the nuclear power plant.

As of 2021, there have been no reported deaths due to the partial meltdowns, explosions, or fallout from this nuclear disaster. Unlike the Chernobyl disaster, TEPCO workers (mostly composed of older males) volunteered in shifts to monitor the reactors during the accident. They were provided with protective equipment and potassium iodide pills.

? Exercise 7.10.1

Compare the radiation dosages of a TEPCO employee and outside the Fukushima Dai-ichi to that of yearly background radiation (360mrems) and Acute Radiation Syndrome (25 rem).

Answer

Add texts here. Do not delete this text first.

Years After the Accident.

Resources

1) https://www.scientificamerican.com/a...r-power-plant/

2) https://world-nuclear.org/informatio...-accident.aspx

3) https://www.britannica.com/event/Fukushima-accident

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7.11: Transporting and Storage of Nuclear Waste

Waste from Uranium Production

The tailings or waste produced by the extraction or concentration of uranium from its ore contain radioactive isotopes of uranium, thorium, and radium as well as significant concentrations of heavy metal including chromium, lead, molybdenum, and vanadium. More than 200 pounds of tailings are produced for each pound of uranium. This sandy waste material must be contained in carefully monitored sites known as tailings piles (Figure **7.11.1**).



Figure **7.11.1**: Moab uranium tailings site is located in Utah. (Public Domain; US Dept. of Energy via Wikipedia)

Uranium production processes do not affect the level of radioactivity and do not produce significant chemical waste. An enrichment process for one ton of uranium hexafluoride produces 130 kg of UF_6 (3.5% U-235) and 870 kg of depleted UF_6 containing U-238. Depleted uranium has few applications. However, its high density 18.7 g/cm^3 makes it useful in armor plating and radiation shielding. In addition, depleted uranium is a potential energy source for fast breeder reactors.

Waste from Nuclear Power Generation

In the open fuel cycle, the spent fuel rods remain in the pools under at least 20 feet of water. This aqueous layer protects the surroundings from radiation. Currently, most reactor sites in the United States utilize this type of storage. The Nuclear Regulatory Commission (NRC) requires all facilities to store spend fuel rods at least three years under water. Most nuclear plants will keep rods in water up to around ten years and then transfer waste to a dry system (cask).

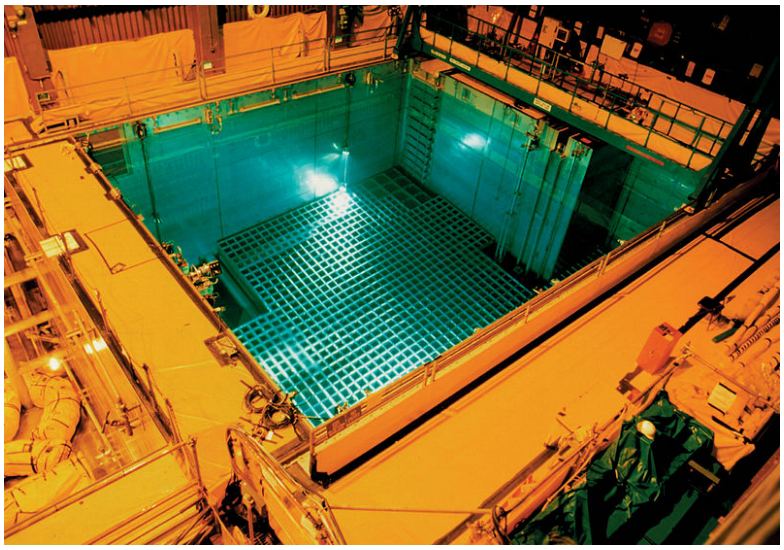


Figure **7.11.2**: Spent fuel pond at San Onofre Nuclear Generating Station in San Clemente, California. (CC BY 2.0; Nuclear Regulatory Commission from US via Wikipedia)

Once fuel rods are removed from the pool, they are placed in a cylinder in a chemically inert atmosphere of helium gas (Figure **7.11.3**). The cylinder is then sealed and encased in steel and concrete to contain the radiation and enhance security for storage or transportation to a permanent repository. All nuclear power plants are allowed to use dry cask storage on site. If a facility is full, then dry fuel rods can be transferred to a decommissioned nuclear power plant. Rods stored on or off site can be transported to a temporary consolidated storage site.

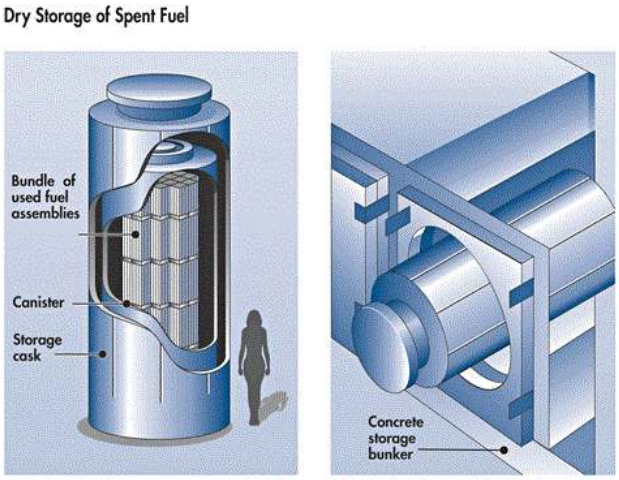


Figure **7.11.3**: Dry Cast Storage. Courtesy of the U. S. Nuclear Regulatory Commission

No Term range plan

At this time (2017), there is **no** permanent location in the United States that will store nuclear power waste.

In 2009, the total amount of nuclear waste generated by reactors was 62,683 metric tons. Seventy eight percent of this waste is in wet storage. The remaining twenty two percent is contained in dry cask. Annually, United States' reactors produce between 2000-2400 tons (1 ton = 2000 pounds) of nuclear waste. To understand this amount of weight, view the vehicle below. Built by Ford Motor Company, the 2017 version of the all wheel drive Edge weighs 4,060 pounds (Figure **7.11.4**). This amount is relative in size to the total amount of nuclear waste generated by all United States reactors in one year.



Figure **7.11.4**: Ford Motor Company's mid-sized SUV named the Edge. Image taken from: upload.wikimedia.org/wikiped...Y7A3333%29.jpg

Nuclear waste is radioactive waste, meaning that it spontaneously emits radiation. It usually originates from the by-products of nuclear reactions in applications such as medicine and research. Radioactive waste degrades with time, releasing alpha, beta, and gamma radiation that pose many health risks to the environment and most organisms, including humans. Due to the harmful nature of nuclear waste, there is strict government regulation on the safe disposal of it. There are several types of waste, and as such, many different ways of discarding it.

Closed or Open Fuel Cycle?

Spent fuel in the open and closed fuel cycles generates radioactive waste. The components of spent reactor fuel can either be treated as waste (in the open fuel cycle) or reprocessed (in the closed fuel cycle). At this time, the United States has a open nuclear fuel cycle. This means that once nuclear fuel has been used it will be stored in ponds or casks. Other countries close their fuel cycles. . In other words, the waste from fuel rods is extracted and reprocessed to be reused again for fuel or for nuclear weapons.

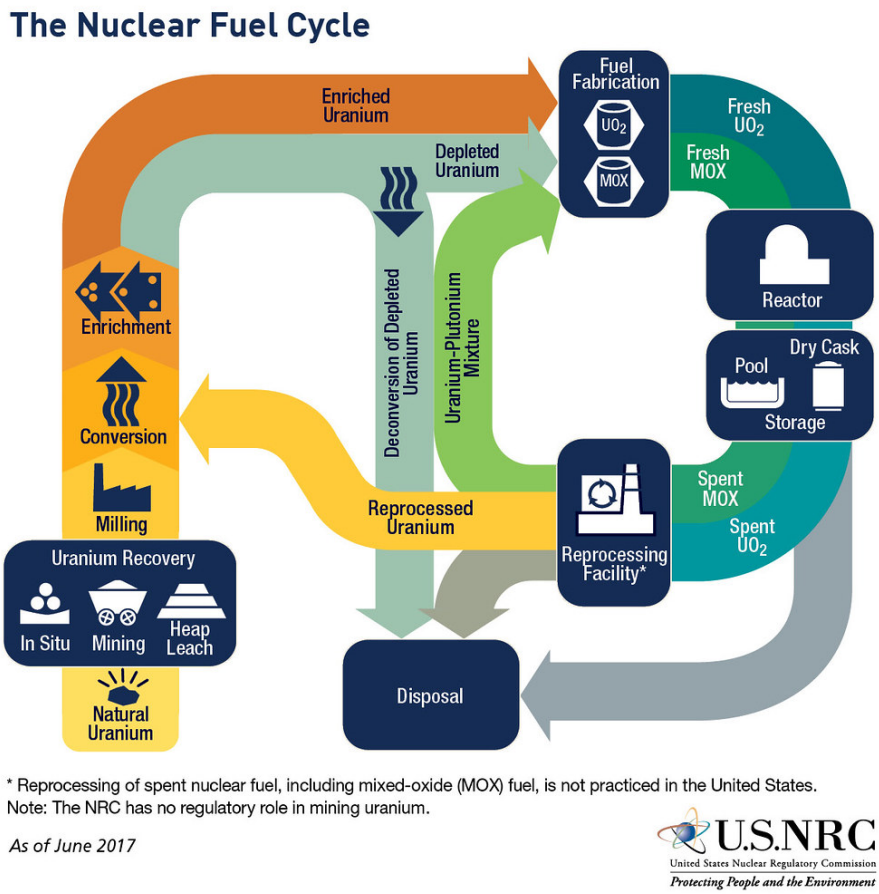


Figure **7.11.5**: Image taken from: https://c1.staticflickr.com/5/4372/3...e2d0031c_b.jpg

Importance of Nuclear Waste

The controversy behind nuclear technology is due to the radioactive waste it creates. Some elements used in nuclear reactors have extremely long half-lives and must be shielded from humans and the environment for thousands of years. For example, plutonium-239, an isotope used in the production of nuclear weapons, has a half-life of 24,200 years while uranium-235 Hiroshima has a half-life of 700 million years. These elements emit large quantities of radioactivity that is extremely dangerous. Too much exposure can be followed by Acute Radiation Syndrome (ARS), which includes skin burns, nausea, vomiting, and eventually death within days if the exposure and dosage of radiation is high.

All Sources of Nuclear Waste

There are currently a number of nuclear productions that result in radioactive waste.

1. Nuclear Weapons: From the weapons to the tools and machinery used in its production, proportional amounts of radioactivity can be found in all of them. After their use, these contaminated items must be disposed of while the radioactivity slowly degrades.
2. Medicine and Research Applications: X-rays and other disease detecting technology in the medical field also consist of radiation albeit in a less harmful amount. For example, technetium-99m is an isomer that can be consumed to allow doctors to take images of the body's process. However, even the syringes contribute to the problem of nuclear waste
3. Nuclear Power: Most radioactive waste comes from the nuclear power plants situated around the world. There is a 20-30 ton waste that comes from each nuclear reactor every month it is in use.
4. Agriculture: Nuclear power is also used in eliminating bacteria through the disruption of their genetic structure. This insures that they can no longer proliferate and grow in the food.

Classification of Nuclear Waste

There are three different types of radioactive waste that result from nuclear applications in the United States:

1. *Low Level Waste* (LLW) – waste that is usually results from medicine or other industrial uses such as tools, rags, medical tubes, protective clothing, and others. There are three facilities in the U.S. that handle low-level waste by land disposal. This waste is shipped to four compact states in the country.



Figure **7.11.6**: Locations that receive low level nuclear waste. These include: **Richland, WA, Clive, UT, Barnwell, SC, and Andrews TX.** Image taken from: https://www.nrc.gov/waste/llw-dispos...locations.html

2. High Level Waste (HLW) – is the highly radioactive waste resulting from spent nuclear fuel from production or power reactors, as well as from the chemical processing of spent nuclear fuel and irradiated target assemblies Nuclear weapon components consisting of Pu-239 or U-235 are also classified as being high level waste. Because of the level of contamination, the waste must stored for long periods of time at some sort of geological repository. It is not uncommon for spent nuclear fuel to be stored underwater. **HLW is currently being stored at the ninety-nine reactors sites, Hanford, WA, and Savannah River Site (Aiken, SC)**

3. Uranium Mill Tailings – this category of waste comes from remains after extracting uranium from its natural ore. Large amounts are currently left out in the open of abandoned mining sites. However, if it remains uncovered and not disposed of correctly, the waste can mix with the sand and travel to water sources, polluting the environment to a great extent.

Weapons Grade Plutonium Disposal

The highly radioactive liquid waste from reactors used to produce plutonium for the nuclear weapons of the United States is stored in tanks at the Hanford, Washington, and Savannah River, South Carolina. The Hanford site manages the largest volume of high-level waste, but the Savannah River site contains more total radioactivity. At Hanford, high-level waste alkaline liquid, salt cake, and sludge are stored in 149 single-shell and 28 double-shell underground tanks, while Savannah River has 51 tanks. These tanks contain approximately 88 million gallons of liquid, which is not only radioactive but also chemically toxic. The composition of the liquid varies from tank to tank. These facilities produced a combined total of 120 tons of plutonium for 20,000 nuclear warheads.

Management of Nuclear Waste

1. Deep Geological Repository: This method is currently still being tested and facilities are being built. The idea is to seal the radioactive waste into special casks and to deposit them hundreds meters deep into a geographically stable area to allow it to decay. There is currently only one facility in the U.S. but a few more located around the globe.
2. Transmutation: at the moment researchers are searching for a method to transmute the dangerous material into something less harmful, making it easier to dispose.
3. Re-use: Currently, there is a Canadian patent to filter the waste and reuse whatever material that has not been altered. However, this practice requires a substantial amount of energy and is still in the very early stages of development.

4. Space disposal: This has the best alternative to geological repositories because the waste can no longer harm the environment on earth. Of course, there are significant consequences of shooting radioactive waste into space such as damaging space shuttles and pollution. At the same time, space disposal would have to be agreed upon internationally.

Possible HLW Storage in the United States

In 1982, the Nuclear Waste Policy Act required the Department of Energy (DOE) to remove spent fuel from all United States' reactor sites by 1988. Unfortunately, this has not occurred yet. As a result, nuclear facilities have been awarded a total of five billion dollars (2015) to keep their waste fuel on campuses. These monies originated from a taxpayer fund.

In 1987, the DOE was encouraged to investigate an area that could house significant amounts of HLW radioactive waste. By the year 2001, the Department of Energy had spent nine billion federal dollars on their research. They selected Yucca Mountain, located about 100 miles northwest of Las Vegas, Nevada. This chosen site is arid, geographically stable, and remote. In addition, the waste would be store 1000 feet below dry rock and 1000 feet above the water table. It was hoped that this national geological repository would receive both high-level spent nuclear fuel from civilian power plants and defense-related activities (Figure **7.11.8**). T

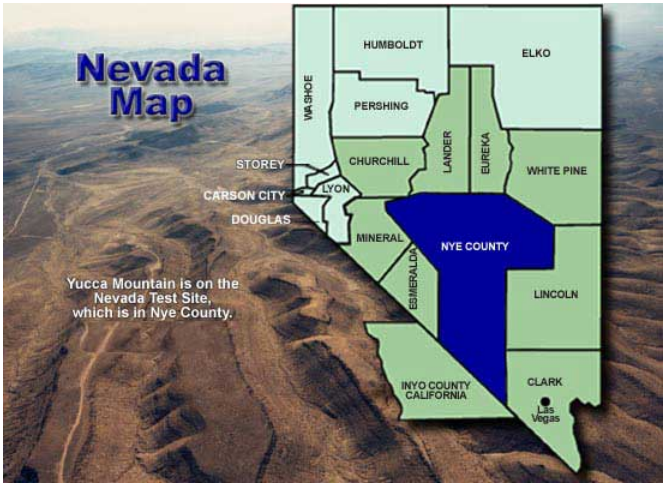


Figure **7.11.7**: Yucca Mountain Site in Nevada. Courtesy of the U.S. Department of Defense

As of 2017, all high level waste is being stored at 131 different locations. Thirty-nine states and sixty-six reactor sites utilize above and underground storage. Already, more than 3000 shipments of used reactor fuel has crossed over 1.7 million miles nationwide by tractor trailer or railcar.

Funding for the construction of Yucca Mountain was awarded by 2002. From 1983-2006, **13.54 billion dollars** was spent on the study and construction of Yucca Mountain. In 2007, the NRC estimated the lifetime cost (this would include construction,transportation, and ultimate decommissioning of site) of Yucca Mountain would be **96.18 billion** dollars. Federal funding for Yucca Mountain ended in 2011 for various reasons.

If Yucca were to start receiving waste, a railroad would need to be completed near the repository. The DOE estimates that an average of 175 rail and truck shipments annually could transport the 65,000 metric tons of waste. At this rate, this process would take twenty-four years.

Waste from Reprocessing Spent Fuel – The Closed Fuel Cycle

Reducing weapons grade Pu-239 has been a goal of both the United States and Russia. In 2000, both countries signed an agreement entailing that each country would dispose of 34 metric tons (1 metric ton = 2,205 pounds) of weapons grade plutonium. One approach to this would be to incorporate Pu-239 into reactor fuel. Current United States reactors would need to be altered for this alternative fuel. Pure weapon's grade Pu-239 would not be placed in a nuclear reactor. Instead, the material would undergo the MOX (mixed oxide) process. Excess plutonium (from weapons) can be combined with LEU (in oxide form) and placed in an altered reactor. This would decrease plutonium supplies as well as reduce required U-235 enrichment.

The MOX process can be applied to used U-235 fuel rods. The fission process process transmutates U-238 into Pu-239. If fuel rods are extracted safely from reactor, the plutonium can be isolated and combined into MOX fuel. Depending upon reactor design, MOX fuel can contain between 5 to 10% weapons grade plutonium Purified U-235 levels of MOX fuel would remain under 5%.

From 2005-2008, Duke Energy Corporation ran MOX in Catawba Nuclear Unit One reactor. This particular unit is located in York, South Caroline (18 miles south of Charlotte, NC). Protestors marched in opposition of MOX being used. In addition, the United States did not have a industrial plant to produce MOX. This fuel was fabricated by the company, AERVA MOX Services which is located in France. The United States would ship weapons grade plutonium out of Charleston Harbor across the ocean to this country. AERVA MOX Services would ship the fuel back to Charleston Harbor and tractor trailers would transport MOX to Catawba.

In 2007, the United States began construction on MOX facility at Savannah River Site (Aiken, South Carolina). Shaw AREVA MOX services consortium will build a Mixed Oxide Fuel Fabrication Facility (MFFF) to turn 3.5 tons/year of weapons grade plutonium into 150 MOX fuel assemblies. This company was awarded $2.7 billion for construction costs. At this time (2017), the United States' MOX facility is still being built.

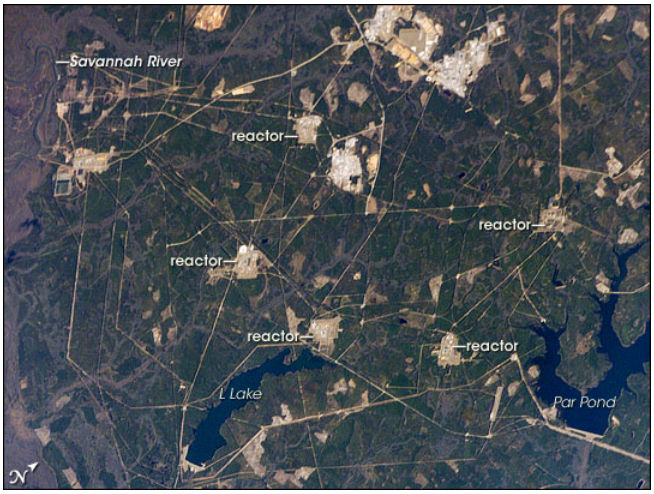


Figure 7.11.8: A 2010 image of the United States' MFFF at Savannah River Site. As of this time, 62% of the facility was completed. (Public Domain; Image Science & Analysis Laboratory, of the NASA Johnson Space Center via Wikipedia)

MOX has been used by many countries. Most of the fuel is produced by France and the United Kingdom. Commercial (LW) reactors in France, Germany, Belgium, Switzerland, and the United Kingdom have used MOX for several years.

Study Questions 7.11.1

1. What are the two ways nuclear reactor facilities store used fuel rods?
2. What is HLW and LLW? How would radioactive medical waste, nuclear fuel waste, and nuclear bomb waste be classified?
3. Can nuclear waste be chemically altered to reduce half-life?
4. At this time, does the United States have an open or closed nuclear fuel cycle? Explain your answer.
5. In the United States, where is the LLW stored?
6. In the United States, where is reactor waste stored. Where is bomb waste stored?
7. What is MOX? What is the purpose of using MOX?
8. Does the United States use MOX fuel?
9. How did the United States obtain MOX fuel?
10. Where is MOX facility being built in the United States?
11. What is Yucca Mountain? Where is located? Why was it selected for nuclear waste storage? Is it currently receiving nuclear waste? How would the waste be transported to this destination if it were to open?

Answer

1. Nuclear fuel rods are first stored in a cooling pool above ground. After a couple of years, the cooled rods can be transferred to a dry, cask system.

2. HLW = high level nuclear waste and LLW = low level nuclear waste. Medical waste would be classified as being low level. Bomb and reactor waste are both high level. High level usually contains plutonium and/or uranium.

3. No, you cannot chemically alter a nucleus. Half-life cannot be changed by chemical means. One would have to transmute the waste to alter it.

4. The United States does not reprocess used fuel rods. This would be mean the fuel cycle is still open and rods must be stored. Other countries extract plutonium from fuel rods and use it for fuel. These countries would have a closed nuclear fuel cycle.

5. LLW is stored at four compact states: South Carolina, Texas, Utah, and Washington State.

6. Reactor waste is stored at commercial reactor sites (66 areas), Hanford, WA, and Aiken, SC (Savannah River Site). Bomb waste is stored at Hanford and Savannah River Site (SRS).

7. MOX stands for mixed oxide fuel. LEU is mixed with oxygen and plutonium to make a new type of fissionable fuel for commercial reactors. This helps reduce plutonium supplies and conserves uranium.

8. The United States did use MOX in the Catawba reactors. At this time, the United States does not use MOX fuel (we can't make it).

9. The United States shipped Pu-239 out of Charleston Harbor to France. AERVA corporation moxed fuel for us and shipped it back to Charleston. MOX was transported to the Catawba reactors (York, SC) by tractor trailer or railroad car.

10. A MOX facility is being built at SRS (Savannah River Site) in Aiken, SC.

11. Yucca is a hollowed out mountain that was designed to receive all HLW. It was selected due to climate, geography, and distance from people. It is not currently receiving waste due to governmental lawsuits. The waste would be transported from all reactors sites, Hanford, WA, and Aiken, SC by tractor trailer or railroad car (no planes!!!).

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2. Scarborough, Kate. *Nuclear Waste*. United Kingdom: Franklin Watts, 2003. Print.
3. http://www.yuccamountain.org/pdf/ocrwm_tslc-2008.pdf

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7.12: Decommissioning and Dismantling Nuclear Reactors

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7.13: Additional Types of Nuclear Reactors

Categorizing Nuclear Reactors

As of 2017, the United States only used light water (LW) moderator thermal reactors. Fission powered both boiling water (BWR) and pressurized water (PWR) reactors. For research purposes, the United States does utilize heavy water, graphite moderator, and fast neutron reactors. The United States does not employ graphite moderated or liquid metal cooled reactors for commercial purposes.

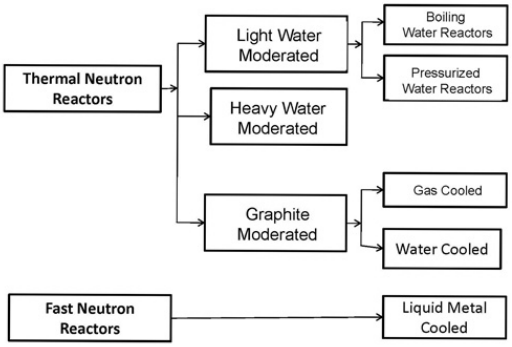


Figure **7.13.1**: Types of Nuclear Reactors

Breeder Reactors

Because $^{235}_{92}\mathrm{U}$ is only 0.7 percent of naturally occurring uranium, its supply is fairly limited and could well only last for about 50 years of full-scale use. The other 99 percent of the uranium can also be utilized if it is first converted into plutonium by neutron bombardment:

$$^{238}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \longrightarrow ^{239}_{94}\mathrm{Pu} + 2\,^{0}_{-1}\mathrm{e}$$

$^{239}_{94}\mathrm{Pu}$ is also fissionable, and so it could be used in a nuclear reactor as well as $^{235}_{92}\mathrm{U}$.

The production of plutonium can be carried out in a breeder reactor which not only produces energy like other reactors but is designed to allow some of the fast neutrons to bombard the $^{235}_{92}\mathrm{U}$, producing plutonium at the same time. More fuel is then produced than is consumed.

Breeder reactors present additional safety hazards to those already outlined. They operate at higher temperatures and use very reactive liquid metals such as sodium in their cooling systems, and so the possibility of a serious accident is higher. In addition the large quantities of plutonium which would be produced in a breeder economy would have to be carefully safeguarded. Plutonium is an α emitter and is very dangerous if taken internally. Its half-life is 24,000 years, and so it will remain in the environment for a long time if dispersed. Moreover, $^{239}_{94}\mathrm{Pu}$ can be separated chemically (not by the much more expensive gaseous diffusion used to concentrate $^{235}_{92}\mathrm{U}$ from fission products and used to make bombs. Such a material will obviously be attractive to terrorist groups, as well as to countries which are not currently capable of producing their own atomic weapons.

Today many nations are considering an expanded role for nuclear power in their energy portfolios. This expansion is driven by concerns about global warming, growth in energy demand, and relative costs of alternative energy sources. In 2008, 435 nuclear reactors in 30 countries provided 16% of the world's electricity. In January 2009, 43 reactors were under construction in 11 countries, with several hundred more projected to come on line globally by 2030.



Figure 7.13.2: A Nuclear Power Plant. Dukovany Nuclear Power Station

Nuclear reactors produce energy through a controlled fission chain reaction. While most reactors generate electric power, some can also produce plutonium for weapons and reactor fuel. Power reactors use the heat from fission to produce steam, which turns turbines to generate electricity. In this respect they are similar to plants fueled by coal and natural gas. The components common to all nuclear reactors include a fuel assembly, control rods, a coolant, a pressure vessel, a containment structure, and an external cooling facility.

The speed of the neutrons in the chain reaction determines the reactor type (Figure 7.13.1). Thermal reactors use slow neutrons to maintain the reaction. These reactors require a moderator to reduce the speed of neutrons produced by fission. Fast neutron reactors, also known as fast breeder reactors (FBR), use high speed, unmoderated neutrons to sustain the chain reaction.

Figure* 7.13.3*: *Types of Nuclear Reactors*

Thermal reactors operate on the principle that uranium-235 undergoes fission more readily with slow neutrons than with fast ones. Light water (H2O), heavy water (D2O), and carbon in the form of graphite are the most common **moderators**. Since slow neutron reactors are highly efficient in producing fission in uranium-235, they use **fuel assemblies** containing either natural uranium (0.7% U-235) or **slightly enriched uranium** (0.9 to 2.0% U-235) fuel. Rods composed of neutron-absorbing material such as cadmium or boron are inserted into the fuel assembly. The position of these **control rods** in the reactor core determines the rate of the fission chain reaction. The **coolant** is a liquid or gas that removes the heat from the core and produces steam to drive the turbines. In reactors using either light water or heavy water, the coolant also serves as the **moderator**. Reactors employing gaseous coolants (CO_2 or He) use graphite as the moderator. The **pressure vessel**, made of heavy-duty steel, holds the reactor core containing the fuel assembly, control rods, moderator, and coolant. The **containment structure,** composed of thick concrete and steel, inhibits the release of radiation in case of an accident and also secures components of the reactor from potential intruders. Finally, the most obvious components of many nuclear power plants are the **cooling towers**, the external components, which provide cool water for condensing the steam to water for recycling into the containment structure. Cooling towers are also employed with coal and natural gas plants.

Reactor Fundamentals

It is important to realize that while the U-235 in the fuel assembly of a thermal reactor is undergoing fission, some of the **fertile** U-238 present in the assembly is also absorbing neutrons to produce **fissile** Pu-239. Approximately one third of the energy produced by a thermal power reactor comes from fission of this plutonium. Power reactors and those used to produce plutonium for weapons operate in different ways to achieve their goals. Production reactors produce less energy and thus consume less fuel than power reactors. The removal of fuel assemblies from a production reactor is timed to maximize the amount of plutonium in the spent fuel (Figure 7.13.3). Fuel rods are removed from production reactors after only several months in order to recover the maximum amount of plutonium-239. The fuel assemblies remain in the core of a power reactors for up to three years to maximize the energy produced. However it is possible to recover some plutonium from the spent fuel assemblies of a power reactor.

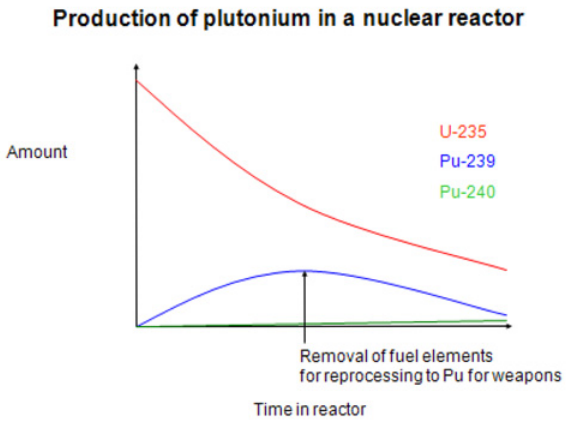


Figure 7.13.3: The Fate of Plutonium in a Thermal Reactor

The power output or capacity of a reactor used to generate electricity is measured in megawatts of electricity, MW(e). However, due to the inefficiency of converting heat into electricity, this represents only about one third of the total thermal energy, MW(t), produced by the reactor. Plutonium production is related to MW(t). A production reactor operating at 100 MW(t) can produce 100 grams of plutonium per day or enough for one weapon every two months.

Another important property of a reactor is its capacity factor. This is the ratio of its actual output of electricity for a period of time to its output if it had been operated at its full capacity. The capacity factor is affected by the time required for maintenance and repair and for the removal and replacement of fuel assemblies. The average capacity factor for U.S. reactors has increased from 50% in the early 1970s to over 90% today. This increase in production from existing reactors has kept electricity affordable.

Thermal Reactors

Currently the majority of nuclear power plants in the world are water-moderated, thermal reactors. They are categorized as either light water or heavy water reactors. Light water reactors use purified natural water (H_2O) as the coolant/moderator, while heavy water reactors employ heavy water, deuterium oxide (D_2O). In light water reactors, the water is either pressured to keep it in superheated form (in a pressurized water reactor, PWR) or allowed to vaporize, forming a mixture of water and steam (in a boiling water reactor, BWR). In a PWR (Figure 7.13.4), superheated water flowing through tubes in the reactor core transfers the heat generated by fission to a heat exchanger, which produces steam in a secondary loop to generate electricity. None of the water flowing through the reactor core leaves the containment structure.

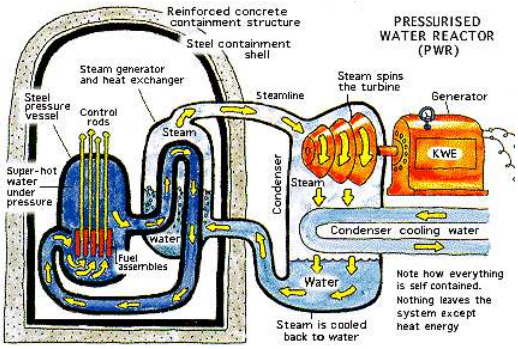


Figure* 7.13.4: Pressurized Water Reactor. Courtesy of the Uranium Information Centre*

In a BWR (Figure 7.13.5), the water flowing through the core is converted to directly to steam and leaves the containment structure to drive the turbines. Light water reactors use low enriched uranium as fuel. Enriched fuel is required because natural water absorbs some of the neutrons, reducing the number of nuclear fissions. All of the 103 nuclear power plants in the United States are light water reactors; 69 are PWRs and 34 are BWRs.

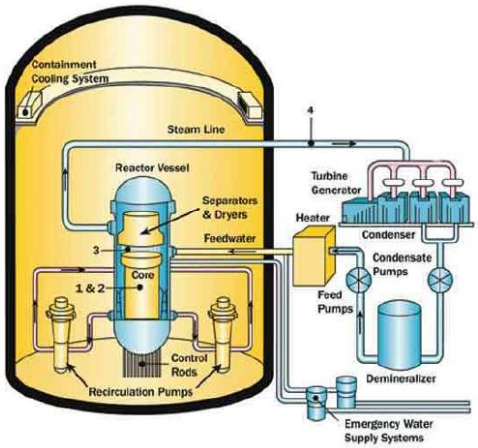


Figure **7.13.5**: Boiling Water Reactor. (1) the core inside the reactor vessel creates heat, (2) a steam-water mixture is produced when very pure water (reactor coolant) moves upward through the core, absorbing heat, (3) the steam-water mixture leaves the top of the core and enters the two stages of moisture separation where water droplets are removed before the steam is allowed to enter the steam line, and (4) the steam line directs the steam to the main turbine, causing it to turn the turbine generator, which produces electricity. Courtesy of the U.S. Nuclear Regulatory Commission

Heavy water reactors use $\mathbf{D_2O}$ as the coolant/moderator, allowing natural, unenriched uranium to be used as the fuel. This is possible because $\mathbf{D_2O}$ absorbs fewer neutrons than $\mathbf{H_2O}$. The heat transfer system is similar to that of the PWR, with the steam generator located within the containment structure. The heavy water reactor shown in Figure **7.13.6**, known as CANDU, was developed in Canada and sold globally. The cost advantage in fuel is offset by the expense of producing $\mathbf{D_2O}$ by a chemical exchange process or electrolysis. The individual fuel assemblies of a heavy water reactor can be replaced without shutting down the reactor, thus eliminating the down time involved with refueling a light water reactor. However, spent fuel produced by a heavy water reactor contains more plutonium and tritium than that from light water reactors. This, coupled with the difficulty in monitoring a continuously fueled reactor, causes concerns about the proliferation of nuclear weapons. Thus, heavy water is classified as a "sensitive material" because a nation possessing it can produce plutonium directly from natural uranium, eliminating the need for uranium enrichment.

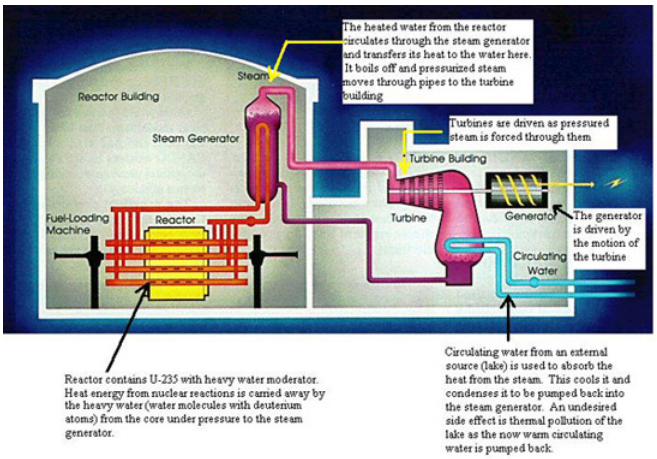


Figure **7.13.6**: Heavy Water Reactor. Courtesy of Atomic Energy of Canada Limited

Another type of thermal reactor is graphite moderated and gas cooled. Twenty-six Magnox reactors (Figure **7.13.7**), employing pressurized carbon dioxide as the coolant, were built in the United Kingdom but are currently being phased out of service. These gas cooled reactors have the same advantages as the heavy water reactors in that they can use natural uranium fuel and be fueled continuously.

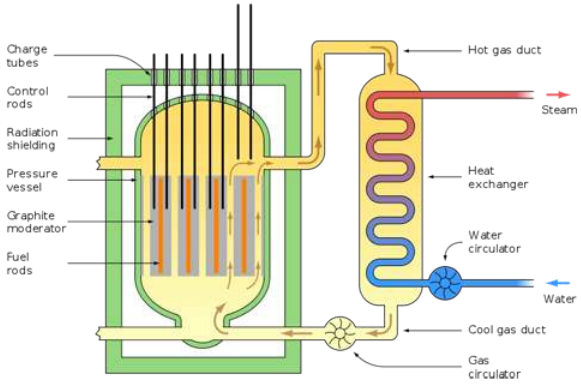


Figure 7.13.7: Gas Cooled Reactor. (Courtesy Osterreichisches Ökologie-Institut)

The pebble bed represents a new design for a gas cooled reactor (Figure 7.13.8). It uses helium as the coolant and a fuel consisting of low enriched uranium dioxide coated with silicon carbide and pyrolitic carbon encased in small graphite spheres. The graphite serves as the moderator. Fresh fuel is added at the top of the reactor and the spent fuel removed from the bottom, allowing continuous operation. The helium coolant is maintained at high temperatures and pressures, which increases the efficiency of heat transfer and power production. South Africa is leading the effort to develop this reactor technology.

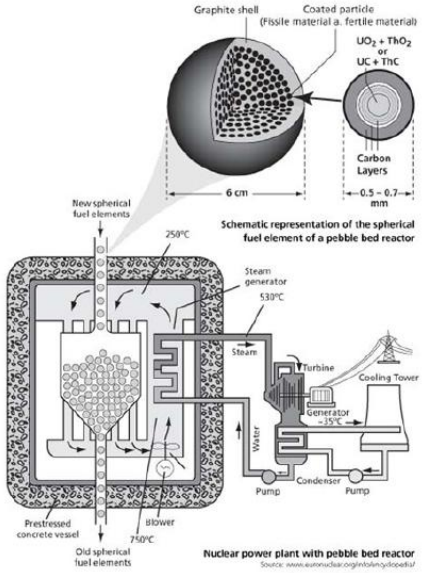


Figure 7.13.8: Pebble Bed Reactor. Courtesy of the European Nuclear Society

Fast Neutron Reactors

In contrast to thermal reactors, the neutrons in a fast neutron reactor (or fast breeder reactor, FBR) are not slowed by the presence of a moderator (Figure 7.13.9). The coolant, usually a liquid sodium or lead, is a substance that does not slow or absorb neutrons. It also has excellent heat transfer properties, which allow the reactor to be operated at lower pressures and higher temperatures than thermal reactors.

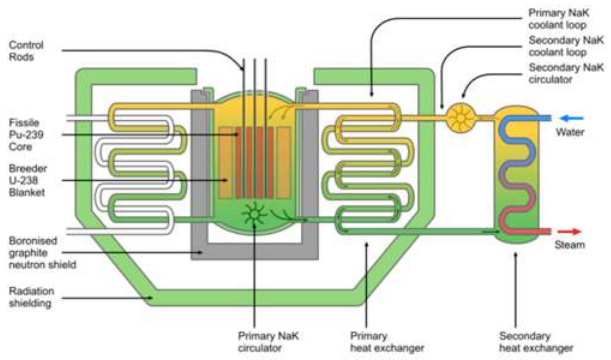


Figure **7.13.9**: Fast Neutron Breeder Reactor. Courtesy of Nationmaster

An FBR is configured and operated to produce more fuel than it consumes. Fast neutrons are readily absorbed by fertile uranium-238, which then can undergo successive beta emissions to become fissile Pu-239. Thorium-232 is another fertile isotope that can absorb neutrons and produce fissile uranium-233 by beta emissions. These fissile isotopes can be reprocessed for nuclear reactor fuel or weapons. Because fast neutrons are not as efficient in producing fission as slow ones, FBRs require uranium oxide containing 20% U-235, plutonium oxide, or a mixture of these oxides, known as MOX, as fuel.

Originally FBRs were thought to be a means of extending global uranium resources by producing fissile Pu-239 or U-233 as reactor fuel. However, problems with reactor operations and material components combined with the discovery of new uranium deposits mean that FRBs are not economically competitive with existing thermal reactors. FBR research has produced technical advances but the limiting factor continues to be the price of FBR-produced reactor fuel versus the cost of uranium fuel. FBRs are more complex than other types of reactors and also raise concerns about the proliferation of plutonium for use in nuclear weapons.

Summary of Reactor Types

Table **7.13.1** summarizes the characteristics of the reactors discussed above.

Table **7.13.1**: Reactor Characteristics

https://chem.libretexts.org/@go/page/85515

Reactor Type	Function	Coolant	Moderator	Chemical Form of Fuel	Fuel Enrichment Level*
Thermal					
Boiling Water	electricity	light water	light water	uranium dioxide	low enriched uranium
Pressurized Water	electricity, nautical power	light water	light water	uranium dioxide	low enriched uranium
Heavy Water	electricity, plutonium production	heavy water	heavy water	uranium dioxide or uranium metal	natural, unenriched uranium
Gas Cooled Graphite Moderated	electricity, plutonium production	carbon dioxide or helium	graphite	uranium dicarbide or uranium metal	slightly enriched or natural uranium
Water Cooled Graphite Moderated	electricity, plutonium production	light water	graphite	uranium dicarbide or uranium metal	slightly enriched uranium
Pebble Bed Gas Cooled Graphite Moderated**	electricity	pressurized helium	graphite and silicon carbide	uranium dioxide or thorium dioxide	low enriched uranium
Fast Neutron					
Fast Neutron Breeder	electricity, plutonium production	molten sodium or lead	none required	various mixtures of plutonium dioxide and uranium dioxide	various mixtures of plutonium dioxide and uranium dioxide

*Percentage of U-235 isotope in the fuel compared to U-238 isotope. Natural uranium contains 0.7% U-235, slightly enriched uranium from 0.8 to 3.0% U-235, and low enriched uranium from 3.0 to 5.0% U-235.
** Currently under development.

Reactor Safety Concerns

Reactor safety has been called into question by two major accidents, one in 1979 at the Three Mile Island (TMI) nuclear power plant in Pennsylvania and the other in 1986 at Chernobyl RBMK (Reactor Bolshoy Moshchnosty Kanalnyin) in the former Soviet Union (Figure **7.13.10**). The latter was the worst reactor accident in history, with 31 people dying of direct radiation poisoning and thousands more exposed to high doses of radiation over a period of nearly 20 years. Disputes still fester regarding total damage of the Chernobyl disaster, although an extensive study reported by a UN sponsored group of scientists indicates that the damage was somewhat less than earlier feared. The Chernobyl reactor used a graphite moderator and water coolant without a containment structure. Although some of the design flaws were corrected after this accident, RMBKs are considered to be the most dangerous reactors.



Figure* 7.13.10*: *Chernobyl Nuclear Power Plant Following the 1986 Accident. Courtesy of the U.S. Department of Energy*

Although the TMI accident was much smaller in scope and resulted in no deaths, it had a profound psychological impact on the public's view of commercial nuclear power. The TMI plant was a pressurized light-water reactor, whereas Chernobyl had a reactor design similar to the one used for the reactors at Hanford, Washington, which produced plutonium for the United States nuclear weapons. Both accidents involved human error overriding safety features built into the reactor systems. Features of the new generations of reactors including passive safety systems and fewer pipes and valves are designed to minimize the potential for accidents and to limit the damaging effects should such an accident occur.

A Brief History of Nuclear Power Reactors

The first nuclear reactors were used to produce plutonium for nuclear weapons. These water-cooled, graphite reactors operated in the United States from 1944 to 1982 and were also used in the Soviet Union during the Cold War. Nuclear reactors were first used to power a submarine, the USS *Nautilus*, in 1954. That same year the Obninsk 5 megawatt nuclear power plant in the Soviet Union became the first reactor to be linked to an electrical grid. The first commercial nuclear power plants went online at Calder Hall in the United Kingdom in 1956 and Shippingport, Pennsylvania in 1957. The number of nuclear power reactors grew at a rapid rate before leveling off in the late 1980s.

In addition to the reactors for generating electricity mentioned above, there are also 220 reactors powering ships and submarines. Another 284 reactors operating in 56 nations are used for research in a variety of areas. Approximately 20% of the electricity used in the United States is generated by 103 nuclear reactors, although no new reactors have been placed in operation since the 1970s. France leads the world in the generation of electricity with more than 70% coming from nuclear sources. France, Japan, Russia, and Great Britain reprocess spent reactor fuel from commercial reactors.

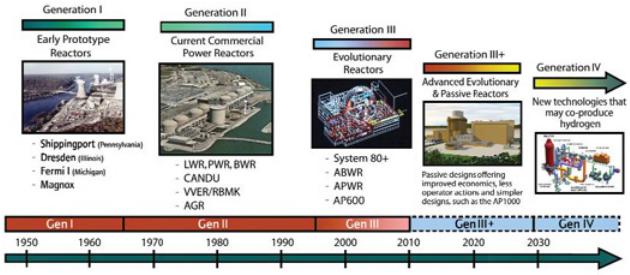


Figure 7.13.11: Evolution of Nuclear Reactors. Courtesy of the U.S. Energy Information Administration

Interest in nuclear power has increased driven in large part by concerns over energy supplies and climate charge. Reactor designs have evolved from the first generation of reactors cited above to the generation II systems that included the PWR, BWR, and Magnox reactors of the 1970s and 1980s (Figure 7.13.11). Table 7.13.2 includes some of the designs for generation III and III+ reactors. These systems are touted to be more economical to build and operate, as well as containing improved passive safety features. Figures 11 and 12 show some of the advances in reactor design for the European Pressured Water Reactor and the Westinghouse AP1000 PWR.

Table 7.13.1: Designs for Generation II and III+ Reactors

https://chem.libretexts.org/@go/page/85515

Design	Manufacturer	Approximate Capacity (MWe)	Reactor type	Status (2008)
AP 600	Westinghouse	650	PWR	Certified
AP1000	Westinghouse	1117	PWR	Certified
ABWR	GE and Tosuiba	1371	BWR	Certified
System 80+	Westinghouse	1300	PWR	Certified
ESBWR	GE	1550	BWR	Undergoing Certification
EPR	AREVA NP	1600	PWR	Pre-certification
Pebble Bed Modular	Westinghouse, Eskom	180	High Temperature Graphite	Pre-certification

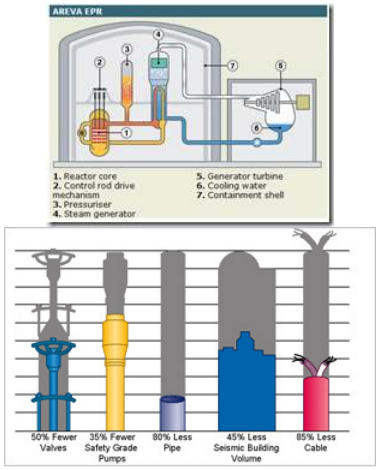
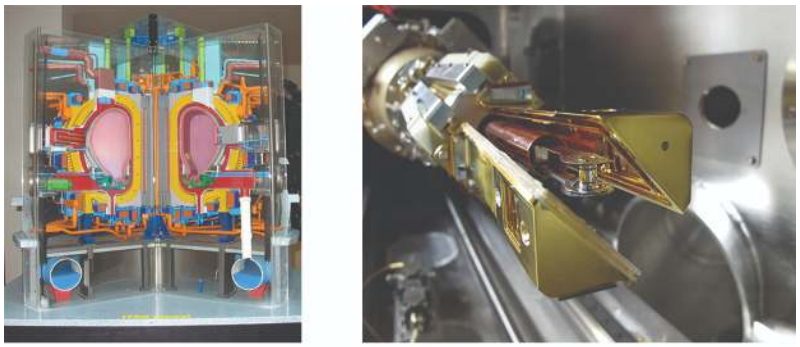


Figure **7.13.12**: European Pressured Water Reactor Courtesy of Areva Figure 12 – Design Features of the Westinghouse AP1000, Courtesy of Westinghouse

Finally, designs for Generation IV reactors are being developed for deployment by 2030. These reactor designs will continue to address concerns associated with economics, safety, proliferation, waste, and reactor security.

Useful fusion reactions require very high temperatures for their initiation—about 15,000,000 K or more. At these temperatures, all molecules dissociate into atoms, and the atoms ionize, forming plasma. These conditions occur in an extremely large number of locations throughout the universe—stars are powered by fusion. Humans have already figured out how to create temperatures high enough to achieve fusion on a large scale in thermonuclear weapons. A thermonuclear weapon such as a hydrogen bomb contains a nuclear fission bomb that, when exploded, gives off enough energy to produce the extremely high temperatures necessary for fusion to occur.



(a) (b)

Figure **7.13.13**: (a) This model is of the International Thermonuclear Experimental Reactor (ITER) reactor. Currently under construction in the south of France with an expected completion date of 2027, the ITER will be the world's largest experimental Tokamak nuclear fusion reactor with a goal of achieving large-scale sustained energy production. (b) In 2012, the National Ignition Facility at Lawrence Livermore National Laboratory briefly produced over 500,000,000,000 watts (500 terawatts, or 500 TW) of peak power and delivered 1,850,000 joules (1.85 MJ) of energy, the largest laser energy ever produced and 1000 times the power usage of the entire United States in any given moment. Although lasting only a few billionths of a second, the 192 lasers attained the conditions needed for nuclear fusion ignition. This image shows the target prior to the laser shot. (credit a: modification of work by Stephan Mosel)

Another much more beneficial way to create fusion reactions is in a fusion reactor, a nuclear reactor in which fusion reactions of light nuclei are controlled. Because no solid materials are stable at such high temperatures, mechanical devices cannot contain the plasma in which fusion reactions occur. Two techniques to contain plasma at the density and temperature necessary for a fusion reaction are currently the focus of intensive research efforts: containment by a magnetic field and by the use of focused laser beams (Figure **7.13.13**). A number of large projects are working to attain one of the biggest goals in science: getting hydrogen fuel to ignite and produce more energy than the amount supplied to achieve the extremely high temperatures and pressures that are required for fusion. At the time of this writing, there are no self-sustaining fusion reactors operating in the world, although small-scale controlled fusion reactions have been run for very brief periods.Contributors

Complete Bibliography on Nuclear Reactors from Alsos Digital Library for Nuclear Issues

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7.E: Nuclear Energy (Exercises)

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CHAPTER OVERVIEW

8: Water Chemistry

8.1: Water Cycle
8.2: EPA's Primary and Secondary Drinking Water Standards
8.3: Biological Contamination of Water
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8.1: Water Cycle

Learning Objectives

- Recall the percentages of fresh and salt water sources on Earth.
- Know the processes and phases of the water (hydrologic) cycle.
- Understand hydrologic terms: stream, pond, river, reservoir, wetland, aquifer, and ocean.
- Recall the large consumers of water in the United States and in the world.

Water is composed of one oxygen atom bonded with two hydrogen atoms (H_2O). Despite its simplicity, water has remarkable properties. It expands when it freezes, has high surface tension (because of the polar nature of the molecules that stick together), and has a high boiling point for a liquid. Without water, life might not be able to exist on Earth, and this planet would not have the tremendous complexity and diversity that we see.



Figure 8.1.1: This Florentine Bell Tower is one of Furman University most beloved landmarks. The original Furman Bell Tower was built in 1854 on what used to be the men's campus in Downtown Greenville. During that time,the bells rang to signal the start of classes and to celebrate victories for the athletic teams. Image courtesy of Elizabeth R. Gordon.

Distribution of Earth's Water

Earth’s oceans contain 97% of the planet’s water, so just 3% is fresh water, water with low concentrations of salts (Figure 8.1.2). The majority of the Earth's water can be classified as being **saline** (or salt containing). Most freshwater is trapped as ice in the vast glaciers and ice sheets of Greenland. A storage location for water such as an ocean, glacier, pond, or atmosphere is known as a **reservoir**. 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**.

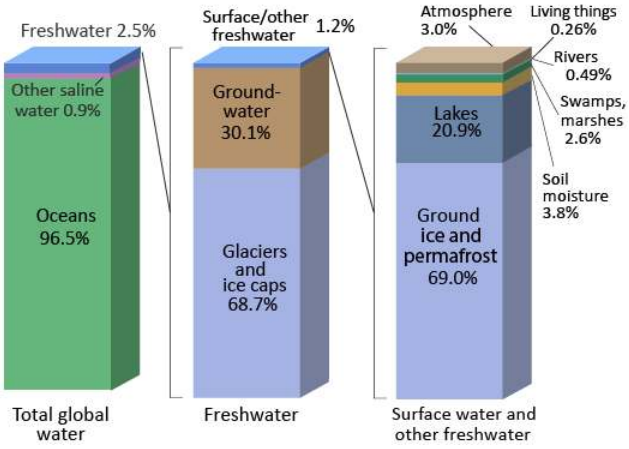


Figure* 8.1.2*: *The distribution of Earth's water. In the first bar, notice how only 2.5% of Earth's water is freshwater - the amount needed for life to survive. The middle bar shows the breakdown of freshwater. Almost all of it is locked up in ice and in the ground. Only a little more than 1.2% of all freshwater is surface water, which serves most of life's needs.The right bar shows the breakdown of surface freshwater. Source: Igor Shiklomanov's chapter "World Freshwater resources" in Peter H. Gleick (editor), 1993 Water in Crises: A guide to the World's Freshwater Resources. The numbers are rounded.*

The Hydrologic Cycle

Because Earth's water is present in all three states, it can get into a variety of environments around the planet. The movement of water around Earth's surface is the **hydrologic (water) cycle** (Figure 8.1.3).

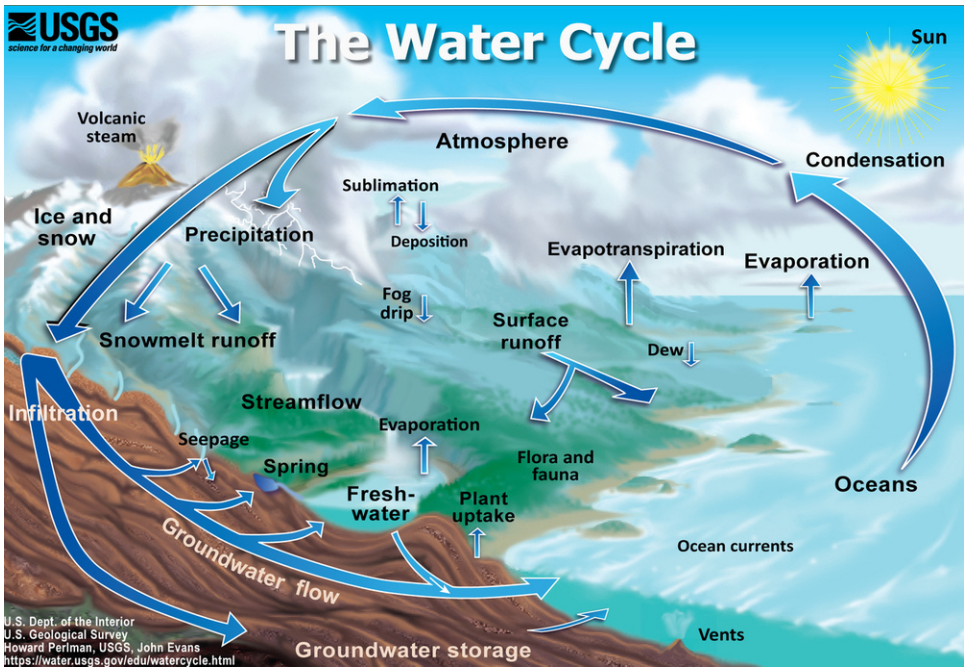


Figure 8.1.3: *Because it is a cycle, the water cycle has no beginning and no end. Earth's water is always in movement, and the natural water cycle, also known as the hydrologic cycle, describes the continuous movement of water on, above, and below the surface of the Earth. Water is always changing states between liquid, vapor, and ice, with these processes happening in the blink of an eye and over millions of years.*

The Sun, while many millions of kilometers away, provides the energy that drives the water cycle. It impacts the water cycle by supplying the energy needed for evaporation. Most of Earth's water is stored in the oceans where it can remain for hundreds or thousands of years. Water changes from a liquid to a gas by **evaporation** to become water vapor. The Sun's energy can evaporate water from the ocean surface or from lakes, streams, or puddles on land. Only the water molecules evaporate; the salts remain in the ocean or a freshwater reservoir.

The water vapor remains in the atmosphere until it undergoes **condensation** to become tiny droplets of liquid. The droplets gather in clouds, which are blown around the globe by the wind. As the water droplets in the clouds collide and grow, they fall from the sky as **precipitation**(rain, sleet, hail, or snow). Precipitation can fall back into the ocean and/or land surface.



Figure 8.1.4: Snow is one form of precipitation and a key transport mechanism in the water cycle. Image courtesy of Elizabeth R. Gordon

When water falls from the sky as rain it may enter streams and rivers that flow downward to oceans and lakes. Water that falls as snow may sit on a mountain for several months. Snow may become part of the ice in a glacier, where it may remain for hundreds or thousands of years. Snow and ice may go directly back into the air by **sublimation**, the process in which solid changes directly into a gas without first becoming a liquid. Although you probably have not seen water vapor sublime from a glacier, you may have seen dry ice sublime in the air.

Snow and ice slowly melt over time to become liquid water, which provides a steady flow of fresh water to streams, rivers, and lakes below. A water droplet falling as rain could also become part of a stream or a lake. At the surface, the water may eventually evaporate and reenter the atmosphere. A significant amount of water infiltrates into the ground. Soil moisture is an important reservoir for water (Figure 8.1.5). Water may seep through dirt and rock below the soil through pores infiltrating the ground to go into Earth's groundwater system. Groundwater enters **aquifers** that may store fresh water for centuries. Alternatively, the water may come to the surface through springs or find its way back to the oceans.

Water trapped in soil is important for plants to grow. Plants and animals depend on water to live and they also play a role in the water cycle. Plants take up water from the soil and release large amounts of water vapor into the air through their leaves, a process is known as *transpiration*.

It is important to note that water molecules cycle around. If climate cools and glaciers and ice caps grow, there is less water for the oceans and sea level will fall. The reverse can also happen.

Components of the Hydrologic Cycle

Most precipitation falls in the form of rain, but there are other forms such as snow, hail, and sleet. Once it runs sufficiently, surface water runoff is generated when the ground is saturated or impervious. **Surface water** is a major component of the hydrological cycle and one that we interact with very regularly. It includes lakes, wetlands, storm water **runoff** (overland flow), ponds, potholes, rivers and streams.

Streams and Rivers

A river forms from water moving from a higher altitude to lower altitude, under the force of gravity. When rain falls on land, it can seep into the ground or become runoff (water running on the surface). If the water runs on the land surface, it can converge as it moves towards lower elevation. The converging runoff can concentrate into single channels of conveyance called creeks, stream, or rivers. Streams and rivers that join up to form a larger river are called **tributaries**, Figure 8.1.5. The land area drained by a river and all its tributaries is called a **watershed** or river basin.

The area adjacent to a river that floods frequently is a called a **flood plain**. These regions temporarily store excess water during storm events and frequently contain fertile soils. Properly functioning flood plains reduce the negative impacts of floods (by reducing severity of flood) and they assist in filtering storm water which results in protecting the water quality of rivers. Also, flood plains act as areas of recharge for groundwater.



In South Carolina, the Santee River system flows throughout the state (Figure **8.1.6**). From North Carolina, the Saluda River runs through the South Carolina upstate region. The Saluda River converges with the Broad River south of Columbia, South Carolina. The combination of these two waterways form the Congaree River. Just north of Rock Hill, South Carolina, the Catawba River enters into the Wateree Reservoir. Once this water flows to Columbia, the Catawba River becomes the Wateree River. All of these rivers and water systems provide water for the upstate of South Carolina.

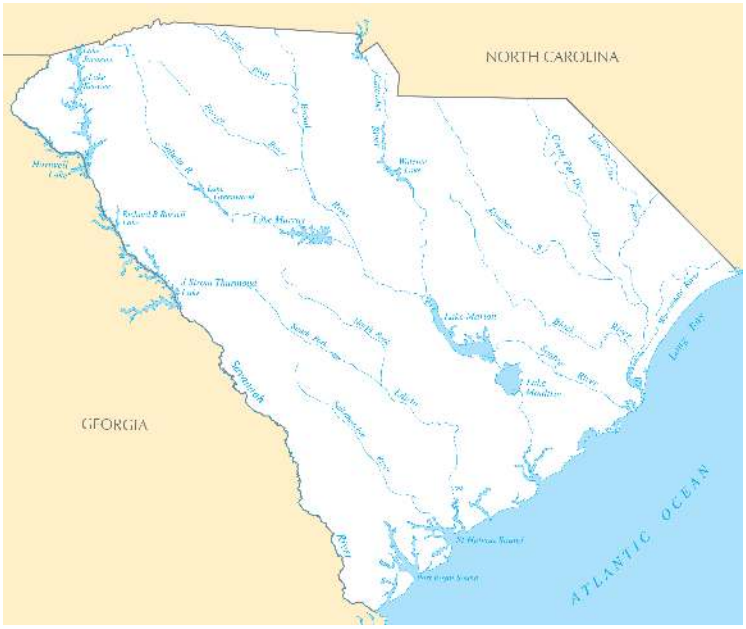


Figure **8.1.6**: Large rivers of South Carolina (CC BY-SA 1.0; http://mapsof.net)

Rivers are important for supplying water to the cities and populations of any state. In addition, rivers contain important biological communities and provide recreational opportunities like swimming, fishing, and white water rafting. Large cities, communities, factories, industries, and power stations are located along many rivers. It is, therefore, very important to protect the quality and integrity of rivers all over the world.

Lakes,reservoirs, and ponds

If water flows to a place that is surrounded by higher land on all sides, a lake will form. A smaller version of this type of aquatic system is called a pond. When dams are constructed to stop rivers from flowing, lakes are transformed into reservoirs. Once

constructed, reservoirs can provide water for consumption, cooling capacity for power plants, irrigation for agriculture, and recreation activities.

In the South Carolina upstate, Hartwell Reservoir provides cooling water for Oconee Nuclear Reactor Station. In addition, many South Carolina residents enjoy fishing, boating, and residing on the reservoir.

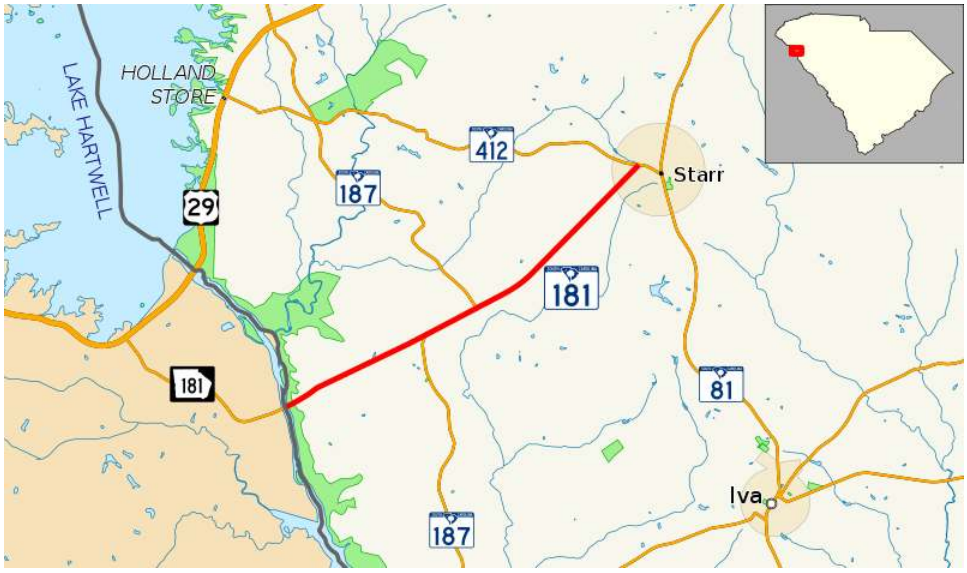


Figure 8.1.1: Map of South Carolina Highway 101 (CC BY-SA 1.0 https://www.census.gov/cgi-bin/geo/s...iles/index.php;)

Wetland

A **wetland** is an area which is home to standing water for notable parts of the year, has saturated soils for a large part of the year and has plants that require large amounts of water to survive. Wetlands include swamps, marshes, and bogs. Wetlands are identified using three characteristics: soils (water-saturated soils are present), hydrology (shallow water table) and vegetation (wetland plants that are adapted to areas that are saturated with water for long periods of time). Wetlands are important areas of biological diversity and productivity. These are also important areas where geochemical and biological cycles/ processes are consistently taking place. For instance, wetlands are considered as areas of significant carbon sequestration (storage), which impacts global climate change. They also act as filters for storm-water runoff before it enters rivers and lakes.

Oceans

As you have probably already guessed, oceans are an important component of the hydrologic cycle because they store majority of all water on Earth (about 95%). Most of the major rivers drain into them. The five oceans covering the surface of the Earth are the Atlantic, Indian, Pacific, Arctic and the Southern Ocean (Figure 8.1.8).



Figure 8.1.8: *The five oceans found on planet Earth. The Pacific Ocean is the largest. Source: upload.wikimedia.org/wikiped...n_drainage.png*

Approximately 90 % of the water that is evaporated into the hydrologic cycle comes from the ocean. The ocean contains many forms of life uniquely adapted to survive in this habitat. Unfortunately, humans have degraded the oceans and their life through pollution, excess fishing, carbon dioxide acidification, and resource exploitation.

Storage and Flow

Almost 99% of the available fresh water is found below the surface as groundwater. This resource results from recycling of water in the hydrologic cycle. When precipitation falls, water travels on the surface and some can infiltrate into the ground. Groundwater is replenished when water moves from the surface, through unsaturated rocks or sediment (**unsaturated**), all the way down the **saturated parts** (saturated zone) in a process called infiltration and becomes groundwater (Figure 8.1.10). The top of the saturated portion is called the **water table**, which is the boundary between saturated and unsaturated zone.

Groundwater is found in **aquifers**, which are bodies of rock or sediment that store (and yield) large amounts of usable water in their pores. Aquifer productivity is controlled by **porosity** and **permeability**. Porosity is the percentage of open space in a rock or sediment body. Permeability is the ability of subsurface material to transmit fluids. Groundwater is found in the saturated zone of a rock body where all pores are filled with water. An important concept is that surface water always moves from higher elevation to lower elevation while groundwater always moves from higher energy (hydraulic head) to lower energy.



Figure **8.1.10**: Model of groundwater system showing the different components of an unconfined groundwater system: http://water.usgs.gov/edu/earthgwaquifer.html

Groundwater will continue to flow until it emerges as a spring, or discharges into surface water bodies on the land or in the ocean. To utilize groundwater, we drill holes (wells) into the ground and pump the water out.

Water Consumption

One of the most important natural resources is water. In some areas of the world, water sources are extremely limited or contaminated. If a geographical area lacks this resource, then agriculture and industry will have difficulty producing goods and foods. If water is contaminated, individuals who reside in these areas will be more likely to develop waterborne illnesses. Lack of water limits a consumer's ability to drink, eat, and bathe.

The table below illustrates who uses the majority of water sources. Be sure to note the differences between the United States and Global percentage applications.

Table* 8.1.2*: *Water Use in the United States and Globally*

Use	United States	Global
Agriculture	34%	70%
Domestic (drinking, bathing)	12%	10%
Industry	5%	20%
Power plant cooling	49%	small

Contributors and Attributions

- Template:ContribCandelaGeo
- Elizabeth R. Gordon (Furman University)

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8.2: EPA's Primary and Secondary Drinking Water Standards

Learning Objectives

- Recognize the accomplishments of the Safe Water Drinking Act (original law and amendments)
- Distinguish between primary and secondary contaminants.
- Classify a contaminant as being organic, inorganic, disinfectant, disinfectant byproduct, radionuclide, or microbial.
- Distinguish between Maximum Contaminant Level (MCL) and Maximum Contaminant Level Goal (MCLG) drinking water standards.
- Recognize contaminant units- ppm, ppb, picoCuries, MFL, and millirems.
- Recall who monitors tap water, well water, and bottled water.

The Safe Water Drinking Act (1974)

Up until 1974, public drinking water supplies in the United States were monitored and regulated by state and local authorities. Lists of contaminants with their various concentrations could vary from state to state. As the chemical industry grew, these same state agencies noted the increased presence of existing and new organic chemicals in public water systems. In order to standardize drinking water across the country, the Environmental Protection Agency (EPA) enacted the Safe Water Drinking Act of 1974.



Figure **8.2.1**: AFGE members and environmental activists participated in an event at the Washington, D.C. EPA headquarters to thank EPA workers for their work. (CC BY 2.0; AFGE).

The 1974 act enabled the EPA to monitor and regulate public water systems that serve over 25 people. Implementation and enforcement of drinking water standards would still be performed by each state. Regarding drinking water sources (surface and ground), the EPA and state agencies protect and monitor these as well. Levels of contaminants would be defined using the concentration terms Maximum Contaminant Level (MCL) and Treatment Technique (TT)

The first set of drinking water standards included only 22 chemicals and/or pathogens. EPA established two major types of contaminants: primary and secondary. The first of these types (primary) contaminants are substances (examples could include Hg, As, and U) that can be toxic in small amounts. On the other hand, secondary contaminants are less toxic species (Fe and Zn) and would include cosmetic issues (color, taste, and odor) of drinking water.

All primary contaminants have enforceable concentration values. For the majority of these pollutants, EPA lists concentration limits by using the term **Maximum Contaminant Level (MCL)**. If a water supplier exceeds a given MCL for a toxin, then fines and penalties could by imposed by the EPA. A few pathogens (Giardia Lamblia and Legionella) use Treatment Technique (TT) notation rather than numerical MCL concentrations. Water that contains any amount of these pathogens must be sanitized immediately with a standardized EPA procedure.

Table **8.2.1**: Exert of the EPA's Primary Drinking Water Contaminant Listing

Primary Contaminant	Classification	MCLG[1](mg/L)	MCL or TT[1](mg/L)	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Giardia lamblia	Microorganism	zero	TT[3]	Gastrointestinal illness (such as diarrhea, vomiting, and cramps)	Human and animal fecal waste
Thallium	Inorganic	0.0005	0.002	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories

In Table **8.2.1**, a **Maximum Contaminant Level Goal (MCLG)** column is displayed for each of the two drinking water impurities. MCLG values are not enforced by the EPA. Instead, these concentrations are suggested values that water suppliers should strive to meet. Every six years, the EPA reviews each primary contaminant with its MCL standard. During these times, they analyze data in regards to health risk assessment. If they choose to lower a MCL (smaller value) of a contaminant, then less health issues should occur. Unfortunately, reducing a concentration requires more technology which will cost the supplier and the consumer more money. By providing MCLG limits, the EPA encourages a water company to gradually work towards lowering a toxin's concentration.

Primary Drinking Water Contaminants

The National Primary Drinking Water Regulations (NPDWR) are legally enforceable primary standards and treatment techniques that apply to public water systems. Primary standards and treatment techniques protect public health by limiting the levels of contaminants in drinking water. A partial list of of standards for different water contaminants is given in the tables below. A more comprehensive and updated list can be found on this link.

These types of toxins are classified into **one of the six** EPA classifications: microorganisms, disinfectants, disinfectant byproducts, inorganics, organics, or radionuclides. Primary contaminants are regulated because the have the capacity to do great harm to humans, plants, and animals. If a water distributor (must serve at least 200 homes) exceeds one of these mandated standards, then the EPA may impose a fine on the company.



Figure **8.2.2**: Clark Hill Dam is located on the South Carolina/Georgia border. (CC BY; Elizabeth Gordon).

Concentration Units for Pollutants/Toxins

Typically, concentrations of primary contaminants are listed in parts per million. Metric amounts of a part per million are milligrams of the toxin per liter of the water sample.

$$\text{ppm} = \frac{mg}{Liters}$$

For extremely toxic substance, smaller units like parts per billion (ppb) might be used to express concentration. Metric amounts of a part per billion are micrograms of toxin per liter of water sample.

$$\text{ppb} = \frac{\mu g}{Liters}$$

The EPA measures a few pollutants using different concentration units. For example, asbestos based products are reported in fibers per liter (MFL). This silica material has been used in the construction and in the automotive industries. The insulating and noncombustible nature of asbestos enabled builders to make homes that were less flammable. In addition, mechanics can install asbestos lined brakes that would not become flammable. Unfortunately, the wide spread use of asbestos has lead to lung diseases like mesothelioma and asbestos. Today, the EPA has placed limitations of asbestos, but has not banned the use of this material in some industries. For more current information of EPA's stance on asbestos limitations, please click on this link.



Figure 8.2.3: Corrugated asbestos roof. Image courtesy of de.Wikipedia.org/wiki/Benutzer:Hawedi

Other primary contaminants that utilize alternative concentration units are radio nuclides and disinfectant byproducts. Radio nuclides are materials that naturally emit radioactive particles or waves. Examples of these would include Ra-226 and Uranium. Both of these elements have unstable nuclei that produce ionizing radiation. Exposure to even tiny amounts of radio nuclides can increase a person's likelihood of developing cancer. For this reason, the EPA regulates ionizing radiation using small concentrations (ppb). In addition, the EPA uses units like millirem and picocuries for some radio nuclides. The unit millirem focuses on biological exposure to radiation. For information regarding the millirem and or Curie units, click on this OER link. As for picocurie, this term defines an isotope's rate of nuclei decomposition.

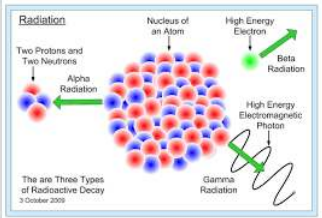


Figure 8.2.4: Types of ionizing radiation produced from a radio nuclide. Image courtesy of: PublicDomainPictures.net

Chemicals used to disinfect drinking water and rid it of pathogens are regulated as primary contaminants. These types of compounds will react with the water to form trace amounts of carcinogen organohalides. For this reason, the EPA regulated disinfectants using Maximum Residual Disinfectant Level Goal (MRDLG) and Maximum Residual Disinfectant Level (MRDL) rather than MCLG and MCL. Once again, the goal portion of this term is a future limit and the level is a fineable standard.

Example 8.2.1

Toxicity of primary contaminants can be understood by looking at the MCL value. The lower the concentration, the more dangerous a contaminant is. Using the primary drinking water standards, determine which organic compound is the most toxic.

Solution

Dioxin is the most toxic organic compound listed on the primary drinking water standards..

Amendment SDWA of 1986

This change to the Safe Drinking Water Act established MCLGs and increased the total of regulated contaminants to 83. The EPA installed more monitoring devices to detect organic contaminants. Research was done to detect pathogens more effectively to reduce disease. Lastly, public notifications from water systems to the consumers would be made announced if severe water issues occurred.

Amendment of SDWA of 1996

This particular legislation provided more protection and assessment of water sources (lakes, river, streams). In addition, water companies were required to provide consumers with a water quality report. States could seek federal money for upgrading their water quality processes. Cost benefit analysis would be done to determine risk and reward of lowering the concentration of a contaminant. For small regulated water companies, more financial and technical assistance would be offered to help them maintain drinking water standards.

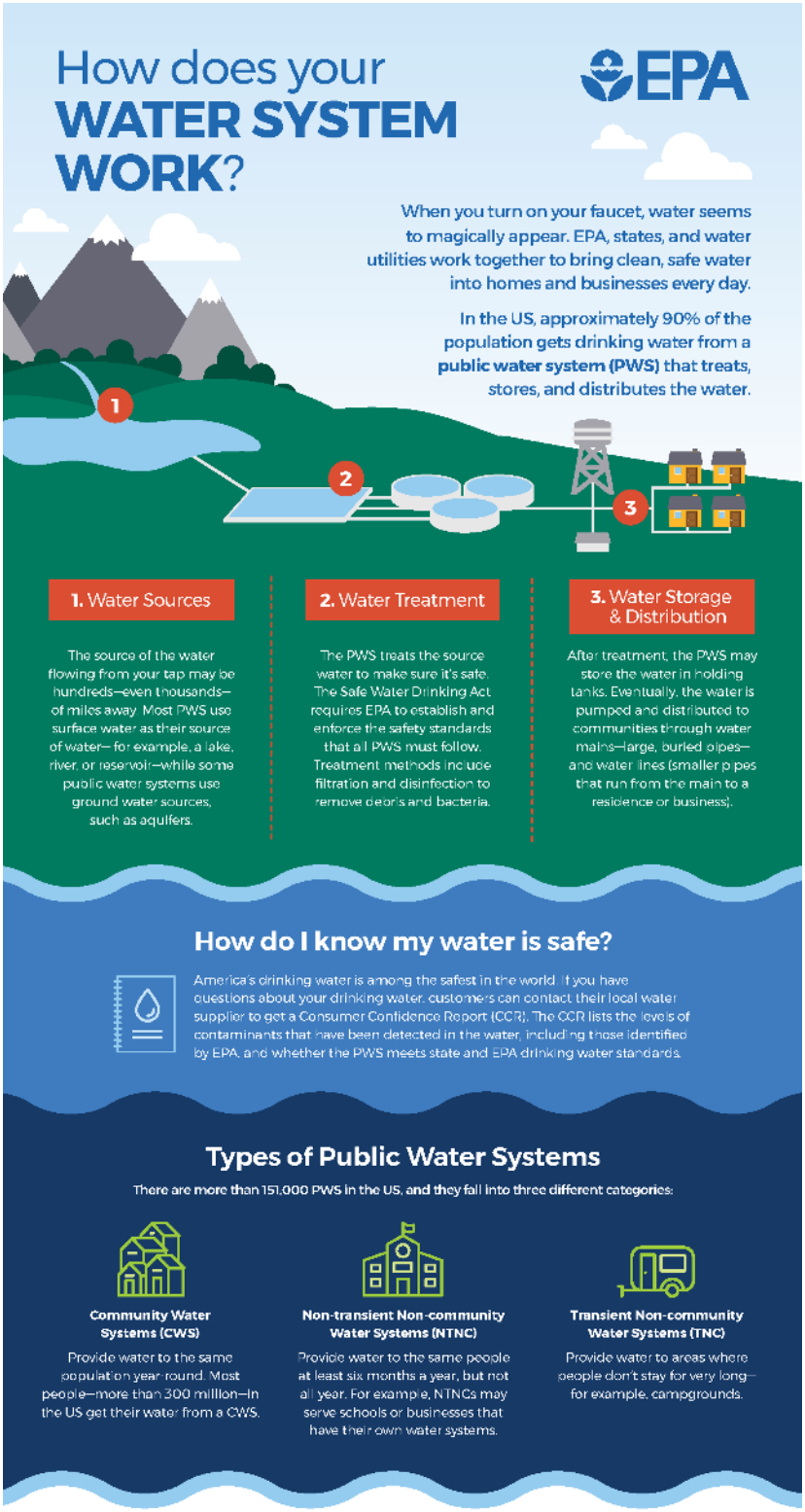


Figure 8.2.5: Regulating drinking water in the United States. Image taken from: https://www.google.com/url?sa=i&url=...AAAAAdAAAAABAD

Non-regulated Water

The EPA does not regulate private wells which serve less than 25 people or bottled water in the United States. Well water monitoring is the responsibility of the well owner. As for bottled water, the Food and Drug Administration (FDA) oversees this commodity by using EPA drinking water standards.

Notes (taken from 14.6-Delmar Link)

[1]Definitions:

- Maximum Contaminant Level Goal (MCLG) - The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.
- Maximum Contaminant Level (MCL) - The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.
- Maximum Residual Disinfectant Level Goal (MRDLG) - The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.
- Treatment Technique (TT) - A required process intended to reduce the level of a contaminant in drinking water.
- Maximum Residual Disinfectant Level (MRDL) - The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

[2] Units are in milligrams per liter (mg/L) unless otherwise noted. Milligrams per liter are equivalent to parts per million (PPM).

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8.3: Biological Contamination of Water

Learning Objectives

- Identify the three categories of pathogens that produce water-borne diseases.
- Provide one example of each pathogen, typical sources, and health problems.
- Summarize how water-borne diseases can be prevented and treated.
- Recall areas of the world where water is not properly sanitized.
- List foods and beverages that need to be avoided when using water that is not sanitized.
- Recall how long to boil water if under an advisory.
- Realize that boiling does not remove inorganics, metals, or organics.
- Besides boiling, discuss the chemical sanitation process of how to sanitize water at home (EPA method below).

Water Borne Diseases

If water is not cleaned properly, residents of a community can contract various illnesses. Viruses, bacteria, and parasites can enter a water supply unknowingly. All three of these species are pathogenic, or disease-causing. In the United States, the Environmental Protection Agency (EPA) quantifies and monitors these pathogens in water systems that serve at least 200 consumers. The EPA classifies these contaminants as being microorganisms (even though a biologist might dispute this terminology).



Video **8.3.1**: The Coalition for Global Community Health is working within existing social structures in Belén, Iquitos, Peru to uphold the human rights of the community members. We speak directly with community members in an open forum to learn about their needs, desires, and ideas for creating an opportunity to change their communities for the better

Approximately 829,000 people die each year due to developing diarrheal illnesses from water based illnesses. Of the number, over 297,000 of these fatalities are children under five years of age. From a worldwide perspective, 785 million lack access to an improved water source. That is, this large group of people do not extract their water from a household connection, public standpipe, borehole/protected well, protected spring, or rainwater collection. Implementing water sanitation and hygiene for people who live in these countries could prevent at least 9.1% of the global disease burden and 6.3% of all deaths.



Figure 8.3.1:This young girl was collecting water from a sacred pond in Ogi, Nigeria, but she won't get Guinea worm because the water had been treated, and steps had been installed, so people couldn't contaminate the water. Creator: CDC/ The Carter Center. (Copyright, Public Health Library).

One of the many waterborne pathogens that can be contracted by drinking unclean water is Giardiasis. The picture below shows how a person might contract Giardiasis from *giardia*, a parasite. This particular pathogen can live in a body up to six months. Once detected through a stool sample, a patient can be prescribed specific antibiotics like Flagyl to treat the infection. Unfortunately, there is no vaccine for preventing Giardiasis.

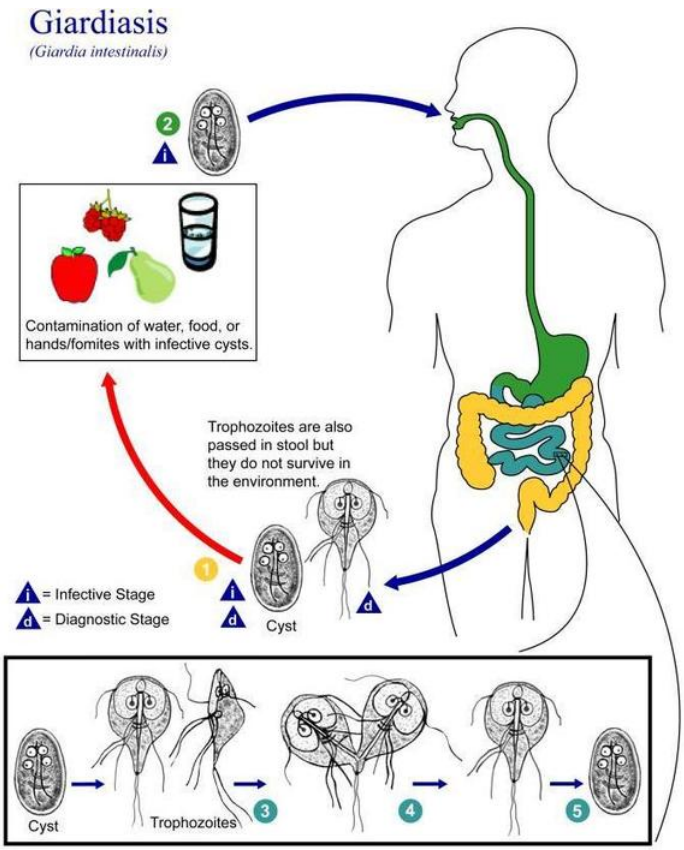


Figure 8.3.2: The life cycle of Giardia.

The table below shows water-borne diseases that can result from viruses, bacteria, and parasites. In some cases, vaccines are available. When eating, drinking, or swimming, it is important to be aware of how you could be affected by these pathogens. Sanitation of drinking water with chlorine-based compounds reduces the power of these pathogens. In addition, proper handling of foods and beverages could reduce your risk of developing one or more of the following health problems.

Table **8.3.1**: Pathogens that cause waterborne illnesses.

Pathogen Name	Pathogen Type	Source	Health problem	Prevention/Treatment
Giardia	Parasite	Fecal contamination and uncooked food	Vomiting, diarrhea, and cramps	Medication afterward
Cryptosporidium	Parasite	Fecal contamination	Vomiting, diarrhea, fever, and cramps	Medication afterward
Typhoid	Bacteria	Fecal contamination	High fever, stomach pains, headache, and rash	Vaccination/Antibiotics
E. coli	Bacteria	Fecal contamination	Diarrhea and cramps	Fluids
Legionella	Bacteria	Found naturally in heated water	Causes Legionnaires (a type of pneumonia)	Medications afterward
Cholera	Bacteria	Related to fecal contamination or undercooked or raw shellfish	Diarrhea	Vaccine/Rehydration, antibiotics, and Zinc
Hepatitis A	Virus	Contaminated food and water	Vomiting, dark urine, and yellowing of the eyes.	Vaccination/Fluids
Polio	Virus	Fecal contamination	Flu symptoms, paralysis	Vaccination

When traveling to places that do not have comprehensive water sanitation procedures, it is important to avoid certain foods and beverages. Ice and tap water should be avoided to reduce risk of exposure to pathogens. In addition, vegetables and fruits that do not have a peel could cause water borne illness. If possible, purchase bottled water from a reputable company (Nestle is common in Asia and South America)



Center for Disease Control (CDC) Sanitizing Information

Water advisories may be declared if sanitation is compromised. In these situations, boiling, halogen disinfection, or filtration could be utilized to make water **potable** (drinkable). The Centers for Disease Control has developed a document to compare these different methods of sanitation. Look below to see the most effective ways to make water safe.

This document should only serve as a guide for individuals intending to use untreated or poorly treated water as a drinking water source. This document may also aid travelers and backcountry water users in researching drinking water treatment methods. Except for boiling, few of the water treatment methods are 100% effective in removing all pathogens.

Table Key for Pathogen Removal	
-	not effective
+	low effectiveness
++	moderate effectiveness
+++	high effectiveness
++++	very high effectiveness

Contaminant	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water	Methods that may remove some/all of the contaminant				
			REMEMBER: If boiling water is not a feasible option, the most effective pathogen reduction method in untreated or poorly treated drinking water is a combination treatment, using the appropriate filtration and disinfection methods.				
			Boiling (Rolling boil for 1 minute minimum) *	Filtration **	Disinfection***		Combination Filtration and Disinfection****
					Iodine or Chlorine	Chlorine Dioxide	
Protozoa- ***Cryptosporidium***	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	++++	+++ Absolute ≤ 1.0 micron filter (NSF Standard 53 or 58 rated "cyst reduction / removal" filter)	–	+ to ++	++++ Absolute ≤ 1.0 micron filter (NSF Standard 53 or 58 rated "cyst reduction / removal" filter)
Protozoa- ***Giardia intestinalis*** **(aka** ***Giardia lamblia*****)**	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	++++	+++ Absolute ≤ 1.0 micron filter (NSF Standard 53 or 58 rated "cyst reduction / removal" filter)	+ to ++	+++	++++ Absolute ≤ 1.0 micron filter (NSF Standard 53 or 58 rated "cyst reduction / removal" filter)
Bacteria- **(e.g.,** ***Campylobacter, Salmonella, Shigella, E. coli*****)**	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	++++	++ Absolute ≤ 0.3 micron filter	+++	+++	++++ Absolute ≤ 0.3 micron filter
Viruses- **(e.g., enterovirus, hepatitis A, norovirus, rotavirus)**	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	++++	–	+++	+++	+++

Treatment methods listed above:

* **Boiling** can be used as a pathogen reduction method that should kill all pathogens. Water should be brought to a rolling boil for 1 minute (at altitudes greater than 6,562 feet (>2,000 m), boil water for 3 minutes.)

** **Filtration** can be used as a pathogen reduction method against most microorganisms, depending on the pore size of the filter, amount of the contaminant, particle size of the contaminant, and charge of the contaminant particle. Manufacturer's instructions must be followed. More information on selecting an appropriate water filter can be found at www.cdc.gov/crypto/factsheets/filters.html. Only filters that contain a chemical disinfectant matrix will be effective against some viruses.

*** **Disinfection** can be used as a pathogen reduction method against microorganisms. However, contact time, disinfectant concentration, water temperature, water turbidity (cloudiness), water pH, and many other factors can impact the effectiveness of chemical disinfection. The length of time and concentration of disinfectant varies by manufacturer and effectiveness of pathogen reduction depends on the product. Depending on these factors, 100% effectiveness may not be achieved. Manufacturer's instructions must be followed.

**** If boiling water is not possible, a **Combination of Filtration and Chemical Disinfection** is the most effective pathogen reduction method in drinking water for backcountry or travel use. Manufacturer's instructions must be followed.

Other treatment methods can be effective against some of the above pathogens:

- **Ultraviolet Light (UV Light)** can be used as a pathogen reduction method against some microorganisms. The technology requires effective prefiltering due to its dependence on low water turbidity (cloudiness), the correct power delivery, and correct contact times to achieve maximum pathogen reduction. UV might be an effective method for pathogen reduction in untreated or poorly treated water; there is a lack of independent testing data available on specific systems. Manufacturer's instructions must be followed.
- **MIOX®** systems use a salt solution to create mixed oxidants, primarily chlorine. As a result, refer to the category above for chlorine disinfection. Manufacturer's instructions must be followed.

Important: Water that has been disinfected with iodine is **NOT** recommended for pregnant women, people with thyroid problems, those with known hypersensitivity to iodine, or continuous use for more than a few weeks at a time.

In addition to using the appropriate drinking water treatment methods listed above, you can also protect yourself and others from waterborne illness by:

- **Burying human waste 8 inches deep and at least 200 feet away from natural waters.**
- **Practicing good personal hygiene. Wash hands before handling food, eating, and after using the toilet.**

Halogen based solids can be purchased at most home improvement stores, pool stores, Walmart, and Target. These chemicals will alter taste and smell of water. These chemicals are also needed when properly sanitizing a pool or a hot tub. Halogen tablets are quite cheap and an effective way for sanitizing any type of water.

EPA: EMERGENCY DISINFECTION OF DRINKING WATER

In an emergency situation where regular water service has been interrupted – like a hurricane, flood, or water pipe breakage – local authorities may recommend using only bottled water, boiled water, or disinfected water until regular water service is restored. The instructions below show you how to boil and disinfect water to kill most disease-causing microorganisms that may be present in the water. However, boiling or disinfection will not destroy other contaminants, such as heavy metals, salts, and most other chemicals.

> *ONLY USE WATER THAT HAS BEEN PROPERLY DISINFECTED FOR DRINKING, COOKING, MAKING ANY PREPARED DRINK, WASHING DISHES, AND FOR BRUSHING TEETH.*

Use **bottled wate**r or water you have properly prepared and stored as an emergency water supply.

Boil water, if you do not have bottled water. Boiling is sufficient to kill pathogenic bacteria, viruses and protozoa (WHO, 2015).

- If water is cloudy, let it settle and filter it through a clean cloth, paper towel, or coffee filter.
- Bring water to a rolling boil for at least one minute. At altitudes above 5,000 feet (1,000 meters), boil water for three minutes.
- Let the water cool naturally and store it in clean containers with covers.
- To improve the flat taste of boiled water, add one pinch of salt to each quart or liter of water, or pour the water from one clean container to another several times.

Disinfect water using household bleach, if you can't boil water. Only use regular, unscented chlorine bleach products that are suitable for disinfection and sanitization as indicated on the label. The label may say that the active ingredient contains 6 or 8.25% of sodium hypochlorite. Do not use scented, color safe, or bleaches with added cleaners.

- If water is cloudy, let it settle and filter it through a clean cloth, paper towel, or coffee filter.
- Locate a clean dropper from your medicine cabinet or emergency supply kit.
- Locate a fresh liquid chlorine bleach or liquid chlorine bleach that is stored at room temperatures for less than one year.
- Use the table on the next page as a guide to decide how much bleach you should add to the water, for example, add 8 drops of 6 % bleach or 6 drops of 8.25% bleach to each gallon of water. Double the amount of bleach if the water is cloudy, colored, or very cold.
- Stir and let stand for 30 minutes. The water should have a slight chlorine odor. If it doesn't, repeat the dosage and let stand for another 15 minutes before use.
- If the chlorine taste is too strong, pour the water from one clean container to another and let it stand for a few hours before use.

Volume of Water	Amount of 6% Bleach to Add†	Amount of 8.25% Bleach to Add†
1 quart/liter	2 drops	2 drops
1 gallon	8 drops	6 drops
2 gallons	16 drops (1/4 tsp.)	12 drops (1/4 tsp.)
4 gallons	1/3 tsp.	1/4 tsp.
8 gallons	2/3 tsp.	1/2 tsp.

†Bleach may contain 6 or 8.25% sodium hypochlorite

ADDITIONAL WATER GUIDANCE FOR EMERGENCIES

Prepare and store an emergency water supply. Visit the Federal Emergency Management Agency (FEMA) website for additional guidance on preparing and storing an emergency water supply.

Look for other sources of water in and around your home. Although bottled water is your best choice, you may be able to find other sources of water by melting ice cubes or draining your hot water tank or pipes. You can also use river or lake water. It is generally better to use flowing water than still, stagnant water. However, do not use water with floating material in it or water that has a dark color or questionable odor. Regardless of the source, treat the water by following the instructions above. If you have a well on your property that has been flooded, make sure to disinfect and test the well water after the flood. Contact your state or local health department for advice or go here.

Consider how the water looks and how to filter it if needed. Disinfection does not work as well when water is cloudy or colored. If water is cloudy, let it settle. Then filter the water through a clean cloth, paper towel, or coffee filter. Store the settled and filtered water in clean containers with covers

OTHER DISINFECTION METHODS

If you don't have liquid bleach, you can use one of the other disinfection methods described below.

- *Granular calcium hypochlorite*. The first step is to make a chlorine solution that you will use to disinfect your water. For your safety, do it in a ventilated area and wear eye protection. Add one heaping teaspoon (approximately ¼ ounce) of high-test granular calcium hypochlorite (HTH) to two gallons of water and stir until the particles have dissolved. The mixture will produce a chlorine solution of approximately 500 milligrams per liter. To disinfect water, add one part of the chlorine solution to every 100 parts of water you are treating. This is about the same as adding 1 pint (16 ounces) of the chlorine solution to 12.5 gallons of water. If the chlorine taste is too strong, pour the water from one clean container to another and let it stand for a few hours before use. CAUTION: HTH is a very powerful oxidant. Follow the instructions on the label for safe handling and storage of this chemical.
- *Common household iodine* (or "tincture of iodine"). You may have iodine in your medicine cabinet or first aid kit. Add five drops of 2% tincture of iodine to each quart or liter of water that you are disinfecting. If the water is cloudy or colored, add 10 drops of iodine. Stir and let the water stand for at least 30 minutes before use.
- *Water disinfection tablets*. You can disinfect water with tablets that contain chlorine, iodine, chlorine dioxide, or other disinfecting agents. These tablets are available online or at pharmacies and sporting goods stores. Follow the instructions on the product label as each product may have a different strength.

Safe Drinking Water Hotline: 1-800-426-4791 water.epa.gov/drink/hotline

Example 8.3.1

1. Do all waterborne pathogens cause stomach illnesses?
2. If your community is under a water advisory, then how long should you boil tap water to kill pathogens?
3. Vaccinations and preventive medications can protect you from which pathogens?
4. When properly diluted, which common household cleaner can sanitize tap water?

Answer

1. Legionella bacteria causes respiratory problems. Also, hepatitis and polio viruses do not produce stomach illnesses.
2. Water should be boiled rigorously for at least one minute to kill most pathogens.
3. Vaccines can be used to prevent: hepatitis, typhoid, cholera, and polio. In the United States, most children have been vaccinated from hepatitis and polio. When traveling to destinations that lack sanitized water, it would be beneficial to request prescription medications from your health care professional. Refer to the chart above regarding which diseases can be treated with medications.
4. A diluted (watered down) form of bleach (sodium hypochlorite) can be used to sanitize water. Please note the different types of bleach that can be purchased. In addition, do not use color safe or scented bleach.

References

1. World Health Organization. Drinking-water (who.int)
2. The Center For Disease Control. Global WASH Fast Facts | Global Water, Sanitation and Hygiene | Healthy Water | CDC

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8.4: Chemical Contamination of Water

Learning Objectives

- Realize how combustion processes affect water sources.
- Define the pH and composition of acid rain (three specific formulas/names).
- Know the precursors of acid rain.
- Recall the environmental and biological effects of acid rain.
- Understand the differences between hard and soft water.
- Connect inorganic water contaminants with biological and environmental issues.
- Know the sources of inorganic and organic contaminants.
- Differentiate between organic and inorganic substances when given a formula.

The US Safe Drinking Water Act defines the term "contaminant" as meaning any physical, chemical, biological, or radiological substance or matter in water. Therefore, the "contaminant" definition very broadly applies as being anything other than water molecules. Drinking water may reasonably be expected to contain at least small amounts of some contaminants. Some drinking water contaminants may be harmful if consumed at certain levels in drinking water while others may be harmless. The presence of contaminants does not necessarily indicate that the water poses a health risk.

Air Pollutants

Water can become contaminated at any part of the water cycle. Air pollution can affect water vapor and water liquid. Combustion sources like vehicles and power plants generate compounds like NO_xs, SO_xs, CO, CO_2, and other various inorganic and organic volatile organic compounds (VOC) species. Some of these compounds can become soluble in water. This could affect pH (or acidity) level of water surface water. Rain water with a pH below 5.6 is considered to be acid rain.

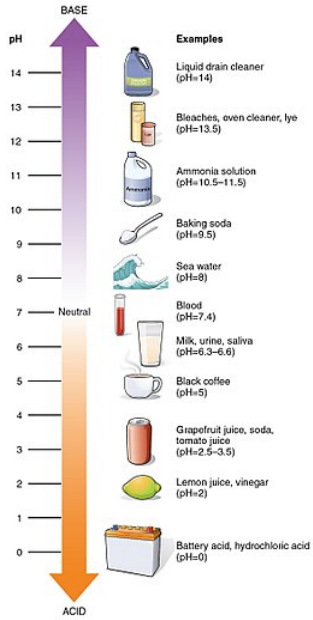


Figure **8.4.1**: pH scale. (Copyright; OpenStax College via Anatomy & Physiology, Connexions Web site. http://cnx.org/content/col11496/1.6/)

Normally, the pH of water is a neutral value (or pH= 7). When NO_xs, SO_xs, CO, CO_2 enter the water cycle, then the pH level is lowered below 7.0. If these gases are absorbed in rain clouds, then acid rain results. Specific acids involved in acid rain are **sulfuric (H_2SO_4), nitric (HNO_3),** and **carbonic (H_2CO_3)**. This environmental problem affects living organisms and building materials. Acid solutions can corrode metals and make them soluble as well.

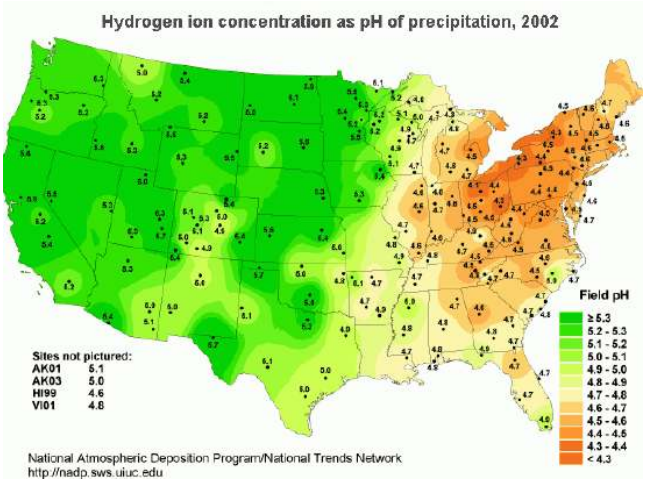


Figure 8.4.2: pH of rainwater over the continental United States.

In the United States, the northeast has the most problems with acid rain. Concentrated populations that use electrical energy and vehicles contribute greatly to the pH reduction of rainwater. Reducing gaseous output requires capping combustion sources (vehicles and power plants). Acidity in rain is measured by collecting samples of rain and measuring its pH. To find the distribution of rain acidity, weather conditions are monitored and rain samples are collected at sites all over the country. The areas of greatest acidity (lowest pH values) are located in the Northeastern United States. This pattern of high acidity is caused by a large number of cities, the dense population, and the concentration of power and industrial plants in the Northeast. In addition, the prevailing wind direction brings storms and pollution to the Northeast from the Midwest, and dust from the soil and rocks in the Northeastern United States is less likely to neutralize acidity in the rain.

Acid rain from sulfuric acid

However, the majority of acid rain is accounted for by the presence of sulfuric acid (H_2SO_4).

$$SO_2\,(g) + O_2\,(g) \longrightarrow SO_3\,(g)$$

Sulfur dioxide reacts with water to form sulfuric acid

$$SO_3\,(g) + H_2O \longrightarrow H_2SO_4 \tag{8.4.1}$$

Although sulfuric acid may be produced naturally in small quantities from biological decay and volcanic activity, it is produced almost entirely by human activity, especially the combustion of sulfur-containing fossil fuels in power plants.

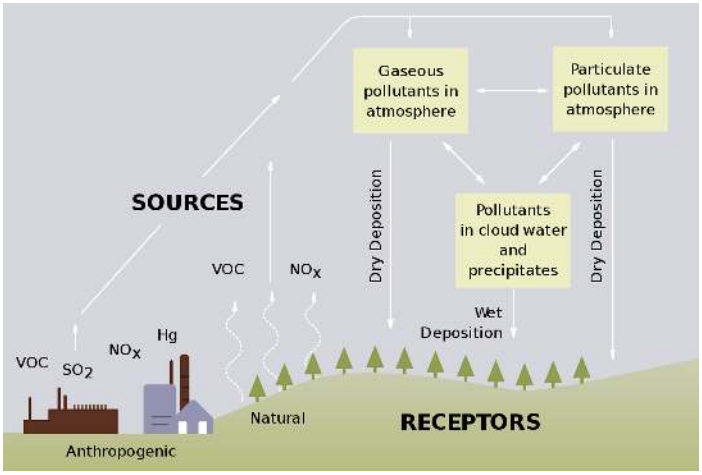


Figure 8.4.3: Processes involved in acid deposition (note that only SO_2 and NO_x play a significant role in acid rain). (public domain; EPA)

Acid rain from nitric acid

Some of acid rain is accounted for by nitric acid (HNO_3) that originates from natural processes, but especially from high-temperature air combustion, such as occurs in car engines and power plants, that produces large amounts of NO gas. This gas then forms nitric acid via several steps. First nitric oxide (NO) is formed during lightning storms by the reaction of nitrogen and oxygen

$$N_2(g) + O_2(g) \longrightarrow 2\,NO(g) \tag{8.4.2}$$

and NO is oxidized to nitrogen dioxide (NO_2)

$$NO(g) + \tfrac{1}{2}\,O_2(g) \longrightarrow NO_2(g) \tag{8.4.3}$$

$NO_2(g)$ then reacts with water droplets to generate nitric acid (HNO_3)

$$3\,NO_2(g) + H_2O(l) \longrightarrow 2\,HNO_3(aq) + NO(g)$$

Table 8.4.2: Source of Water contamination in the United States

Combustion products	Sources
CO_2 and CO	Combustion of any material (any fuel or tree)
NO_X (NO_2 and NO_3)	High-temperature combustion of any fuel (gas, diesel, or coal), a product of lightning
SO_x (SO_2 and SO_3)	Combustion of sulfur-based fuels (diesel and coal), volcanic release
VOC (volatile organic compound)	Combustion of any carbon-based fuel (gas, diesel, or coal), fumes from paints or solvents

Inorganic Contaminants

Solubility of these species can be determined by consulting a solubility table (e.g., Table 4.7.1). These chemicals might be naturally present in a water source. Industry and agriculture also use and dispose of these types of chemicals as well. In determining the source of any pollutant, it is helpful to know a region's geology and proximity to chemical consumers. In this section, we will focus on a few inorganic species that can affect drinking water quality.

Hard Water

When water is described as being hard, then this means it has a large concentration of minerals. The **ions** that contribute to this problem are **calcium** (Ca^{2+})**, magnesium** (Mg^{2+})**, carbonate** $(CO_3)^{2-}$, and **iron** (Fe^{2+}/Fe^{3+}). Hard water is not toxic, but can affect industrial processes. These ions will bond together to form insoluble salts that are called precipitates. Building up of these newly formed solids is called scale. Precipitates can collect in boilers, cooling towers, and any equipment that employs water. This buildup can affect how the equipment works by damaging it internally.

Video: Hard Water

Watch this video below to get an idea of what hard water is.



https://youtu.be/Ts6PNYk7-a0

1. What chemical species cause hard water?
2. How does hard water affect industry?
3. Hard water is known to contribute to the formation of kidney stones. How else can this type of water affect the body?

Soft Water

Soft water does not contain an excessive amount of alkaline minerals. Instead, **potassium** (K^+) and **sodium** (Na^+) ions are present. Soft water does not form scale but does produce excessive lathers with soap. Although industry and consumers prefer soft water, the sodium content can affect health if ingested at a high concentration.

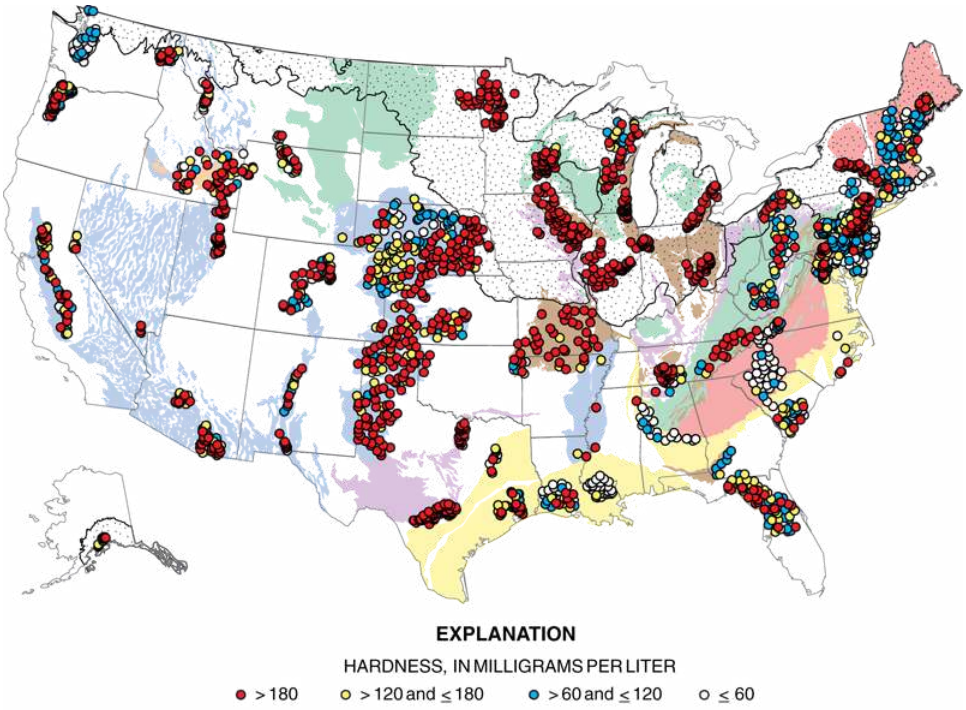


Figure 8.4.4: Hardness of groundwater from domestic wells, a USGS study. A study from the National Water-Quality Assessment (NAWQA) Program assessed water-quality conditions for about 2,100 domestic wells across the United States. (Public Domain; USGS).

Eutrophication

When pollutants enter a water system they originate from either point or non-point sources. If a single identifiable source can be located, then the pollutant originated from a point source. In contrast, non point sources indirectly contaminant water, air, or soil. Examples of non-point sources would be run-off and acid rain. Obviously, non-point pollutants are more difficult to regulate.

In agriculture, nitrates $(NO_3)^-$ are used as fertilizers. Farmers can choose to use synthetic or natural (manure) nitrates. Regulating concentrations of these species could be difficult if all sources are not investigated and monitored. An excessive amount of these substances leads to eutrophication. Many nitrate $(NO_3)^-$ and phosphate $(PO_4)^{3-}$ containing compounds are soluble in water. Once dissolved, these substances can travel to lakes and ponds. Here, these chemicals activate plants and algae to grow. Overgrowth of plant-life in water can inhibit oxygen from entering the water. As a result, aquatic animals are more likely to die in this environment. In addition, decomposition of organic material (once living) will be slow and smelly.



Figure 8.4.5: Algal bloom in village river. Taken in a small village in mountains near Chengdu, Sichuan, China. (CC BY-SA 3.0; River algae Sichuan - Trophic state index - Wikipedia)

Eutrophication can be halted in phosphate $(PO_4)^{3-}$ contamination is controlled. This involves limiting the use of some fertilizers and removing phosphates from detergents. Reducing nitrates can be a more challenging task. All compounds containing this polyatomic ion are extremely soluble. Moreover, controlling nitrate concentration from fecal material can be difficult.



Toxic Inorganic Species

Some inorganic compounds are quite soluble in water. If an aquatic system is acid, then solubility of these types of species can change. Lead and mercury based compounds are not as soluble as those in group IA of the periodic table. When the pH of water becomes acid, many of these once insoluble compounds now become dissolved and visually undetectable.

Lead (Action Level is 0.015 ppm)

Occupational exposure to lead is one of the most prevalent overexposures. Industries with high potential exposures include construction work, most smelter operations, radiator repair shops, and firing ranges. Other sources of lead based compounds include house paint (from before 1978), toys (older than 1976 or from abroad), pipes, faucets, jewelry, wet batteries (gasoline engine based), pottery, and Kohl/Kajol eyeliners.

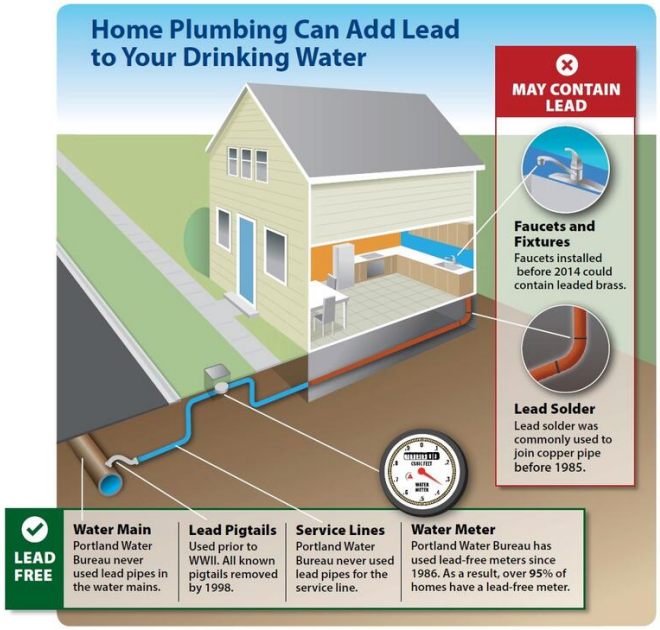


Figure 8.4.6: Lead and drinking water. (Copyright; City of Portland)

Gasoline products may contain lead compounds to diminish knocking of a combustion engine. These additives increase the octane level of a fuel which enables the engine to burn more effectively. Unfortunately, releasing lead-based fumes can impair a person's nervous system. In addition, other disorders and diseases (kidney issues, gastrointestinal problems, growth delays, anemia, and learning difficulties) will become more prevalent in an area that has signification combustion of lead based fuels. Children will be more impacted by lead poisoning than adults. Often, the damage done to this group of people is irreversible. By the early 1970's, the Environmental Protection Agency (EPA) started focusing on phasing out leaded fuel products. By the mid 1980's, most US vehicles used only unleaded fuels. The EPA banned lead based fuel in 1996. Today, only the aviation industry and off-road vehicles are allowed to use leaded fuel in the United States.

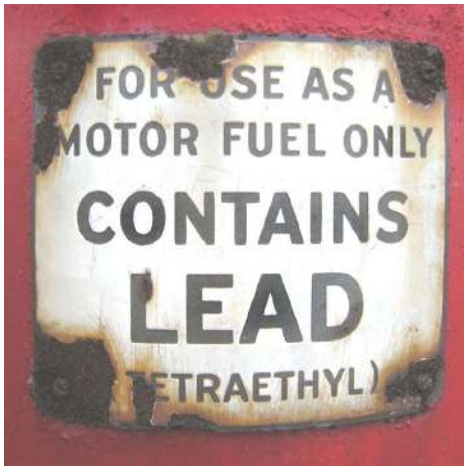


Figure 8.4.7: ead warning on a gas pump at Keeler's Korner, Lynnwood, Washington. Keeler's Korner, a former grocery store and gas station (built 1927) listed on the National Register of Historic Places, listed 1982, NRHP listing #82004287. (CC-BY-SA 3.0; https://commons.wikimedia.org/wiki/User:Jmabel)

Arsenic (0.010 ppm or 10 ppb)

Common sources of exposure to higher-than-average levels of arsenic include near or in hazardous waste sites and areas with high levels naturally occurring in soil, rocks, and water.

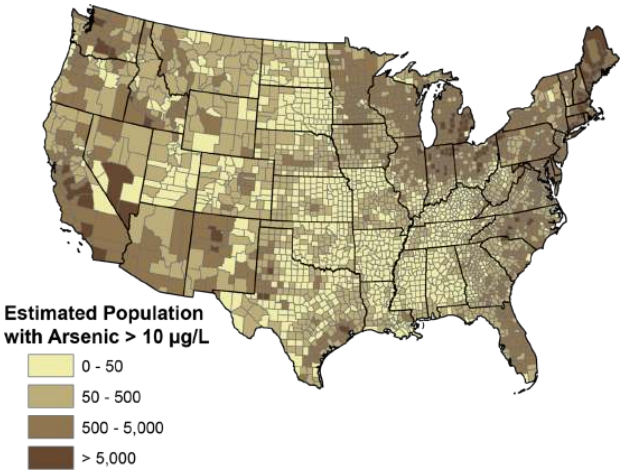


Figure **8.4.8**:This map shows estimates of how many private domestic well users in each county may be drinking water with levels of arsenic of possible concern for human health.(µg/L, micrograms per liter) (USGS; Arsenic and Drinking Water | U.S. Geological Survey (usgs.gov))

Arsenic compounds can be found in lead/copper smelting processes, lumber pressurizing (copper chromated arsenate compounds are no longer used in the United States) and pesticide applications (organic arsenic compounds are used to treat cotton fields and orchards). Exposure to high levels of arsenic can cause skin lesions, neurological problems, gastrointestinal/live illnesses, various cancers, and death.



Mercury (0.002 ppm)

Common sources of mercury exposure include mining, production, and transportation of mercury, as well as mining and refining of gold and silver ores. High mercury exposure results in permanent nervous system and kidney damage. Once inorganic mercury enters aquatic systems, it can transform into organic mercury or organometallic mercury. An example of one of these compounds is methyl mercury (CH_3Hg). This type of compound is quite toxic and has bioaccumulation effects.

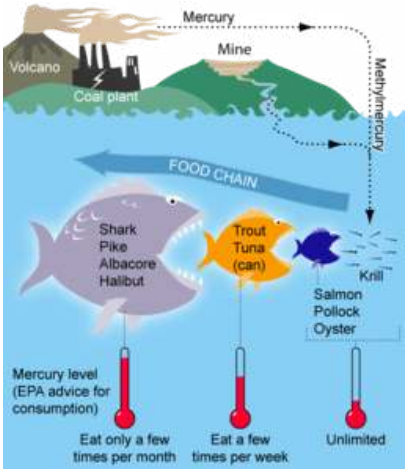


Figure 8.4.9: This figure shows some common sources of mercury, the conversion to toxic methylmercury and the outline of EPA consumption recommendations for certain types of fish based on mercury levels. (Copyright; Bretwood Higman, Ground Truth Trekking.via http://www.groundtruthtrekking.org/Graphics/Large/MercuryFoodChain-01.png)

Cadmium (0.005 ppm)

Cadmium is an extremely toxic metal that exists naturally in the Earth's crust as a common. Agricultural crops absorb cadmium compounds from the soil. The average person is exposed to cadmium through the consumption of plant based food, burning of cadmium based materials (air pollution), and drinking of tap water. Tobacco consumers receive additional cadmium when they smoke. Lastly, artists might use cadmium based pigments for dramatic colors in their paintings.



Figure 8.4.10: The Berkeley Pit, an open pit copper mine in Butte, Montana. (Copyright; User:Cybergrl23 via Wikipedica Commons)

At industrial workplaces, cadmium can be introduced to the atmosphere when any metal ore is being processed or smelted. Some forms of steel and batteries (Ni-Cd) contain cadmium mixtures. Several deaths from acute exposure have occurred among welders who have unsuspectingly welded on cadmium-containing alloys or with silver solders. This chemical substance is carcinogenic and causes a signature painful bone disease. Lastly, cadmium exposure can cause significant damage to kidneys.

Uranium (30 ppb)

Natural deposits of this element are found in the earth crust are sometimes associated with mountainous regions of the world. In the United States, uranium ores can be found in the western part of the country. If uranium becomes soluble, then it can leach or move to other locations contaminating water and soil nearby.

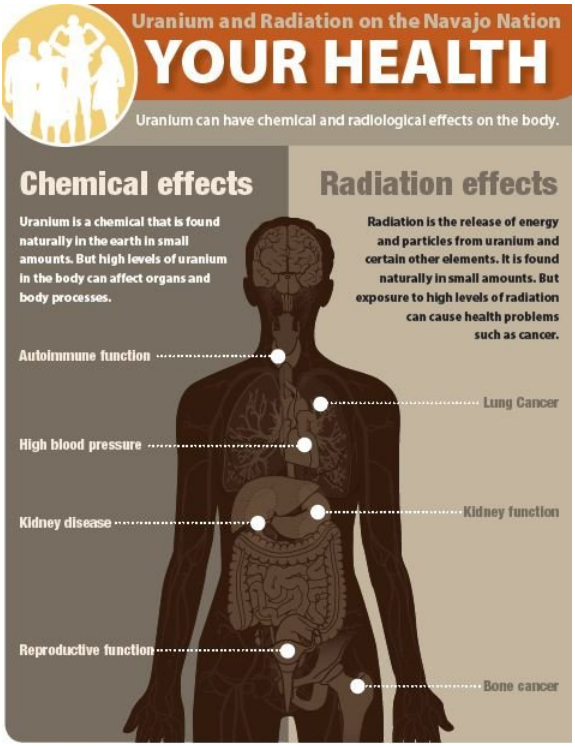


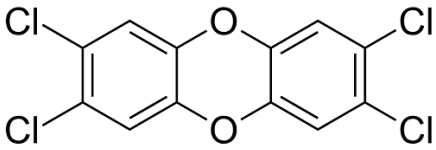
Figure 8.4.11: Your Health: Uranium and Radiation on the Navajo Nation. (epa.gov; Health Effects of Uranium | US EPA)

Enriched U-235 (2-5%) is used for fuel in all US commercial nuclear power plants. Waste products of fuel use are stored for long periods of time above ground at most nuclear reactor facilities. Fuel waste can be stored in a wet or dry environment. Either method requires isolation from humans and the environment since the waste will be radioactive for a long time. Enriched U-235 (90%) was fuel for the Little Boy atomic bomb which was dropped over Hiroshima in 1945. At the time, purification of this form of uranium was difficult and costly. This resulted in the production of only one uranium type atomic weapon.

Organic Chemical Concerns

Dioxin (3.0×10^{-8} ppm)

Dioxins are mainly byproducts of industrial practices. They are produced through a variety of incineration processes, including improper municipal waste incineration and burning of trash, and can be released into the air during natural processes, such as forest fires and volcanoes. Dioxins are also produced in the bleaching process used by the paper industry. These chemicals have been classified as Persistent Organic Polluters (POPS) because of their long residual life-times in the environment. These compounds are fat soluble and will accumulate in fatty tissues of living organisms which in turn affects the health of the food chain.



Dioxin based compounds harm hormonal and reproductive systems. In addition, immunity disorders and chloroacne can result if someone has been exposed to these types of chemicals. A famous case of intentional dioxin (TCDD) poisoning involved a former Ukrainian presidential candidate named Vicktor Yushchenko. In 2004, environmental toxicologists in Austria detected extremely high concentrations of dioxins in Yushchenko's blood. Also, medical experiments noted the change in his complexion before and after the poisoning. For more information regarding this incident, please click here.

When synthesizing Agent Orange (a herbicide used before and during the Vietnam War), chemists simultaneously and unintentionally produced dioxin. Exposure to this chemical derivative increased cancer rates to those exposed.



(PCB) Polychlorinated Biphenyls (5.0 x 10^{-4} ppm)

Once used as electrical insulators, the United States produced this family of compounds from the late 1930's through the 1970's. These compounds did not decompose, conduct electricity, and could withstand high temperature environments. For these reasons, PCBs were commonly incorporated into electrical transformers, fluorescent lights, capacitors and older household appliances (televisions and refrigerators).

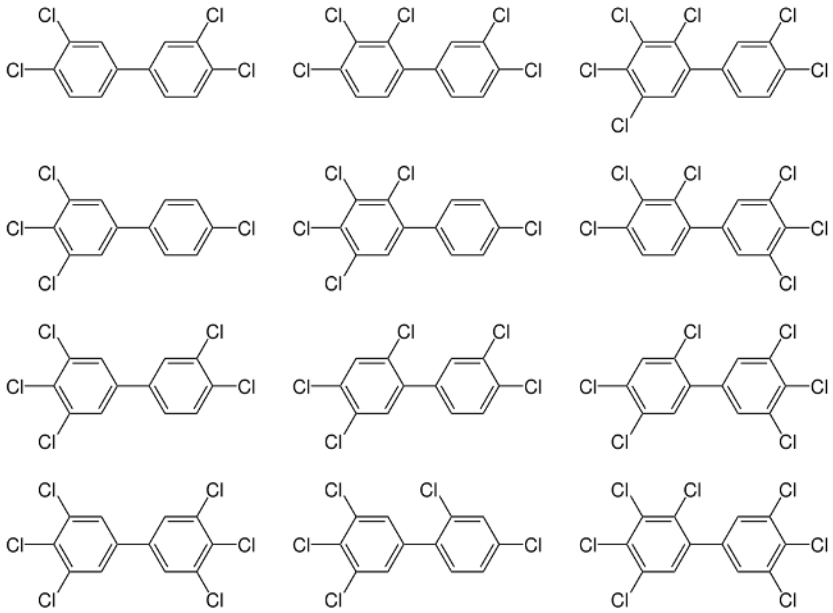


Figure 8.4.12: Structures of dioxin-like PCBs.. (Copyright; User:Leyo via Own work based on: *M. Van den Berg et al. (2006). "The 2005 World Health Organization Reevaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-Like Compounds". Toxicological Sciences 93 (2): 223–241. DOI:10.1093/toxsci/kfl055. PMID 16829543.*)

These compounds are classified as human carcinogens. In certain concentrations, PCB exposure can manifest as chloracne. Chronic exposure to PCBs can cause liver and central nervous system damage. Lastly, PCBs can cause reproductive issues as well.

> file:///C:/Users/egordon/Downloads/c...disaster-5.pdf

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5. Learn about Dioxin | US EPA

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8.5: Water Concentration Units

Learning Objectives

- Analyze ppm and ppb values to determine toxicity.
- Recall basic metric prefixes and conversion factors.
- Calculate ppm and ppb concentrations if provide mass and volume amounts.
- Compare calculated values to EPA primary standards.
- Classify contaminant as being primary or secondary.
- If contaminant is primary, then recognize it as being inorganic, organic, microbial, radionuclide, disinfectant, or disinfectant byproduct.

Parts Per Million (PPM)

Many of the EPA's primary contaminants are regulated in ppm concentrations. Recall from section 8.2, the meaning of ppm in terms of the metric system. These are very small concentrations of solutions. To visualize how tiny these units are, watch the video below.



In aqueous solutions, 1 ppm is essentially equal to 1 mg/L

$$1 \text{ ppm} = \frac{1 \text{ mg Solute}}{1 \text{ L Solution}}$$

The equation represents the allowable milligram toxin amount per liter of drinking water. A small ppm value correlates to lethal substances. Click here to view the EPA MCL primary drinking water concentrations. You will note that many of them are represented by ppm amounts.

For parts per billions, 1 ppb corresponds to 1 µg/L.

$$1 \text{ ppb} = \frac{1 \ \mu\text{g Solute}}{1 \text{ L Solution}}$$

A simple method of converted a ppm concentration to ppb units is to multiply by 1000. When given a ppb value, simply dividing that number by 1000 will produce a ppm amount.

Example 8.5.1

When calculating ppm, remember to employ the metric system. Often, the mass of the contaminant may be given in grams or another metric unit. This mass should be converted to milligrams before it can be placed into the ppm equation. It is common to make laboratory volume measurements in milliliters. These too, must converted to liters before inserting into the equation above. Check your learning management system (moodle) for video footage of your instructor working ppm/ppb problems.

Your drinking water contains .00055 grams of chlorite per 200 mL of water. Does this exceed the EPA drinking water standard? Also, which type of primary contaminant is this chemical (hint: use the hyperlink above and scroll until you see the classification)?

Solution

$$.00055 \cancel{g} \times \frac{1000\, mg}{1 \cancel{g}} = .55\, mg \tag{8.5.1}$$

$$= 5.5 \times 10^{-1}\, mg \tag{8.5.2}$$

$$200 \cancel{ml} \times \frac{1\, L}{10^3 \cancel{ml}} = .200\, L$$

$$= 2.0 \times 10^{-1}\, L$$

$$2.75 \text{ ppm} = \frac{.55 \text{ mg Solute}}{.2 \text{ L Solution}}$$

This is larger than the EPA drinking water standard for chlorite (MCL= 1.0 ppm). This contaminant is a byproduct of disinfection.

Remember to use the EPA's National Primary Drinking Water Regulations handout as a reference guide to assist you in learning more about a specific contaminant.

Example 8.5.2

Based upon MCL values which contaminant is more toxic: Diquat or Thallium? Also, classify Diquat and Thallium as being one of the six primary drinking water contaminants.

Solution

The MCL value for Diquat is .02ppm while allowed Thallium concentration is .002 ppm. The smaller the MCL concentration the more dangerous the contaminant is. Therefore, Thallium is the more toxic of these two chemicals. Looking at the EPA legend, Diquat is an organic chemical and Thallium is an inorganic element.

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8.6: Sanitation of Drinking Water

Learning Objectives

- Understand why drinking water required sanitation.
- Know the three different types of water sanitation methods.
- Provide advantages and disadvantages of each type of sanitation method.
- Define the terms residual protection and disinfection byproducts.

Chlorine-based methods

Chlorination is the process of adding chlorine compounds to drinking water to disinfect it and kill germs. In 1908, New Jersey was the first state to utilize chlorinated compounds for sanitizing drinking water. This method is quite cheap for most countries and rids water of bacteria and most viruses. Regarding protozoa (Giardia and Cryptospordium), results can vary depending upon the type of chlorine product that it used and how long it is applied (refer to this CDC table). Chlorine does offer residual protection from treatment facility to consumer and is quite cheap. In the United States, chlorine (Cl_2) has been used to sanitize both drinking and waste waters since the early twentieth century. Gaseous chlorine (Cl_2) is known to be quite corrosive, poisonous, and explosive.



Video **8.6.1**: Chlorine and Exposure Concerns. (Copyright; https://www.youtube.com/@IAQMarketer). (3:45min)

After watching the video above, answer the questions below:

1) Provide the physical and chemical properties of chlorine (Cl_2).

2) When was chlorine gas used as a chemical weapon?

3) What are some biological reactions to chlorine gas exposure?

4) Name the two household cleaners that should never be mixed together.

Other chlorine-based sanitizing agents include chlorine dioxide (ClO_2), sodium hypochlorite (NaClO), calcium hypochlorite ($Ca(ClO)_2$, and chloroamines (e.g., NH_2Cl). The first of these, chlorine dioxide. is a gaseous compound that is capable of destroying viruses and bacteria in drinking water, but requires higher dosages to kill protozoa like Giardia. Sanitizing procedures involving chlorine dioxide require longer contact time at higher dosages than other using pure chlorine. Hypochlorite $(ClO)^-$ based compounds are effective at killing viruses and bacteria. Like chlorine dioxide, hypochlorites do not deactivate all protozoa. Deactivating Cryptosporidium can be challenging using chlorine based methods. In order to remove this protozoa, water must be flushed through a filtered which has a pore size of equal to or less than 1 micron (micrometer). Filters should be labeled as "absolute 1 micron." If reverse osmosis it used to purify water, Cryptosporidium and all other disease causing pathogens will be removed as well.



Figure 8.6.1: Image of chlorine dioxide dissolved in water. (Copyright, https://commons.wikimedia.org/wiki/User:Iridos)

Chloroamines are a group of chemical compounds that contain chlorine (Cl_2) and ammonia (NH_3). The specific form of chloroamine used in drinking water disinfection is called monochloramine (NH_2Cl). These sanitizers do not kill harmful organisms as fast as chlorine gas and can decompose when exposed to heat, light, and bacteria. Effective chloramine levels range from 1.0 to 4.0 ppm. These compounds provide long-lasting residual protection For this reason, monochlorinamine is often utilized as a secondary sanitizer in addition to chlorine or non-chlorine methods of sanitization.

All forms of chlorination do alter smell and taste of drinking water. In addition, chlorine (most often responsible are the chloroamines compounds) can react with other chemicals in tap water to produce organochlorides. The EPA classifies these newly formed compounds as disinfectant byproducts and regulates them as primary drinking water contaminants.

Ozone (O_3) Disinfection

Ozone disinfection, or ozonation, is powerful oxidizing process which is toxic to most waterborne organisms. This method of disinfection is widely used in Europe. Ozone deactivates cyst formation of protozoa (like Giardia). In addition, this chemical effectively kills viruses and bacteria.

Ozone machines were first constructed in the mid-1800's. New devices produce O_3 molecules by passing oxygen through ultraviolet light or a "cold" electrical discharge. To use ozone as a disinfectant, it must be created on-site and then added to the water by bubble contact. Unlike chlorine, the ozonation process does not alter the taste or smell of water.



Video 8.6.2: Demonstration-Effects of Panasonic's "Ozone Water" Device (1.11 min).

Unfortunately, ozone does not provide any residual protection once water has left the treatment facility. For water that must travel far distances to consumers, chlorine or chloramine should be added throughout a distribution system to remove any potential

pathogens during the transportation process

However, although fewer by-products are formed by ozonation, it has been discovered that ozone reacts with bromide ions in water to produce concentrations of a suspected carcinogen called bromate $(BrO_3)^{1-}$. Bromide $(Br)^-$ can be found in fresh water supplies in sufficient concentrations to produce (after ozonation) more than 10 parts per billion (ppb) of bromate — the maximum contaminant level established by the EPA. Other disadvantages to using ozonation methods are energy requirements and cost. Of the three types of sanitization processes (chlorination, ozonation, and UV irradiation), this technique is the most expensive.

Ultraviolet Disinfection (UV)

Ultraviolet radiation (namely UVC) can be used to eradicate viruses, bacteria, and parasites from drinking water. This method of sanitation does not produce byproducts or alter physical properties (taste or smell) of the water.



Video **8.6.3**: Understanding Ultraviolet UV Radiation and its Effects. (Copyright, Larson Electronics). (1:54 min).

However, ionizing radiation has difficulty inactivating parasitic cysts in turbid (unclear) water. Like ozonation, UV irradiation offers no residual protection and is pricier than chlorination. Smaller ultraviolet units do supply over 2 million people in 28 developing countries clean water for drinking, eating, and cooking.



Figure **8.6.2**:Ultraviolet lamp sanitizing water. Image courtesy of: https://www.nab.usace.army.mil/Media/News-Stories/Article/946068/army-water-treatment-plant-brings-a-unique-first/

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4) cdc.gov

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8.7: Sanitizing Water While Traveling

Learning Objectives

- Know how to sanitize water when traveling or camping.
- Know the capacities and limitations of the LifeStraw and Steripen.
- Understand how iodination and bromination processes can be used to sanitize water.

LifeStraw

When traveling or enjoying the outdoors, you might want to invest in a portable water purification system. Two of the most common of these are the LifeStraw and Steripen. LifeStraws uses physical filtration with no chemical treatment. This device is effective in removing bacteria and parasites. A personal device can filter around 1000 liters of water. A LifeStraw family unit can filter up to 18,000 liters of water. Unfortunately, most LifeStraws cannot remove metals, dissolved inorganic species (e.g., nitrates), viruses, and some organic chemicals. The average price for a personal unit is $25-$40.



Video **8.7.1**. **Lifestraw Go - Water Bottle with Filter**

SteriPen

SteriPens utilize UVC radiation to kill parasites, viruses, and bacteria. Cost of a personal SteriPen device range from $80 to $100. SteriPens can treat up to 8000 liters of water. Like the LifeStraw, these apparatus cannot remove organic, inorganic, or metallic contaminants.



Video **8.7.2**: The SteriPEN® is the first and fastest portable UV water purifier. It makes water safe to drink by changing the DNA of viruses, bacteria and protozoa—including Giardia and Cryptosporidium—in seconds. Its speed, effectiveness and portability have impressed end users and media alike. Backpacker Magazine, Newsweek, and the Today Show have featured SteriPEN® as a powerful, user-friendly alternative to pumps, chemicals and filters. Learn more at www.steripen.com.

Example 8.7.1

1. What is the specific type of ultraviolet radiation that Steripens used to kill bacteria, viruses, and parasites? Where else does this type of radiation occur?
2. The residents of Flint, Michigan experienced heavy metal and pathogenic contamination in their tap water. If the state of Michigan provided individuals with Lifestraws, then would they have clean water for drinking and cooking purposes?
3. Can Steripens use ultraviolet light to remove metals from drinking water?

Solution

1. Steripens use UVC radiation to kill water pathogens. The sun generated UVC radiation. Unlike UVA and UVB radiation, UVC does not reach the troposphere (where you live) on the earth.
2. The lifestraws mentioned on this page do not remove toxic metals from drinking water. These types of devices only sanitize or remove pathogens (disease causing) substances from water.
3. Metals cannot be removed by irradiating water.

Iodination or Bromination

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8.8: Other Water treatment processes

Learning Objectives

- Objective 1
- Objective 2

Drinking Water Treatment

The process of water treatment to provide safe drinking water for their communities. There are various combinations and types of processes in water treatment depending on the scale of the plant and quality of the raw (source) water. Today, the most common steps in water treatment used by community water systems (mainly surface water treatment).



Figure 8.8.1: Dirty water spilling out of a large glass carboy on its side.(CC-SA-3.0, Ildar Sagdejev, Wikepedia Commons)

Coagulation and Flocculation

Before these processes, raw water is run through a screen to separate visible solids from the liquid. Next, Aluminum sulfate$Al_2(SO_4)_3$ and Calcium hydroxide $Ca(OH)_2$ are added to the liquid. The aluminum based compound is often called alum and induces clumping of suspended particules. This process is called flocculation. Calcium hydroxide (also known as lime) raises the pH of the mixture and produces more charged species (electrolytes) on the suspended particles. These charges are extracted and increase the size of the solid (coagulate) which simplify the filtration process.



The slightly basic water causes $Al(OH)_3$, $Fe(OH)_3$ and $Fe(OH)_2$ to precipitate, bringing the small particulates with them and the water becomes clear. Some records have been found that Egyptians and Romans used these techniques as early as 2000 BC.

Suspension of iron oxide particulates and humic organic matter in water gives water the yellow muddy appearance. Both iron oxide particulates and organic matter can be removed from coagulation and flocculation. The description given here is oversimplified, and many more techniques have been applied in the treatment of water. Coagulation is a major application of lime in the treatment of wastewater.

Other salts such as iron sulfates $Fe_2(SO_4)_3$ and $FeSO_4$, chromium sulfate $Cr_2(SO_4)_3$, and some special polymers are also useful. Other ions such as sodium, chloride, calcium, magnesium, and potassium also affect the coagulation process. So do temperature, pH, and concentration.

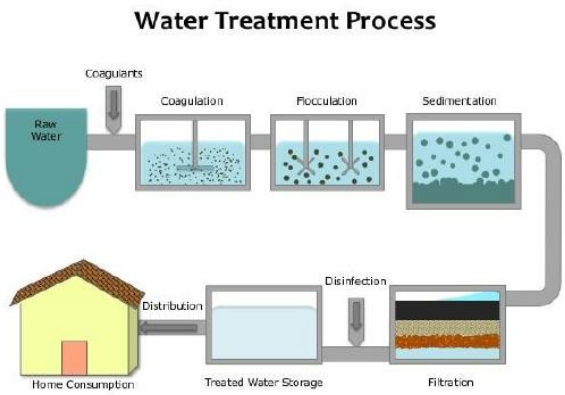


Figure 8.8.2: A diagram showing the process of water purification. (CC-SA-4.0; https://dreamcivil.com/water-treatment-process/)

Sedimentation

During sedimentation, floc settles to the bottom of the water supply, due to its weight. This settling process is called sedimentation. The floc particles are then removed from the bottom of the basins.

Aeration

Bringing air into intimate contact with water for the purpose of exchanging certain components between the two phases is called **aeration**. Oxygenation is one of the purposes of aeration. Others are removal of volatile organic substances, hydrogen sulfide, ammonia, and volatile organic compounds



Figure 8.8.3: Furman University Library (James B. Duke Library) and fountains. (Copyright; https://commons.wikimedia.org/w/inde...edit&redlink=1)

Filtration

Once the floc has settled to the bottom of the water supply, the clear water on top will pass through filters of varying compositions (sand, gravel, and charcoal) and pore sizes, in order to remove dissolved particles, such as dust, parasites, bacteria, viruses, and chemicals.

Sanitization

After the water has been filtered, a chemical disinfectant (chlorine and/or ozone based) or ultraviolet radiation will be applied in order to kill any remaining parasites, bacteria, and viruses, and to protect the water from germs when it is piped to homes and businesses.

Fluoridation

This process is not mandatory for water processing plants in the United States. Around 72% of public water systems have this chemical added in order to reduce dental issues.

Content taken and edited from:

chem.libretexts.org/Bookshelves/Introductory_Chemistry/Map%3A_Chemistry_for_Changing_Times_(Hill_and_McCreary)/14%3A_Water/14.6%3A_Making_Water_Fit_to_Drink

- Chung (Peter) Chieh (Professor Emeritus, Chemistry @ University of Waterloo)

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8.9: Fluoridation of Drinking Water

Learning Objectives

- Recognize the formula of the fluoride ion.
- Name advantages of adding fluoride to munipal drinking water supplies.
- Understand how fluoride affects tooth enamel.
- Name disadvantages of water exhibiting higher levels of fluoride.
- Calculate and compare a sample's fluoride concentration to the EPA's MCL primary drinking water standard.

The mineral fluoride occurs naturally on earth and is released from rocks into the soil, water, and air. All water contains some fluoride. Usually, the fluoride level in water is not enough to prevent tooth decay; however, some groundwater and natural springs can have naturally high levels of fluoride. The picture below illustrate Fluorite crystals which incorporate the fluoride ion (F^-).

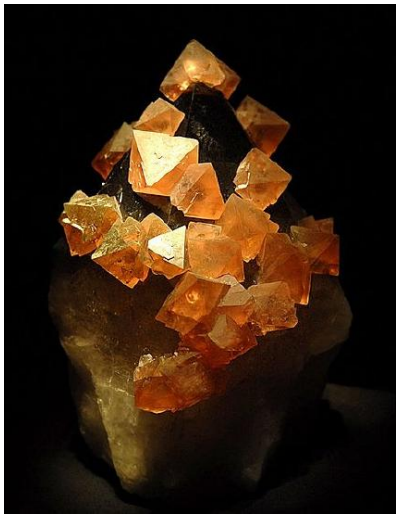


Figure **8.9.1**: Fluorite crystals on display at the Cullen Hall of Gems and Minerals. CC-SA-3.0

History of Fluoride in Water

In the 1930's, scientists examined the relationship between tooth decay in children and naturally occurring fluoride in drinking water. This study found that children who drank water with naturally high levels of fluoride had less tooth decay. This discovery was important because during that time most children and adults in the United States were affected by tooth decay. Many suffered from toothaches and painful extractions—often losing permanent teeth, including molars, even as teenagers.

After much scientific research, in 1945, the city of Grand Rapids, Michigan, was the first to add fluoride to its city water system in order to provide residents with the benefits of fluoride. Since 1945, hundreds of cities have started community water fluoridation By 2012 (more than 210 million people), nearly 75% of the United States served by community water systems had access to fluoridated water. Because of its contribution to the dramatic decline in tooth decay over the past 70 years, CDC named community water fluoridation as 1 of 10 great public health achievements of the 20th century.



Figure 8.9.2: Fluoride in dental health. Image taken from: https://media.defense.gov/2018/Mar/19/2001891929/-1/-1/0/180323-F-PO640-008.JPG

How does Fluoride Work?

Fluoride protects teeth from decay. Bacteria in the mouth produce acid when a person eats sugary foods. This acid eats away minerals from the tooth's surface, making the tooth weaker and increasing the chance of developing cavities. Fluoride helps to rebuild and strengthen the tooth's surface, or enamel. Water fluoridation prevents tooth decay by providing frequent and consistent contact with low levels of fluoride. By keeping the tooth strong and solid, fluoride stops cavities from forming and can even rebuild the tooth's surface.

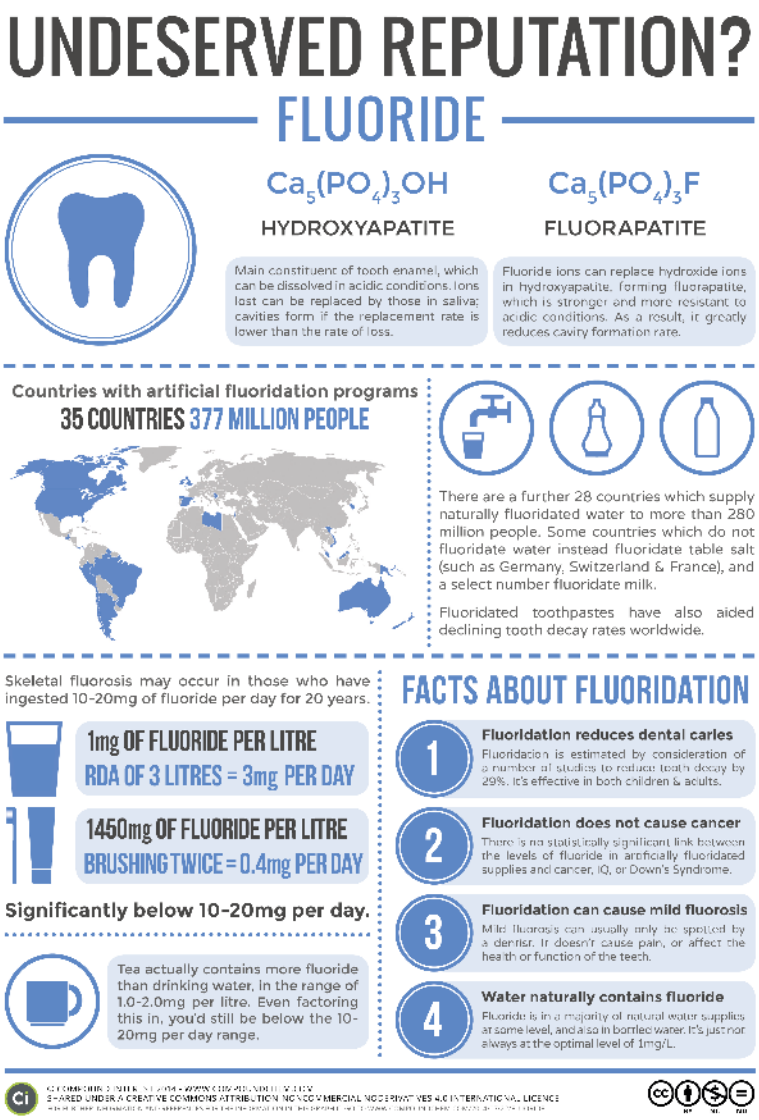


Figure **8.9.3**: Underserved Reputation: Fluoride. (Copyright;Andy Brunning's Compound Interest)

Although other fluoride-containing products, such as toothpaste, mouth rinses, and dietary supplements are available and contribute to the prevention and control of tooth decay, community water fluoridation has been identified as the most cost-effective method of delivering fluoride to all, reducing tooth decay by 25% in children and adults.

EPA Monitoring of F^-

It costs around 50 cents a year per person to fluoridate water for those who live in large communities. This additive is classified as a primary inorganic drinking water contaminant. The EPA has set both Maximum Contaminant Level (MCL) and Maximum Contaminant Level Goal (MCLG) concentrations for fluoride to be 4 ppm.

? Exercise 8.9.1

Your apartment complex's water contains 25 µg of F^- per 10 mL of water. Does this value exceed the EPA MCL value for F^-?

Answer

The MCL EPA standard is 4 ppm. Recall that the units for ppm are mg/L. This problem provides a contaminant concentration in micrograms per liter. You will need to calculate the ppm concentration for the water sample and then compare this to 4 ppm. For the math below, I chose to calculate concentration in ppb and then convert it to ppm.

$$10 \cancel{ml} \times \frac{1\,L}{10^3 \cancel{ml}} = .01\,L$$

$$= 1.0 \times 10^{-2}\,L$$

$$2500 \text{ ppb} = \frac{25 \text{ µg Solute}}{.01 \text{ L Solution}}$$

We can easily obtain ppm by dividing ppb by 1000. Our final ppm concentration for the fluoride sample is 2.5 ppm. This does not exceed the MCL standard.

Negative effects of F^-

There is some debate as to lowering this concentrations. Fluorosis, overexposure to fluoride, can cause pitting and staining of the teeth. This condition is more prevalent in younger individuals. In addition, excess fluoride can affect bone strength. For these reasons, the EPA monitors the amount of fluoride found in water to achieve optimal prevention of tooth decay.



Figure **8.9.4**: Mild Fluorosis in a younger dental patient. Image taken from: en.Wikipedia.org/wiki/Dental_fluorosis

Fluoride in the World

Many countries naturally have fluoride deposits in their water. For others, fluoride is added to drinking water to reduces cavities. Looking at the map below, the areas that are shaded in darker red pigments have fluoride (either naturally or artificially) in the tap water (brown red: 80-100% population, bright red: 60-80% population, lighter red: 20-40% population, pink: 1-20% population, white: less than 1%, and grey: unknown.

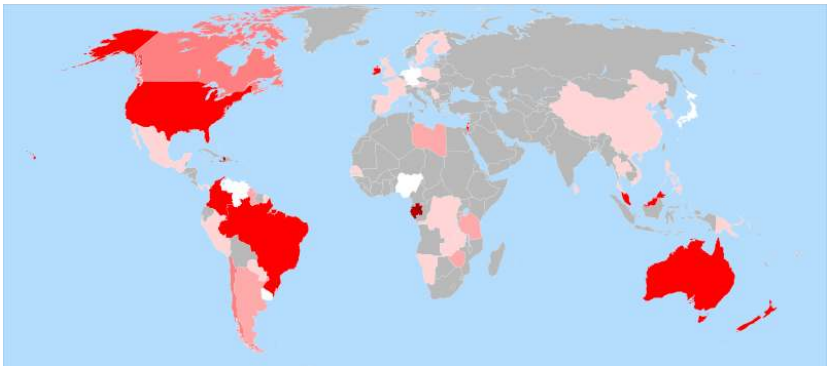


Figure **8.9.5**: The extent of fluoridated water usage around the world. Colors indicate the percentage of population in each country that receives fluoridated water, where the fluoridation is to levels recommended for preventing tooth decay. This includes both artificially and naturally fluoridated water. CC-SA-3.0

References

1)https://uwaterloo.ca/scholar/cchieh/home

2) Andy Brunning Compound Interest

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8.10: Bottled Water Basics

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8.11: Love Canal Case Study

Learning Objectives

- Research the history and structure of the Love Canal.
- Record the responsible polluters of the Love Canal.
- Classify the chemicals that were dumped and correlate this to the community's health issues.
- Create a timeline of chemicals that were discovered and effects on the environment.
- Summarize the reactions made by the community to the state and federal governments.
- Comment on the clean-up procedures of the Love Canal.
- Highlight the components of the CERCLA Act and Superfund Program.
- Summarize the current status of the Love Canal.

History of The Love Canal

In the later part of the 19th century, William T. Love envisioned connecting the Niagara River to Lake Ontario by ways of digging a canal. He dreamed of providing electricity to this area via hydroelectric power. He never completed this project and the unfinished canal became a swimming hole for recreational use. By the 1920's, the City of Niagara falls began dumping waste into the canal. As the years went by, the United States Army poured various hazardous substances into the Love Canal as well. In 1941, Hooker Chemical Company acquired Love Canal, drained it, and continued to bury over 20,000 tons of chemicals over the next 10 years. Eventually, the EPA identified over 200 different chemicals within the canal. Some of these included dioxin, polychlorinated biphenyls (PCBs),lindane, benzene, toluene, and corrosive chemicals.



Hooker Chemical clay capped the Love Canal and then sold it to the Niagara Falls Board of Education for $1.00. As stated within the deed, Hooker would not claim any responsibility for future damages due to the prescience of buried chemicals. On May 7, 1953, the school board accepted this policy, decided to build a school on the property, and then sold the remaining land for residential use. Eventually, a public school (99th Street School) was constructed on the former landfill site. Around 200 homes were erected along the canal banks and 1000 homes were built in the surrounding area.



Figure 8.11.1: Love Canal pre-1978. (Copyright;epa.gov)

Chemical Contamination of a Community

By the fall of 1976, residents of this area reported chemicals seeping into their basements and drums of chemicals rising to the surface of the filled in canal. Health officials advised them to avoid their basements. Heavy rains transported chemicals throughout the area to the Niagara River. Residents of the area noted high rates of birth defects and health issues. Informal and formal studies of the children born in this area were affected negatively by the chemicals. The *Niagara Falls Gazette* published stories about the substances buried in the canal. Lois Gibbs, a resident of the area, took note of these publications and wondered if her son's health issues could be attributed to these chemicals. Her five year-old son had developed liver and urinary tract problems, asthma, and epilepsy after he started attending the school that was built on top of the chemical dump. She requested her son be transferred to a different school away from the canal. Her request was denied and she began a campaign of educator and informing others about the happenings of the Love Canal.



Figure 8.11.2: Protest about the Love Canal contamination by a resident, ca. 1978 or so.(EPA.gov; File:Love Canal protest.jpg - Wikimedia Commons)

Gibbs and her community gathered information regarding health problems within the Love Canal area. They noted a large number of miscarriages, birth defects, and other illnesses. They rallied their concerns to the media and caught the attention of U.S. Representative John J. LaFlace and the Environmental Protection Agency (EPA). In April of 1978, the New York State Commissioner orders the County Health Department to restrict access to the Love Canal Area and to start health studies. Between May of 1978 and the beginning of August of 1978, residents of this area continued to remain at the Love Canal. Testing was done to determine the identity of the chemicals. Blood samples were taken of people who lived in the community. The New York State Governor signed an emergency order that would appropriate $500,000 for medical studies of area residents. On August 2, 1978, the New York State Health Commissioner declared a state of emergency. The 99th Street School was closed. Women and children under the age of two were encouraged to evacuate.

Federal Response to the Love Canal Disaster

On August 7, 1978, President Jimmy Carter provides funding to the State of New York to allow 236 families to leave the Love Canal. The cost of relocation would cost approximately 10 million dollars. During the late 1970's, another 54 families wished to relocate from the outskirts of the canal. These residents were denied and protesting continues. By February of 1979, pregnant women and younger children in this group of people were temporarily relocated. Gibbs and her homeowners associated continued to push the federal government to evacuate more houses that were outside the original evacuation zone.



Figure **8.11.1**: Love Canal evacuated houses. (Epa.gov; LOVE CANAL | Superfund Site Profile | Superfund Site Information | US EPA)

In May of 1980, the federal government purchased these remaining homes after a leaked medical report regarding chromosomal damages of Love Canal residents. Houses closest to the canal were dismantled in 1982. EPA removed the topsoil, installed drainage pipes to protect the groundwater, and installed a drainage plant to process any liquefied chemicals. The canal and surrounding areas were covered with plastic and clay capped. The majority of 20,000 tons of chemicals remain in the Love Canal.

EPA Superfund Program

In December of 1980, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This act is often referred to as the Superfund Program. By pre-taxing the chemical and petroleum industries, the federal government created a trust fund for cleaning up abandoned or uncontrolled hazardous areas. The goals of the Superfund Program are to clean-up contaminated areas, find and requires responsible parties to clean-up these sites, involve the surrounding community during the process, and if possible regenerate Superfund Sites. Under CERCLA, the EPA has constructed two types of response actions to chemical dumping. The first of these is short-term removal which provides quick action to releases or threatened releases of toxic materials. In contrast, the long-term remedial response action addresses contaminated areas that are "serious, but not immediately life threatening epa.gov." The most serious of these sites are placed on the National Priorities List (NPL). Click here to view the current NPL.



Love Canal Clean-up

EPA's Superfund program providing funding for the decontamination of Love Canal. This involved removing soil, installing drainage pipes to protect the groundwater, and constructing drainage plant to process any liquefied chemicals. The canal and surrounding areas were covered with plastic and clay capped. The majority of 20,000 tons of chemicals remain in the Love Canal. In 1995, Occidental Chemical Company (formerly known as Hooker Chemical) was required to pay Superfund $102 million dollars for clean-up. They also reimbursed The Federal Emergency Management Association (FEMA) $27 million dollar for relocation of the Love Canal residents. An additional 8 million dollars was awarded both the Superfund Programs and FEMA by the United States Army (for dumping military chemicals) and the state of New York paid $98 million to the EPA as well. Total clean-up cost for the Love Canal was estimated to be $275 million.

The Superfund Amendments and Reauthorization Act (SARA)

In 1986, expanded the Superfund Project to include more tasks and changes. SARA would suggest innovative treatment techniques and permanent solutions. State and Federal governments would work together together under current laws and policies of each. More community involvement would be encouraged as to how the site would be cleaned up and remediated. The original trust fund of $1.6 billion dollars would be increased to $8.5 billion. More funding would be directed to studying how toxic chemicals affect humans and the environment.



References

1. Epa.gov
2. OpenStax-CNX module-m41444
3. Happy-Birthday-Love-Canal (acs.org)

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8.12: Flint River Case Study

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CHAPTER OVERVIEW

9: Organic Chemistry

Organic chemistry studies the structure, properties and reactions of organic compounds that contain carbon in covalent bonding.

9.1: Introduction to Organic Chemistry
9.2: Alkanes
9.3: Alkenes
9.4: Alkynes
9.5: Cyclics
9.6: Isomers
9.7: Hydrogenation
9.8: Functional Group introduction
9.9: Aromatics
9.10: Alcohols
9.11: Ethers
9.12: Carbonyl Friends
9.13: Amines and Thiols
9.E: Organic Chemistry (Exercises)

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9.1: Introduction to Organic Chemistry

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9.2: Alkanes

The names of all alkanes end with *-ane*. Whether or not the carbons are linked together end-to-end in a ring (called *cyclic alkanes* or *cycloalkanes*) or whether they contain side chains and branches, the name of every carbon-hydrogen chain that lacks any double bonds or functional groups will end with the suffix *-ane*.

Alkanes with unbranched carbon chains are simply named by the number of carbons in the chain. The first four members of the series (in terms of number of carbon atoms) are named as follows:

1. CH_4 = **methane** = one hydrogen-saturated carbon
2. C_2H_6 = **ethane** = two hydrogen-saturated carbons
3. C_3H_8 = **propane** = three hydrogen-saturated carbons
4. C_4H_{10} = **butane** = four hydrogen-saturated carbons

Alkanes with five or more carbon atoms are named by adding the suffix *-ane* to the appropriate numerical multiplier, except the terminal *-a* is removed from the basic numerical term. Hence, C_5H_{12} is called *pentane*, C_6H_{14} is called *hexane*, C_7H_{16} is called *heptane* and so forth.

Straight-chain alkanes are sometimes indicated by the prefix *n-* (for normal) to distinguish them from branched-chain alkanes having the same number of carbon atoms. Although this is not strictly necessary, the usage is still common in cases where there is an important difference in properties between the straight-chain and branched-chain isomers: e.g. *n-hexane* is a neurotoxin while its branched-chain isomers are not.

IUPAC nomenclature

The IUPAC nomenclature is a system on which most organic chemists have agreed to provide guidelines to allow them to learn from each others' works. Nomenclature, in other words, provides a foundation of language for organic chemistry.

Number of Hydrogen to Carbons

This equation describes the relationship between the number of hydrogen and carbon atoms in alkanes:

$$\mathbf{H = 2C + 2}$$

where "C" and "H" are used to represent the number of carbon and hydrogen atoms present in one molecule. If C = 2, then H = 6.

Many textbooks put this in the following format:

$$\mathbf{C_nH_{2n+2}}$$

where "C_n" and "H_{2n+2}" represent the number of carbon and hydrogen atoms present in one molecule. If $C_n = 3$, then $H_{2n+2} = 2(3) + 2 = 8$. (For this formula look to the "n" for the number, the "C" and the "H" letters themselves do not change.)

Progressively longer hydrocarbon chains can be made and are named systematically, depending on the number of carbons in the longest chain.

The following table contains the systematic names for the first twenty straight chain alkanes. It will be important to familiarize yourself with these names because they will be the basis for naming many other organic molecules throughout your course of study.

Drawing Hydrocarbons

Recall that when carbon makes four bonds, it adopts the tetrahedral geometry. In the tetrahedral geometry, only two bonds can occupy a plane simultaneously. The other two bonds point in back or in front of this plane. In order to represent the tetrahedral geometry in two dimensions, solid wedges are used to represent bonds pointing out of the plane of the drawing toward the viewer, and dashed wedges are used to represent bonds pointing out of the plane of the drawing away from the viewer. Consider the following representation of the molecule methane:



Figure 1: Two dimensional representation of methane

In the above drawing, the two hydrogens connected by solid lines, as well as the carbon in the center of the molecule, exist in a plane (specifically, the plane of the computer monitor / piece of paper, etc.). The hydrogen connected by a solid wedge points out of this plane toward the viewer, and the hydrogen connected by the dashed wedge points behind this plane and away from the viewer.

In drawing hydrocarbons, it can be time-consuming to write out each atom and bond individually. In organic chemistry, hydrocarbons can be represented in a shorthand notation called a **skeletal structure**. In a skeletal structure, only the bonds between carbon atoms are represented. Individual carbon and hydrogen atoms are not drawn, and bonds to hydrogen are not drawn. In the case that the molecule contains just single bonds (sp^3 bonds), these bonds are drawn in a "zig-zag" fashion. This is because in the tetrahedral geometry all bonds point as far away from each other as possible, and the structure is not linear. Consider the following representations of the molecule propane:

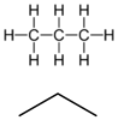
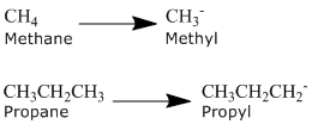


Figure 2: Full structure of propane and skeletal structure of propane

Only the bonds between carbons have been drawn, and these have been drawn in a "zig-zag" manner. Note that there is no representation of hydrogens in a skeletal structure. Since, in the absence of double or triple bonds, carbon makes four bonds total, the presence of hydrogens is implicit. Whenever an insufficient number of bonds to a carbon atom are specified in the structure, it is assumed that the rest of the bonds are made to hydrogens. For example, if the carbon atom makes only one explicit bond, there are three hydrogens implicitly attached to it. If it makes two explicit bonds, there are two hydrogens implicitly attached, etc. Note also that two lines are sufficient to represent three carbon atoms. It is the bonds only that are being drawn out, and it is understood that there are carbon atoms (with three hydrogens attached!) at the terminal ends of the structure.

Alkyl Groups

Alkanes can be described by the general formula C_nH_{2n+2}. An alkyl group is formed by removing one hydrogen from the alkane chain and is described by the formula C_nH_{2n+1}. The removal of this hydrogen results in a stem change from **-ane** to **-yl**. Take a look at the following examples.



The same concept can be applied to any of the straight chain alkane names provided in the table above.

Name	Molecular Formula	Condensed Structural Formula
Methane	CH_4	CH_4
Ethane	C_2H_6	CH_3CH_3
Propane	C_3H_8	$CH_3CH_2CH_3$
Butane	C_4H_{10}	$CH_3(CH_2)_2CH_3$
Pentane	C_5H_{12}	$CH_3(CH_2)_3CH_3$
Hexane	C_6H_{14}	$CH_3(CH_2)_4CH_3$
Heptane	C_7H_{16}	$CH_3(CH_2)_5CH_3$
Octane	C_8H_{18}	$CH_3(CH_2)_6CH_3$
Nonane	C_9H_{20}	$CH_3(CH_2)_7CH_3$
Decane	$C_{10}H_{22}$	$CH_3(CH_2)_8CH_3$
Undecane	$C_{11}H_{24}$	$CH_3(CH_2)_9CH_3$
Dodecane	$C_{12}H_{26}$	$CH_3(CH_2)_{10}CH_3$
Tridecane	$C_{13}H_{28}$	$CH_3(CH_2)_{11}CH_3$
Tetradecane	$C_{14}H_{30}$	$CH_3(CH_2)_{12}CH_3$
Pentadecane	$C_{15}H_{32}$	$CH_3(CH_2)_{13}CH_3$
Hexadecane	$C_{16}H_{34}$	$CH_3(CH_2)_{14}CH_3$
Heptadecane	$C_{17}H_{36}$	$CH_3(CH_2)_{15}CH_3$
Octadecane	$C_{18}H_{38}$	$CH_3(CH_2)_{16}CH_3$
Nonadecane	$C_{19}H_{40}$	$CH_3(CH_2)_{17}CH_3$
Eicosane	$C_{20}H_{42}$	$CH_3(CH_2)_{18}CH_3$

Using Common Names with Branched Alkanes

Certain branched alkanes have common names that are still widely used today. These common names make use of prefixes, such as ***iso***-, ***sec***-, ***tert***-, and ***neo***-. The prefix ***iso***-, which stands for isomer, is commonly given to 2-methyl alkanes. In other words, if there is methyl group located on the second carbon of a carbon chain, we can use the prefix ***iso***-. The prefix will be placed in front of the alkane name that indicates the *total* number of carbons. Examples:

- isopentane which is the same as 2-methylbutane
- isobutane which is the same as 2-methylpropane

To assign the prefixes ***sec***-, which stands for secondary, and ***tert***-, for tertiary, it is important that we first learn how to classify carbon molecules. If a carbon is attached to only one other carbon, it is called a **primary** carbon. If a carbon is attached to two other carbons, it is called a **seconday** carbon. A **tertiary** carbon is attached to three other carbons and last, a **quaternary** carbon is attached to four other carbons. Examples:

- 4-*sec*-butylheptane (30g)
- 4-*tert*-butyl-5-isopropylhexane (30d); if using this example, may want to move sec/tert after iso disc

The prefix ***neo***- refers to a substituent whose second-to-last carbon of the chain is trisubstituted (has three methyl groups attached to it). A neo-pentyl has five carbons total. Examples:

- neopentane

- neoheptane

Alkoxy Groups

Alkoxides consist of an organic group bonded to a negatively charged oxygen atom. In the general form, alkoxides are written as RO^-, where R represents the organic substituent. Similar to the alkyl groups above, the concept of naming alkoxides can be applied to any of the straight chain alkanes provided in the table above.

RO^-
Alkoxy

CH_3O^-
Methoxy

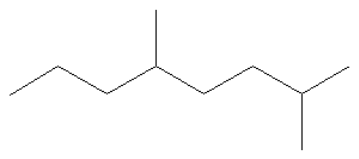
$CH_3CH_2O^-$
Ethoxy

Three Principles of Naming

1. Choose the longest, most substituted carbon chain containing a functional group.
2. A carbon bonded to a functional group must have the lowest possible carbon number. If there are no functional groups, then any substitute present must have the lowest possible number.
3. Take the alphabetical order into consideration; that is, after applying the first two rules given above, make sure that your substitutes and/or functional groups are written in alphabetical order.

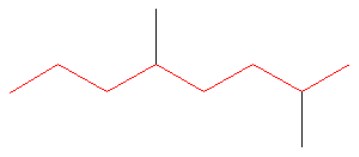
Example 1

What is the name of the follow molecule?

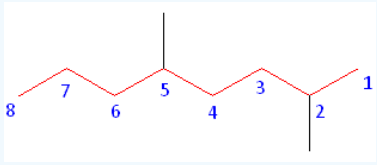


Solution

Rule #1: Choose the longest, most substituted carbon chain containing a functional group. This example does not contain any functional groups, so we only need to be concerned with choosing the longest, most substituted carbon chain. The longest carbon chain has been highlighted in red and consists of eight carbons.



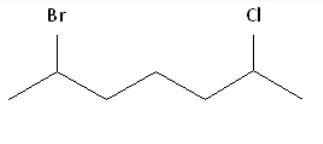
Rule #2: Carbons bonded to a functional group must have the lowest possible carbon number. If there are no functional groups, then any substitute present must have the lowest possible number. Because this example does not contain any functional groups, we only need to be concerned with the two substitutes present, that is, the two methyl groups. If we begin numbering the chain from the left, the methyls would be assigned the numbers 4 and 7, respectively. If we begin numbering the chain from the right, the methyls would be assigned the numbers 2 and 5. Therefore, to satisfy the second rule, numbering begins on the right side of the carbon chain as shown below. This gives the methyl groups the lowest possible numbering.



Rule 3: In this example, there is no need to utilize the third rule. Because the two substitutes are identical, neither takes alphabetical precedence with respect to numbering the carbons. This concept will become clearer in the following examples.

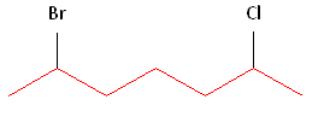
Example 2

What is the name of the follow molecule?

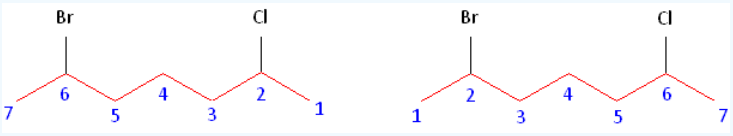


Solution

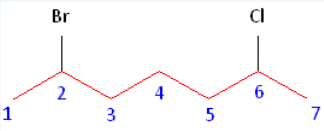
Rule #1: Choose the longest, most substituted carbon chain containing a functional group. This example contains two functional groups, bromine and chlorine. The longest carbon chain has been highlighted in red and consists of seven carbons.



Rule #2: Carbons bonded to a functional group must have the lowest possible carbon number. If there are no functional groups, then any substitute present must have the lowest possible number. In this example, numbering the chain from the left or the right would satisfy this rule. If we number the chain from the left, bromine and chlorine would be assigned the second and sixth carbon positions, respectively. If we number the chain from the right, chlorine would be assigned the second position and bromine would be assigned the sixth position. In other words, whether we choose to number from the left or right, the functional groups occupy the second and sixth positions in the chain. To select the correct numbering scheme, we need to utilize the third rule.

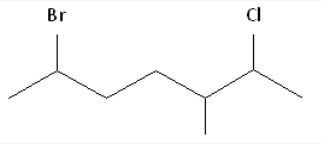


Rule #3: After applying the first two rules, take the alphabetical order into consideration. Alphabetically, bromine comes before chlorine. Therefore, bromine is assigned the second carbon position, and chlorine is assigned the sixth carbon position.



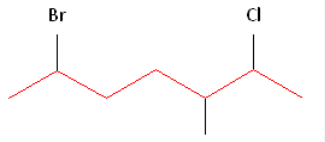
Example 3

What is the name of the follow molecule?

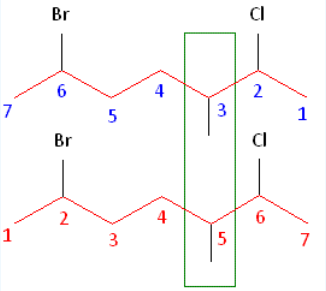


Solution

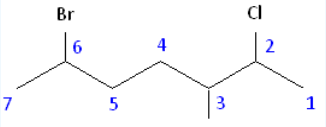
Rule #1: Choose the longest, most substituted carbon chain containing a functional group. This example contains two functional groups, bromine and chlorine, and one substitute, the methyl group. The longest carbon chain has been highlighted in red and consists of seven carbons.



Rule #2: Carbons bonded to a functional group must have the lowest possible carbon number. After taking functional groups into consideration, any substitutes present must have the lowest possible carbon number. This particular example illustrates the **point of difference principle**. If we number the chain from the left, bromine, the methyl group and chlorine would occupy the second, fifth and sixth positions, respectively. This concept is illustrated in the second drawing below. If we number the chain from the right, chlorine, the methyl group and bromine would occupy the second, third and sixth positions, respectively, which is illustrated in the first drawing below. The position of the methyl, therefore, becomes a **point of difference**. In the first drawing, the methyl occupies the third position. In the second drawing, the methyl occupies the fifth position. To satisfy the second rule, we want to choose the numbering scheme that provides the lowest possible numbering of this substitute. Therefore, the first of the two carbon chains shown below is correct.



Therefore, the first numbering scheme is the appropriate one to use.



Once you have determined the correct numbering of the carbons, it is often useful to make a list, including the functional groups, substitutes, and the name of the parent chain.

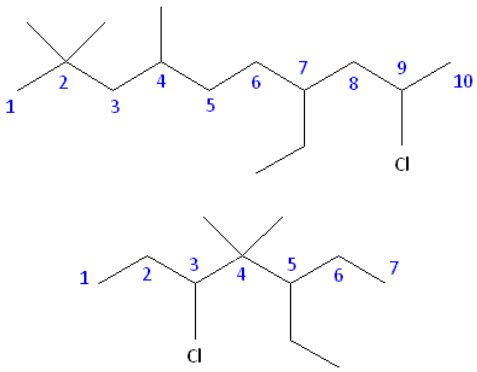
Rule #3: After applying the first two rules, take the alphabetical order into consideration. Alphabetically, bromine comes before chlorine. Therefore, bromine is assigned the second carbon position, and chlorine is assigned the sixth carbon position.

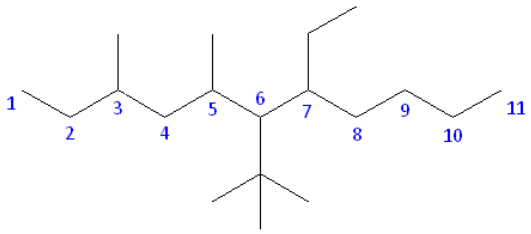
Parent chain: heptane 2-Chloro 3-Methyl 6-Bromo

6-bromo-2-chloro-3-methylheptane

Problems

What is the name of the follow molecules?





Contributors

- Jonathan Mooney (McGill University)
- Template:ContribWikiOrgo

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9.3: Alkenes

Alkenes contain carbon-carbon double bonds and are unsaturated hydrocarbons with the molecular formula is C_nH_{2n}. This is also the same molecular formula as cycloalkanes. Alkenes are named using the same general naming rules for alkanes, except that the suffix is now -ene. There are a few other small differences:

- The main chain of carbon atoms must contain both carbons in the double bond. The main chain is numbered so that the double bond gets the smallest number.
- Before the root name, the number of the carbon atom at which the double bond starts (the smaller number) is written.
- If more than one double bond is present, the prefixes di-, tri-, tetra-, etc. are used before the -ene, and (strangely) the letter "a" is added after the prefix for the number of carbon atoms.

Introduction

Alkenes and alkynes are hydrocarbons which respectively have **carbon-carbon double bond** and **carbon-carbon triple bond** functional groups. The molecular formulas of these **unsaturated** hydrocarbons reflect the multiple bonding of the functional groups:

Alkenes are named as if they were alkanes, but the "-ane" suffix is changed to "-ene". If the alkene contains only one double bond and that double bond is terminal (the double bond is at one end of the molecule or another) then it is not necessary to place any number in front of the name.

> ***butane:*** C_4H_{10} $(CH_3CH_2CH_2CH_3)$
> ***butene:*** C_4H_8 $(CH_2=CHCH_2CH_3)$

If the double bond is not terminal (if it is on a carbon somewhere in the center of the chain) then the carbons should be numbered in such a way as to give the first of the two double-bonded carbons the lowest possible number, and that number should precede the "ene" suffix with a dash, as shown below.

> ***correct:*** *pent-2-ene* $(CH_3CH=CHCH_2CH_3)$
> ***incorrect:*** *pent-3-ene* $(CH_3CH_2CH=CHCH_3)$
> *The second one is incorrect because flipping the formula horizontally results in a lower number for the alkene.*

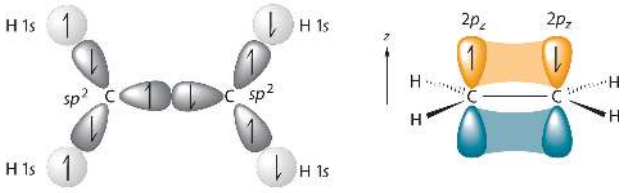
If there is more than one double bond in an alkene, all of the bonds should be numbered in the name of the molecule - even terminal double bonds. The numbers should go from lowest to highest, and be separated from one another by a comma. The IUPAC numerical prefixes are used to indicate the number of double bonds.

> ***octa-2,4-diene:*** $CH_3CH=CHCH=CHCH_2CH_2CH_3$
> ***deca-1,5-diene:*** $CH_2=CHCH_2CH_2CH=CHCH_2CH_2CH_2CH_3$

Note that the numbering of "2-4" above yields a molecule with two double bonds separated by just one single bond. Double bonds in such a condition are called "conjugated", and they represent an enhanced stability of conformation, so they are energetically favored as reactants in many situations and combinations.

Alkane	C_nH_{2n+2}	This is the maximum H/C ratio for a given number of
Alkene	C_nH_{2n}	Each double bond reduces the number of hydrogen atoms by 2.

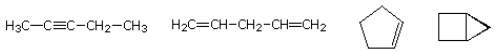
The parent structure is the longest chain containing both carbon atoms of the double bond. The two carbon atoms of a double bond and the four atoms attached to them lie in a plane, with bond angles of approximately 120° A double bond consists of one sigma bond formed by overlap of sp^2 hybrid orbitals and one pi bond formed by overlap of parallel 2 p orbitals



(a) C_2H_4 σ-bonded framework (b) C_2H_4 π bonding

Figure 1: (a) The σ-bonded framework is formed by the overlap of two sets of singly occupied carbon sp^2 hybrid orbitals and four singly occupied hydrogen 1*s* orbitals to form electron-pair bonds. This uses 10 of the 12 valence electrons to form a total of five σ bonds (four C–H bonds and one C–C bond). (b) One singly occupied unhybridized $2p_z$ orbital remains on each carbon atom to form a carbon–carbon π bond. (Note: by convention, in planar molecules the axis perpendicular to the molecular plane is the *z*-axis.)

The molecular formula of a hydrocarbon provides information about the possible structural types it may represent. For example, consider compounds having the formula C_5H_8. The formula of the five-carbon alkane pentane is C_5H_{12} so the difference in hydrogen content is 4. This difference suggests such compounds may have a triple bond, two double bonds, a ring plus a double bond, or two rings. Some examples are shown here, and there are at least fourteen others!

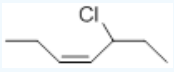


IUPAC Rules for Alkene and Cycloalkene Nomenclature

1. The **ene** suffix (ending) indicates an alkene or cycloalkene.
2. The longest chain chosen for the root name must include both carbon atoms of the double bond.
3. The root chain must be numbered from the end nearest a double bond carbon atom. If the double bond is in the center of the chain, the nearest substituent rule is used to determine the end where numbering starts.
4. The smaller of the two numbers designating the carbon atoms of the double bond is used as the double bond locator. If more than one double bond is present the compound is named as a diene, triene or equivalent prefix indicating the number of double bonds, and each double bond is assigned a locator number.
5. In cycloalkenes the double bond carbons are assigned ring locations #1 and #2. Which of the two is #1 may be determined by the nearest substituent rule.
6. Substituent groups containing double bonds are:

H_2C=CH– Vinyl group
H_2C=CH–CH_2– Allyl group

Example 1



In this diagram this is a cis conformation. It has both the substituents going upward. This molecule would be called (cis) 5-chloro-3-heptene.)

Trans would look like this

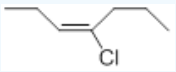
v. On the other hand if there are 3 or 4 non-hydrogen different atoms attached to the alkene then use the E, Z system.

E (entgegen) means the higher priority groups are opposite one another relative to the double bond.

Z (zusammen) means the higher priority groups are on the same side relative to the double bond.

(You could think of Z as Zame Zide to help memorize it.)

Example 2



Solution

In this example it is E-4-chloro-3-heptene. It is E because the Chlorine and the CH_2CH_3 are the two higher priorities and they are on opposite sides.

vi. A hydroxyl group gets precedence over th double bond. Therefore alkenes containing alchol groups are called alkenols. And the prefix becomes --enol. And this means that now the alcohol gets lowest priority over the alkene.

vii. Lastly remember that alkene substituents are called alkenyl. Suffix --enyl.

Here is a chart containing the systemic name for the first twenty straight chain alkenes.

Name	Molecular formula
Ethene	C_2H_4
Propene	C_3H_6
Butene	C_4H_8
Pentene	C_5H_{10}
Hexene	C_6H_{12}
Heptene	C_7H_{14}
Octene	C_8H_{16}
Nonene	C_9H_{18}
Decene	$C_{10}H_{20}$
Undecene	$C_{11}H_{22}$
Dodecene	$C_{12}H_{24}$
Tridecene	$C_{13}H_{26}$
Tetradecene	$C_{14}H_{28}$
Pentadecene	$C_{15}H_{30}$
Hexadecene	$C_{16}H_{32}$
Heptadecene	$C_{17}H_{34}$
Octadecene	$C_{18}H_{36}$
Nonadecene	$C_{19}H_{38}$
Eicosene	$C_{20}H_{40}$

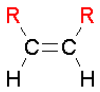
Did you notice how there is no methene? Because it is impossible for a carbon to have a double bond with nothing.

Geometric Isomers

Double bonds can exist as geometric isomers and these isomers are designated by using either the cis / trans designation or the modern E / Z designation.

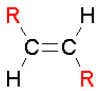
cis Isomers

.The two largest groups are on the same side of the double bond.



trans Isomers

...The two largest groups are on opposite sides of the double bond.



E/Z nomenclature

E = entgegan ("trans") Z = zusamen ("cis")

Priority of groups is based on the atomic mass of attached atoms (not the size of the group). An atom attached by a multiple bond is counted once for each bond.

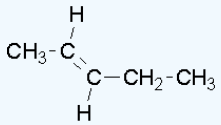
fluorine atom > isopropyl group > n-hexyl group

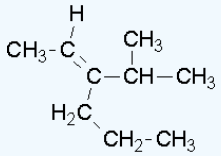
deuterium atom > hydrogen atom

$$-CH_2-CH=CH_2 > -CH_2CH_2CH_3$$

Example 3

Try to name the following compounds using both conventions...

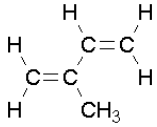




Common names

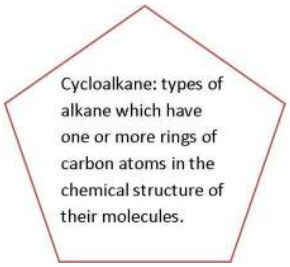
Remove the -ane suffix and add -ylene. There are a couple of unique ones like ethenyl's common name is vinyl and 2-propenyl's common name is allyl. That you should know are...

- vinyl substituent $H_2C=CH-$
- allyl substituent $H_2C=CH-CH_2-$
- allene molecule $H_2C=C=CH_2$
- isoprene



Endocyclic Alkenes

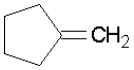
Endocyclic double bonds have both carbons in the ring and exocyclic double bonds have only one carbon as part of the ring.



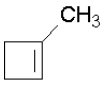
Cyclopentene is an example of an endocyclic double bond.



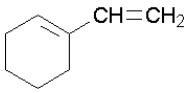
Methylenecylopentane is an example of an exocyclic double bond.



Name the following compounds...

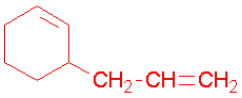


1-methylcyclobutene. The methyl group places the double bond. It is correct to also name this compound as 1-methylcyclobut-1-ene.

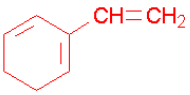


1-ethenylcyclohexene, the methyl group places the double bond. It is correct to also name this compound as 1-ethenylcyclohex-1-ene. A common name would be 1-vinylcyclohexene.

Try to draw structures for the following compounds...



- 2-vinyl-1,3-cyclohexadiene



Outside links

- http://www.vanderbilt.edu/AnS/Chemis...0a/alkenes.pdf

References

1. Vollhardt, Peter, and Neil E. Schore. Organic Chemistry: Structure and Function. 5th Edition. New York: W. H. Freeman & Company, 2007.

Problems

Try to name the following compounds...



1-pentene or pent-1-ene



2-ethyl-1-hexene or 2-ethylhex-1-ene

Try to draw structures for the following compounds...

- 2-pentene

$$CH_3–CH=CH–CH_2–CH_3$$

- 3-heptene

$$CH_3–CH_2–CH=CH–CH_2–CH_2–CH_3$$

b. Give the double bond the lowest possible numbers regardless of substituent placement.

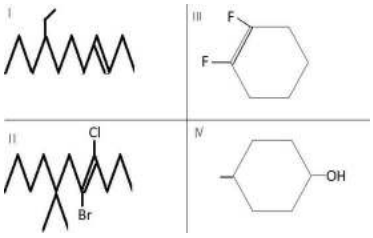
• Try to name the following compound...


J

• Try to draw a structure for the following compound...

4-methyl-2-pentene J

Name the following structures:



v. Draw (Z)-5-Chloro-3-ethly-4-hexen-2-ol.

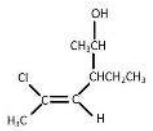
Answers

I. trans-8-ethyl-3-undecene

II. E-5-bromo-4-chloro-7,7-dimethyl-4-undecene

III. Z-1,2-difluoro-cyclohexene

IV. 4-ethenylcyclohexanol.



V.

Contributors and Attributions

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- William Reusch, Professor Emeritus (Michigan State U.), Virtual Textbook of Organic Chemistry
- Jonathan Mooney (McGill University)

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9.4: Alkynes

Alkynes are organic molecules made of the functional group carbon-carbon triple bonds and are written in the empirical formula of C_nH_{2n-2}. They are unsaturated hydrocarbons. Like alkenes have the suffix –ene, alkynes use the ending –yne; this suffix is used when there is only one alkyne in the molecule. If a molecule contains both a double and a triple bond, the carbon chain is numbered so that the first multiple bond gets a lower number. If both bonds can be assigned the same number, the double bond takes precedence. The molecule is then named "n-ene-n-yne", with the double bond root name preceding the triple bond root name (e.g. 2-hepten-4-yne).

Introduction

HC ☰ CH

Here are the molecular formulas and names of the first ten carbon straight chain alkynes.

Name	Molecular Formula
Ethyne	C_2H_2
Propyne	C_3H_4
1-Butyne	C_4H_6
1-Pentyne	C_5H_8
1-Hexyne	C_6H_{10}
1-Heptyne	C_7H_{12}
1-Octyne	C_8H_{14}
1-Nonyne	C_9H_{16}
1-Decyne	$C_{10}H_{18}$

The more commonly used name for ethyne is acetylene, which used industrially.

Naming Alkynes

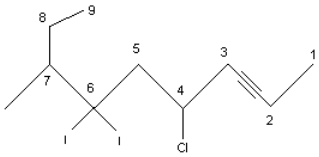
Like previously mentioned, the IUPAC rules are used for the naming of alkynes.

Rule 1

Find the longest carbon chain that includes both carbons of the triple bond.

Rule 2

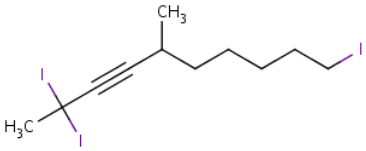
Number the longest chain starting at the end closest to the triple bond. A 1-alkyne is referred to as a terminal alkyne and alkynes at any other position are called internal alkynes. For example:



4-chloro-6-diiodo-7-methyl-2-nonyne

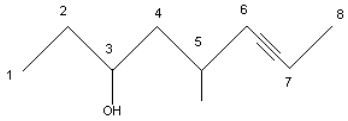
Rule 3

After numbering the longest chain with the lowest number assigned to the alkyne, label each of the substituents at its corresponding carbon. While writing out the name of the molecule, arrange the substituents in alphabetical order. If there are more than one of the same substituent use the prefixes di, tri, and tetra for two, three, and four substituents respectively. These prefixes are not taken into account in the alphabetical order. For example:



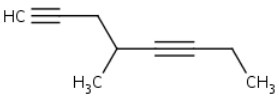
2,2,10-triiodo-5-methyl-3-decyne

If there is an alcohol present in the molecule, number the longest chain starting at the end closest to it, and follow the same rules. However, the suffix would be –ynol, because the alcohol group takes priority over the triple bond.



5- methyl-7-octyn-3-ol

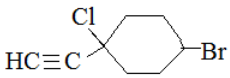
When there are two triple bonds in the molecule, find the longest carbon chain including both the triple bonds. Number the longest chain starting at the end closest to the triple bond that appears first. The suffix that would be used to name this molecule would be –diyne. For example:



4-methyl-1,5-octadiyne

Rule 4

Substituents containing a triple bond are called alkynyl. For example:



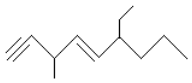
1-chloro-1-ethynyl-4-bromocyclohexane

Here is a table with a few of the alkynyl substituents:

Name	**Molecule**
Ethynyl	-C?CH
2- Propynyl	-CH_2C?CH
2-Butynyl	-CH_3C?CH_2CH_3

Rule 5

A molecule that contains both double and triple bonds is called an alkenyne. The chain can be numbered starting with the end closest to the functional group that appears first. For example:



6-ethyl-3-methyl-1,4-nonenyne

Reference

1. Vollhardt, Peter, and Neil E. Schore. Organic Chemistry: Structure and Function. 5th Edition. New York: W. H. Freeman & Company, 2007.

Problems

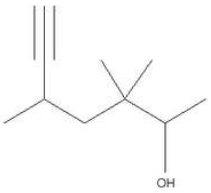
Name or draw out the following molecules:

1. 4,4-dimethyl-2-pentyne

2. 4-Penten-1-yne

3. 1-ethyl-3-dimethylnonyne

4.



Contributors and Attributions

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- Jonathan Mooney (McGill University)

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9.5: Cyclics

Although cyclohexane can be isolated from petroleum products, a major source of this chemical is the hydrogenation of benzene. Much of the cyclohexane produced is used to manufacture intermediates for the production of nylon. Items such as nylon balloons no doubt had their start in a chemical plant where hydrogen gas and benzene were reacted at high temperatures to form cyclohexane. This cycloalkane then undergoes nitration to begin the process of forming the long strands of nylon that can be made into balloons, ropes, clothing, and many other useful products.

Cyclic Hydrocarbons

A **cyclic hydrocarbon** is a hydrocarbon in which the carbon chain joins to itself in a ring. A **cycloalkane** is a cyclic hydrocarbon in which all of the carbon-carbon bonds are single bonds. Like other alkanes, cycloalkanes are saturated compounds. Cycloalkanes have the general formula C_nH_{2n}. The simplest cycloalkane is cyclopropane, a three-carbon ring.

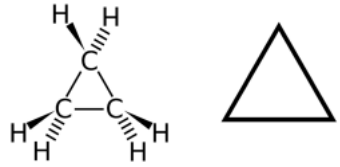
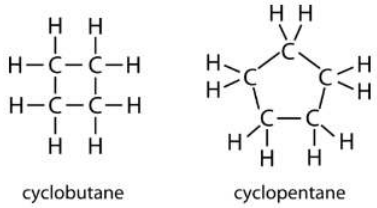


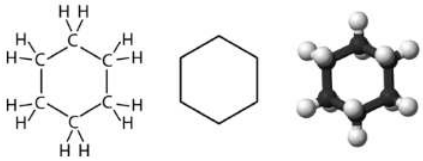
Figure 7.5.1: *Cyclopropane is the simplest cycloalkane. Its highly strained geometry makes it rather unstable and highly reactive.*

The structural formulas of cyclic hydrocarbons can be represented in multiple ways, two of which are shown above. Each atom can be shown as in the structure on the left from the figure above. A convenient shorthand is to omit the element symbols and only show the shape, as in the triangle on the right. Carbon atoms are understood to be the vertices of the triangle.

The carbon atoms in cycloalkanes are still sp^3 hybridized, with an ideal bond angle of $109.5°$. However, an examination of the cyclopropane structure shows that the triangular structure results in a $C–C–C$ bond angle of $60°$. This deviation from the ideal angle is called ring strain and makes cyclopropane a fairly unstable and reactive molecule. Ring strain is decreased for cyclobutane, with a bond angle of $90°$, but is still significant. Cyclopentane has a bond angle of about $108°$. This minimal ring strain for cyclopentane makes it a more stable compound.



Cyclohexane is a six-carbon cycloalkane shown below



All three of the depictions of cyclohexane are somewhat misleading because the molecule is not planar. In order to reduce the ring strain and attain a bond angle of approximately $109.5°$, the molecule is puckered. The puckering of the ring means that every other carbon atom is above and below the plane. The figure below shows two possibilities for the puckered cyclohexane molecule. Each of the structures is called a conformation. The conformation on the right is called the boat conformation, while the one on the left is called the chair conformation.

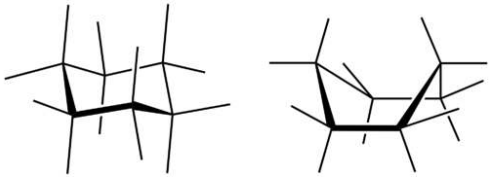
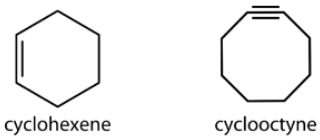


Figure 7.5.2: *Chair (left) and boat (right) conformations for cyclohexane.*

While both conformations reduce the ring strain compared to a planar molecule, the chair is preferred. This is because the chair conformation results in fewer repulsive interactions between the hydrogen atoms. However, interconversion readily occurs between the two conformations.

Larger cycloalkanes also exist, but are less common. Cyclic hydrocarbons may also be unsaturated. A **cycloalkene** is a cyclic hydrocarbon with at least one carbon-carbon double bond. A **cycloalkyne** is a cyclic hydrocarbon with at least one carbon-carbon triple bond. Shown below are the simplified structural formulas for cyclohexene and cyclooctyne.



Summary

Definition of cyclic hydrocarbon and cyclic alkane are given. Names and structures of typical cyclic hydrocarbons are given.

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9.6: Isomers

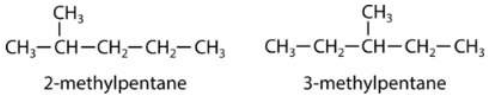
As we get more into the complexities of organic chemistry, we will see how molecular shape affects reactions. One common reaction for alkenes is the addition of hydrogen across the double bond to form the corresponding alkane. Because of the geometry of the reaction, the different 2-butene shapes have different heats of reaction. These differences are important both from a theoretical standpoint as well as from the point of view of industrial applications. Greater energy requirements mean a higher cost and a more expensive product.

Isomers

One of the interesting aspects of organic chemistry is that it is three-dimensional. A molecule can have a shape in space that may contribute to its properties. Molecules can differ in the way the atoms are arranged - the same combination of atoms can be assembled in more than one way. These compounds are known as **isomers**. Isomers are molecules with the same molecular formulas, but different arrangements of atoms. We will look at some isomer possibilities for alkanes and alkenes.

Structural Isomers

A **structural isomer** is one in which two or more organic compounds have the same molecular formulas but different structures. The two pentane molecules below differ only in the location of the methyl group.



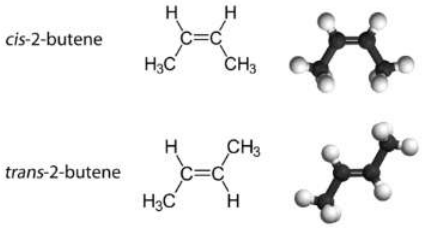
Alkenes can also demonstrate structural isomerism. In alkenes, there are multiple structural isomers based on where in the chain the double bond occurs. The condensed structural formulas of 1-butene and 2-butene show this.



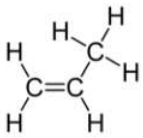
The number in the name of the alkene refers to the lowest numbered carbon in the chain that is part of the double bond.

Geometric Isomers

With a molecule such as 2-butene, a different type of isomerism called geometric isomerism can be observed. **Geometric isomers** are isomers in which the order of atom bonding is the same but the arrangement of atoms in space is different. The double bond in an alkene is not free to rotate because of the nature of the pi bond. Therefore, there are two different ways to construct the 2-butene molecule. The image below shows the two geometric isomers, called *cis*-2-butene and *trans*-2-butene.



The *cis* isomer has the two single hydrogen atoms on the same side of the molecule, while the *trans* isomer has them on opposite sides of the molecule. In both molecules, the bonding order of the atoms is the same. In order for geometric isomers to exist, there must be a rigid structure in the molecule to prevent free rotation around a bond. If the double bond in an alkene was capable of rotating, the two geometric isomers above would not exist. In addition, the two carbon atoms must each have two different groups attached in order for there to be geometric isomers. Propene has no geometric isomers because one of the carbon atoms has two single hydrogens bonded to it.



Physical and chemical properties of geometric isomers are generally different. While *cis*-2-butene is a polar molecule, *trans*-2-butene is nonpolar. Heat or irradiation with light can be used to bring about the conversion of one geometric isomer to another. The input of energy must be large enough to break the pi bond between the two carbon atoms, which is weaker than the sigma bond. At that point,the now single bond is free to rotate and the isomers can interconvert.

As with alkenes, alkynes display structural isomerism beginning with 1-butyne and 2-butyne. However, there are no geometric isomers with alkynes because there is only one other group bonded to the carbon atoms that are involved in the triple bond.

Summary

- Structural and geometric isomers are defined.
- Examples of alkane and alkene isomers are given.

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9.7: Hydrogenation

In the late 1970's the lipid hypothesis came in to existences stating that eating saturated fats leads to elevated LDL (Low Density Lipoprotein) which was perceived to be "bad cholesterol." This will result in coronary heart disease which is hardening and narrowing of arteries resulting in heart attack. Fats were eventually classified in to 2 categories: "healthy fats" and "unhealthy fats". Unhealthy fats where perceived to be *saturated* fats and healthy fats where perceived to be *unsaturated* fats.

A meta-analysis of 72 studies with over 103,052 people have found no validity in the lipid hypothesis. The conclusion of the Meta-Analysis was,"In contrast to current recommendations, this systematic review found no evidence that saturated fat increases the risk of coronary disease, or that polyunsaturated fats have a cardio protective effect."[1] Dietary fats play a critical role in human health. They help keep cells healthy, help with brain development, help with the use of fat soluble vitamins, and they help cushion organs protecting them against blunt trauma. Fats come in multiple forms, saturated, unsaturated and trans fats just to name a few.

Saturated fats are solid at room temperature due to their molecular shape. The term saturated is in reference to an sp^3 carbon chain that has its remaining sp^3 orbitals bonded with hydrogen atoms. Thus the term "saturated". It's "saturated" with hydrogen. Saturated fats have a chain like structure which allows them to stack very well forming a solid at room temperature. Unsaturated fats are not linear due to double bonded carbons which results in a different molecular shape because the sp^2 carbons are trigonal planar, not tetrahedral (sp^3 carbons) as the carbons are in saturated fats. This change in structure will cause the fat molecules to not stack very well resulting in fats that are liquid at room temperature. Butter is mostly saturated fat, that's why it's solid at room temperature. Olive Oil is liquid at room temperature, thus it's an unsaturated fat. An unsaturated fat can be made in to a saturated fat via hydrogenation reactions.

Hydrogenation Reaction

Unsaturated fatty acids may be converted to saturated fatty acids by the relatively simple hydrogenation reaction. Recall that the addition of hydrogen to an alkene (unsaturated) results in an alkane (saturated). A simple hydrogenation reaction is:

$$\mathbf{H_2C{=}CH_2 + H_2 \rightarrow CH_3CH_3}$$

alkene plus hydrogen yields an alkane

Vegetable oils are commonly referred to as "polyunsaturated". This simply means that there are several double bonds present. Vegetable oils may be converted from liquids to solids by the hydrogenation reaction. Margarines and shortenings are "hardened" in this way to make them solid or semi-solids.

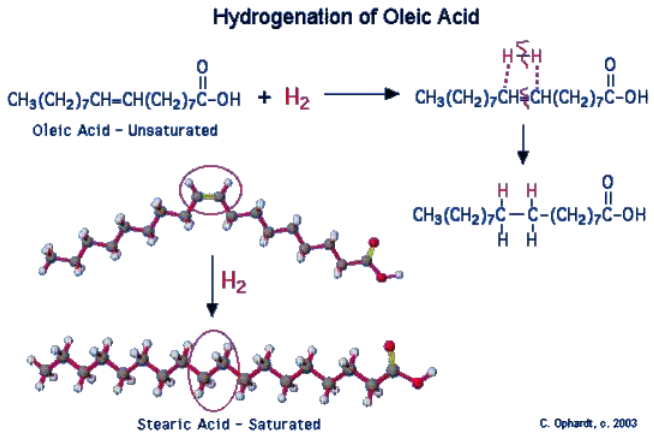
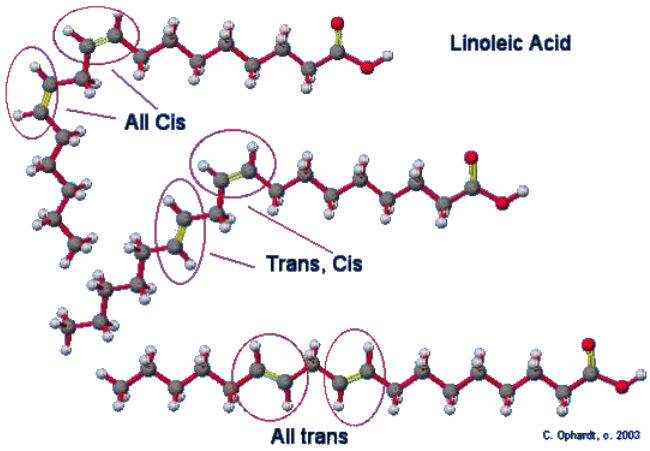


Figure 1: Hydrogenation of a oleic fatty acid

Vegetable oils which have been partially hydrogenated, are now partially saturated so the melting point increases to the point where a solid is present at room temperature. The degree of hydrogenation of unsaturated oils controls the final consistency of the product. What has happened to the healthfulness of the product which has been converted from unsaturated to saturated fats?

Trans Fat

A major health concern during the hydrogenation process is the production of trans fats. Trans fats are the result of a side reaction with the catalyst of the hydrogenation process. This is the result of an unsaturated fat which is normally found as a cis isomer converts to a trans isomer of the unsaturated fat. Isomers are molecules that have the same molecular formula but are bonded together differently. Focusing on the sp^2 double bonded carbons, a cis isomer has the hydrogens on the same side. Due to the added energy from the hydrogenation process, the activation energy is reached to convert the cis isomers of the unsaturated fat to a trans isomer of the unsaturated fat. The effect is putting one of the hydrogens on the opposite side of one of the carbons. This results in a trans configuration of the double bonded carbons. The human body does not recognize trans fats.



Although trans fatty acids are chemically "monounsaturated" or "polyunsaturated," they are considered so different from the cis monounsaturated or polyunsaturated fatty acids that they can not be legally designated as unsaturated for purposes of labeling. Most of the trans fatty acids (although chemically still unsaturated) produced by the partial hydrogenation process are now classified in the same category as saturated fats.

The major negative is that trans fat tends to raise "bad" LDL- cholesterol and lower "good" HDL-cholesterol, although not as much as saturated fat. Trans fat are found in margarine, baked goods such as doughnuts and Danish pastry, deep-fried foods like fried chicken and French-fried potatoes, snack chips, imitation cheese, and confectionery fats.

Contributors

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- Antonio Rodriguez

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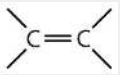
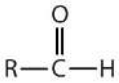
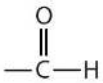
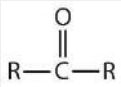
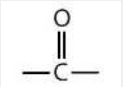
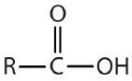
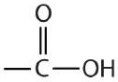
9.8: Functional Group introduction

Learning Objectives

- to describe functional groups and explain why they are useful in the study of organic chemistry.

Previously, we considered several kinds of hydrocarbons. Now we examine some of the many organic compounds that contain functional groups. We first introduced the idea of the functional group, a specific structural arrangement of atoms or bonds that imparts a characteristic chemical reactivity to the molecule. If you understand the behavior of a particular functional group, you will know a great deal about the general properties of that class of compounds. In this chapter, we make a brief yet systematic study of some of organic compound families. Each family is based on a common, simple functional group that contains an oxygen atom or a nitrogen atom. Some common functional groups are listed in Table 7.8.1.

Table 7.8.1 Selected Organic Functional Groups

Name of Family	General Formula	Functional Group	Suffix*
alkane	RH	none	*-ane*
alkene	$R_2C{=}CR_2$		*-ene*
alkyne	RC≡CR	–C≡C–	*-yne*
alcohol	ROH	–OH	*-ol*
thiol	RSH	–SH	*-thiol*
ether	ROR	–O–	ether
aldehyde			*-al*
ketone			*-one*
carboxylic acid			*-oic acid*

*Ethers do not have a suffix in their common name; all ethers end with the word *ether*.

Concept Review Exercises

1. What is the functional group of an alkene? An alkyne?
2. Does $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$ have a functional group? Explain.

Answers

1. carbon-to-carbon double bond; carbon-to-carbon triple bond
2. No; it has nothing but carbon and hydrogen atoms and all single bonds.

Key Takeaway

- The functional group, a structural arrangement of atoms and/or bonds, is largely responsible for the properties of organic compound families.

Exercises

1. What is the functional group of 1-butanol ($CH_3CH_2CH_2CH_2OH$)?
2. What is the functional group of butyl bromide, $CH_3CH_2CH_2CH_2Br$?

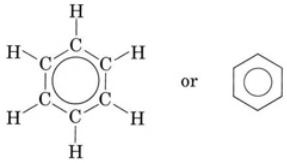
Answer

1. OH

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9.9: Aromatics

Aromatic hydrocarbons are one of the three classes of compounds found in petroleum. They are less abundant than the alkanes and cycloalkanes, amounting to only a few percent of the total, but they are quite important commercially. Most aromatic hydrocarbons contain a **benzene ring**. You will recall from the discussion on resonance that benzene, C_6H_6 contains a flat ring of six carbon atoms joined by bonds which are intermediate in character between single and double bonds. The benzene ring is usually indicated by



In the latter structure the lines represent C—C bonds, but carbon and hydrogen atoms, as well as C—H bonds, have been omitted. The benzene ring is very stable, surviving unchanged in most chemical reactions. It is very different in reactivity and shape from the puckered six-membered rings found in cycloalkanes. Below are 3D Jmol models of both cyclohexane and benzene.

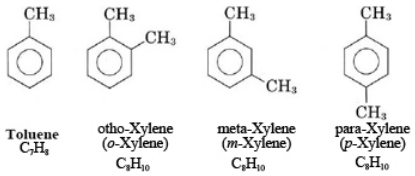
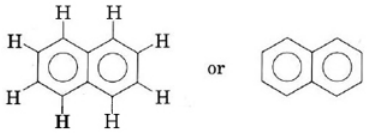


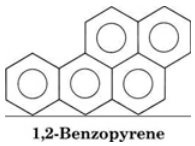
Figure **9.9.1**: Examples of aromatic hydrocarbons found in crude oil

> Note that the three xylenes are also isomers. Compounds containing two benzene rings joined together, such as naphthalene, are also found in crude oil, though they are much rarer than benzene-related compounds.



Aromatic hydrocarbons are much more common in coal than in petroleum, though in the United States they are mostly manufactured from the latter. In addition to their use in motor fuel, they may be made into dyes, plastics, explosives, detergents, insecticides, medicines, and many other products. In 2000, a total of 6.74×10^{12} liters of benzene were produced in the US, after compensation for exportation and importation.

Some aromatic compounds, benzene among them, are toxic. The compound 1,2-benzopyrene was the cause of the first demonstrated case of occupational disease.



During the eighteenth century chimney sweeps in London were found to have extremely high rates of skin cancer relative to the average person. This was eventually traced to the carcinogenic (cancer-causing) properties of 1,2-benzopyrene in the soot which coated the insides of the chimneys they cleaned. Small quantities of the compound were produced by inefficient combustion of coal in the fireplaces used to heat London houses.

References

1. Price, C. "Summary of available production volumes in millions of gallons per year for selected volatile organic compounds(VOCs) studied by the National Water Quality Assessment(NAWQA) Program." USGS. March 07, 2005.

water.usgs.gov/nawqa/vocs/national_assessment/aboutvocs/prod_data.xls

Contributors and Attributions

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9.10: Alcohols

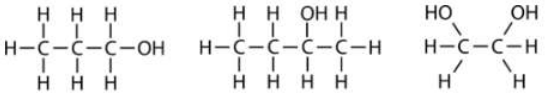
Water freezes at 0°C which creates problems for cars in the winter. The water in the engine would freeze and crack the engine block. To prevent this, antifreeze is added to lower the freezing point of the liquid. The most common antifreeze is an alcohol known as propylene glycol. It has largely replaced the much more toxic ethylene glycol. Methanol can also be used as an antifreeze, mainly in windshield wiper fluid.

Alcohols

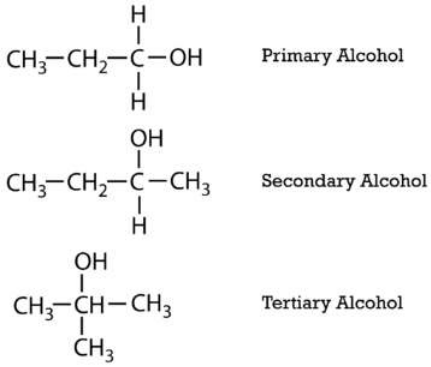
An **alcohol** is an organic compound that contains one or more hydroxyl (–OH) groups. The general formula for alcohols is R–OH. Do not confuse alcohols with inorganic bases that contain the hydroxide ion (OH^-). The –OH group in an alcohol is covalently bonded to a carbon atom and does not ionize in solution. The steps for naming alcohols are listed below.

1. Name the parent compound by finding the longest continuous carbon atom chain that also contains the hydroxyl group. If there is one hydroxyl group in the molecule, change the final *-e* in the name of the alkane to *-ol*. If there is more than one hydroxyl group, use the full name of the alkane and add a suffix to indicate the number of hydroxyl groups. For example, two hydroxyl groups is *-diol*, three is *-triol*, etc.
2. Number the carbon chain in a way that makes the sum of the hydroxyl numbers as low as possible.
3. Add the numerical prefix into the name before the name of the alcohol.
4. Separate numbers with commas and separate numbers from names or prefixes with a hyphen. There are no spaces in the name.

Following are three examples of alcohols and their IUPAC names.



Aliphatic alcohols can be classified according to the number of R groups attached to the carbon with the hydroxyl group. If one R group is attached to that carbon, the alcohol is a primary alcohol. If two R groups are attached, the alcohol is a secondary alcohol. If three R groups are attached, the alcohol is a tertiary alcohol. Shown below is an example of each. The primary alcohol is 1-propanol, the secondary alcohol is 2-butanol, and the tertiary alcohol is 2-methyl-2-propanol.



Properties of Alcohols

The smallest and lightest alcohols (methanol, ethanol, propanol) are completely soluble in water in all proportions. In a solution, the hydroxyl groups of alcohol molecules and the water molecules form hydrogen bonds with each other, resulting in complete miscibility. However, as the length of the carbon chain increases, the solubility decreases. The solubility of 1-butanol is 7.4 g per 100 g of water, while that of 1-pentanol is 2.7 g per 100 g of water, and 1-octanol is 0.06 g per 100 g of water. The carbon chain portion of the larger alcohol molecule is nonpolar and leads to the decreased solubility of the overall compound.

The presence of hydrogen bonds in alcohols also explains the relatively high boiling points of alcohols compared to the alkanes of similar molar mass (see table below).

Table 25.9.1: Boiling Point Comparison of Alkanes and Alcohols

Compound	Formula	Molar Mass (g/mol)	Boiling Point (°C)
ethane	CH_3CH_3	32	-88
methanol	CH_3OH	30	64.7
propane	$CH_3CH_2CH_3$	44	-42.1
ethanol	CH_3CH_2OH	46	78.3

Only weak London dispersion forces hold molecules of nonpolar alkanes together in the liquid phase. Consequently, less energy is required to break these molecules away from the surface of the liquid and turn them into a vapor. The stronger hydrogen bonding between alcohol molecules means that more energy is required to convert the liquid to vapor, and boiling points are therefore high.

This page briefly discusses some of the important uses of simple alcohols, such as methanol, ethanol and propan-2-ol.

Alcoholic Drinks

The word "alcohol" in alcoholic drinks refers to ethanol (CH_3CH_2OH).

Industrial methylated spirits

Ethanol is usually sold as industrial methylated spirits, which is ethanol with a small quantity of methanol and possibly some color added. Because methanol is poisonous, industrial methylated spirits are unfit to drink, allowing purchasers to avoid the high taxes levied on alcoholic drinks.

Use of ethanol as a fuel

Ethanol burns to produce carbon dioxide and water, as shown in the equation below, and can be used as a fuel in its own right or in mixtures with petrol (gasoline). "Gasohol" is a petrol/ethanol mixture containing approximately 10–20% ethanol. Because ethanol can be produced by fermentation, this is a useful method for countries without an oil industry to reduce the amount of petrol imports.

$$CH_3CH_2OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$$

Ethanol as a solvent

Ethanol is widely used as a solvent. It is relatively safe and can be used to dissolve many organic compounds that are insoluble in water. It is used, for example, in many perfumes and cosmetics.

Methanol as a fuel

Methanol also burns to form carbon dioxide and water:

$$2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$$

It can be used a a petrol additive to improve combustion, and its use as a fuel in its own right is under investigation.

Methanol as an industrial feedstock

Most methanol is used to make other compounds, for example, methanal (formaldehyde), ethanoic acid, and methyl esters of various acids. In most cases, these are then converted into further products.

Contributors and Attributions

-
- Jim Clark (Chemguide.co.uk)

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9.11: Ethers

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9.12: Carbonyl Friends

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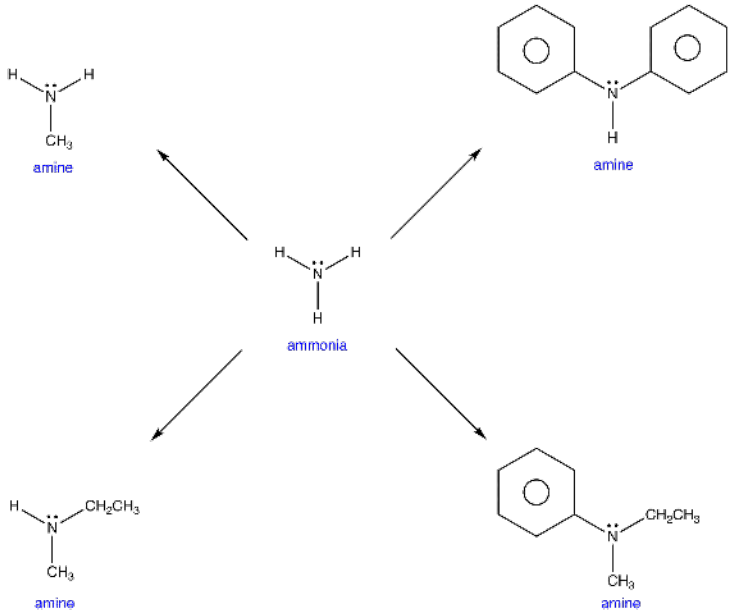
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9.13: Amines and Thiols

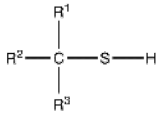
Amine

A compound obtained by replacing one or more hydrogen atoms in the ammonia molecule by alkyl and/or aryl groups is called an amine.



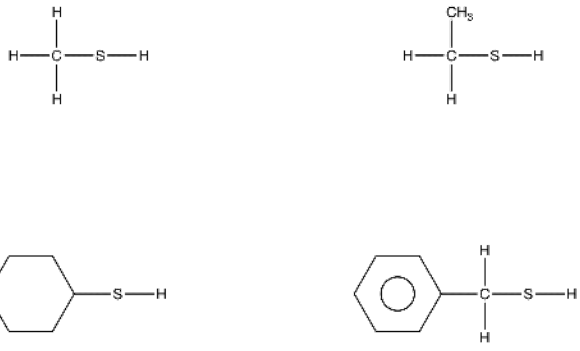
Thiols

A thiol, thio alcohol, or mercaptan is a compound that has the following general structural formula.



R^1—R^3 could be hydrogen atoms, alkyl groups, aryl groups, or any combination thereof.

eg:



The sulfhydryl group in a thiol is called the thiol group.

Contributors and Attributions

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9.E: Organic Chemistry (Exercises)

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CHAPTER OVERVIEW

10: Pharmaceuticals

Pharmaceuticals are drugs used to diagnose, cure, treat, or prevent disease. Drug therapy is an important part of the medical field and relies on the science of pharmacology for continual advancement and on pharmacy for appropriate management. A very broad definition of a drug would include "all chemicals other than food that affect living processes." If the effect helps the body, the drug is a medicine. However, if a drug causes a harmful effect on the body, the drug is a poison. The same chemical can be a medicine and a poison depending on conditions of use and the person using it. Another definition would be "medicinal agents used for diagnosis, prevention, treatment of symptoms, and cure of diseases."

10.1: Chemotherapy
10.2: DEA Drug Schedules
10.3: Analgesics
10.4: Neurotransmitters and Antidepressants
10.5: Stimulants
10.6: Hallucinogens
10.7: Narcotics
10.8: Basics of Neurotransmitters
10.9: Antianxiety Medications
10.10: Amphetamines
10.11: Antipsychotic medication
10.12: Analgesics
10.13: Narcotic Analgesics
10.14: Antidepressant medications

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10.1: Chemotherapy

Learning Objectives

- Define chemotherapy (from a chemical and cultural perspective)
- Explain the FDA drug categories on this page.
- Recall benefits and side effects of corticosteroids (like Prednisone).
- Correlate a drug's chemical name with Brand and generic names (while using the internet).
- List the signs of anaphylaxis.
- Be aware of drug/vitamin interactions when reading an information pack.
- Provide a list of remedies for anaphylaxis.

Chemotherapy, broadly defined, means the treatment of any disease by chemicals including infectious and non-infectious diseases. The original definition applied only to drugs that were used in the treatment of infectious diseases. The proper term for the treatment of non-infectious diseases is pharmacodynamics.



Figure **10.1.1**: Medicines at 1752 Apothecary, Moravian Bethlehem. (Copyright; Bestbudbrian)

A very broad definition of a drug would include "all chemicals other than food that affects living processes." If the effect helps the body, the drug is a medicine. However, if a drug causes a harmful effect on the body, the drug is a poison. The same chemical can be a medicine and a poison depending on conditions of use and the person using it. Another definition would be "medicinal agents used for diagnosis, prevention, treatment of symptoms, and cure of diseases." Contraceptives would be outside of this definition unless the pregnancy was considered a disease.

FDA Drug Categories

The Food and Drug Administration has over 40 different drug families. To access this listing, scan the QR code below.

Figure **10.1.2**: QR code for comprehensive listing of drugs. (Copyright; fda.gov)

For this term, we will be focusing on a few of these categories. When understanding basic pharmaceutical chemistry, review the following terms:

- Analgesics-drugs that relieve pain.
- Antihistamine- drugs that help with allergic responses.
- Antibiotics- medications that fight bacterial infections.
- Decongestant- drug that relieves a stuffy nose
- Antivirals- medications used to combat viruses.
- OTC- over-the-counter medications that do not require a prescription.
- Antipyretics- medications that reduce fevers
- Anticoagulants- substances that reduce blood clotting.
- NSAID- nonsteroidal anti-inflammatory drug- medications that reduce inflammation, but are not steroids.
- Controlled substance- an addictive medication or illegal drug that is regulated by the Drug Enforcement Agency. For legal prescriptions, identification must be presented in order to pick up medication.
- Corticosteroid- prescription steroids that reduce inflammation.

Definition: What is a steroid?

- A steroid is a chemical that can be naturally found or synthetically made. Many of these are present in the human body and are called hormones. Examples of these types of steroids are testosterone and estrogen. On the image below, Estradiol is a form of estrogen. This chemical can be synthetic and is used in birth control pills and hormone replacement therapy (HRT).

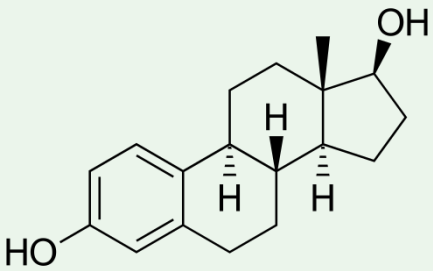


Figure **10.1.3**: Structure of estradiol (Copyright, https://commons.wikimedia.org/wiki/User:NEUROtiker)

Anabolic steroids are a class of chemicals that can increase bodyweight and muscle size. Overuse and abuse of these types of steroids are common. As a result, the Drug Enforcement Agency regulates and controls anabolic steroids. Click here to read about the illegal use of anabolic steroids in athletics.

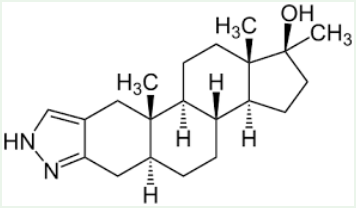


Figure **10.1.4**: Stanozolol. (Copyright, https://commons.wikimedia.org/wiki/User:J%C3%BC).

Corticosteroids are medications that reduce inflammation and immunity. These steroids are used to treat asthma, arthritis, allergic reactions, and other conditions/diseases (reduction of organ rejection, Lupus, Irritable Bowel Diseases, Irritable Bowel Syndrome, Addison's Disease, Chronic Pulmonary Disease (COPD), and Multiple Sclerosis.

Corticosteroids can be found in creams, eye drops, ear drops, and inhalers. In addition, these medications can be administered as a injections, liquids, or pills. The last three of these formulations are most likely to produce unwanted side effects.

Prednisone, a common corticosteroids, is commonly prescribed to reduce allergic reactions. For example, individuals who develop hives to certain plants or insect stings might be prescribed a short protocol of steroids. When asthma patients cannot keep their symptoms under control by using their inhalers, they might be switched to a short treatment of an oral steroid (prednisone). Lastly, patient with long-term Irritable Bowel Diseases (Crohn's or Ulcerative Colitis) can be prescribed prednisone to achieve remission.

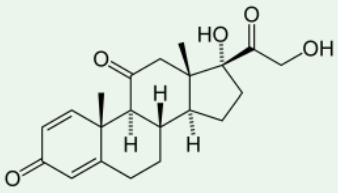


Figure **10.1.5**: Prednisone-2D-skeletal.

Click on this link and answer the questions below:

1) For children taking oral corticosteroids, how can their height be affected?

2) If you are on steroids for over a month, how will your face change?

3) Will you lose or gain weight on steroids?

4) Should diabetics limit their use of corticosteroids? Why or why not?

5) How could your sleeping and mood be affected by taking oral steroids?

6) During flu season, what types of things should steroid patients do to remain healthy?

7) Have you ever been prescribed oral steroids? What type of side effects did you experience?

Drug Names

Drugs have three or more names including a: chemical name, brand/ trade name, and generic or common name. The chemical name is assigned according to the rules of nomenclature of chemical compounds. The brand name is always capitalized and is selected by the manufacturer. The generic name refers to a common established name irrespective of its manufacturer.



Figure **10.1.6**: A package of capsules. (Copyright; Photo was taken for Wikipedia by Moriori Transferred from English Wikipedia; en:Image:Tamiflu.JPG)

In most cases, a drug bearing a generic name is equivalent to the same drug with a brand name. However, this equivalency is not always true. Although drugs are chemically equivalent, different manufacturing processes may cause differences in pharmacological action. Several differences may be crystal size or form, isomers, crystal hydration, purity-(type and number of impurities), vehicles, binders, coatings, dissolution rate, and storage stability.

? Exercise 10.1.1

Using the fda.gov website, determine the use and brand names for the following pharmaceuticals:



Figure **10.1.7**: 3-D structure of Ibuprofen. (Copyright, **Benjah-bmm27**.)

a) Alprazolam (generic name)

b) Ibuprofen (generic name)

c) Fluoxetine (generic name)

Answer

a) This drug has a Trade name of Xanax©. It is used to as a short-term antianxiety agent. This medication can be addictive.

b) This drug has a Trade name of Advil © or Motrin©. Ibuprofen can be used to treat fevers, inflammation, and general pain.

c) This drug has a Trade name of Prozac©. It is classified as being an antidepressant. This medication can be used to treat depression and anxiety. For young people, the FDA has put a Black Box warning on all antidepressants. Younger patients are more likely to suddenly stop an antidepressant without consulting a medical professional. This quick change of brain chemistry can cause suicidal tendencies.

Drug Reactions

Before taking a new medication, review the patient information packet or access the drug's information on the fda.gov website. Foods (like grapefruit), Vitamins, and OTC drugs (antacids) can affect the potency of prescribed medication. In addition, combining alcohol with antidepressants, tranquilizers, and narcotics could result in serious health issues or even death.

Allergic responses to medications and the environment can arise at any time of one's lifetime. It is important to keep track of these allergies and report them when you see a medical professional. Allergic responses to medication can result in hives, rash, itching, fever, swelling, shortness of breath, wheezing, runny nose, and itchy, watery eyes.



Figure **10.1.8**: A medical illustration depicting urticaria.(Copyright, :BruceBlaus)

Anaphylaxis

A severe allergic response to a medication, food, or the environment is called anaphylaxis. Symptoms of this condition include the following: trouble breathing, tightening of chest and throat, dizziness, seizure, vomiting/diarrhea, change in pulse, drop in blood

pressure, and nausea. If the patient has issues breathing or experiences seizures, they need to be transported to the hospital ASAP. For less severe symptoms, calling a medical professional would be an appropriate plan.

Over-the-counter antihistamines can be effective in reducing some of the symptoms of anaphylaxis. Generic forms of Benadryl©, Zyrtec©, Claritin©, and Allegra© can help alleviate an allergic response. If a patient continues to have issues with severe allergic reactions, then they should be prescribed an epinephrine pen (Epi-pen). Individuals who have experienced anaphylaxis should keep an Epi-pen close at all times.



References

1) Fda.gov

2) Mayoclinic.org

Contributors

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10.2: DEA Drug Schedules

Learning Objectives

- Explain the purpose of the Comprehensive Drug Abuse Prevention, and Control Act of 1970.
- Name the two governmental agencies that regulate highly abused substances.
- Explain DEA controlled substances scheduling.
- List examples of substances found in the five schedules.
- Provide legal and illegal applications of GHB.
- Compare and contrast the chemical structures of CBD and THC.
- Know basic uses (legal and illegal) of CBD and THC.

Controlled Substances

Under the Nixon administration, the United States passed the Comprehensive Drug Abuse Prevention,and Control Act of 1970. This law enabled the federal government to regulate the manufacturing and distribution of narcotics, depressants, hallucinogens, anabolic steroids, and amphetamines. In 1973, the Drug Enforcement Administration (DEA) was created to assist the Food and Drug Administration with regulating addiction medications and illicit substances.



Figure **10.2.1**: Elvis Presley meeting Richard Nixon. On December 21, 1970, at his own request, Presley met then-President Richard Nixon in the Oval Office of The White House. Elvis is on the right. Waggishly, this picture is said to be 'of the two greatest recording artists of the 20th century'. The Nixon Library & Birthplace sells several souvenir items with this photo and the caption, "The President & The King." (Copyright, White House photograph by Ollie Atkins via https://www.archives.gov/exhibits/nixon-met-elvis/).

Within Title II of the Comprehensive Drug Abuse Prevention and Control Act of 1970, the Controlled Substances Act (CSA) was embedded to provide criteria as to how a drug is declared to be illegal. This particular legislation was amended in 1986 to include analogs (similar chemicals) of the already defined illegal substances.



Video **10.2.1**: What are Schedule Drugs? | Controlled Substances | PTCB EXAM | Schedule Drugs and Types | https://youtu.be/aBKrrWGpOEM

In the United States, legal and illegal drugs that could be potentially abused are classified (scheduled) and defined as being controlled substances by the Drug Enforcement Administration (DEA). According to this federal agency, there are five levels of scheduled substances. Substances listed in the first tier of DEA scheduling have the highest potential for abuse and are defined as having no legal medical use. The Food and Drug Administration (FDA) and Congress do assist the DEA in altering the scheduling of drugs and illicit substances.

Table **10.2.1**: Selected DEA controlled substances (Copyright; Elizabeth Gordon)

Schedule	Examples of Substances
1	Heroin, Lysergic acid diethylamide (LSD), Marijuana (cannabis), Ecstasy/MDMA (methylenedioxymethamphetamine), Phencyclidine (PCP), and Peyote.
2	Cocaine, Methamphetamine, Methadone, Hydromorphone (Dilaudid®), Meperidine (Demerol®), Oxycodone (Oxycontin ®), Amphetamine stimulants (Adderall®, Ritalin®, Vivance®, and Concerta®), Hydrocodone, Fentanyl, and Morphine.
3	Codeine (less than 90 mg dose), anabolic steroids, Ketamine, and Testosterone.
4	Alprazolam (Xanax®), Clonazepam (Klonopin®), Diazepam (Valium®), Lorazepam (Ativan®), Zolpidem (Ambien®), and Eszopiclone (Lunesta®).
5	Codeine cough syrup (less than 200 mg per dose), Lomotil ®, Promothezine (Phenergan®), and Ondansetron hydrochloride dihydrate (Zofran®).

Scheduling of Gamma-Hydroxybutyrate (GHB)

In the late 1980's, Gamma-Hydroxybutyrate (other chemical names include 4-Hydroxybutanoic acid) was sold at many health food stores in the United States. GHB was marketed and sold as a natural sleep aid and a weight-loss supplement. Also, GHB manufacturers claimed that this substance could increase muscle mass. Dieters and bodybuilders stocked-piled GHB supplements. Unfortunately, no scientific study has ever proven that GHB is capable of reducing weight or gaining muscle mass.

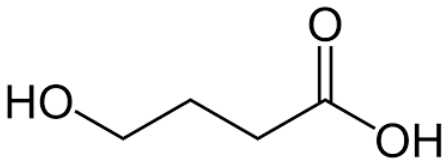


Figure **10.2.2**: Structural formula of the chemical compound gamma-hydroxybutyrate (GHB, 4-hydroxybutanoic acid, $C_4H_8O_3$). (Copyright, NEUROtiker)

Immediately, consumers of this substance noticed the euphoric and hallucinogenic properties after use. In lower concentrations, GHB can reduce anxiety and inhibition. In larger concentrations, GHB can increase libido, cause extreme nausea, and render users unconscious. Quickly, GHB became known as a date-rape drug due to its ability to subdue a victim. Also, this water-soluble chemical can cause amnesia and will be metabolized and excreted by the body quite quickly. GHB acts within 15-30 minutes of ingestion and the effects can last 3 to 6 hours.



Video **10.2.2**: How does the FDA classify GHB as a drug? Two ways, depending on the form of the drug, as this criminal defense lawyer explains.

On November 8, 1990, the Food and Drug Administration (FDA) stopped all manufacturing and sales of GHB due to an increase in overdoses and death. For years, GHB and its analogs remained off the DEA scheduling of controlled substances. On November 11, 1999, Congress passed the **Hillory J. Farias and Samantha Reid-Date-Rape Drug Prohibition Act of 1999**. This legislation amended the Controlled Substances Act (CSA) to include GHB, GHB salts, and GHB isomers. On March 13, 2000, GHB was officially listed as being a scheduled 1 substance. In 2002, the FDA approved GHB for the treatment of narcolepsy. Sold under the name Xyrem, this compound can be prescribed legally and is a scheduled 3 substance.

Example 10.2.1

Looking at the DEA scheduling of controlled substances, why do you think cocaine and methamphetamine are scheduled II substances? Access the dea.gov website to see reasoning as to why these two chemicals are not listing scheduled I.

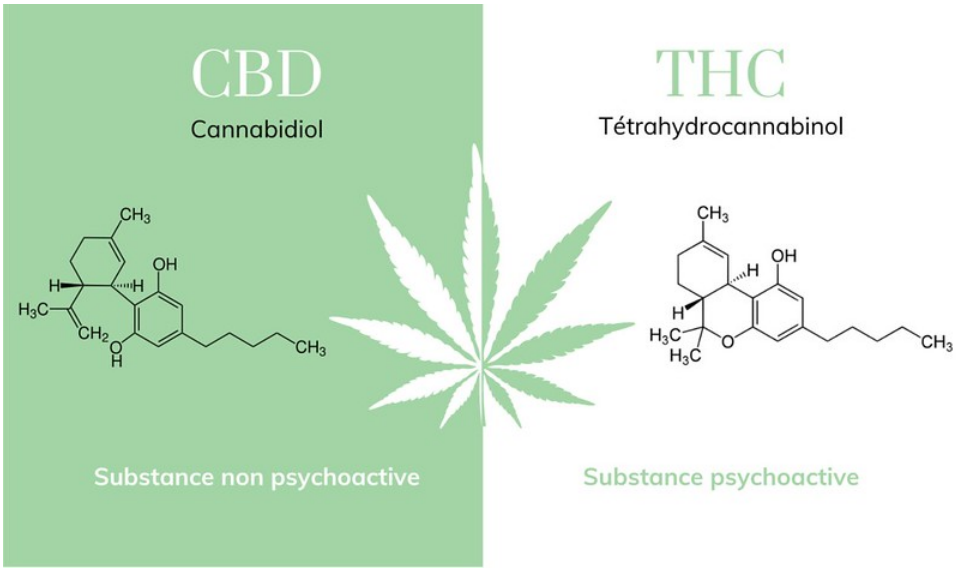


Figure **10.2.3**: Visual CBD: Molecules thc et cbd. (Copyright, molecules thc et cbd | Comparatif des molecules entre CBD et… | Flickr,)

The Cannabis plant contains around 550 different chemicals. Of this amount, 100 of these chemicals are classified as being cannabinoids which affect cannabinoid receptors in the body. Cannabinoids that stimulate CB2 receptors do not induce euphoria. One such Cannabidiol also known as CBD can reduce inflammation and pain. CBD extracted directly from the hemp plant and containing less than .3% of THC (dry weight) is legal and not scheduled by the Drug Enforcement Agency (DEA).

The active ingredient in marijuana, Tetrahydrocannabinol (THC), affects CB1 receptors which induce euphoria. As of January 2025, the DEA and FDA still rank Marijuana as being a scheduled 1 controlled substance. Both of these agencies have deemed marijuana to have no federally approved medication applications. However, synthetic forms of Tetrahydrocannabinol (THC), the psychoactive ingredient in marijuana, have been approved for various medical uses. For example, Marinol is a scheduled III substance used to treat extreme nausea and vomiting in AIDS and cancer patients.

Individual states have enacted their own laws regarding the legalization of marijuana. By accessing this link, you can view the current status of each state. Some states have legalized marijuana for medical use. In these areas, marijuana has been used to treat severe pain, reduce muscle spasms in Amyotrophic lateral sclerosis (ALS) and Multiple sclerosis (MS) patients, increase appetite with people diagnosed with Irritable bowel diseases (IBD) and eating disorders, and reduce eye pressure for patients diagnosed with Glaucoma.

Example 10.2.1

Using this link, research the questions below:

1) In 2022, how many people in the United States used Cannabis products?

2) Which mental health conditions have been linked to Cannabis use?

3) How can children become accidently poisoned by Cannabis?

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10.3: Analgesics

Learning Objectives

- Define the term "analgesic."
- Compare and contrast OTC analgesics with Narcotic analgesics.
- Relate the four common OTC analgesic's generic names to chemical and Brand names.
- Know side effects of taking each of the four OTC analgesics.
- Explain what buffering does to a medication.
- Detect analgesics in a combination medication.
- Determine what the different drugs in a combination medicine do (when provided a label)
- Compare and contrast opiates with opioids.
- Determine which mg amount corresponds to the opioid when provided a label of a narcotic analgesic.
- Know the medical purposes and side effects of taking a narcotic.
- Provide the name for the strongest narcotic on this page.
- Understand how Oxycontin differs from oxycodone.
- Provide a list of medications/substances that should not be combined with narcotics.
- Name one antidote for opioid/opiate overdose.
- Describe the history of the early opiates.
- Explain what "doctor shopping" is.

Analgesics are medications that relieve pain. Many of these medications can be purchased without a prescription and are labeled as being over the counter (OTC). All of these OTC formulations have generic counterparts that are chemically equivalent to the brand name. When purchasing these substances, be sure to note the price difference between generic and name-brand analgesics. Also, you should be aware that countries outside the United States use different names for their analgesics and dosages per unit.

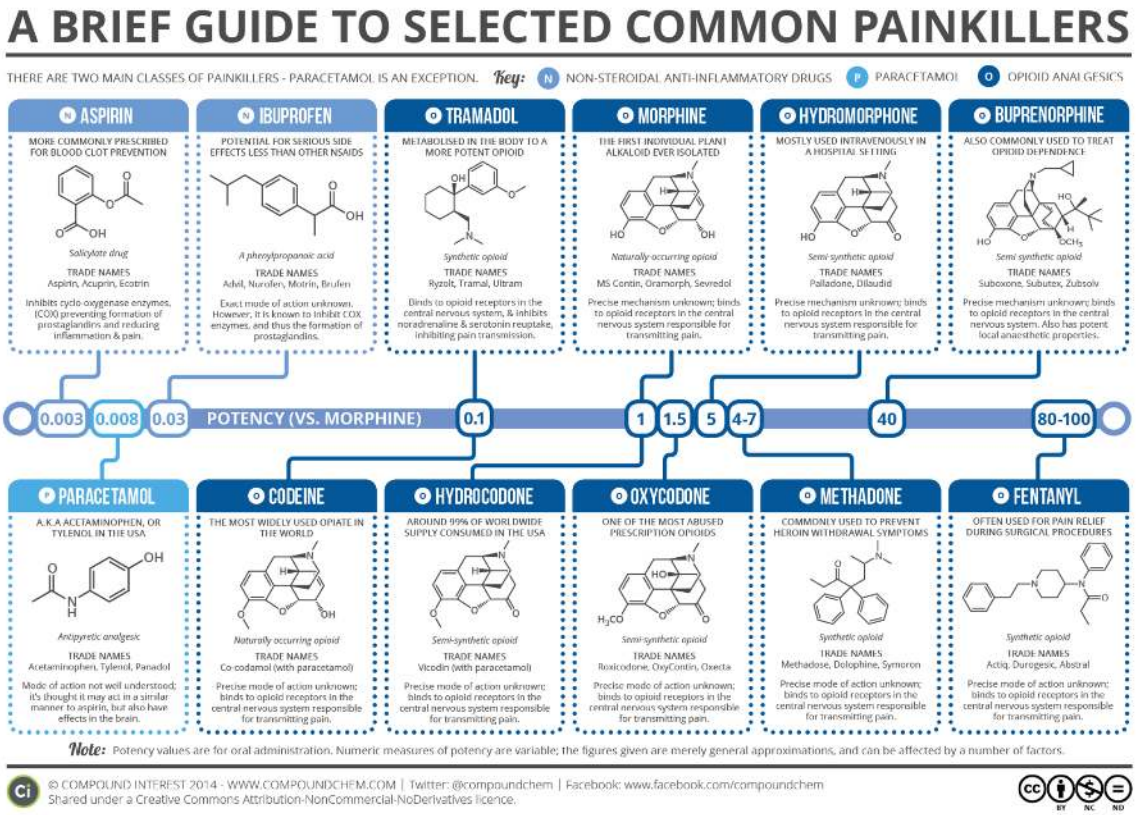


Figure **10.3.1**: OTC and Prescription Analgesics (CC BY-NC-ND; Andy Brunning)

Selecting an OTC Analgesic

For general and occasional pain, consumers have the option of taking one of four OTC pain killers. All of these medications act as antipyretics. Of the four drugs, only one of these analgesics cannot alleviate pain due to inflammation.

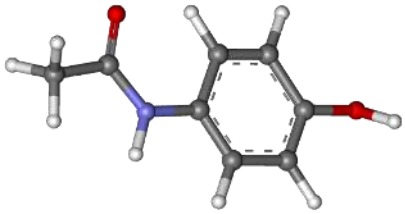


Figure **10.3.2**: Acetaminophen molecule structure(Copyright; Wiki media Images (pixabay.com))

Acetaminophen (Tylenol®, Paracetamol®)

American formulations of this OTC pain killer are available in regular strength (325 mg of acetaminophen per tablet) or extra strength (500 mg of acetaminophen per tablet). Dosages should be extended to 4-6 hour increments when treating fever. Acetaminophen reduces general pain but is not a nonsteroidal anti-inflammatory drug (NSAID). It does not demonstrate anticoagulant effects and is the safest to use on pregnant women and pediatric patients. Of the four OTC analgesics, this molecule does not contain an organic acid functional group (COOH). Being a somewhat pH-neutral molecule, acetaminophen is milder on the stomach than the other analgesics listed below.

Organic and biochemists are both employed in the making of pharmaceuticals. The reaction pathways drawn to describe the steps of synthesis are called mechanisms. Click on the short video below to visualize the reaction mechanism utilized to produce acetaminophen.



Video **10.3.1**: Acetaminophen Synthesis.

Acetylsalicylic Acid (Bayer Aspirin®, Goody's®, Ecotrin®)

In 1853, French chemist, Charles Gerhardt, synthesized the organic molecule known today as acetylsalicylic acid. Medical applications of this molecule did not occur until the later part of the 1890s. German chemist, Felix Hoffman, produced the first pure sample of acetylsalicylic acid. In hopes to alleviate the intense pain associated with rheumatoid arthritis, the Bayer Chemical Company's trademark Aspirin® was marketed to the European continent. Immediately after World War I, Bayer's Aspirin and Heroin trademark products were given to allied nations as part of the Treaty of Versailles agreement.



Figure **10.3.3**: One of the first advertisements for Bayer Aspirin aimed at American consumers, just before the U.S. patent for aspirin was to expire. (Copyright, New York Times, February 19, 1917, p. 6 (via ProQuest Historical Newspapers: "Display Ad 26 -- No Title")

Aspirin, like Tylenol ®, can reduce fevers and general pain. This particular pharmaceutical is an anticoagulant and NSAID. The acetylsalicylic acid molecule does contain an organic acid functional group (COOH). As a result of this molecular structure, Aspirin products can be harsh on the stomach and gastrointestinal tract. At high doses Concentrations of the active ingredient acetylsalicylic acid, can be 81 mg (heart therapy), 325 mg (regular strength), and 500 mg (extra strength).

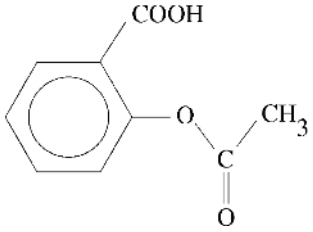


Figure **10.3.4**: Organic structure of acetylsalicylic acid. (Copyright, https://commons.wikimedia.org/wiki/User:Rob_Hooft)/

Due to its anticoagulant properties, aspirin products should be avoided by people who have bleeding diseases and who are undergoing surgery. For this reason, pregnant women should avoid aspirin therapy unless a physician notes otherwise. Pediatric patients could develop Reye's Syndrome if they use aspirin-based medications to reduce fevers. Individuals who take high doses of aspirin can experience tinnitus (ringing in the ears). This analgesic can also trigger respiratory events in asthmatic patients.

Buffered Aspirin

This type of aspirin contains an antacid ingredient, various carbonates CO_3^{2-}, and/or weak hydroxides OH^-, that will minimize the acidic effects of this analgesic. The normal pH of stomach acid is around 1. Regular (or non-buffered) aspirin-based products can reduce this value even more. A buffered analgesic will keep the stomach pH value stable and will reduce the likelihood of developing stomach ulcers and reflux. Generics and the trade brand Bufferin® are available as OTC options.

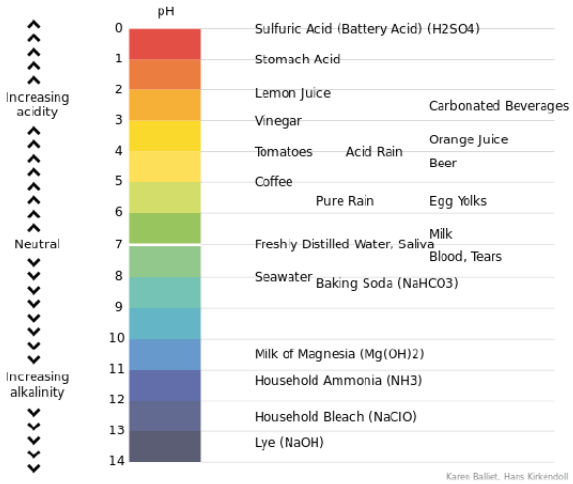


Figure **10.3.5**: A visual representation of pH with values indicated for common substances.(Copyright, https://commons.wikimedia.org/w/inde...edit&redlink=1)

Ibuprofen (Advil® and Motrin®)

In the 1950s, British chemist Stewart Adams focused his research on developing a new drug that would minimize the effects of rheumatoid arthritis. For years, aspirin products were used, but several adverse reactions had been reported. Favorable clinical trials was granted to Adams's employer, Boots UK. By 1969, ibuprofen was available as a prescription medication in the UK. Prescription availability in the United States occurred in 1974. Both the UK and the United States converted the status of ibuprofen from prescription to over-the-counter in the early to mid-1980s.

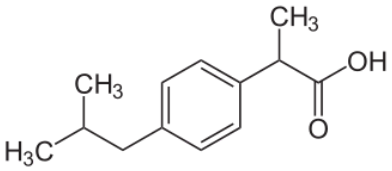


Figure **10.3.6**: Structure of ibuprofen.

Ibuprofen does contain the acidic COOH group. For this reason, it is best for patients with stomach issues to avoid or minimize the use of this analgesic. Being an antipyretic and NSAID, this medication is safe for use for those who do not have bleeding disorders (anticoagulant). OTC regular-strength tablets or capsules contain 200 mg of the active ingredient. Like Tylenol, it is recommended that patients should wait between 4-6 hours between dosages. Some asthmatics have experienced mild to severe reactions while taking this drug. Of the four OTC analgesics shown on this page, acetaminophen and ibuprofen are safe to use on pediatric patients provided they are not asthmatic or have gastrointestinal problems.

Ibuprofen is extremely effective in treating dysmenorrhea. With the addition of caffeine, the painkilling effect can be intensified with analgesics like acetaminophen, aspirin, and ibuprofen.

Naproxen (Aleve®)

This analgesic possesses the longest chemical half-live (12 hours) than the previously mentioned medications. For this reason, it is recommended to extend dosage to 8-12 hours (other analgesics are dosed between 4-6 hours).

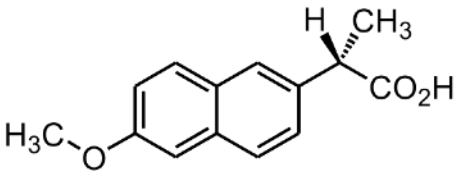


Figure **10.3.7**:Structure of Naproxen.

The naproxen sodium formulation of this NSAID is more rapidly absorbed than the naproxen version. Both versions are NSAIDS and act as antipyretics. Once again, the acidic COOH group is present and will cause adverse reactions in individuals who suffer

from gastrointestinal issues. Sold in 220 mg tablets, naproxen has anticoagulant properties which make it a risky option for many types of patients (pre-surgical and pregnant women). Lastly, naproxen products can trigger asthma symptoms.

General Warning

If a patient has kidney or liver disease, it is best to avoid all analgesics. Liver damage is more common when combining alcohol with analgesics or if taking excessive amounts of these medications. If taken on a daily basis, tolerance to an analgesic can occur.

Combination Products

When taking combination products for allergies, colds, flu, or other illnesses, it is important to note all the active ingredients listed in a product. For example, many cold and flu formulations contain an analgesic with antihistamines and/or decongestants. By analyzing the label, a consumer is less likely to double up on one of the listed ingredients. For example, the OTC flu medication displayed below contains an analgesic, cough suppressant, and a nasal decongestant. When taking Theraflu, there is no need to take an additional analgesic.



Figure **10.3.8**: Theraflu medication.

Pediatric formulations of analgesics or combination products that include analgesics will have different concentrations of active ingredients than medicine that has been designed for adults. By following the dosing directions on the packaging, adults can ensure that they are not under or over-dosing a child.

Example 10.3.1

Look up the following combination products and determine the analgesics that are present. Also, indicate applications for each pharmaceutical.

a) Pamprin®

b) Excedrin®

c) Nyquil® and Dayquil®

d) Mucinex Sinus-Max®

Narcotic Analgesics

For intense pain and/or chronic pain, narcotics could be prescribed by a health care professional. These substances are very addictive and classified DEA schedule 2. The term "Opiate" implies that a narcotic-based pain killer could be derived from the opium poppy. In nature, the seed pod of the opium poppy plant excretes codeine and morphine.



Figure **10.3.9**: This photo shows a seed head of Opium Poppy *Papaver somniferum* with white latex.

Opium poppies are commonly grown in many parts of the Middle East, Asia, and South America. Here, the sap is extracted and collected. Upon exposure to air, the sap turns brown and is then formed into a ball-like structure. Crude opium can enter the pharmaceutical industry legally if imported and processed correctly. Many countries do not allow opium-based poppies to be grown and extraction of the natural opiates to occur.



Even though opiates are natural products of a plant, they can also be synthesized in an organic chemistry laboratory. If morphine and are codeine are produced in a chemical laboratory, we now refer to these substances as being opioids. Both of these compounds can exist naturally and can be made by a chemist. Narcotics, like oxycodone, hydrocodone, and heroin are classified as being opioids as well. These three compounds along with others cannot be extracted from a plant and are made in a laboratory.

Medical applications of opiates and opioids

Hospitals can dispense morphine or fentanyl for patients who are experiencing extreme pain. This could include pain resulting from surgery or trauma. Fentanyl is also applied in the palliative care field of medicine. Lesser potent opioids, like codeine, are used to suppress the cough reflex for flu patients. Over-the-counter cough syrups do not include codeine and therefore are not classified as controlled substances.



Figure 10.3.10: Promethazine-codeine cough syrup. (Copyright, https://commons.wikimedia.org/wiki/User:Stickpen)

When leaving the hospital, a patient might be prescribed narcotics that have relatively low doses of oxycodone or hydrocodone. Typically, these opioids are combined with an over-the-counter analgesic and have brand names like Lortab® (hydrocodone/acetaminophen), Percocet® (oxycodone/acetaminophen), or Percodan® (oxycodone/aspirin).

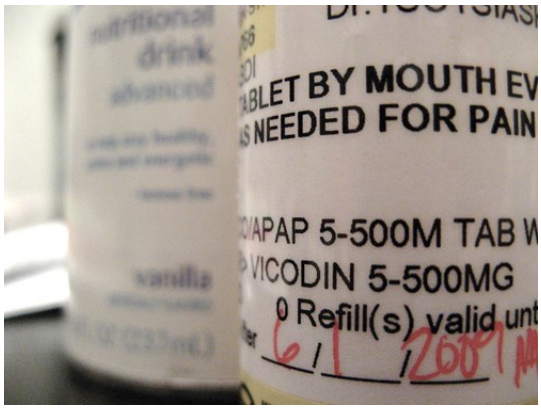


Figure 10.3.11: Vicodin prescription label. (Copyright, https://search.creativecommons.org/p...9-9d0cf0a2a430).

Often, narcotics are combined with over-the-counter analgesics. The label shown above is a combination medicine that can be prescribed for at-home pain management. Vicodin is a combination of hydrocodone and acetaminophen. The dosage on this label is 5-500mg. The first of these two values (5mg) will always coincide with the narcotic concentration. The second of these two numbers represents the acetaminophen concentration. If a medication already contains an OTC analgesic, then do not double up by taking an additional OTC drug or another narcotic-based pill.

If a patient is dispensed with pure oxycodone, then this drug is equivalent to Oxycontin®. This medication does not contain an over the counter analgesic. It is not available in generic form and uses an extended timed release mechanism. Legal concentrations for this particular opioid range from 5 to 80 mg. Within the past couple of years, the drug's manufacture (Purdue Pharma) has been investigated and sued regarding the marketing and use of this medication. Watch the clip below to see one perspective of how this medication has affected the opioid crisis.



Narcotics are extremely addictive and cause many different health issues. These medications should only be utilized to treat severe pain. Also, patients who are prescribed drugs that contain hydrocodone or oxycodone should attempt to transition from these controlled substances to an OTC analgesic as soon as possible. Common side effects of hydrocodone and oxycodone include euphoria, sedation, dizziness, nausea, vomiting, respiratory depression, severe constipation, and addiction.

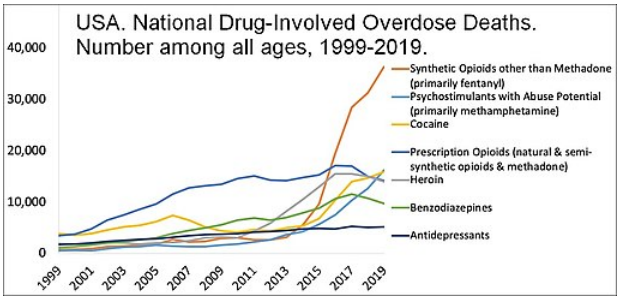


Figure **10.3.12**: National Drug-Involved Overdose Deaths by Specific Category—Number Among All Ages, 1999-2019. Overall, drug overdose deaths rose from 2018 to 2019, with **70,630 drug overdose deaths** reported **in 2019.** Deaths involving **other synthetic opioids** other than methadone (primarily **fentanyl**) continued to rise, with more than **36,359** overdose deaths reported in 2019. Those involving psychostimulants with abuse potential (primarily methamphetamine) also continued to increase (Source: CDC WONDER)." (Copyright, National Institute on Drug Abuse).

It is important to never mix narcotics with any other controlled substance or alcohol. Narcotics depress the respiratory system. Alcohol and antianxiety drugs, like Valium® and Xanax®, can affect breathing rate and the lungs' ability to process oxygen. As a result, narcotic users could lose consciousness and die.

Heroin (diacetylmorphine)

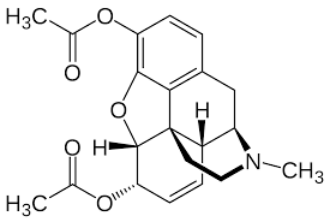


Figure **10.3.13**: Structure of heroin. (Copyright, https://commons.wikimedia.org/wiki/User:NEUROtiker)

Unfortunately, prescription-based narcotics are known to be heavily abused. One may choose to "doctor shop" in order to obtain additional prescriptions for legal, narcotic analgesics. In order to acquire multiple prescriptions, a person might choose to solicit a physician who resides in a different town and/or state. If unsuccessful, a patient could focus their efforts in acquiring a DEA schedule I substance, Heroin.



Figure **10.3.14**: Bayer heroin bottle, originally containing 5 grams of Heroin substance. The label on the back references the 1924 US ban, and has a batch number stamp starting with 27, so it probably dates from the 1920s. (Copyright, https://en.Wikipedia.org/wiki/User:Mpv_51)

First synthesized around the mid-1870s as an alternative to morphine. At the time, Civil War veterans were heavily addicted to morphine. Before and during the Civil War, this narcotic was used to treat pain and dysentery. Regrettably, research reported that Heroin was more addictive and more powerful (3 to 5 times) than its precursor

Heroin is classified as an opioid. This narcotic can be produced semisynthetically by extracting the morphine from an opium poppy. Then, an acid is added to produce the chemical structure shown above. Heroin can be obtained from pure synthetic means as well.

Naloxone (Narcan®)

Signs of a narcotic overdose include constricted pupils, loss of consciousness, choking/gurgling sounds, clammy/discolored skin, and limp body. Emergency services (EMS) should be called immediately, and attempt should be made to keep the person awake (while laying them on their side). Once EMS arrives, they will administer naloxone via a nose spray or injection. This medication occupies the opiate/opioid receptor sites within the brain. Molecules like naloxone remove the narcotic effect and in most cases save lives.



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10.4: Neurotransmitters and Antidepressants

Neurotransmitters

The nervous system is made of nerve cells called neurons. These cells help with the transmissions of messages. Chemicals called neurotransmitters assist in the transmission of messages across gaps or synapses.

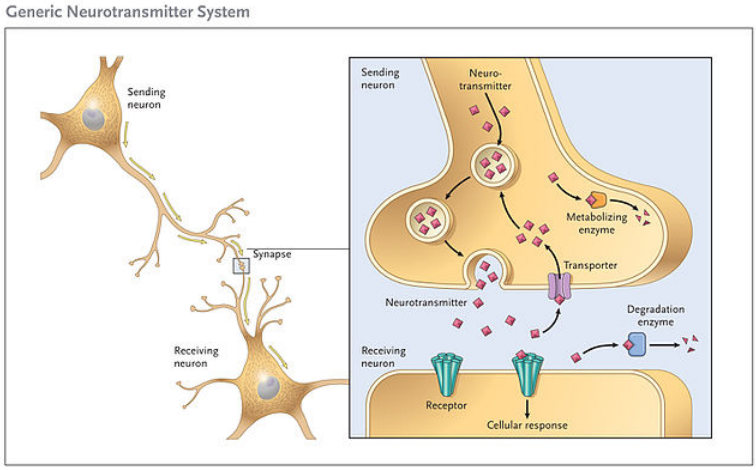


Figure 10.4.1: Generic Neurotransmitter System. (Copyright, NIDA(NIH)).

One theory that explains mental illness incorporates the various amounts of neurotransmitters. Using this theory, the lack or excess of specific neurotransmitters can be associated with depression, anxiety, bipolar disorder, or schizophrenia. Other disorders or health conditions, namely Attention Deficient Hyperactivity Disorder (ADHD) and Parkinson's Disease have also been linked with varying levels of neurotransmitters.

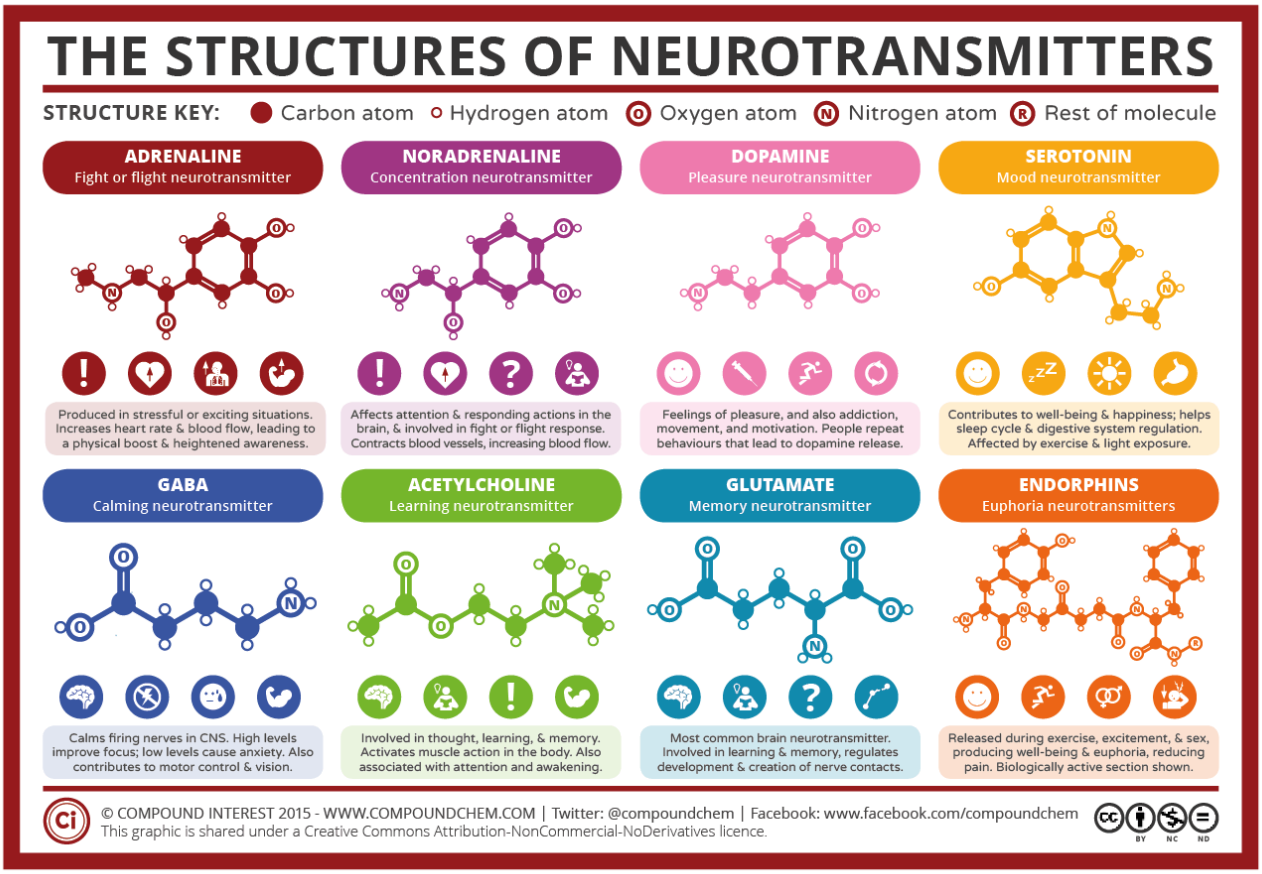


Figure **10.4.2**: The Structures of Neurotransmitters.(CC BY-NC-ND; Andy Brunning)

The Noradrenaline neurotransmitter is also called norepinephrine. When evaluating antidepressants or other mental health medications, it is important to be aware of this terminology. For a brief overview of the correlation between neurotransmitters and mental health, watch the video below.



Mental health conditions can result from a person's life experiences and/or genetics. Sometimes, drug usage or brain trauma can trigger mental illness. It is important to note all health conditions that are present in your family tree (biological). Also, recognizing emotional trauma and then seeking counseling/medical treatment is important for navigating a mental health condition.



Figure 10.4.3: Nason family picture circa 1905. Image courtesy of Elizabeth R. Gordon

Depression symptoms

Can be short or long-term. Experience-sadness, sleeping and eating issues, withdrawal, feelings of hopelessness, loss of interest/pleasure, lack of energy, feelings of worthlessness/guilt, slowed processing, trouble concentrating, frequent thought of suicide/death, anxiety, and unexplained health problems.

Treatments for depression

psychotherapy, brain stimulation, medication, exercise, light therapy. Discussions to have with dr: meds/vitamins you are on, self-medication is not answer, stopping antidepressants without assistance, and report problems with meds. Limit alcohol and refrain from illicit and scheduled drugs. FDA black-box warning for antidepressants in people under 25.

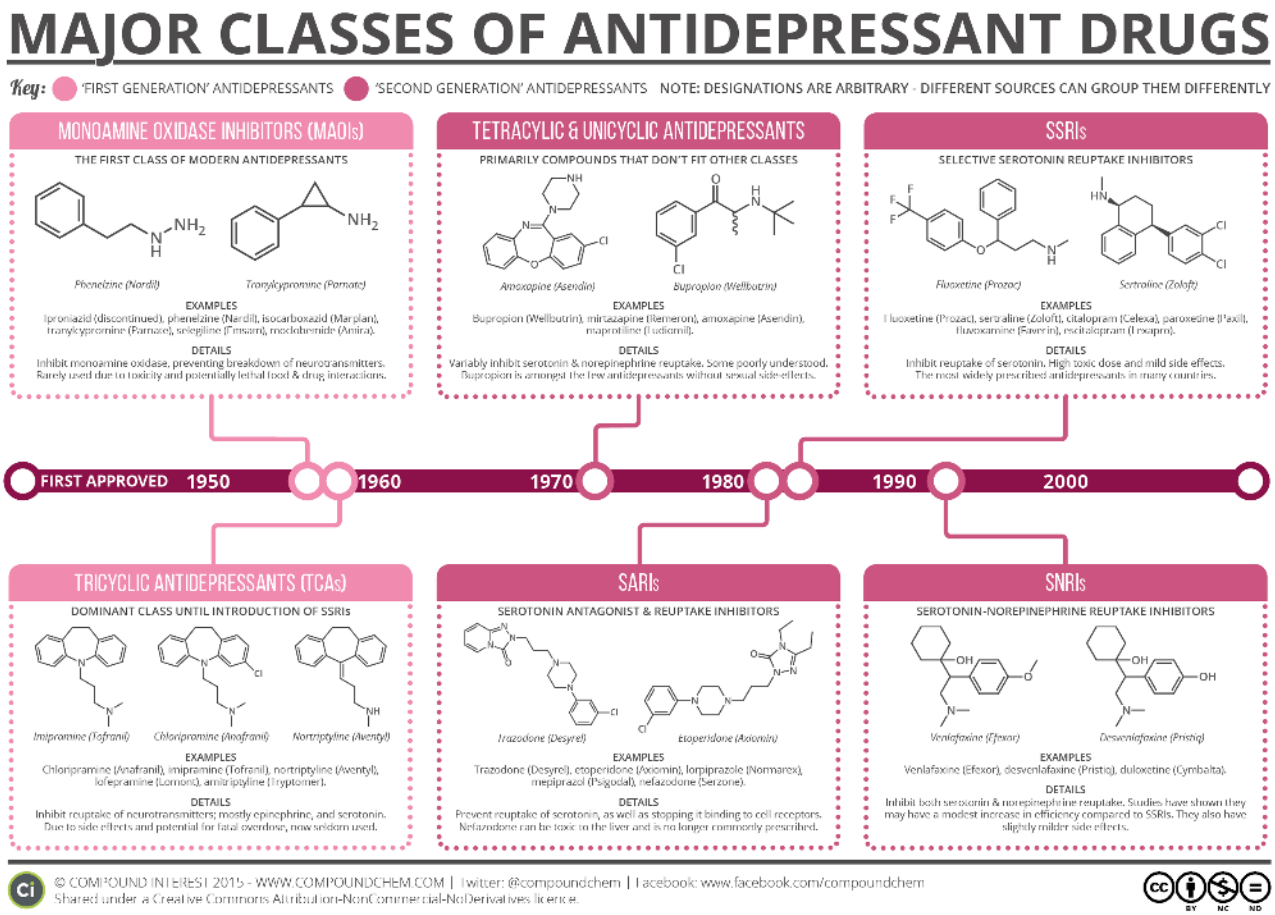


Figure **10.4.4**: Major Classes of Antidepressant Drugs.(CC BY-NC-ND; Andy Brunning)

Finding the correct antidepressant

Trial and Error-take for six weeks, then wean, and start another. Since the early 2000's, Mayo Clinic has been researching gene technology. Test is now offered by Assurex Health and called Genesight.

https://genesight.com/gene-test-for-...surex%20Health

Common Side Effects of Antidepressants

This carry varies with the patient and type of medicine. Most common include weight gain, fatigue, dizziness, loss of sexual desire, nausea, dry mouth, blurred vision, agitation, insomnia, and constipation.

Support and information regarding mental health conditions.

National Alliance on Mental Illness

Figure **10.4.3**: Official logo of the National Alliance on Mental Illness. (National Alliance on Mental Illness, http://www.nami.org/Template.cfm?Sec...ntentID=121014)

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10.5: Stimulants

What is a Stimulant?

These classes of chemicals induce alertness and stimulant the brain and nervous system. Side effects of stimulant use include wakefulness, increased speech, and motor activity, and decreased appetite. Amphetamines are a type of stimulant that incorporates a nitrogen-containing organic functional group. These compounds have been noted to block the reuptake of dopamine.

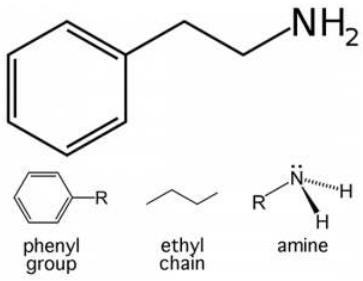


Figure 10.5.1: The skeletal structure of phenethylamine. (Copyright, http://countyourculture.com/2010/11/02/phenethylamine-and-amphetamine/)

Early Stimulant Use

For over 5000 years, the Chinese have extracted the compound Ephedrine from locally grown Ephedra plants. Native peoples of the United States were known to isolate this compound as well. Both cultures used Ephedrine to treat asthma, hay fever, and congestion. Ephedrine was noted to have a stimulant effect on its users. Chemically similar to adrenaline, ephedrine was a more stable compound and could be taken orally. By the mid-1920s, the pharmaceutical company, Eli Lily, synthesized ephedrine and introduced it into western medicine.

Figure 10.5.1: : https://commons.wikimedia.org/wiki/C...phedra_viridis. (Copyright, https://commons.wikimedia.org/wiki/User:Dcrjsr)

Ephedrine can decrease appetite, increase blood pressure and heart rate, and cause sleeping problems. Mental health can be affected by ephedrine use. Patients may experience hallucinogens, anxiety, and chemical dependence.

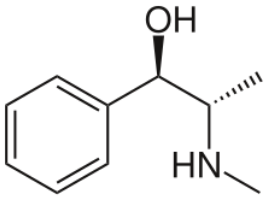


Figure 10.5.2: Chemical structure of Ephedrine, done using BKchem. (Copyright, https://commons.wikimedia.org/wiki/User:Bryan_Derksen)

Amphetamines

While researching the synthesis and application of ephedrine, organic chemists decided to focus on constructing more stimulant-based compounds. These compounds, called amphetamines, are defined as having a basic molecular formula including $C_9H_{13}N$. Amphetamines are a mixture of two compounds, levoamphetamine and dextroamphetamine, that are mirror images of one another. Dextroamphetamine, often referred to as d-amphetamine, has a more powerful stimulant effect than levoamphetamine.

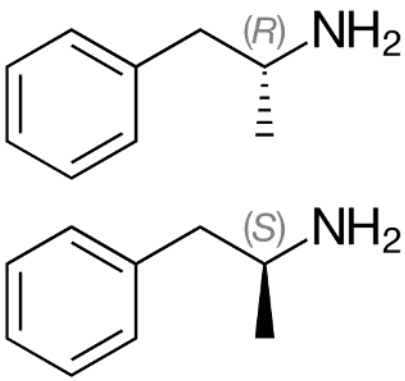


Figure **10.5.3**: Skeletal formulae of two amphetamine enantiomers: (*R*)-(−)-amphetamine (also known as L-amphetamine or levoamphetamine), and

- (*S*)-(+)-amphetamine (also known as D-amphetamine or dextroamphetamine). (https://commons.wikimedia.org/wiki/U...Vaccinationist, PubChem).

In 1932, the amphetamine, Benzedrine, was available to purchase over-the-counter. This inhaled amphetamine was used primarily by asthmatics and people who had lower than normal blood pressure. By the mid-1930s, other OTC formulations of amphetamines were utilized to treat narcolepsy and attention deficit hyperactivity disorder (ADHD). Noted side-effects of using amphetamines were: increased energy, appetite suppression, and decreased need for sleep. By 1959, the Food and Drug Agency (FDA) banned all over-the-counter forms of amphetamines.



Figure **10.5.3**: http://www.museedeslettres.fr/public...ed5db0dc7e0eee. (Copyright,https://commons.wikimedia.org/wiki/User:Prosopee).

Methamphetamine

Around 1919, Japanese scientists synthesized a methylated (CH_3) version of amphetamine. This new chemical was purified by crystallization. It could be packaged in pill or injectable form. By 1938, methamphetamine was marketed as an antidepressant in Germany. Also, the German government decided to supply Nazi soldiers with millions of tablets. L and D- amphetamines were used by Allied soldiers as well.

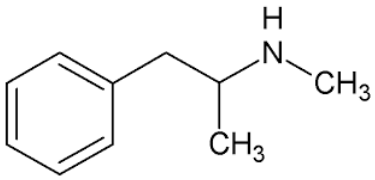


Figure **10.5.4**: Chemical structure of Methamphetamine. (Copyright, https://commons.wikimedia.org/w/inde...edit&redlink=1)

Prescription Amphetamines

Dextroamphetamine and Amphetamine(Adderall/Adderall XR) or mixed amphetamine salts -ADHD and narcolepsy. could raise blood pressure. Pre-existing heart condition -consult with a physician. Diarrhea/Constipation/Weight loss/Insomnia/Dry Mouth/Palpitations/Changes in Libido. Effects of Adderall (9 hours) and Adderall XR (10-13 hours)

Dextroamphetamine (Dexedrine)-ADHD and narcolepsy. Pre-existing heart condition -consult with a physician. Diarrhea/Constipation/Weight loss/Insomnia/Dry Mouth/Palpitations/Changes in Libido

Lisdexamfetamine (Vyvanse/Tyvense/Elvanse)- ADHD, binge eating disorder, same types of side effects as seen as above. Effects last up to 14 hours

Non-amphetamine Stimulants

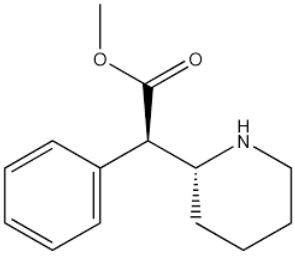


Figure **10.5.4**: D-methylphenidate-plane. (Copyright, https://en.Wikipedia.org/wiki/User:Angsaar).

Methylphenidate (Concerta/Ritalin)- ADHD and narcolepsy. blurry vision, dry mouth, sleeping issues, anxiety, and dizziness. Circulation issues/raise blood pressure/heart rate. If have a heart condition, discuss it with a physician.

Note: All prescribed stimulants are Scheduled II.

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10.6: Hallucinogens

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10.7: Narcotics

Narcotic agents are potent analgesics which are effective for the relief of severe pain. Analgesics are selective central nervous system depressants used to relieve pain. The term analgesic means "without pain". Even in therapeutic doses, narcotic analgesics can cause respiratory depression, nausea, and drowsiness. Long term administration produces tolerance, psychic, and physical dependence called addiction.

Introduction

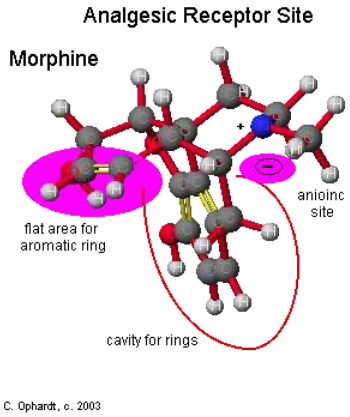
Narcotic agents may be classified into four categories:

1. Morphine and codeine - natural alkaloids of opium.
2. Synthetic derivatives of morphine such as heroin.
3. Synthetic agents which resemble the morphine structure.
4. Narcotic antagonists which are used as antidotes for overdoses of narcotic analgesics.

The main pharmacological action of analgesics is on the cerebrum and medulla of the central nervous system. Another effect is on the smooth muscle and glandular secretions of the respiratory and gastro-intestinal tract. The precise mechanism of action is unknown although the narcotics appear to interact with specific receptor sites to interfere with pain impulses.

Receptor Site

A schematic for an analgesic receptor site may look as shown in the graphic below with morphine. Three areas are needed: a flat areas to accommodate a flat nonpolar aromatic ring, a cavity to accept another series of rings perpendicular, and an anionic site for polar interaction of the amine group.



Enkephalins

Recently investigators have discovered two compounds in the brain called enkephalins which resemble morphine in structure. Each one is a peptide composed of 5 amino acids and differ only in the last amino acid. The peptide sequences are: tyr-gly-gly-phe-leu and tyr-gly-gly-phe-met. Molecular models show that the structures of the enkephalins has some similarities with morphine. The main feature in common appears to be the aromatic ring with the -OH group attached (tyr). Methadone and other similar analgesics have 2 aromatic rings which would be similar to the enkephalins (tyr and phe).

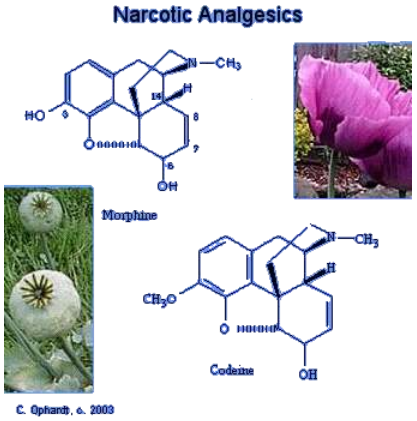
Analgesics may relieve pain by preventing the release of acetylcholine. Enkephalin molecules are released from a nerve cell and bind to analgesic receptor sites on the nerve cell sending the impulse. The binding of enkephalin or morphine-like drugs changes the shape of the nerve sending the impulse in such a fashion as to prevent the cell from releasing acetylcholine. As a result, the pain impulse cannot be transmitted and the brain does not preceive pain.

Morphine and Codeine

Morphine exerts a narcotic action manifested by analgesia, drowsiness, changes in mood, and mental clouding. The major medical action of morphine sought in the CNS is analgesia. Opiates suppress the "cough center" which is also located in the brain stem, the

medulla. Such an action is thought to underlie the use of opiate narcotics as cough suppressants. Codeine appears to be particularly effective in this action and is widely used for this purpose.

Narcotic analgesics cause an addictive physical dependence. If the drug is discontinued, withdrawal symptoms are experienced. Although the reasons for addiction and withdrawal symptoms are not completely known, recent experiments have provided some information. A nucleotide known as cyclicadenosine monophosphate (cAMP) is synthesized with the aid of the enzyme adenylate cyclase. Enkephalin and morphine-like drugs inhibit this enzyme and thus decrease the amount of cAMP in the cells. In order to compensate for the decreased cAMP, the cells synthesize more enzyme in an attempt to produce more cAMP. Since more enzyme has been produced, more morphine is required as an inhibitor to keep the cAMP at a low level. This cycle repeats itself causing an increase in the tolerance level and increasing the amounts of morphine required. If morphine is suddenly withheld, withdrawal symptoms are probably caused by a high concentration of cAMP since the synthesizing enzyme, adenylate cyclase, is no longer being inhibited.



Morphine and codeine are contained in opium from the poppy (*Papaver Somniterum*) plant found in Turkey, Mexico, Southeast Asia, China, and India. This plant is 3-4 feet tall with 5-8 egg shaped capsules on top. Ten days after the poppy blooms in June, incisions are made in the capsules permitting a milky fluid to ooze out. The following day the gummy mass (now brown) is carefully scraped off and pressed into cakes of raw opium to dry.

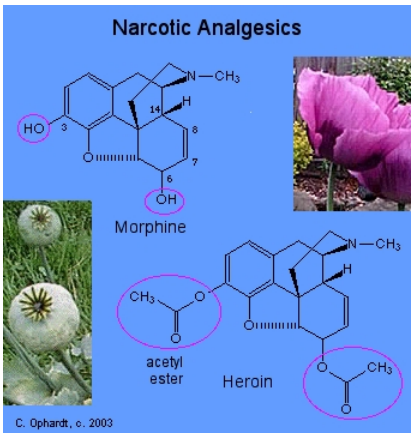
Opium contains over 20 compounds but only morphine (10%) and codeine (0.5%) are of any importance. Morphine is extracted from the opium and isolated in a relatively pure form. Since codeine is in such low concentration, it is synthesized from morphine by an ether-type methylation of an alcohol group. Codeine has only a fraction of the potency compared to morphine. It is used with aspirin and as a cough suppressant.

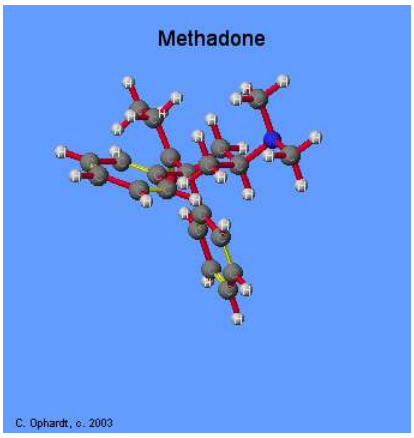
Heroin

Heroin is synthesized from morphine by a relatively simple esterification reaction of two alcohol (phenol) groups with acetic anhydride (equivalent to acetic acid). Heroin is much more potent than morphine but without the respiratory depression effect. A possible reason may be that heroin passes the blood-brain barrier much more rapidly than morphine. Once in the brain, the heroin is hydrolyzed to morphine which is responsible for its activity.

Synthetic narcotic analgesics include meperidine and methadone. Meperidine is the most common subsitute for morphine. It exerts several pharmacological effects: analgesic, local anesthetic, and mild antihistamine. This multiple activity may be explained by its structural resemblance to morphine, atropine, and histamine.

Methadone is more active and more toxic than morphine. It can be used for the relief of may types of pain. In addition it is used as a narcotic substitute in addiction treatment because it prevents morphine abstinence syndrome. Methadone was synthesized by German chemists during Wold War II when the United States and our allies cut off their opium supply. And it is difficult to fight a war without analgesics so the Germans went to work and synthesized a number of medications in use today, including demerol and darvon which is structurally simular to methadone. And before we go further lets clear up another myth. Methadone, or dolophine was not named after Adolf Hitler. The "dol" in dolophine comes from the latin root "dolor." The female name Dolores is derived from it and the term dol is used in pain research to measure pain e.g., one dol is 1 unit of pain.

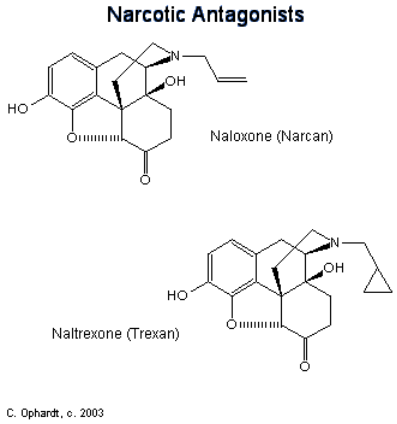




Even methadone, which looks strikingly different from other opioid agonists, has steric forces which produce a configuration that closely resembles that of other opiates. See the graphic on the left and the top graphic on this page. In other words, steric forces bend the molecule of methadone into the correct configuration to fit into the opiate receptor. When you take methadone it first must be metabolized in the liver to a product that your body can use. Excess methadone is also stored in the liver and blood stream and this is how methadone works its 'time release trick' and last for 24 hours or more. Once in the blood stream metabolized methadone is slowly passed to the brain when it is needed to fill opiate receptors. Methadone is the only effective treatment for heroin addiction. It works to smooth the ups and down of heroin craving and allows the person to function normally.

Narcotic Antagonists

Narcotic Antagonists prevent or abolish excessive respiratory depression caused by the administration of morphine or related compounds. They act by competing for the same analgesic receptor sites. They are structurally related to morphine with the exception of the group attached to nitrogen.



Nalorphine precipitates withdrawal symptoms and produces behavioral disturbances in addition to the antogonism action. Naloxane is a pure antagonist with no morphine like effects. It blocks the euphoric effect of heroin when given before heroin. Naltrexone became clinically available in 1985 as a new narcotic antagonist. Its actions resemble those of naloxone, but naltrexone is well is well absorbed orally and is long acting, necessitating only a dose of 50 to 100 mg. Therefore, it is useful in narcotic treatment programs where it is desired to maintain an individual on chronic therapy with a narcotic antagonist. In individuals taking naltrexone, subsequent injection of an opiate will produce little or no effect. Naltrexone appears to be particularly effective for the treatment of narcotic dependence in addicts who have more to gain by being drug-free rather than drug dependant

Contributors and Attributions

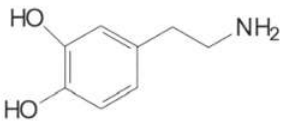
- Charles Ophardt, Professor Emeritus, Elmhurst College; Virtual Chembook
- Poppies image from: leda.lycaeum.org

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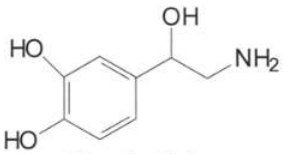
- **Narcotic Analgesic Drugs** by Charles Ophardt is licensed CC BY-NC-SA 4.0.

10.8: Basics of Neurotransmitters

Dopamine (DA), 4,5-dihydroxyphenethylamine or 4-(2-aminoethyl)1,2-benzenediol, is a known neurotransmitter that is involved in the chemical transmission of nerve impulses in the mammalian brain. It is a member of the catecholamine family and a precursor to epinephrine (adrenaline) and norepinephrine (noradrenaline) in the biosynthetic pathways.



Dopamine



Norepinephrine

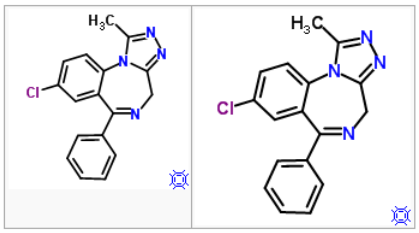
DA has a molecular formula of $C_8H_{11}NO_2$ and a formula weight of 153.18 [ref. 1]. It is a water-soluble hormone released by the hypothalamus. Imbalance in dopamine activity can cause brain dysfunction related to two major disorders, Parkinson's disease and schizophrenia [ref. 2,3]. Researchers are also looking at dopamine neurotransmission in drug abuse ranging from stimulants, such as amphetamines and cocaine, to depressants, such as morphine and other opioids, and alcohol [ref. 3].

Several amine neurotransmitters such as DA, noradrenaline (norepinephrine), adrenaline and serotonin are electroactive so that they can be monitored electrochemically. Most undergo a chemical reaction following the initial electron transfer step, an *ec* mechanism, as evaluated by cyclic voltammetry (CV) in this experiment. In biological fluids, prior separation with HPLC is recommended in conjunction with an electrochemical detector (HPLC-ECD).

Great strides in learning about the role and fate of DA and other neurotransmitters in brains have come about in recent years due to the ability to monitor these compounds in-vivo. The major breakthrough making this possible came when Adams and co-workers [ref. 4] implanted small carbon electrodes (fibers) in rat brain to detect in-vivo catecholamine neurotransmitters. The development and application of the methodology are discussed in *"Probing Brain Chemistry: Voltammetry Comes of Age"* [ref. 5]. This article is available online and is a recommended reading as background to this experiment. Venton and Wightman [ref. 6] in a more recent article propose calling this new subject area "psychoanalytical chemistry" in which sensors, like microelectrodes, can detect neurotransmitter dopamine and determine how its neurochemistry affects and correlates with animal behavior.

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10.9: Antianxiety Medications



- **Main ChemSpider page**
- Molecular formula: $C_{17}H_{13}ClN_4$
- Molar mass: 308.765
- CAS Registry Number: 28981-97-7
- Appearance: Not available
- Melting point: 228 to 2290 °C
- Boiling point: Not available
- Solubility: Not available
- Safety sheet: Not available

From Wikipedia

Alprazolam, available under the trade name Xanax, is a potent, short-acting anxiolytic of the benzodiazepine class. It is commonly used for the treatment of anxiety disorders, especially of panic disorder, but also in the treatment of generalized anxiety disorder(GAD) or social anxiety disorder. Alprazolam, like other benzodiazepines, binds to specific sites on the GABAA receptor. It possesses anxiolytic, sedative, hypnotic, skeletal muscle relaxant, anticonvulsant, and amnestic properties. Alprazolam is available for oral administration in compressed tablet (CT) and extended-release capsule (XR) formulations.

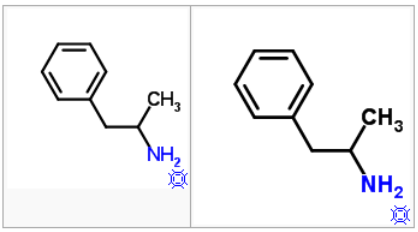
Peak benefits achieved for generalized anxiety disorder (GAD) may take up to a week. Tolerance to the anxiolytic/antipanic effects is controversial with some authoritative sources reporting the development of tolerance, tolerance will, however, develop to the sedative-hypnotic effects within a couple of days. The first approved use was panic disorder and within two years of its original marketing Xanax became a blockbuster drug in the US. Presently, alprazolam is the most prescribed and the most misused benzodiazepine in the US. The potential for misuse among those taking it for medical reasons is controversial with some expert reviews stating that the risk is low and similar to that of other benzodiazepine drugs Compared to the large number of prescriptions, relatively few individuals increase their dose on their own initiative or engage in drug-seeking behavior. Alprazolam is classified as a schedule IV controlled substance by the U.S. Drug Enforcement Administration (DEA).

Other names

Alprax; Anxyl; Panistat; Panix; Xanax; Xanor

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10.10: Amphetamines



- **Main ChemSpider page**
- Molecular formula: $C_9H_{13}N$
- Molar mass: 135.206
- CAS Registry Number: 300-62-9
- Appearance: Not available
- Melting point: Not available
- Boiling point: Not available
- Solubility: Not available
- Safety sheet: Not available

Adderall

Adderall is a combination drug containing salts of the two enantiomers of amphetamine, a central nervous system (CNS) stimulant of the phenethylamine class. Adderall is used in the treatment of attention deficit hyperactivity disorder (ADHD) and narcolepsy. It is also used as an athletic performance enhancer and cognitive enhancer, and recreationally as an aphrodisiac and euphoriant. By salt content, the active ingredients of Adderall are 25% levoamphetamine salts (the levorotary or 'left-handed' enantiomer) and 75% dextroamphetamine salts (the dextrorotary or 'right-handed' enantiomer).

Adderall is generally well-tolerated and effective in treating the symptoms of ADHD and narcolepsy. At therapeutic doses, Adderall causes emotional and cognitive effects such as euphoria, change in desire for sex, increased wakefulness, and improved cognitive control. At these doses, it induces physical effects such as decreased reaction time, fatigue resistance, and increased muscle strength. In contrast, much larger doses of Adderall can impair cognitive control, cause rapid muscle breakdown, or induce a psychosis (e.g., delusions and paranoia). The side effects of Adderall vary widely among individuals, but most commonly include insomnia, dry mouth, and loss of appetite. The risk of developing an addiction is insignificant when Adderall is used as prescribed at fairly low daily doses, such as those used for treating ADHD; however, the routine use of Adderall in larger daily doses poses a significant risk of addiction due to the pronounced reinforcing effects that are present at higher doses. Recreational doses of Adderall are generally much larger than prescribed therapeutic doses, and carry a far greater risk of serious adverse effects.

The two amphetamine enantiomers that compose Adderall (i.e., levoamphetamine and dextroamphetamine) alleviate the symptoms of ADHD and narcolepsy by increasing the activity of the neurotransmitters norepinephrine and dopamine in the brain, which results from their interactions with trace amine associated receptor 1 (TAAR1) and vesicular monoamine transporter 2 (VMAT2) in neurons. Dextroamphetamine is a more potent stimulant than levoamphetamine, but levoamphetamine has slightly stronger cardiovascular and peripheral effects and a longer elimination half-life (i.e., it remains in the body longer) than dextroamphetamine. The levoamphetamine component of Adderall has been reported to improve the treatment response in some individuals relative to dextroamphetamine alone. Adderall's active ingredient, amphetamine, shares many chemical and pharmacological properties with the human trace amines, particularly phenethylamine and , the latter of which is a positional isomer of amphetamine.

Amphetamine

Amphetamine (contracted from) is a potent central nervous system (CNS) stimulant that is used in the treatment of attention deficit hyperactivity disorder (ADHD), narcolepsy, and obesity. Amphetamine was discovered in 1887 and exists as two enantiomers: levoamphetamine and dextroamphetamine. Amphetamine properly refers to a specific chemical, the racemic free base, which is

equal parts of the two enantiomers, levoamphetamine and dextroamphetamine, in their pure amine forms. The term is frequently used informally to refer to any combination of the enantiomers, or to either of them alone. Historically, it has been used to treat nasal congestion and depression. Amphetamine is also used as an athletic performance enhancer and cognitive enhancer, and recreationally as an aphrodisiac and euphoriant. It is a prescription drug in many countries, and unauthorized possession and distribution of amphetamine are often tightly controlled due to the significant health risks associated with recreational use.

The first pharmaceutical amphetamine was Benzedrine, a brand which was used to treat a variety of conditions. Currently, pharmaceutical amphetamine is prescribed as racemic amphetamine, Adderall, dextroamphetamine, or the inactive prodrug lisdexamfetamine. Amphetamine, through activation of a trace amine receptor, increases monoamine and excitatory neurotransmitter activity in the brain, with its most pronounced effects targeting the catecholamine neurotransmitters norepinephrine and dopamine.

At therapeutic doses, amphetamine causes emotional and cognitive effects such as euphoria, change in desire for sex, increased wakefulness, and improved cognitive control. It induces physical effects such as decreased reaction time, fatigue resistance, and increased muscle strength. Larger doses of amphetamine may impair cognitive function and induce rapid muscle breakdown. Drug addiction is a serious risk with large recreational doses but is unlikely to arise from typical long-term medical use at therapeutic doses. Very high doses can result in psychosis (e.g., delusions and paranoia) which rarely occurs at therapeutic doses even during long-term use. Recreational doses are generally much larger than prescribed therapeutic doses and carry a far greater risk of serious side effects.

Amphetamine belongs to the phenethylamine class. It is also the parent compound of its own structural class, the substituted amphetamines, which includes prominent substances such as bupropion, cathinone, MDMA, and methamphetamine. As a member of the phenethylamine class, amphetamine is also chemically related to the naturally occurring trace amine neuromodulators, specifically phenethylamine and , both of which are produced within the human body. Phenethylamine is the parent compound of amphetamine, while is a positional isomer of amphetamine that differs only in the placement of the methyl group.

Other names

1-Phenyl-2-propanamine (IUPAC Name); 1-phenyl-2-aminopropane; 1-Phenylpropan-2-amine; adderall; alpha-Methylphenethylamine; alpha-methylphenylethylamine; alpha-Methyl-benzeneethanamine

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Template:Wikipedia

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10.11: Antipsychotic medication

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10.12: Analgesics

A. Aspirin-like Drugs

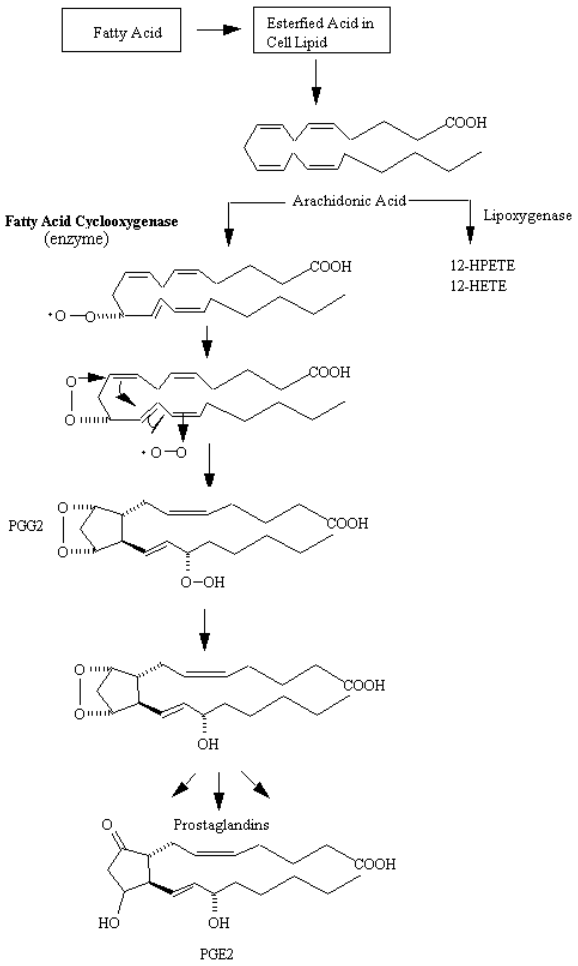
The anti-inflammatory, analgesic, and antipyretic drugs are a heterogeneous group of compounds, often chemically unrelated (although most of them are organic acids), which nevertheless share certain therapeutic actions and side effects. The prototype is aspirin; hence these compounds are often referred to as aspirin-like drugs. All aspirin-like drugs are antipyretic, analgesic, and anti-inflammatory, but there are important differences in their activities. For example, acetaminophen is antipyretic and analgesic but is only weakly anti-inflammatory. The reason for the differences are not clear; variations in the sensitivity of enzymes in the target tissues may be important.

When employed as analgesics, these drugs are usually effective only against pain of low-to-moderate intensity, particularly that associated with inflammation. Aspirin drugs do not change the perception of sensory modalities other than pain. The type of pain is important; chronic postoperative pain or pain arising from inflammation is particularly well controlled by aspirin-like drugs, whereas pain arising from the hollow viscera is usually not relieved.

As antipyretics, aspirin-like drugs reduce the body temperature in feverish states. Although all such drugs are antipyretics and analgesics, some are not suitable for either routine or prolonged use because of toxicity; phenylbutaxone is an example. This class of drugs finds its chief clinical application as anti inflammatory agents in the treatment of musculoskelatal disorders, such as rheumatoid arthritis, osteoarthritis, and ankylosing spondylitis. In general, aspirin-like drugs provide only symptomatic relief from the pain and inflammation associated with the disease and do not arrest the progression of pathological injury.

Chemistry of Action

There has been substantial progress in elucidating the mechanism of action of aspirin-like drugs, and it is now possible to understand why such heterogeneous agents have the same basic therapeutic activities and often the same side effects. Indeed, their therapeutic activity appears to depend to a large extent upon the inhibition of a defined biochemical pathways responsible for the biosynthesis of prostaglandins (see figure below) and related autacoids.



Aspirin-like drugs inhibit the conversion of arachidonic acid to the unstable endoperoxide intermediate, PGG2, which is catalyzed by the cyclooxygenase. Individual agents have differing modes of inhibitory activity on the cyclooxygenase. Aspirin itself acetylates a serine at the active site of the enzyme. Platelets are especially susceptible to this action because (unlike most other cells) they are incapable of regenerating the enzyme, presumably because they have little or no capacity for protein biosynthesis. In practical terms this means that a single dose of aspirin will inhibit the platelet cyclooxygenase for the life of the platelet (8 to 10 days); in man a dose as small as 40 mg per day is sufficient to produce this effect. In contrast to aspirin, salicylic acid has no acetylating capacity and is almost inactive against cyclooxygenase *in vitro*. Nevertheless, it is as active as aspirin in reducing the synthesis of prostaglandins *in vivo*. The basis of this action and, thus, of the anti-inflammatory effect of salicylic acid is not clearly understood. Since aspirin is rapidly hydrolyzed to salicylic acid in vivo (half-life in human plasma, approximately 15 minutes), the acetylated and nonacetylated species probably act as pharmacologically distinct entities.

Most of the other common aspirin-like drugs are irreversible inhibitors of the cyclooxygenase, although there are some exceptions. For indomethacin, the mode of inhibition is particularly complex and probably involves a site on the enzyme different from that which is acetylated by aspirin.

Pain

Prostaglandins are associated particularly with the development of pain that accompanies injury or inflammation. Large doses of PGE2 or PGF2a , given to women by injection to induce abortion, cause intense local pain. Prostaglandins can also cause headache and vascular pain when infused intravenously in man. While the doses of prostaglandins required to elicit pain are high in comparison with the concentrations expected *in vivo*, induction of hyperalgesia occurs when minute amounts of PGE1 are given intradermally to man. Furthermore, in experiments in man where separate infusions of PGE1, bradykinin, or histamine caused no pain, marked pain was experienced when PGE1 was added to bradykinin or histamine. When PGE1 was infused with histamine, itching was also noted.

Fever

The hypothalamus regulates the set point at which body temperature is maintained. In fever, this set point is elevated, and aspirin-like drugs promote its return to normal. These drugs do not influence body temperature when it is elevated by such factors as exercise or increases in the surrounding temperature.

Fever may be a result of infection, tissue damage, inflammation, graft rejection, malignancy, or other disease states. A multitude of microorganisms can cause fever. There is evidence that bacterial endotoxins act by stimulating the biosynthesis and release by neutrophils and other cells of an endogenous pyrogen, a protein with a molecular weight of 10,000 to 20,000. The current view is that the endogenous pyrogen passes from the general circulation into the central nervous system, where it acts upon discrete sites within the brain, especially the preoptic hypothalamic area. There is evidence that the resultant elevation of body temperature is mediated by the release of prostaglandins and that aspirin-like drugs suppress the effects of endogenous pyrogen by inhibiting the synthesis of these substances. The evidence includes the ability of prostaglandins, especially PGE2, to produce fever when infused into the cerebral ventricles or when infected into the hypothalamus. Fever is a frequent side effect of prostaglandins when they are administered to a women as abortifacients. Moreover some studies have demonstrated an increase in prostaglandin-like substances in the cerebrospinal fluid when endogenous pyrogen is injected intravenously. The fever produced by the administration of pyrogen, but not that by prostaglandins, is reduced by aspirin-like drugs.

Side Effects

Aspirin is very useful, but it has many side effects and therefore must be used carefully. Like most powerful drugs, an overdose of aspirin or salicylates can be fatal. If a child or adult takes an overdose of aspirin, induce vomiting to empty the unabsorbed medication from the stomach (if the person is still awake and conscious). Obtain emergency medical care right away.

The most common side effects of aspirin are heartburn and other symptoms of stomach irritation such as indigestion, pain, nausea, and vomiting. The stomach irritation may lead to bleeding from the stomach, which may cause black stools. These symptoms may be reduced by taking aspirin with meals, with an antacid, with a glass of milk, or by taking enteric-coated or timed-release aspirin. Also, it is best not to take aspirin with alcohol or coffee (or other beverages containing caffeine, such as tea or cocoa and many soft drinks). Alcohol and caffeine make the stomach more sensitive to irritation. The non aspirin salicylate preparations sometimes are less irritating to the stomach and may be substituted for aspirin by your doctor.

A few people develop asthma, hay fever, nasal congestion, or hives from aspirin or non-steroid anti-inflammatory drugs (NSAIDs). These people should never take aspirin, nor should people who have active stomach or duodenal ulcers. Anyone who has ever had a peptic ulcer should be very careful about taking aspirin because it can lead to a recurrence.

Aspirin is known to interfere with the action of the platelets. As a result, some people who take a lot of aspirin experience easy bruising of the skin. Therefore, people who have major bleeding problems should not take aspirin. Also, keep in mind that aspirin should not be taken for 10-14 days before surgery (including surgery in the mouth) to avoid excessive bleeding during or after the operation. These side effects probably depend on aspirin-like drugs' ability to block endogenous prostaglandin biosynthesis. Platelet function appears to be disturbed because aspirin-like drugs prevent the formation by the platelets of thrombozane A2 (TXA2), a potent aggregating agent. This accounts for the tendency of these drugs to increase the bleeding time.

Aspirin increases oxygen consumption by the body, increasing carbon dioxide production-an effect that stimulates respiration. Therefore, overdose with aspirin is often characterized by marked increases in respiratory rate, which cause the overdosed individual to appear to pant. This occurrence results in other, severe, metabolic consequences.

Prolongation of gestation by aspirin-like drugs has been demonstrated in both experimental animals and the human female. Furthermore, prostaglandins of the E and F series are potent uterotropic agents , and their biosynthesis by the uterus increases dramatically in the hours before parturition. It is thus hypothesized that prostaglandins play a major role in the initiation and progression of labor and delivery.

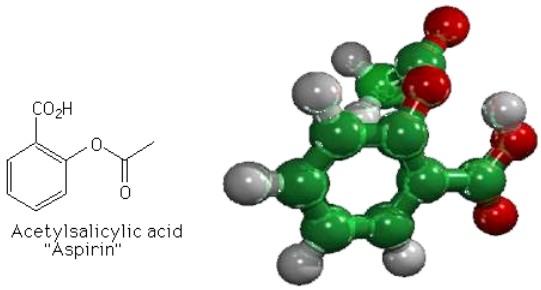
High doses of salicylate may cause ringing in the ears and slight deafness. Sometimes, however, these symptoms indicate mild overdose, which could become more serious.

Aspirin and NSAIDs sometimes affect the normal function of the kidneys and aspirin-like drugs promote the retention of salt and water by reducing the prostaglandin-induced inhibition of both the reabsorption of chloride and the action of antidiuretic hormone. This may cause edema in some patients with arthritis who are treated with an aspirin-like drug.

Recent reports have said there could be a link between the use of aspirin and the development of Reye's syndrome. Reye's syndrome is a rare but possibly fatal disease seen most often in children and teenagers. It usually affects those recovering from chicken pox or a viral illness such as the flu. These reports have raised concern in pediatricians (doctors who specialize in treating children) and parents of children with arthritis who need to take large doses of aspirin to control their disease.

Aspirin

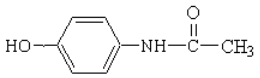
In the U.S., about 10 to 20 thousand tons of aspirin are consumed each year; it is our most popular analgesic. Aspirin is one of the most effective analgesic, antipyretic, and anti-inflammatory agents.



Chemical structure

Acetaminophen (Tylenol)

Acetaminophen is an effective alternative to aspirin as an analgesic and antipyretic agent. However, its anti-inflammatory effect is minor and not clinically useful. It is commonly felt that acetaminophen may have fewer side effects than aspirin, but it should be noted that an acute overdose may produce severe or even fatal liver damage. Acetaminophen does not inhibit platelet aggregation and therefore is not useful for preventing vascular clotting.



Acetaminophen (4'-hydroxyacetanilide)

Side effects are usually fewer than those of aspirin; the drug produces less gastric distress and less ringing in the ears. However, as stated previously, overdose can lead to severe damage of the liver.

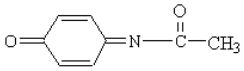
Acetaminophen has been proved to be a reasonable substitute for aspirin when analgesic or antipyretic effectiveness is desired, especially in patients who cannot tolerate aspirin. This might include patients with peptic ulcer disease of gastric distress or those in whom the anticoagulant action of aspirin might be undesirable.

Aspirin is often combined with acetaminophen in a single tablet for relief of arthritis and other painful conditions. Sometimes other drugs such as caffeine, an antihistamine, nasal drying agents, and sedatives are also added. Although some of these preparations may have special uses for certain acute conditions such as a cold or a headache, they should not be taken for a chronic (long-term) form of arthritis. If a combination is required, each drug should be prescribed separately. The dose of each should be adjusted individually to achieve the greatest benefit with the fewest side effects.

Researchers attribute the pain-relieving activity of acetaminophen to the drug's ability to elevate the pain threshold, although the precise mechanisms involved in this process have not been clearly identified. The antipyretic, or fever-reducing, effect of acetaminophen is far better understood. Research shows that the drug inhibits the action of fever-producing agents on the heat-

regulating centers of the brain by blocking the formation and release of prostaglandins in the central nervous system. However, unlike aspirin and other NSAIDs, acetaminophen has no significant effect on the prostaglandins involved in other body processes.

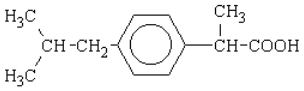
Despite claims to the contrary, stomach upset and hepatic toxicity are statistically as much a problem with acetaminophen as with aspirin-like drugs. Acetaminophen is normally metabolized in the liver and kidney by P450 enzymes. No toxicity is observed with therapeutic doses, however, after ingestion of large quantities (>2,000 mg/kg), a highly reactive metabolite, N-acetyl-p-benzoquinoneimine, is generated (see figure below). This species is electrophilic intermediate which is conjugated with glutathion to a non-toxic compound. Overdosing depletes glutithione and N-acetyl-p-benzoquinone reacts with nucleophilic portions (sulfhdryl groups) of critical liver cell protein. This results in cellular dysfunction and hepatic and renal toxicity. Antidote treatment consists of amino acid supplements to replenish glutathione. The P450 metabolizing enzymes differ somewhat in character between the liver and kidney. Factors that enhance renal toxicity include chronic liver disease, possibly gender, concurrent renal insults, and conditions that alter the activity of P450-metabolizing enzyme systems.



N-acetyl-p-benzoquinoneimine

Other Aspirin-Like Drugs

Other aspirin-like drugs include diflunisal, phenylbutazone, apazone, indomethacine, sulindac, fenamates, tolmetin, ibuprofen (see figure below), and piroxicam.

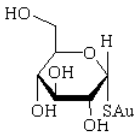


Ibuprofen

Gold

Gold is not of course an aspirin-like drug. However, its end effect is similar to aspirin, so it will be briefly considered here. Gold in elemental form has been employed for centuries as an antipruritic (anti itch medication) to relieve the itching palm. At present, gold treatment includes different forms of gold salts used to treat rheumatoid arthritis and related diseases. In some people, it helps relieve joint pain and stiffness, reduce swelling and bone damage, and reduce the chance of joint deformity and disability.

The significant preparations of gold are all compounds in which the gold is attached to sulfur. The three prominent drugs are aurothioglucose, auranofin, and gold sodium thiomalate.



Aurothioglucose

It takes months for gold compounds to leave the body. This means that side effects to gold therapy may take some time to resolve. Sometimes side effects even appear after the last gold injection. Rash and a metallic taste in the mouth are side effects of gold injections that may not seem serious at first. However, they are early warning signs for more serious reactions. If either of these side effects develop, the health care provider should be contacted promptly.

Some side effects may cause multiple symptoms, not all of which may occur. Side effects with multiple symptoms are:

1. Low platelet count (thrombocytopenia). Most often this appears to be an immunological disturbance that results in an accelerated degradation of platelets. Symptoms may include: black, tarry stools, blood in urine, stool, or vomit, small red dots on the skin, nose bleeds, unusual bruising or bleeding.
2. Anaphylaxis. Symptoms include sudden onset of the following soon after a gold injection: trouble swallowing, tightness in the throat, fainting, trouble breathing, wheezing, hives, swelling of the face, usually the lips or around the eyes, liver damage,

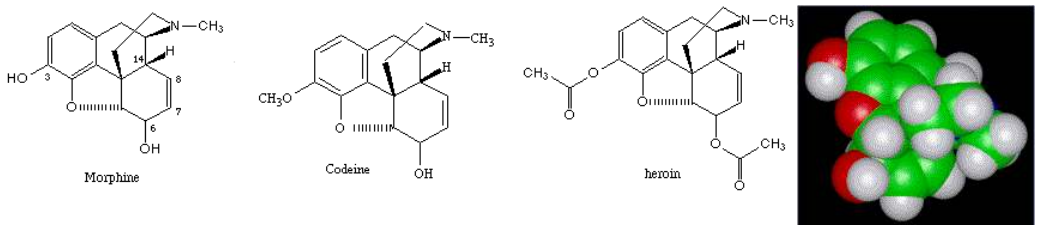
abdominal pain for more than a few days, light colored stools, albuminuria, yellow eyes or skin, ulcerative colitis, severe abdominal pain or cramps, diarrhea that lasts more than a few days, blood in stool.

B. Opiates, Opiate Antagonists, and Opiate Receptors

The term opiate refers to any natural or synthetic drug that exerts actions upon the body similar to those induced by morphine, the major pain-relieving agent obtained from the opium poppy (Papaver somniferum). They were so highly regarded in the nineteenth century as remedies for pain, anxiety, cough, and diarrhea that some physicians referred to them as G.O.M.- `God's Own Medicine'. Opiates interact with what appear to be several closely related receptors, and they share some of the properties of certain naturally occurring peptides, the enkephalins, endorphins, and dynorphins.

Opiates

The term opium refers to the crude resinous extract obtained from the opium poppy. Crude opium contains a wide variety of ingredients, including morphine and codeine, both of which are widely used in medicine. The bulk of the ingredients of opium, however, consists of such organic substances as resins, oils, sugars, and proteins that account for more than 75 % of the weight of the opium but exert little pharmacological activity. Morphine is the major pain relieving drug found in opium, being approximately 10% of the crude exudate. Codeine is structurally close to morphine (see figs below), although it is much less potent and amounts to only 0.5% of the opium extract. Heroin does not occur naturally but is a semisynthetic derivative produced by a chemical modification of morphine that increases the potency (see figs. below). It takes only 3 mg. of heroin to produce the same analgesic effect as 10 mg of morphine. However, at these equally effective doses, it may be difficult to distinguish between the effects of the two compounds.



filled structure of morphine

Mechanism of Action

Studies of the binding of opioid drugs and peptides to specific sites in brain and other organs have suggested the existence of perhaps as many as eight types of receptors. In the CNS, there is reasonably firm evidence for four major categories of receptors, designated m, k, d , and s . To add confusion, there may well be subtypes of each of these receptors. Although there is considerable variation in binding characteristics and anatomical distribution among different species, inferences have been drawn from data that attempt to relate pharmacological effects to interactions with a particular constellation of receptors. For example, analgesia has been associated with both m and k receptors, while dysphoria or psychotomimetic (alteration of behavior or personality) effects have been ascribed to s receptors; based primarily on their localization in limbic regions of the brain, d receptors are thought to be involved in alterations of affective behavior. The actions of opioid drugs that are currently available have usually been interpreted with respect to the participation of only three types of receptors - m, k, and s ; at each, a given agent may act as an agonist, a partial agonist, or an antagonist (see table). The m receptor is thought to meduate supraspinal analgesia, respiratory depression, euphoria, and physical dependance; the k receptor, spinal analgesia, miosis, and sedation; the s receptor, dysphoria, hallucinations, and respiratory and vasomotor stimulation.

It has been observed that opioids can selectively inhibit certain excitatory inputs to identified neurons. For example, the iontophoretic administration (the induction of an ionized substance through intact skin by the application of a direct current) of morphine into the substantia gelatinosa suppresses the discharge of spinal neurons in lamina IV of the dorsal horn that is evoked by noxious stimuli (e.g. heat) without changing responses to other inputs. While a postsynaptic action at discrete dedritic sites cannot

be excluded, these findings suggest that opioids selectively inhibit the release of excitatory transmitters from terminals of nerves carrying pain related stimuli. In other situations, postsynaptic actions of opioids appear to be important. For example, application of opioids to neurons in the locus ceruleus reduces both spontaneous discharge and responses evoked by noxious stimuli. However, excitation of the neurons by antidromic stimulation (i.e. causing the neurons to fire backwards) is also suppressed, and the cells are hyperpolarized by the drugs.

Opioids have been observed to inhibit prostaglandin-induced increases in the accumulation of cyclic AMP in in brain tissue. Of potential relevance to mechanisms that underlie the phenomena of tolerance and withdrawal, the responses to prostaglandins recover in the continued presence of opioids.

Opioid-induced analgesia is due to actions of several sites within the CNS and involves several systems of neurotransmitters. Although opioids do not alter the threshold or responsivity of afferent nerve endings to noxious stimulation or impair the conduction of the nerve impulses along peripheral nerves, they may decrease conduction of impulses of primary afferent fibers when they enter the spinal cord and decrease activity in other sensory endings. There are opioid binding sites (μ receptors) on the terminal axons of primary afferents within laminae I and II (substantia gelatinosa) of the spinal cord and in the spinal nucleus of the trigeminal nerve. Morphine-like drugs acting at this site are thought to decrease the release of neurotransmitters, such as substance P, that mediate transmission of pain impulses.

High doses of opioids can produce muscular rigidity in man, and both opioids and endogenous peptides cause catalepsy, circling, and stereotypical behavior in rats and other animals. These effects are probably related to actions at opioid receptors in the substania nigra and striatum, and involve interactions with both dopaminergic and GABA-ergic neurons.

The mechanism by which opioids produce euphoria, tranquility, and other alterations of mood remains unsettled. Microinjections of opioids into the ventral tegmentum activate dopaminergic neurons that project to the nucleus accumbens. Animals will work to receive such injections, and activation (or disinhibition) of these neurons has been postulated to be a critical element in the reinforcing effects of opioids and opioid-induced euphoria. However, the administration of dopaminergic antagonists does not consistently prevent these reinforcing effects. The neural systems that mediate opioid reinforcement in the ventral tegmentum appear to be distinct from those involved in the classical manifestations of physical dependence and analgesia.

Basic Effects of Morphine

CNS. Morphine exerts a narcotic action manifested by analgesia, drowsiness, changes in mood, and mental clouding. The major medical action of morphine sought in the CNS is analgesia, which may usually be induced by doses below those that cause other effects on the CNS, such as sedation or respiratory depression. The relief of pain by morphine-like opioids is relatively selective, in that other sensory modalities (touch, vibration, vision, hearing, etc.) are not inhibited. Patients frequently report that the pain is still present but that they feel more comfortable. Continuous dull pain is relieved more effectively than sharp intermittent pain, but with sufficient amounts of morphine it is possible to relieve even the severe pain associated with renal or biliary colic. In fact, its analgesic action appears to result not from a decrease of pain impulses into the CNS but from an altered perception of the painful stimuli.

Respiration. A second major action of morphine-like drugs is to depress respiration through interaction with μ receptors located in the brainstem. At high doses, respiration may become so slow and irregular that life is threatened. In man, death from morphine poisoning is nearly always due to respiratory arrest. The primary mechanism of respiratory depression by morphine involves a reduction in the responsiveness of the brain stem respiratory centers to increases in carbon dioxide tension (P_{CO2}). High concentrations of opioid receptors, as well, as endogenous peptides, are found in the medullary areas believed to be important in ventilatory control. Respiratory depression is mediated by a subpopulation of μ receptors (μ 1), distinct from those that are involved in the production of analgesia (μ 2). Thus, a 'pure' μ 1-opioid agonist could theoretically produce analgesia with little respiratory depression.

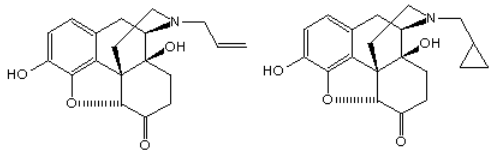
Cough. Opiates suppress the "cough center" which is also located in the brainstem, the medulla. Such an action is thought to underlie the use of opiate narcotics as cough suppressants. Codeine appears to be particularly effective in this action and is widely used for this purpose.

Gastrointestinal Tract. The opiates have been used for centuries for the relief of diarrhea and for the treatment of dysentery, and these uses were developed long before these agents were used as analgesics or euphoiants. Opiates appear to exert their effect on the gastrointestinal tract primarily in the intestine, where peristaltic movements, which normally propel food down the intestine, are markedly diminished. Also, the tone of the intestine is greatly increased to the point where almost complete spastic paralysis of movement occurs. This combination of decreased propulsion and increased tone leads to a marked decrease in the movement of food through the intestine. This stasis is followed by a dehydration of the feces, which hardens the stool and further retards the advance of material. All these effects contribute to the constipating properties of opiates. Indeed, nothing more effective has yet been developed for treating sever diarrhea.

Opiate Antagonists

Naloxone, when administered to normal individuals, produces no analgesia, euphoria, or respiratory depression. However, it rapidly precipitates withdrawal in narcotic-dependent individuals. Naloxone antagonizes the actions of morphine at all its receptors; however its affinity for m receptors is generally more than ten fold higher than for k or d receptors.

The uses of naloxone include the reversal of the respiratory depression that follows acute narcotic intoxication and the reversal of narcotic-induced respiratory depression in newborns of mothers who have received narcotics. The use of naloxone is limited by a short duration of action and the necessity of parenteral route of administration.



Naltrexone became clinically available in 1985 as a new narcotic antagonist. Its actions resemble those of naloxone, but naltrexone is well is well absorbed orally and is long acting, necessitating only a dose of 50 to 100 mg. Therefore, it is useful in narcotic treatment programs where it is desired to maintain an individual on chronic therapy with a narcotic antagonist. In individuals taking naltrexone, subsequent injection of an opiate will produce little or no effect. naltrexone appears to be particularly effective for the treatment of narcotic dependence in addicts who have more to gain by being drug-free rather than drug dependant.

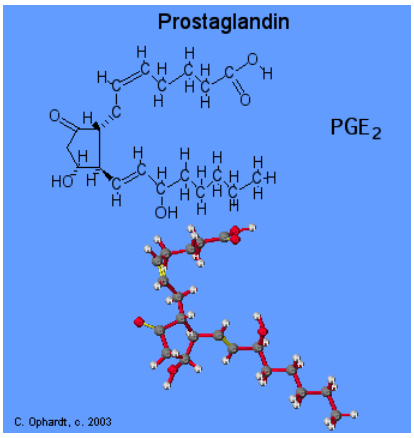
Contributors and Attributions

- Edward B. Walker (Weber State University)

Prostaglandins were first discovered and isolated from human semen in the 1930s by Ulf von Euler of Sweden. Thinking they had come from the prostate gland, he named them prostaglandins. It has since been determined that they exist and are synthesized in virtually every cell of the body. Prostaglandins, are like hormones in that they act as chemical messengers, but do not move to other sites, but work right within the cells where they are synthesized.

Introduction

Prostaglandins are unsaturated carboxylic acids, consisting of of a 20 carbon skeleton that also contains a five member ring. They are biochemically synthesized from the fatty acid, arachidonic acid. See the graphic on the left. The unique shape of the arachidonic acid caused by a series of cis double bonds helps to put it into position to make the five member ring. See the prostaglandin in the next panel



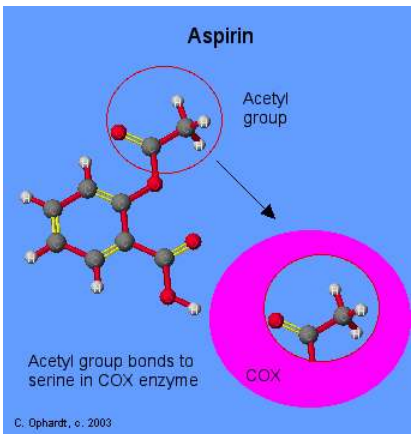
Prostaglandin Structure

Prostaglandins are unsaturated carboxylic acids, consisting of of a 20 carbon skeleton that also contains a five member ring and are based upon the fatty acid, arachidonic acid. There are a variety of structures one, two, or three double bonds. On the five member ring there may also be double bonds, a ketone, or alcohol groups. A typical structure is on the left graphic.

Functions of Prostaglandins

There are a variety of physiological effects including:

1. Activation of the inflammatory response, production of pain, and fever. When tissues are damaged, white blood cells flood to the site to try to minimize tissue destruction. Prostaglandins are produced as a result.
2. Blood clots form when a blood vessel is damaged. A type of prostaglandin called thromboxane stimulates constriction and clotting of platelets. Conversely, PGI2, is produced to have the opposite effect on the walls of blood vessels where clots should not be forming.
3. Certain prostaglandins are involved with the induction of labor and other reproductive processes. PGE2 causes uterine contractions and has been used to induce labor.
4. Prostaglandins are involved in several other organs such as the gastrointestinal tract (inhibit acid synthesis and increase secretion of protective mucus), increase blood flow in kidneys, and leukotriens promote constriction of bronchi associated with asthma.



Effects of Aspirin and other Pain Killers

When you see that prostaglandins induce inflammation, pain, and fever, what comes to mind but aspirin. Aspirin blocks an enzyme called cyclooxygenase, COX-1 and COX-2, which is involved with the ring closure and addition of oxygen to arachidonic acid converting to prostaglandins. The acetyl group on aspirin is hydrolzed and then bonded to the alcohol group of serine as an ester. This has the effect of blocking the channel in the enzyme and arachidonic can not enter the active site of the enzyme. By inhibiting

or blocking this enzyme, the synthesis of prostaglandins is blocked, which in turn relives some of the effects of pain and fever. Aspirin is also thought to inhibit the prostaglandin synthesis involved with unwanted blood clotting in coronary heart disease. At the same time an injury while taking aspirin may cause more extensive bleeding.

Contributors

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10.13: Narcotic Analgesics

Narcotic agents are potent analgesics which are effective for the relief of severe pain. Analgesics are selective central nervous system depressants used to relieve pain. The term analgesic means "without pain". Even in therapeutic doses, narcotic analgesics can cause respiratory depression, nausea, and drowsiness. Long term administration produces tolerance, psychic, and physical dependence called addiction.

Introduction

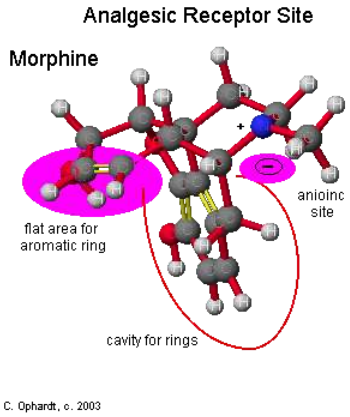
Narcotic agents may be classified into four categories:

1. Morphine and codeine - natural alkaloids of opium.
2. Synthetic derivatives of morphine such as heroin.
3. Synthetic agents which resemble the morphine structure.
4. Narcotic antagonists which are used as antidotes for overdoses of narcotic analgesics.

The main pharmacological action of analgesics is on the cerebrum and medulla of the central nervous system. Another effect is on the smooth muscle and glandular secretions of the respiratory and gastro-intestinal tract. The precise mechanism of action is unknown although the narcotics appear to interact with specific receptor sites to interfere with pain impulses.

Receptor Site

A schematic for an analgesic receptor site may look as shown in the graphic below with morphine. Three areas are needed: a flat areas to accommodate a flat nonpolar aromatic ring, a cavity to accept another series of rings perpendicular, and an anionic site for polar interaction of the amine group.



Enkephalins

Recently investigators have discovered two compounds in the brain called enkephalins which resemble morphine in structure. Each one is a peptide composed of 5 amino acids and differ only in the last amino acid. The peptide sequences are: tyr-gly-gly-phe-leu and tyr-gly-gly-phe-met. Molecular models show that the structures of the enkephalins has some similarities with morphine. The main feature in common appears to be the aromatic ring with the -OH group attached (tyr). Methadone and other similar analgesics have 2 aromatic rings which would be similar to the enkephalins (tyr and phe).

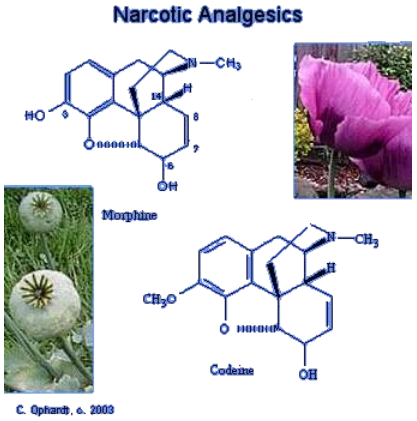
Analgesics may relieve pain by preventing the release of acetylcholine. Enkephalin molecules are released from a nerve cell and bind to analgesic receptor sites on the nerve cell sending the impulse. The binding of enkephalin or morphine-like drugs changes the shape of the nerve sending the impulse in such a fashion as to prevent the cell from releasing acetylcholine. As a result, the pain impulse cannot be transmitted and the brain does not preceive pain.

Morphine and Codeine

Morphine exerts a narcotic action manifested by analgesia, drowsiness, changes in mood, and mental clouding. The major medical action of morphine sought in the CNS is analgesia. Opiates suppress the "cough center" which is also located in the brain stem, the

medulla. Such an action is thought to underlie the use of opiate narcotics as cough suppressants. Codeine appears to be particularly effective in this action and is widely used for this purpose.

Narcotic analgesics cause an addictive physical dependence. If the drug is discontinued, withdrawal symptoms are experienced. Although the reasons for addiction and withdrawal symptoms are not completely known, recent experiments have provided some information. A nucleotide known as cyclicadenosine monophosphate (cAMP) is synthesized with the aid of the enzyme adenylate cyclase. Enkephalin and morphine-like drugs inhibit this enzyme and thus decrease the amount of cAMP in the cells. In order to compensate for the decreased cAMP, the cells synthesize more enzyme in an attempt to produce more cAMP. Since more enzyme has been produced, more morphine is required as an inhibitor to keep the cAMP at a low level. This cycle repeats itself causing an increase in the tolerance level and increasing the amounts of morphine required. If morphine is suddenly withheld, withdrawal symptoms are probably caused by a high concentration of cAMP since the synthesizing enzyme, adenylate cyclase, is no longer being inhibited.



Morphine and codeine are contained in opium from the poppy (*Papaver Somniterum*) plant found in Turkey, Mexico, Southeast Asia, China, and India. This plant is 3-4 feet tall with 5-8 egg shaped capsules on top. Ten days after the poppy blooms in June, incisions are made in the capsules permitting a milky fluid to ooze out. The following day the gummy mass (now brown) is carefully scraped off and pressed into cakes of raw opium to dry.

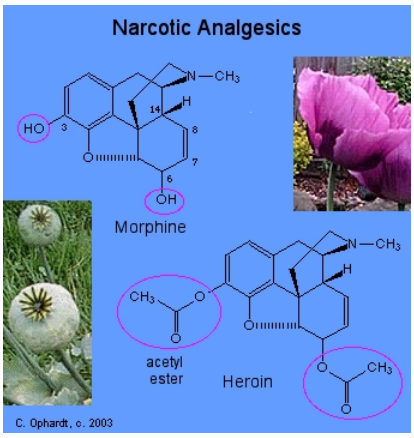
Opium contains over 20 compounds but only morphine (10%) and codeine (0.5%) are of any importance. Morphine is extracted from the opium and isolated in a relatively pure form. Since codeine is in such low concentration, it is synthesized from morphine by an ether-type methylation of an alcohol group. Codeine has only a fraction of the potency compared to morphine. It is used with aspirin and as a cough suppressant.

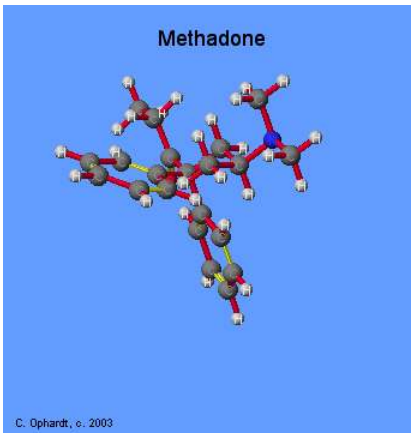
Heroin

Heroin is synthesized from morphine by a relatively simple esterification reaction of two alcohol (phenol) groups with acetic anhydride (equivalent to acetic acid). Heroin is much more potent than morphine but without the respiratory depression effect. A possible reason may be that heroin passes the blood-brain barrier much more rapidly than morphine. Once in the brain, the heroin is hydrolyzed to morphine which is responsible for its activity.

Synthetic narcotic analgesics include meperidine and methadone. Meperidine is the most common subsitute for morphine. It exerts several pharmacological effects: analgesic, local anesthetic, and mild antihistamine. This multiple activity may be explained by its structural resemblance to morphine, atropine, and histamine.

Methadone is more active and more toxic than morphine. It can be used for the relief of may types of pain. In addition it is used as a narcotic substitute in addiction treatment because it prevents morphine abstinence syndrome. Methadone was synthesized by German chemists during Wold War II when the United States and our allies cut off their opium supply. And it is difficult to fight a war without analgesics so the Germans went to work and synthesized a number of medications in use today, including demerol and darvon which is structurally simular to methadone. And before we go further lets clear up another myth. Methadone, or dolophine was not named after Adolf Hitler. The "dol" in dolophine comes from the latin root "dolor." The female name Dolores is derived from it and the term dol is used in pain research to measure pain e.g., one dol is 1 unit of pain.

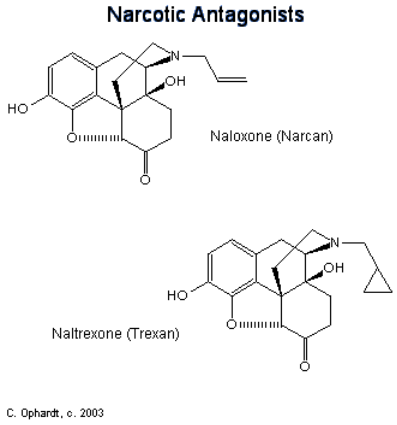




Even methadone, which looks strikingly different from other opioid agonists, has steric forces which produce a configuration that closely resembles that of other opiates. See the graphic on the left and the top graphic on this page. In other words, steric forces bend the molecule of methadone into the correct configuration to fit into the opiate receptor. When you take methadone it first must be metabolized in the liver to a product that your body can use. Excess methadone is also stored in the liver and blood stream and this is how methadone works its 'time release trick' and last for 24 hours or more. Once in the blood stream metabolized methadone is slowly passed to the brain when it is needed to fill opiate receptors. Methadone is the only effective treatment for heroin addiction. It works to smooth the ups and down of heroin craving and allows the person to function normally.

Narcotic Antagonists

Narcotic Antagonists prevent or abolish excessive respiratory depression caused by the administration of morphine or related compounds. They act by competing for the same analgesic receptor sites. They are structurally related to morphine with the exception of the group attached to nitrogen.



Nalorphine precipitates withdrawal symptoms and produces behavioral disturbances in addition to the antogonism action. Naloxane is a pure antagonist with no morphine like effects. It blocks the euphoric effect of heroin when given before heroin. Naltrexone became clinically available in 1985 as a new narcotic antagonist. Its actions resemble those of naloxone, but naltrexone is well is well absorbed orally and is long acting, necessitating only a dose of 50 to 100 mg. Therefore, it is useful in narcotic treatment programs where it is desired to maintain an individual on chronic therapy with a narcotic antagonist. In individuals taking naltrexone, subsequent injection of an opiate will produce little or no effect. Naltrexone appears to be particularly effective for the treatment of narcotic dependence in addicts who have more to gain by being drug-free rather than drug dependant

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10.14: Antidepressant medications

Antidepressant drugs are used to restore mentally depressed patients to an improved mental status. Depression results from a deficiency of norepinephrine at receptors in the brain. Mechanisms that increase their effective concentration at the receptor sites should alleviate depression.

Introduction

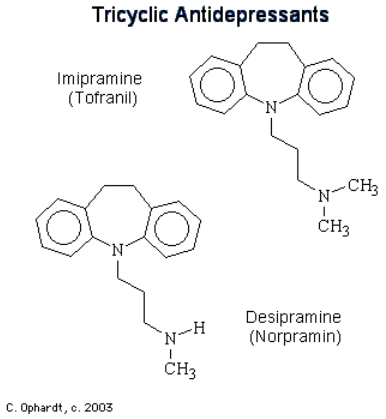
Antidepressant drugs act by one or more of the following stimulation type mechanisms:

1. Increase release of norepinephrine:Amphetamines and electroconvulsive therapy act by this mechanism. Amphetamines mimic norepinephrine.
2. Prevent inactivation of norepinephrine:Monoamine oxidase (MAO) inhibitors are thought to act as antidepressant agents in part by preventing the breakdown and inactivation of norepinephrine.
3. Prevent the re-uptake of norepinephrine:The action of norepinephrine at the receptor site is terminated by the re-uptake of norepinephrine by the neuron from which it was originally released.

Tricyclic Antidepressants

The tricyclic antidepressants are the most effective drugs presently available for the treatment of depression. These act by increasing the release of norepinephrine. Amphetamine and cocaine can also act in this manner. Imipramine, amitriptylin, and other closely related drugs are among the drugs currently most widely used for the treatment of major depression.

- imipramine (Tofranil)
- desipramine (Norpramin)

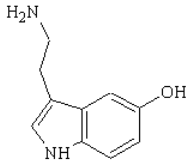


The activity of the tricyclic drugs depends on the central ring of seven or eight atoms which confers an angled or twisted conformation. The side chain must have at least 2 carbons although 3 appear to be better. The amine group may be either tertiary or secondary. All tricyclic antidepressants block the re-uptake of norepinephrine at nerve terminals. However, the potency and selectivity for the inhibition of the uptake of norepinephrine, serotonin, and dopamine vary greatly among the agents. The tertiary amine tricyclics seem to inhibit the serotonin uptake pump, whereas the secondary amine ones seem better in switching off the NE pump. For instance, imipramine is a potent and selective blocker of serotonin transport, while desipramine inhibits the uptake of norepinephrine.

Serotonin

Serotonin (5-hydroxytryptamine or 5-HT) is a monoamine neurotransmitter found in cardiovascular tissue, in endothelial cells, in blood cells, and in the central nervous system. The role of serotonin in neurological function is diverse, and there is little doubt that serotonin is an important CNS neurotransmitter. Although some of the serotonin is metabolized by monoamine oxidase, most of the serotonin released into the post-synaptic space is removed by the neuron through a re-uptake mechanism inhibited by the tricyclic antidepressants and the newer, more selective antidepressant re-uptake inhibitors such as fluoxetine and sertraline.

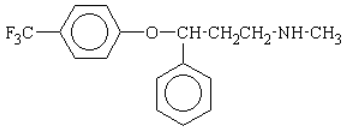
Serotonin



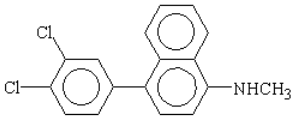
Selective Serotonin Reuptake Inhibitors

In recent years, selective serotonin reuptake inhibitors have been introduced for the treatment of depression. Prozac is the most famous drug in this class. Clomiprimine, fluoxetine (Prozac), sertraline and paroxetine selectively block the re-uptake of serotonin, thereby increasing the levels of serotonin in the central nervous system. Note the similarities and differences between the tricyclic antidepressants and the selective serotonin re-uptake inhibitors. Clomipramine has been useful in the treatment of obsessive-compulsive disorders.

Serotonin Reuptake Inhibitors



Fluoxetine (Prozac)



Sertraline (Zoloft)

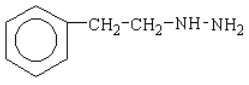
C. Ophardt, c. 2003

Monoamine Oxidase Inhibitors

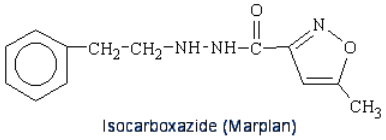
Monoamine oxidase (MAO) causes the oxidative deamination of norephinephrine, serotonin, and other amines. This oxidation is the method of reducing the concentration of the neurotransmitter after it has sent the signal at the receptor site. A drug which inhibits this enzyme has the effect of **increasing the concentration of the norepinephrine which in turn causes a stimulation effect.** Most MAO inhibitors are hydrazine derivatives. Hydrazine is highly reactive and may form a strong covalent bond with MAO with consequent inhibition for up to 5 days.

These drugs are less effective and produce more side effects than the tricyclic antidepressants. For example, they lower blood pressure and were at one time used to treat hypertension. Their use in psychiatry has also become very limited as the tricyclic antidepressants have come to dominate the treatment of depression and allied conditions. Thus, MAOIs are used most often when tricyclic antidepressants give unsatisfactory results.

Monoamine Oxidase (MAO) Inhibitors



Phenelzine (Nardil)



Isocarboxazide (Marplan)

C. Ophardt, c. 2003

Phenelzine is the hydrazine analog of phenylethylamine, a substrate of MAO. This and several other MAOIs, such as isocarboxazide, are structurally related to amphetamine and were synthesized in an attempt to enhance central stimulant properties.

- phenelzine (Nardil)
- isocarboxazid (Marplan)

Contributors

Charles Ophardt (Professor Emeritus, Elmhurst College); Virtual Chembook

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