

ASTRONOMY 10: THE SOLAR SYSTEM (WORKBOOK)



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Astronomy 10: The Solar System (Workbook)

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Detailed Licensing

Detailed Licensing

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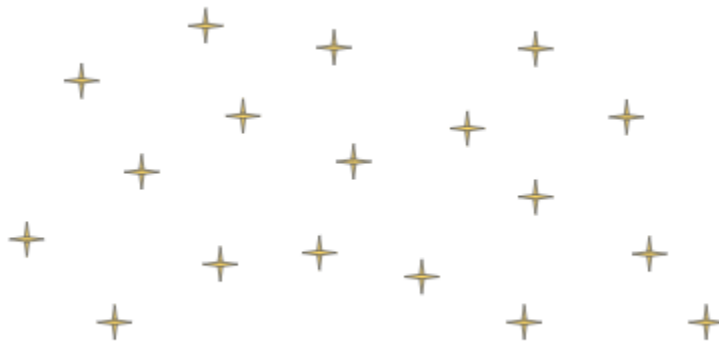
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1.1: Horizon Coordinates

1.1.1 Position of Objects in the Sky

Model

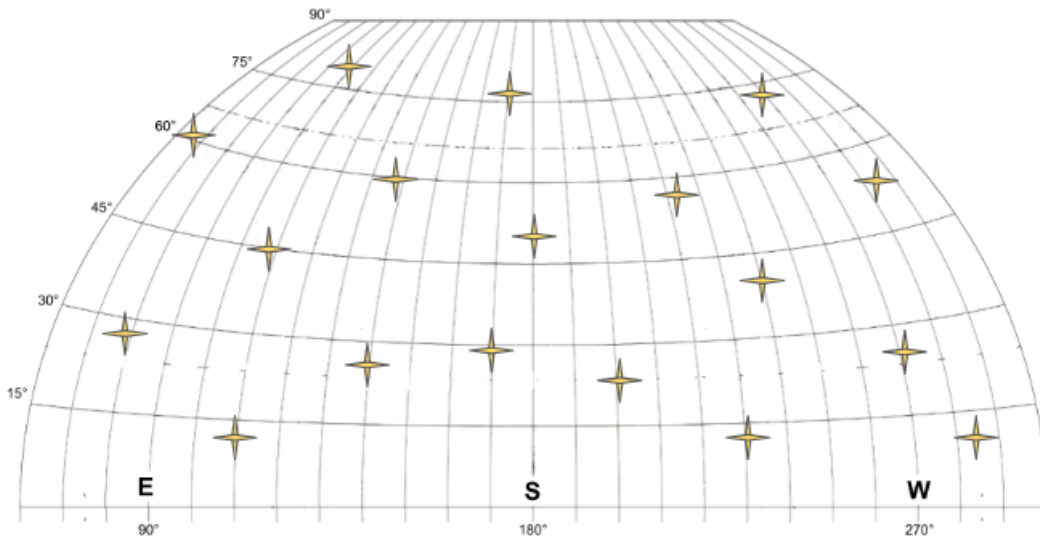


Star field model showing scattered stars used for locating and describing positions in the sky.

1. Choose a star in the sky. Do not point to it or give away its location.
 2. Write instructions for how to locate that star.
 3. Share your instructions with your group. Each member of the group should guess the location of your star. After everyone guesses, put a box around the actual star on your sky.
 4. Discuss as a group:
 - What strategies or instructions worked well?
 - how you could make the process of identifying each other's star easier?
 - What was challenging?
 5. If you were to make a constellation out of the pattern of stars near the star you have chosen, what would it look like? Draw your constellation on the image by drawing lines connecting the stars.
-

1.1.2 Altitude and Azimuth

Model



Altitude and azimuth grid with stars showing positions above the horizon and compass directions.

1. Choose a new star in the model but do not point to it.
2. Write instructions for how to locate that star.
3. Each person should guess the star by circling the star on the other person's sky.
4. After everyone guesses, put a box around the actual star on your sky.
5. Discuss as a group:
 - Was this easier, harder, or the same?
 - Why?
6. In a **Planetarium** or using planetarium software (eg, [Stellarium](#)), choose five stars in different parts of the sky. For each star, identify:
 - **Cardinal Direction** (eg, North or South-East) and **Azimuth**
 - **Altitude**
 - **Apparent Brightness** (very bright, very dim, etc)
 - **Any other identifiers** (characteristics about the star, its position, color, etc)
7. Discuss the questions as a group, then respond in complete sentences:
 1. Why are Cardinal Directions (**Azimuth**) and **Altitude** useful concepts for astronomical observation?
 2. How else can astronomers communicate information about a star to help others locate the same star?

1.1.3 Changing Sky

Model

In a **Planetarium** or using planetarium software (eg, [Stellarium](#)), observe the changing sky at 300x speed.

1. What do you notice about the position of these stars?
 2. Are there any patterns you can identify?
 3. In which parts of the sky do stars rise? In which parts of the sky do stars set?
 4. Do any stars remain still?
-

1.1.4 Polaris and the Circumpolar Region

Model

In a **Planetarium** or using planetarium software (eg, [Stellarium](#)), locate the **North Star (Polaris)**

1. What is the **Azimuth** and **Altitude** of this star? Do either change over the course of the night?
 2. How do stars appear to move in relation to the North Star?
 3. The **Circumpolar Region** is the region of stars in the sky that do not set over the course of a 24 hour cycle. What is the shape of this region and how do its measurements/size relate to the **Azimuth** or **Altitude** of **Polaris**?
-

1.1.5 Effect of Latitude on Polaris and the Circumpolar Region

Model

In a **Planetarium** or using planetarium software (eg, [Stellarium](#)), locate the **North Star (Polaris)**. Chose several different locations on earth (different **latitudes** and **longitudes**) and record the **Altitude** and **Azimuth** of Polaris

1. Identify a pattern (no effect is a type of pattern) between **latitude/longitude** and **Altitude/Azimuth**
 2. Identify a pattern (no effect is a type of pattern) between **latitude/longitude** and **the size and location** of the **Circumpolar Region**.
-

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1.2: Apparent Motion

1.2.1 Star Trails: Sky View

Model

Open the simulation and select **Sky View** at <https://astro.unl.edu/smartphone/StarTrails/>

1. What is the current **latitude**?
2. Which direction do you have to face to see objects rise? At what angle do they rise?
3. Which direction do you have to face to see objects set? At what angle do they set?
4. Which direction do you have to face to see the top of the motion arc?
5. Do all objects rise at the same azimuth?
6. Do all objects set at the same azimuth?
7. What changes when you change the latitude?
8. Draw the paths when you look in each direction and write a one-sentence description of the paths objects take in that sky.

East Description:	West Description:
North Description:	South Description:

1.2.2 Star Trails: Horizon Diagram

Model

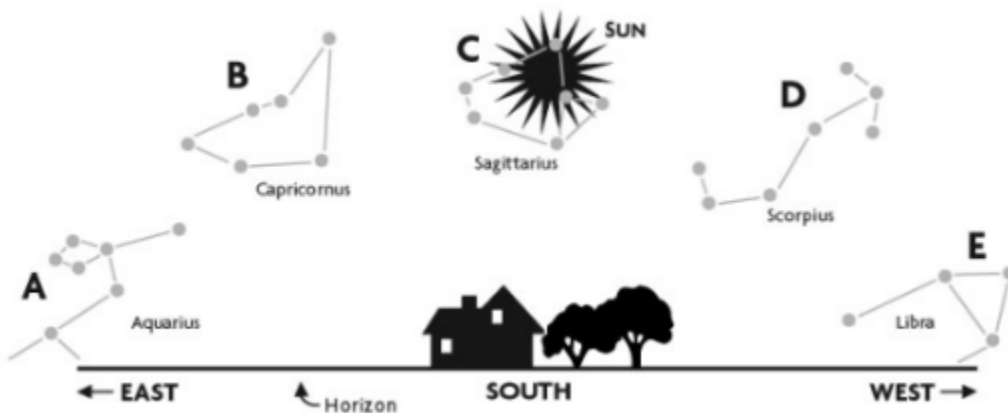
Open the simulation and select **Horizon Diagram** at <https://astro.unl.edu/smartphone/StarTrails/>

The red line represents a meridian line with the **North Celestial Pole** on one end and the **South Celestial Pole** on the other end. The blue line represents the **Celestial Equator**.

1. Adjust the latitude slider. How does the position of the **North Celestial Pole** shift relative to the horizon (flat ground) based on latitude? See if you can be specific and use exact numbers in your response.
2. Adjust the latitude slider. How does the position of the **Celestial Equator** shift relative to the horizon (flat ground) based on latitude? See if you can be specific and use exact numbers in your response.
3. Describe how objects appear to move on this model.
4. Track an individual star that is south of the celestial equator: Does the star always exist or does it eventually disappear? Are there any times where the star is in a position such that the person on the ground would not be able to see it? Explain your reasoning.

1.2.3 Looking South

Model



Southern sky horizon diagram showing constellations rising and setting across the sky.

Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

1. Which constellation is currently rising in the image? How do you know?
2. Which constellation is currently setting in the image? How do you know?
3. Which constellation was the first to rise on this day? Which constellation was the last to rise on this day? Label this on the diagram and explain your reasoning.

4. Is the Sun closer to rising, setting, or directly in between rising and setting? Based on your response, estimate the time of day.
 5. Draw an arrow on each constellation to show the direction it is currently moving.
-

6. On the horizon below, draw the Sun and write the constellation names (you do not need to draw them) where you think they will be at the listed times.

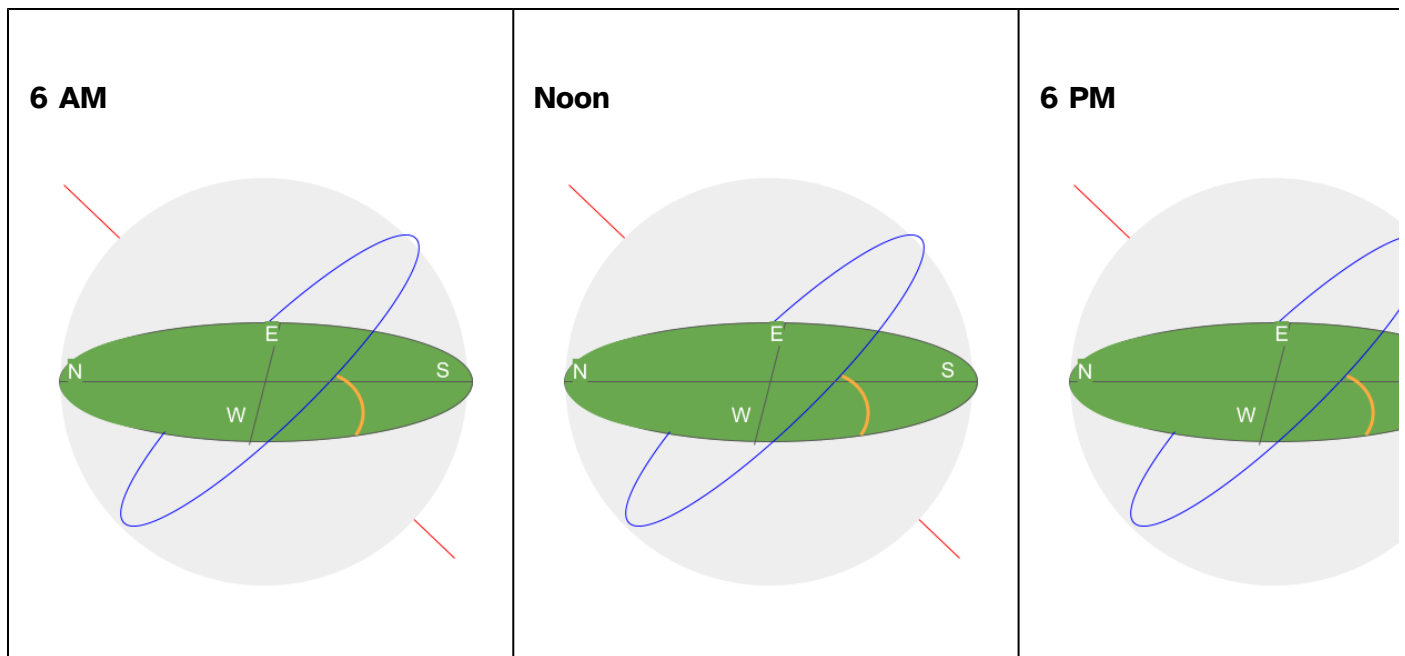
6AM



6PM



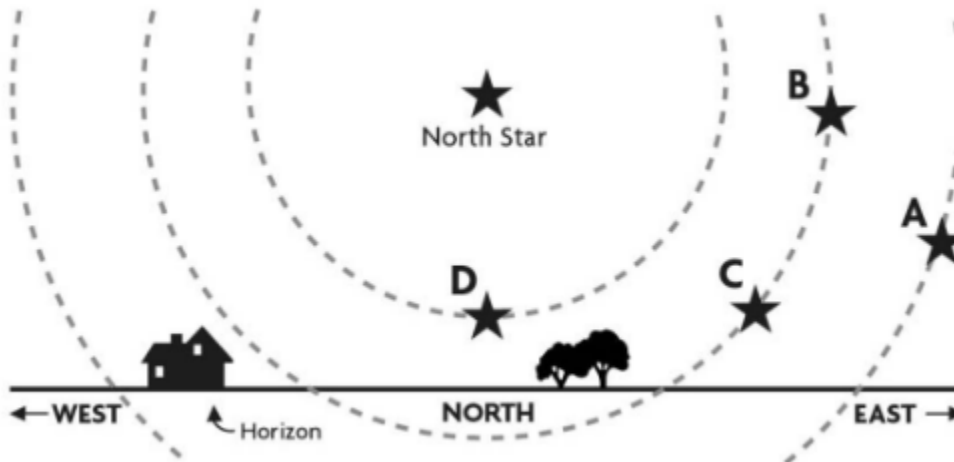
-
7. Draw the Sun and list the constellations based on their letters at the listed times on the celestial sphere model.



1.2.4 Looking North

Model

Examine the model below. The dashed lines show the path those stars will take. On each star, draw an arrow to show the direction it is moving.

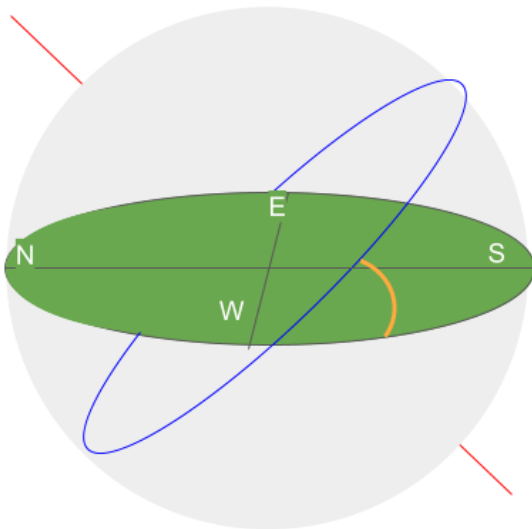


Northern sky diagram showing stars moving around the North Star with dashed motion paths.

Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

1. Which star(s), if any, are currently rising? Which star(s), if any, are currently setting? Explain your reasoning.

2. Rank the stars based on how much time they spend above the horizon in a 24-hour period (1 = most time above the horizon).
3. How does the proximity to the North Star relate to how long a star is above the horizon?
4. Which star will be the first to set? Explain your reasoning.
5. On the diagram below, draw the stars based on where you think they will be 12 hours later.
6. Draw the North Star and stars A-D at their positions that you just drew for question 5 on the celestial sphere model below.



1.3: The Zodiac - Seasonal Stars

1.3.1 Zodiac and the Sun

Model

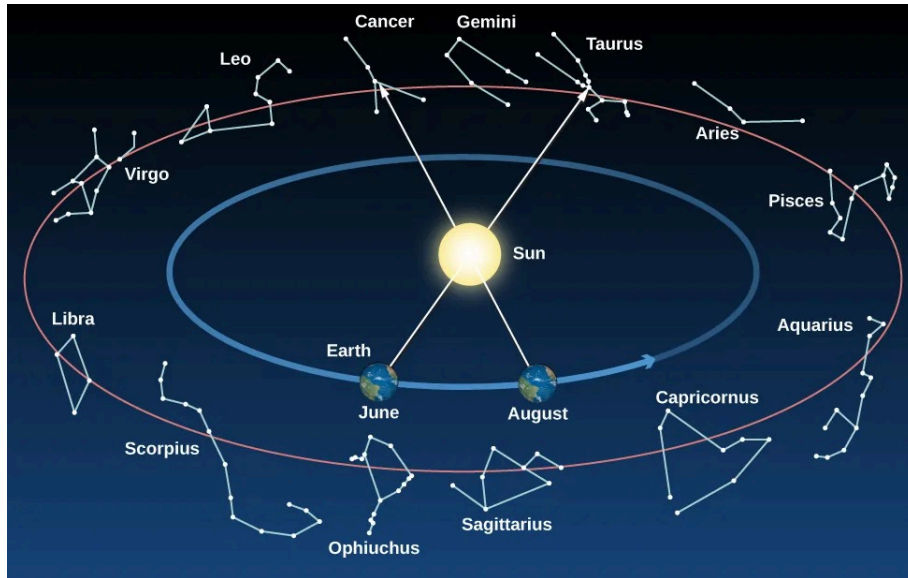
In a **Planetarium** or using planetarium software (eg, [Stellarium](#)), examine the sky and record your observations in the table below. For the last row, choose any date you want (eg, a birthday):

Date	Location of Sun at Noon

1. At noon, is the Sun always in the same constellation throughout the year?
 2. How long does the Sun remain in a particular constellation?
 3. Based on your answer above, how many zodiac constellations should there be? Explain your reasoning.
-

1.3.2 Zodiac in a Yearly Cycle

Model



The Zodiac make a ring around Earth's orbit around the sun. Astrological "sun sign" is constellation across the sun from Earth.

Image Credit: OpenStax Astronomy 2e (<https://openstax.org/details/books/astronomy-2e>)

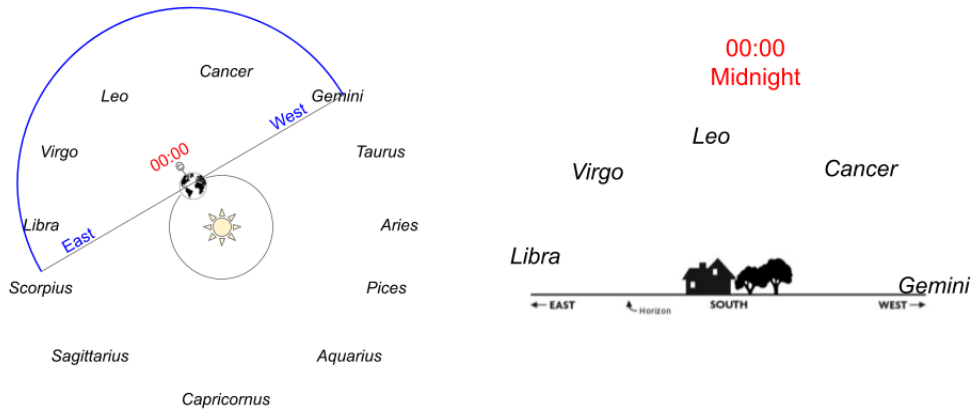
1. When someone is a **Cancer**, is the earth **next to Cancer** or **opposite Cancer** on the other side of the sun?
2. When someone is a **Taurus**, is the earth **next to Taurus** or **opposite Taurus** on the other side of the sun?
3. On your birthday, can you see your zodiac sign? Explain your reasoning.
4. Constellations that are in the middle of the arc that represents your sky are highest in the sky. At what time of day, on your birthday, is your zodiac sign at its highest point in the sky? Explain your reasoning.
5. Work with your group to label the **Earth Locations** by month on one of the images in the model, based on your knowledge of your assigned zodiac signs and your birth dates.
6. Identify which constellations are in your midnight sky on your birthday. Draw them out on the sky view.

Image needed here with Alt Text:

Sky view template for drawing midnight constellations visible from Earth on a selected date.

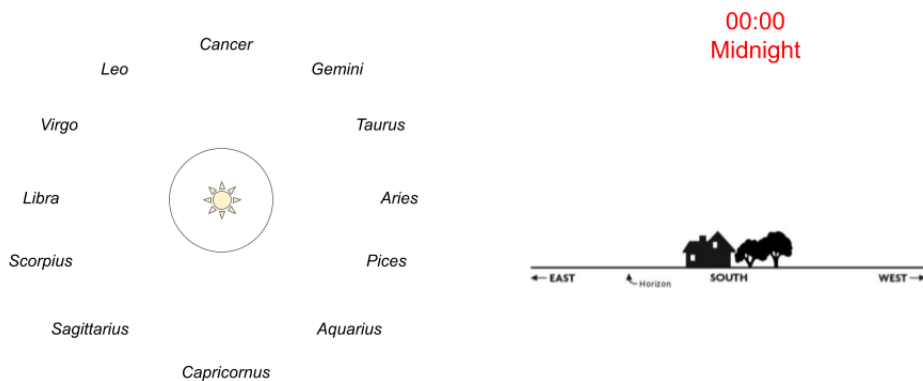
1.3.3 Zodiac in the Night Sky

Model



The Zodiac make a ring around Earth's orbit around the sun with midnight sky shown as the half opposite the sun.

- Describe how to determine your Midnight Sky at different months of the year using the Zodiac chart. Consider:
 - Where on the Earth model should the person be at midnight?
 - What parts of the sky are **not blocked** by Earth?
- Identify which constellations are in your midnight sky on your birthday. Show the Earth location and write the Zodiac constellation names on the sky view template.



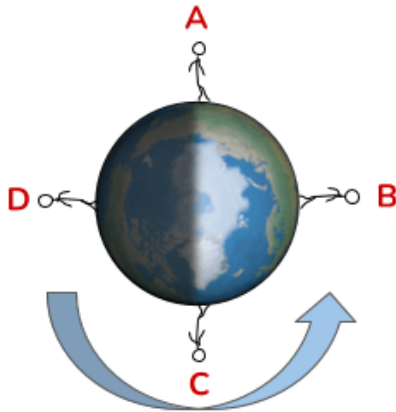
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1.4: Seasonal Sun Position

1.4.1 Time of Day

Model

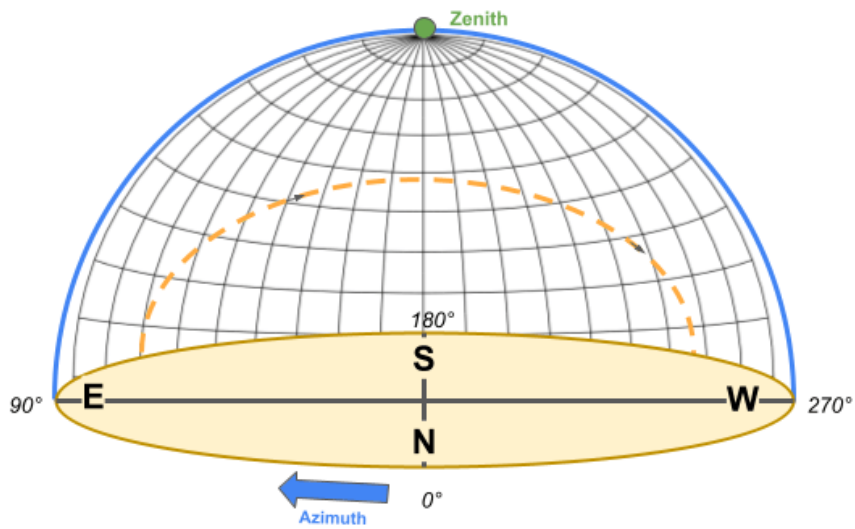
This is a view of the Earth where we are looking down at the North Pole. The Earth spins counterclockwise, carrying the person with it.



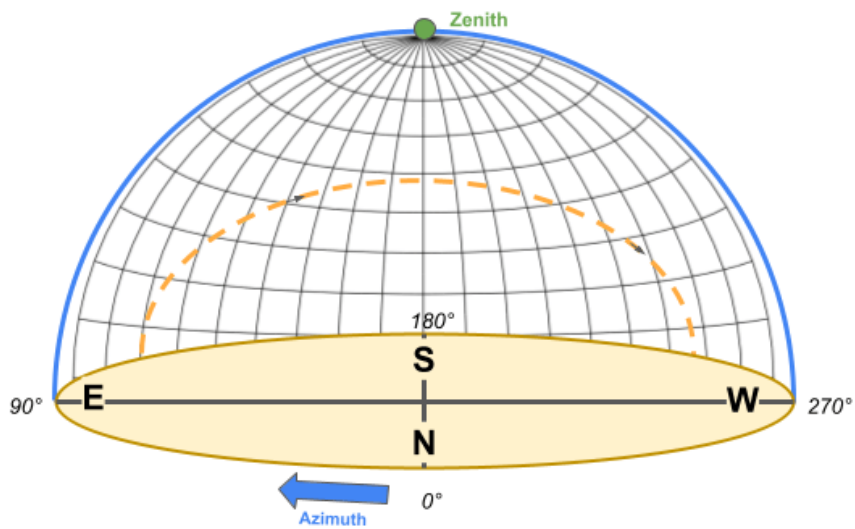
Earth viewed from above the North Pole with people A–D and the Sun showing day and night sides.

1. Which person(s) (A, B, C, or D) is/are experiencing day time? Explain your reasoning.
 2. Which person(s) (A, B, C, or D) is/are experiencing night time? Explain your reasoning.
 3. Which person is experiencing each time of day? Label the times next to the letters.
 - 6AM
 - Noon
 - 6PM
 - Midnight
-
4. Draw a sun figure on the arc to represent the location of the sun in the local view of the sky at each time. Explain your reasoning under the figure.

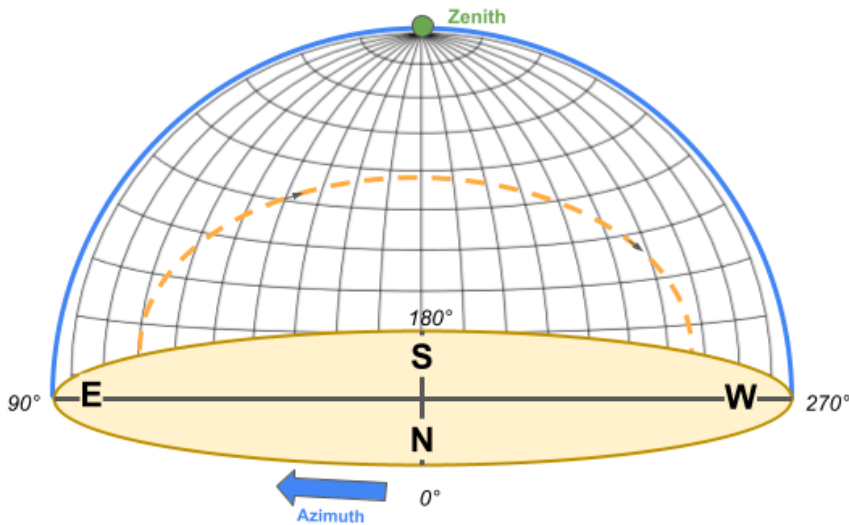
6AM



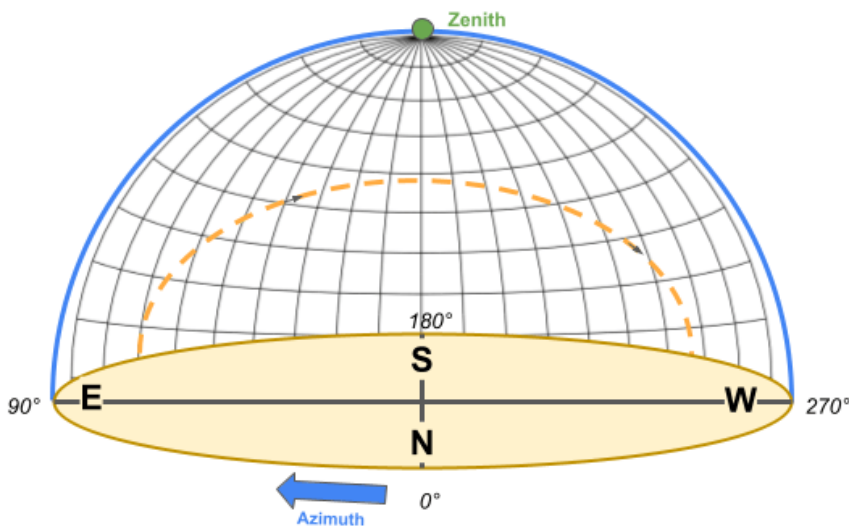
Noon



6PM



Midnight



5. At what time is the position of the sun at its highest point in the sky? What direction do you need to look to see the sun at this time?
6. At sunrise, what direction do you need to look to see the sun?
7. At sunset, what direction do you need to look to see the sun?
8. At both sunrise and sunset, draw a dashed circle on the sky to show the location of the sun one hour later (7AM and 7PM). Label those dashed circles with their times. Then, add these people as stick figures to the original model and label them with their times.

1.4.2 Solar Altitude by Latitude

Model

Use the simulation as a source of evidence for this activity. The sun rays show the position of the sun at noon on the specified day of the year. Open the simulation at:

<https://astro.unl.edu/classaction/animations/coordsmotion/eclipticsimulator.html>

1. Set the month to March. Adjust the latitude to the values in the table below and record what you observe at that latitude.

Latitude and Altitude of the Sun

Latitude	Altitude of the Sun
20° N	
40° N	
60° N	
20° S	
40° S	
60° S	

2. How does your latitude affect the altitude of the sun that you observe at noon in the month of March?
3. Construct an equation for the altitude of the sun (h) and show that your equation works with two different entries in the table above.

$h =$

1.4.3 Seasonal Solar Altitude

Continue to use the simulation at:

<https://astro.unl.edu/classaction/animations/coordsmotion/eclipticsimulator.html>

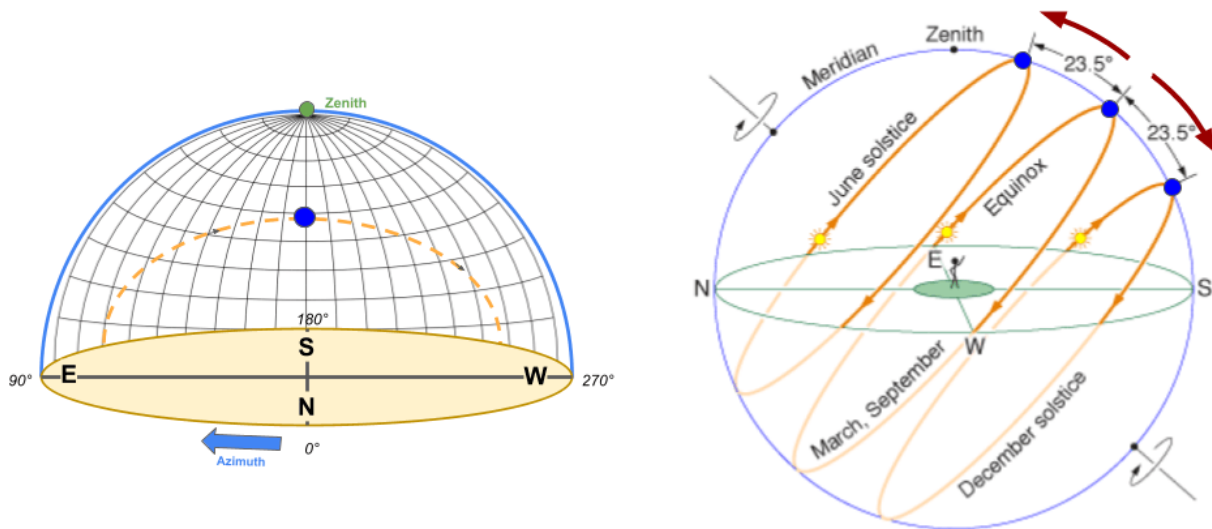
1. Set your latitude to 40° N. What does your equation say the solar altitude should be at noon?
2. Change the month. Is your equation still valid? If not, can you find another month (besides March) that your equation is valid for?
3. Change the month and fill in the table based on your observations. Identify how many degrees higher (+) or lower (-) the measured altitude is compared to your calculated solar altitude.

Seasonal Solar Altitude Observations

Month	Measured Altitude	Degrees +/- Predicted
December		
March		
June		
September		

4. Summarize your results. What pattern do you notice throughout the year? How might this relate to seasons (Summer, Fall, Winter, Spring)?

Summary



The altitude of the sun at noon from your latitude changes throughout the season because the Earth is tilted.

The measured altitude is given by the equation:

$h =$

The seasonal tilt ranges from ° to °.

1.4.4 Seasonal Light

Model

Continue to use the simulation at:

<https://astro.unl.edu/classaction/animations/coordsmotion/eclipticsimulator.html>

1. Set the latitude to 37° N. Switch back and forth between December and June and fill out the table to compare the differences about the sun's rays during these two months.

Seasonal Light Comparison

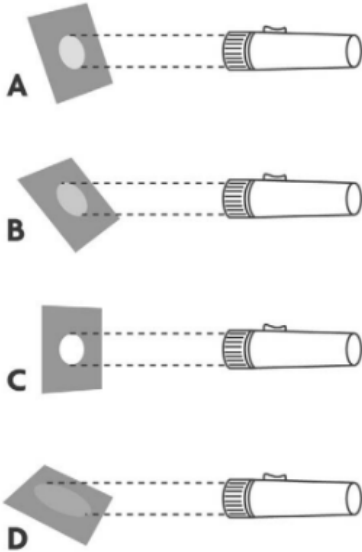
	December	June
Altitude of the sun is (higher / lower)		
Rays are (more vertical / more horizontal)		
Rays are (closer together / farther apart)		
Person is (closer / farther) from shadowed part of Earth		

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1.5: The Reason for the Seasons

1. Seasons

1.5.1 Solar Brightness and Light Angle



Five light beam examples A–E showing different light angles and illuminated areas on a surface.

Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

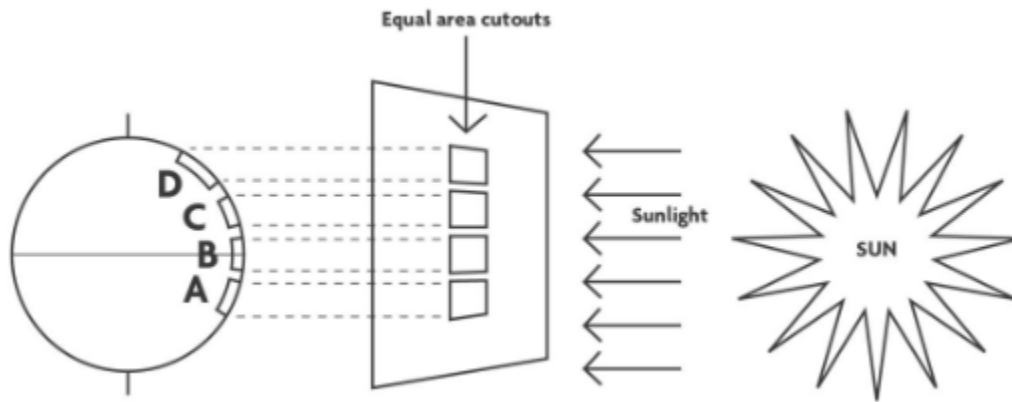
1. Give each lettered example a ranking for: Brightness (1 is brightest), illuminated area (1 is greatest), and angle between light and paper (1 is greatest angle).

Solar Brightness and Light Angle Rankings

Example	Brightness	Illuminated Area	Angle
A			
B			
C			
D			
E			

2. Summarize the patterns you saw above: How does the angle between the ground and a line from the Earth to the sun affect how bright sunlight is on that part of the ground?

1.5.2 Light Angle and Earth Position



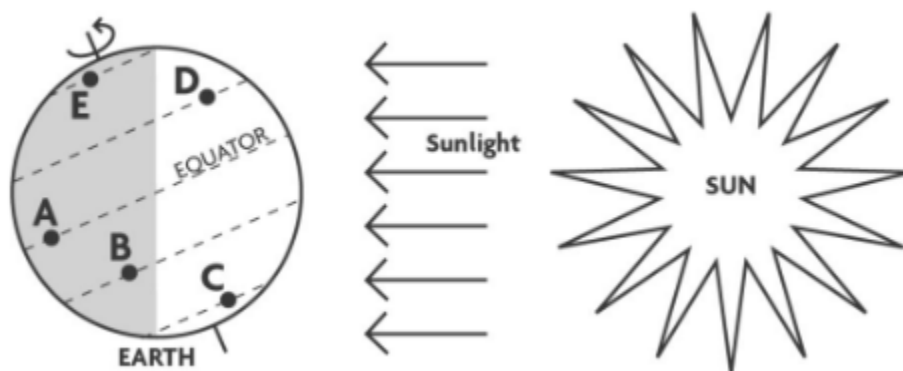
Earth diagram with equal light cutouts showing how sunlight spreads across different latitudes.

Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

1. Examine the area cutouts: How do the areas compare? Based on your response and the patterns in the previous model, how should the amount of light in each cutout compare?
2. Examine the portions of the Earth that receive light from each cutout: How do the areas along the Earth compare? Based on your response and the patterns in the previous model, how should the brightness of light on each portion of the Earth compare?
3. Summarize: What parts of the Earth receive the most light? What parts of the Earth receive the least light?
4. Interpret: What parts of the Earth are warmer? What parts of the Earth do you think are colder? Justify your responses with the patterns you identified in the previous questions.

1.5.3 Seasonal Daylight

Model



Tilted Earth model with latitudes A–E showing daylight and nighttime portions of rotation paths.

Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

1. Each letter represents a latitude. For the time of the year shown, estimate the percentage of time that position is in daylight

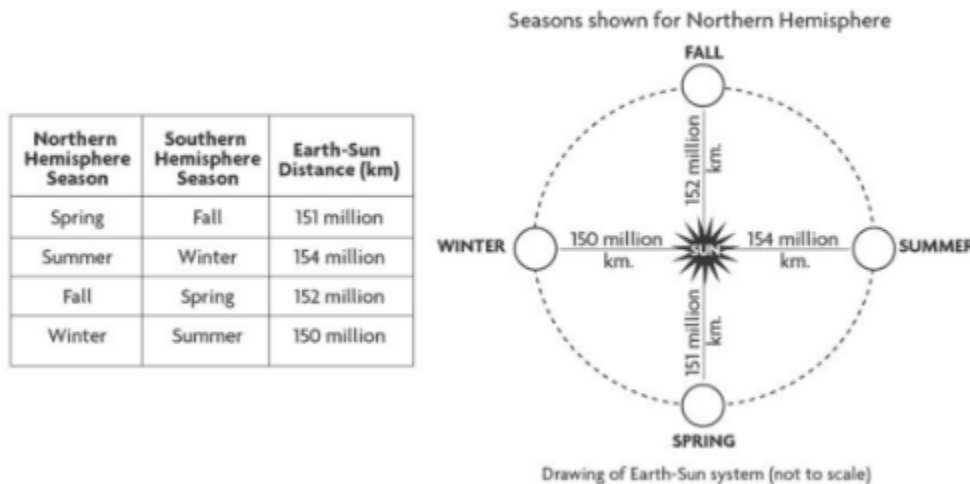
and night, based on the fraction of the dashed line that is on the illuminated and dark portions of the Earth model.

Seasonal Daylight Estimates

Latitude	Daylight %	Night %
A		
B		
C		
D		
E		

- Which portion of the Earth (top or bottom) is tilted more towards the sun?
- For the part of the Earth (top or bottom) that you identified in the previous question, do latitudes near that point experience more daylight or more night?
- Which part of the Earth (top or bottom) do you think spends more time heating up during a 24-hour period? Explain your reasoning.
- Which part of the Earth (top or bottom) do you think is experiencing summer? Explain your reasoning.

1.5.4 Light Angle and Earth Position



Earth orbit diagram showing seasonal positions and varying Earth-Sun distances.

Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

- Would you expect the Earth to be warmer when it is closer or farther from the sun? Explain your thinking.
- During which season is the Earth closest to the sun? Is that a warm or cold season?
- During which season is the Earth farthest from the sun? Is that a warm or cold season?
- Do you think the distance between the Earth and the sun causes the seasons? Explain your reasoning using evidence from this model.
- Consider this student conversation and identify whether you agree or disagree with each student:

Student A: The distance between the Earth and the sun cannot be the cause of the seasons because the Earth is 4 million kilometers closer to the sun in the winter, when it is colder. That doesn't make sense because being closer should make the Earth warmer. The cause of the seasons must be related to the tilt of the Earth, not the distance between the Earth and the sun.

Student B: I agree that the tilt is what causes the seasons, but I think it is related to distance. When the Northern Hemisphere of the Earth is tilted towards the sun, it is closer to the sun than the Southern Hemisphere. So distance does play a part.

Student C: I disagree. The Northern Hemisphere might be closer to the sun than the Southern Hemisphere when it is summer in the Northern Hemisphere, but the whole planet is farther away. So it must be the way the tilt affects how the light reaches us, not the change in distance caused by the tilt.

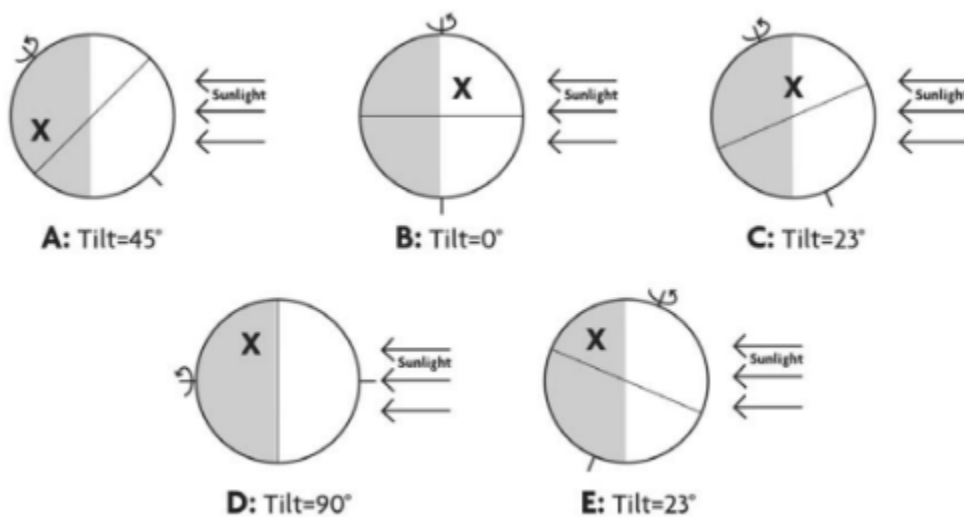
Summary

Explain how each of the following do or do not affect the seasons:

- Distance between Earth and Sun
- Sunlight Angle
- Amount of Daylight Hours

Application

Imagine a person is at the “X” on each figure. Rank the different examples in terms of: Hours of daylight and sun angle. Then rank them in terms of greatest daytime temperature.



Multiple Earth diagrams with person marked X for comparing daylight, sun angle, and temperature.

Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

Application Rankings

Example	Hours of Daylight Rank	Sun Angle Rank	Greatest Daytime Temperature Rank
A			
B			
C			

Example	Hours of Daylight Rank	Sun Angle Rank	Greatest Daytime Temperature Rank
D			
E			

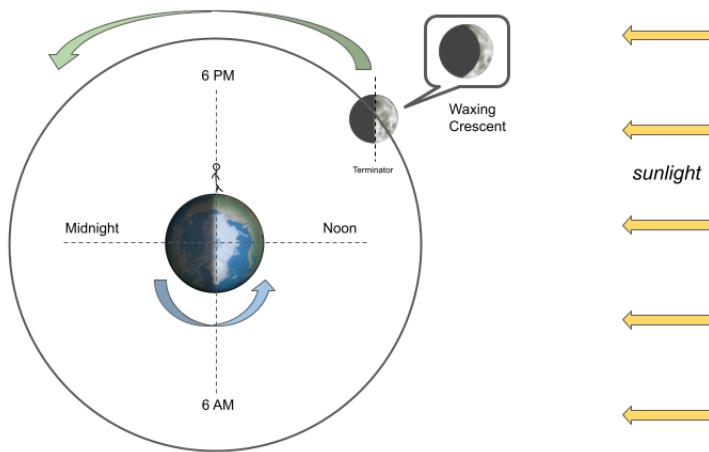
1.6: Monthly Cycles - Lunar Phases

1. Moon Phases

1.6.1 Illuminated Surface

Model

Examine the moon as shown on its orbit around the Earth:



Moon as Waxing Crescent orbiting Earth with sunlight showing illuminated and dark halves of the Moon as well as Moon appearance from Earth.

1. What percent of the moon is dark? What percent is illuminated?
2. Which part of the moon is dark? How does this relate to the direction of the sunlight?
3. What is the name of the line separating light and dark on the moon?
4. Look at just the portion of the moon that is facing Earth, just inside the circle of its orbit: Is that portion of the moon more dark or more illuminated?

Examine the moon in the dialogue box, which represents how it is seen from Earth.

5. What percent of the moon as seen from Earth is dark? What percent is illuminated?
6. Which side (left or right) of the moon is dark? Which side is light?

1.6.2 Identifying Moon Phases

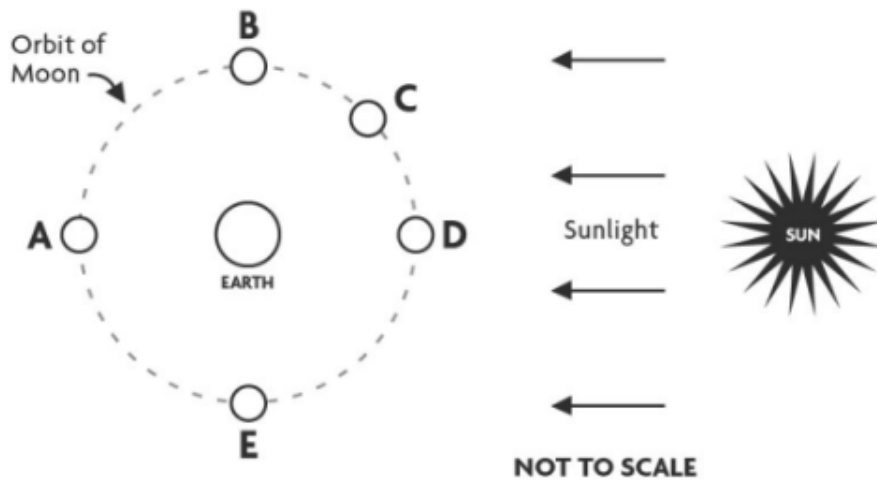
Model

The model below shows the moon in different positions around its orbit.

Mark up the diagram to include the following:

- Add terminators to the Earth and moon in each moon position.

- Shade in the side of the moon that is not illuminated by the sun.
- Imagine you are looking at the moon from Earth. Write “L” next to the left side of the moon and write “R” next to the right side of the moon from your perspective on Earth.



Earth and Moon orbit diagram with Moon positions A–E for analyzing lunar phases.

Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

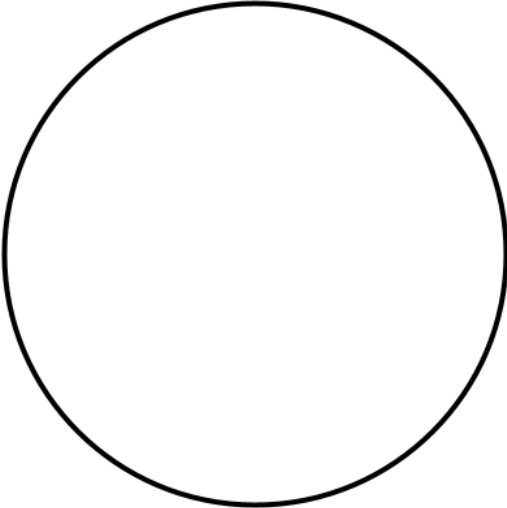
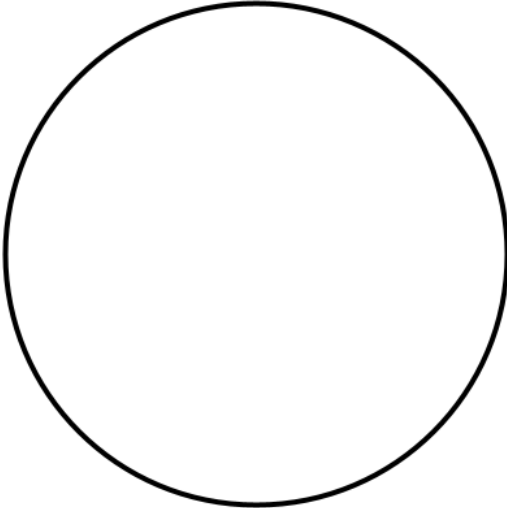
1. Rank the moons (A–E) based on how much of the moon, as viewed from Earth, is illuminated (1 being most illuminated).

Moon Illumination Ranking

Moon Position	Rank
A	
B	
C	
D	
E	

2. Sketch what you expect the moon to look like from Earth at each position.

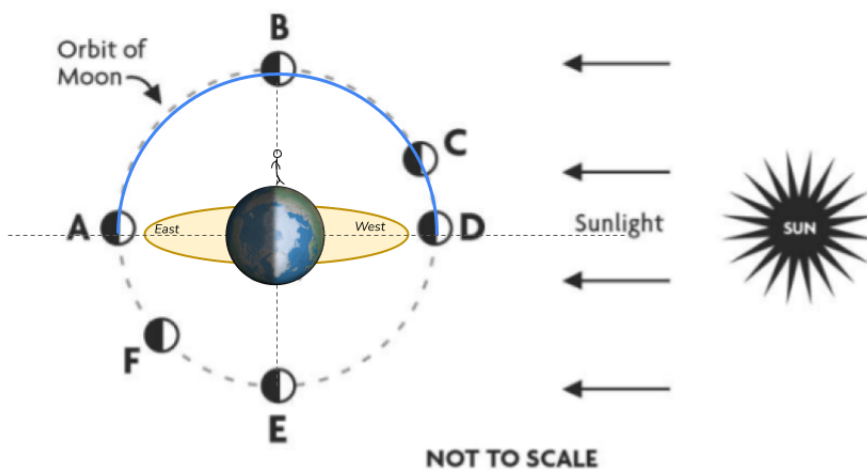
Moon Phase Sketches

A	B	C
		

3. Explain how you determined the moon phases.

1.6.3 Moon Rise and Set Times

Model

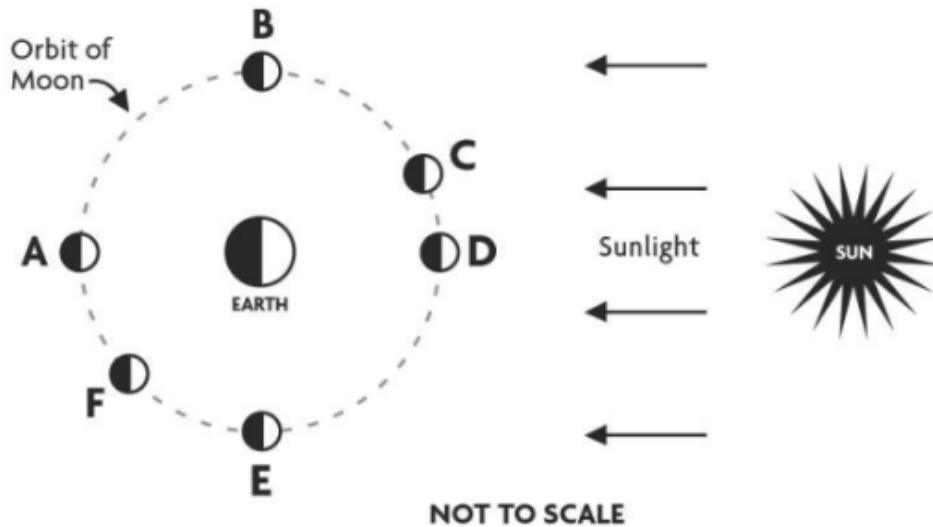


Earth with observer and Moon positions A–F used to determine moonrise and moonset times.

Image Credit: Image adapted from Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

1. What time is it for the person shown on Earth?
2. Which moon (A–F) is on your western horizon? Does that mean that moon would be rising or setting?
3. Which moon (A–F) is on your eastern horizon? Does that mean that moon would be rising or setting?

4. Based on your answers to the previous two questions, which moon would be at its highest point in the sky, equal distance between rising and setting?
5. Where on the Earth would the person need to be for Moon F to be rising? Draw the person at this location and identify what time of day it must be for that person. Sketch the East-West horizon on the figure. Then answer the following questions for this new person-location:
 1. Which moon would have set most recently for the person in the position you drew above? Explain your reasoning.
 2. Which moon will be the next to rise? At what approximate time will it rise? Explain your thinking.



Earth with observer and Moon positions A–F used to determine moonrise and moonset times.

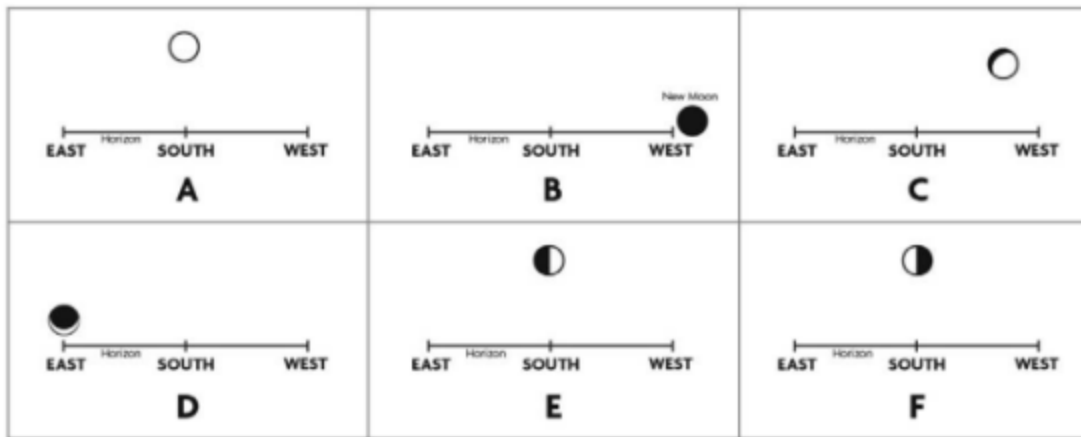
Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

Application

Your instructor will assign you one of the following horizon sky views.

Circle your assigned view and complete the following:

- Draw a model of the Earth, the moon in its orbit around the Earth, the Sun and sunlight for the moon shown in the assigned horizon.
- Draw a stick figure to show where around the Earth the person is to see this sky view.
- Identify the approximate time shown in the sky view.
- Identify the rise and set time for that moon.

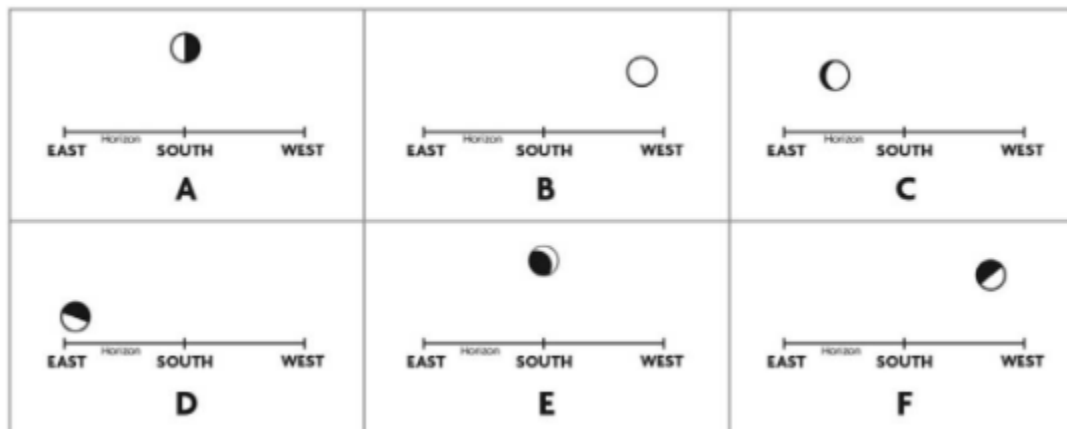


Multiple horizon sky views showing Moon phases for Earth–Moon–Sun modeling activity.

Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

Application Response Area

Assigned Horizon View	Approximate Time	Moon Rise Time	Moon Set Time



Multiple horizon sky views showing Moon phases for Earth–Moon–Sun modeling activity.

Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

Application Response Area

Assigned Horizon View	Approximate Time	Moon Rise Time	Moon Set Time

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1.7: Eclipses

1.7.1 Basic Shadows

Model

The model below shows sunlight coming in from the right. On top, the Moon is between the Earth and the sun and will cast a shadow on the Earth. On the bottom, the Earth is between the sun and the moon and will cast a shadow on the moon.



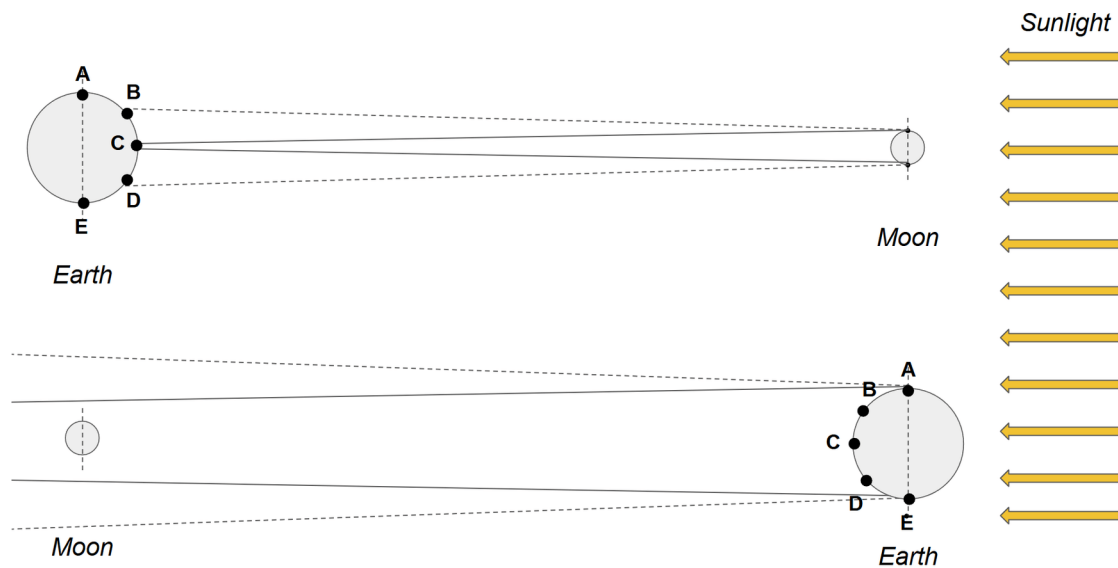
Two models show the Moon and Earth cast shadows on each other with sunlight from the right.

1. Mark up the Model
 1. Shade in the portion of the Moon and Earth that should be dark, based on the location of the sun (to the right of both objects).
 2. On the top model, draw a straight, horizontal line from each of the dots on the top and bottom of the moon to the Earth.
 3. On the bottom model, draw a straight, horizontal line from each of the dots on the top and bottom of the Earth to (or just past) the Moon.
 4. Shade in any additional portion of the Earth or Moon that should be dark, based on the shadows cast by each object
2. Examine your model
 1. Are many people on Earth in the moon's shadow? Or is there just a small portion of Earth that experiences this event? Which people (A-E) would experience this event?
 2. Are there many people on Earth that see the Earth's shadow on the moon? Or is there just a small portion of Earth that can see this event? Which people (A-E) would experience this event?
3. Are you more likely to see a solar eclipse (be in the moon's shadow on Earth) or see a lunar eclipse (see the Earth's shadow on the moon)? Make a claim and provide clear evidence and reasoning from your model.

1.7.2 Umbra and Penumbra

Model

Based on the physical size of the Sun, Earth, and Moon and their distances between each other, partial and full shadows are possible. The solid line represents the **umbra** which is a full shadow (no light). The dashed line represents the **penumbra** which is a partial shadow (some light is blocked but some light is not).



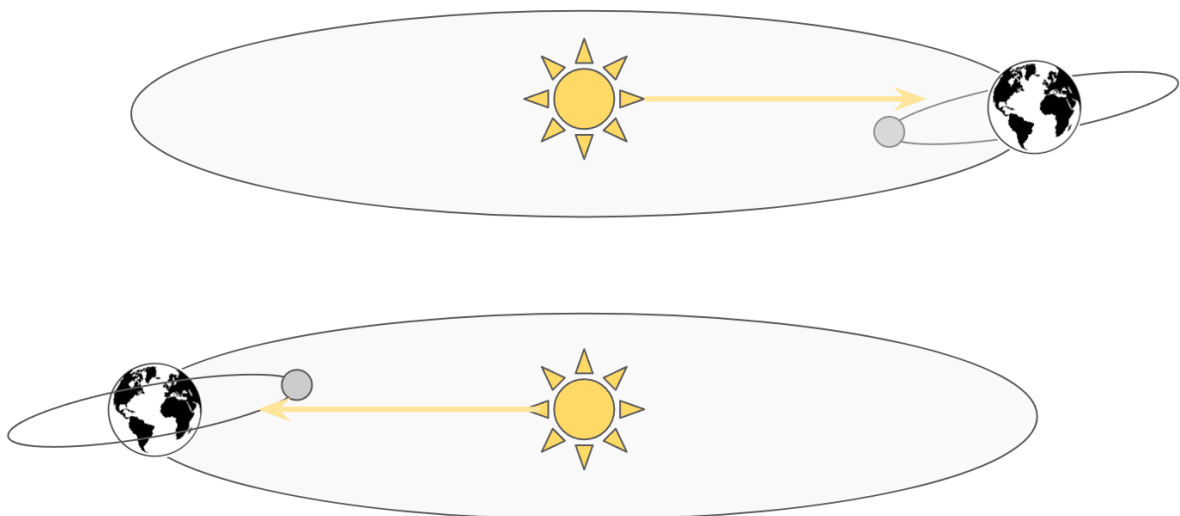
Two models show the Moon and Earth cast their umbral and penumbral shadows.

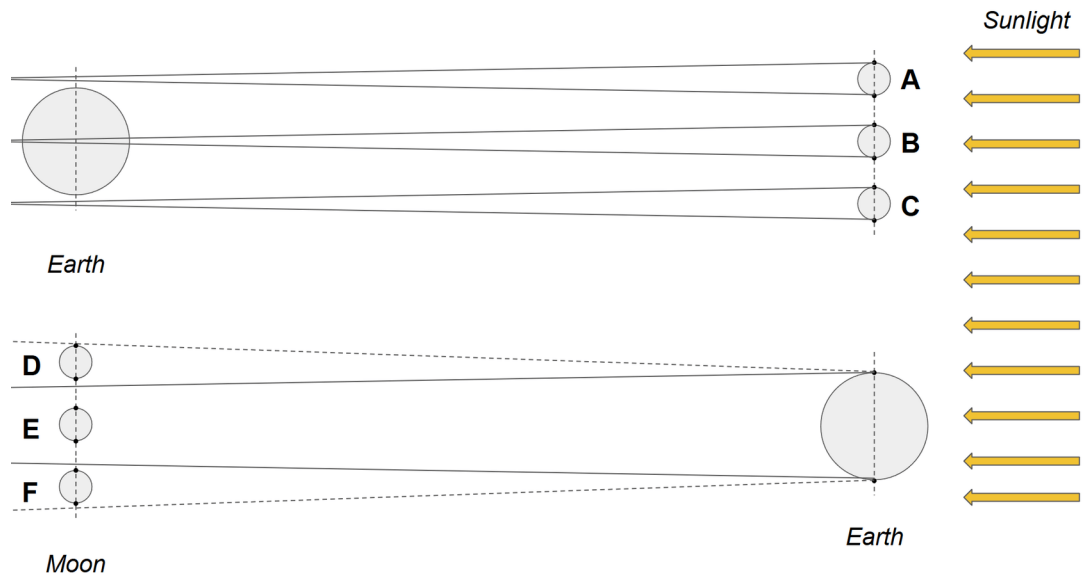
1. *Examine the top model (solar eclipse).*
 1. Which people (A-E) are in the **umbra** and experience the full solar eclipse?
 2. Is the **umbra** a smaller or larger shadow than the basic shadow from 1.7.1?
 3. Which people (A-E) are in the **penumbra** and experience a partial solar eclipse?
 4. Is the **penumbra** a smaller or larger shadow than the basic shadow from 1.7.1?
2. *Examine the bottom model (lunar eclipse).*
 1. Is the moon in the umbra or penumbra in this model? Is there any difference in how many people can see it compared to the model in 1.7.1?

1.7.3 The Moon's Tilted Axis

Model

The orbital axis of the moon is actually tilted with respect to the Earth's orbit around the sun. Depending on where the Earth is in it's orbit, the new moon (responsible for solar eclipses) can be above or below a line from the sun to the Earth.





Two models show the umbral and penumbral shadows from the Earth and Moon with multiple moon positions.

1. Which moon position(s) (A-C) will create a shadow on Earth and result in a solar eclipse?
2. Why won't the other moon position(s) result in a solar eclipse?
3. Which moon position(s) (D-E) will be in the full shadow of the Earth and appear as a total lunar eclipse?
4. Which moon position(s) (D-E) will be in the partial shadow of the Earth and appear as a lesser (penumbral) lunar eclipse?
5. Summarize all the ideas about solar eclipses:
 1. What conditions need to be met in order for a total solar eclipse to occur?
 2. What is this a rare event that not everyone on Earth is able to experience?

2: ORBITS AND GRAVITATION

2.1: Newtonian Gravitation

2.2: Tides

2.3: Kepler Orbits

2.4: Transfer Orbits

2.5: Newtonian Orbits

2.6: Tour of the Solar System and Space Missions

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2.1: Newtonian Gravitation

2.1.1 Gravity and No Gravity

Model

A satellite orbits around the Earth on the path shown. On the figure, draw an arrow on the satellite to show the direction it is moving at this snapshot in time.



Satellite orbiting Earth with position marked for analyzing motion under changing gravity.

1. Imagine that at this moment in time, the force of gravity increased. Draw the path the satellite would travel and label the path **“More Gravity.”** Explain your thinking. How did you determine this path?
2. Imagine that at this moment in time, the force of gravity decreased. Draw the path the satellite would travel and label the path **“Less Gravity.”** Explain your thinking. How did you determine this path?
3. Imagine that at this moment in time, the force of gravity was turned off. Draw the path the satellite would travel and label the path **“No Gravity.”** Explain your thinking. How did you determine this path?

Summary

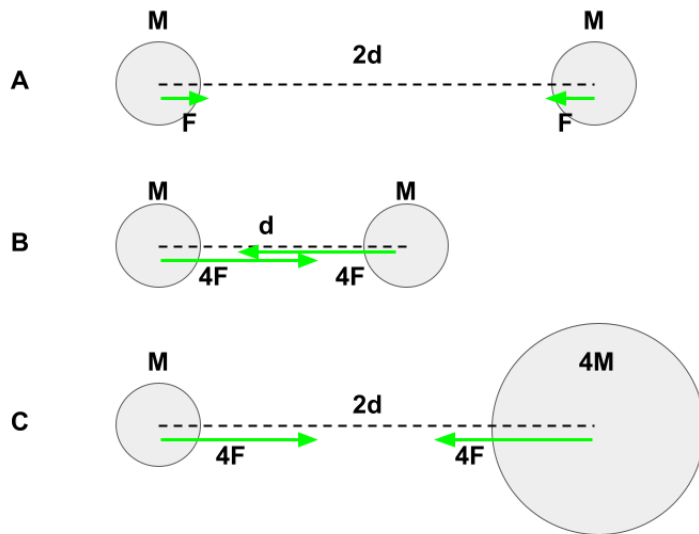
When there are no forces acting on an object in motion, that object will:

Forces cause objects to:

2.1.2 Force of Gravity: Mass and Distance

Model

In the model below, pairs of objects are shown at different distances. The arrows represent the **gravitational force** between the objects. A larger arrow means more force.



Object pairs A, B, and C comparing masses, distances, and gravitational forces.

- Identify the following comparisons. These do not need to be CER format:
 - Compare A and B. What changed about the distance between the objects and the masses of the objects? What changed about the force of gravity between the objects?
 - Compare A and C. What changed about the distance between the objects and the masses of the objects? What changed about the force of gravity between the objects?
 - For each pair of objects, how does the force experienced by the object on the left compare to the force experienced by the object on the right?
- Summarize as a CER (you might use your comparisons as evidence): What makes the force of gravity go up? What makes the force of gravity go down?

Summary

Forces are interactions between two objects that push or pull the objects. These forces change the way an object moves. Forces always come in pairs. In any interaction, each object experiences the same force in opposite directions. This equal and opposite relationship is called **Newton's Third Law**.

The strength of the force of gravity is related to the mass of the interacting objects and the distance between the center of mass of those objects. Both objects experience the same force but in opposite directions. The strength of this force is represented by the relationship:

$$F_{\text{gravity}} \propto \frac{m_1 \times m_2}{r^2}$$

Apply

Rank the following pairs of objects from lowest gravitational force to highest gravitational force. Try putting the values given into the proportional relationship above. You may use a calculator.

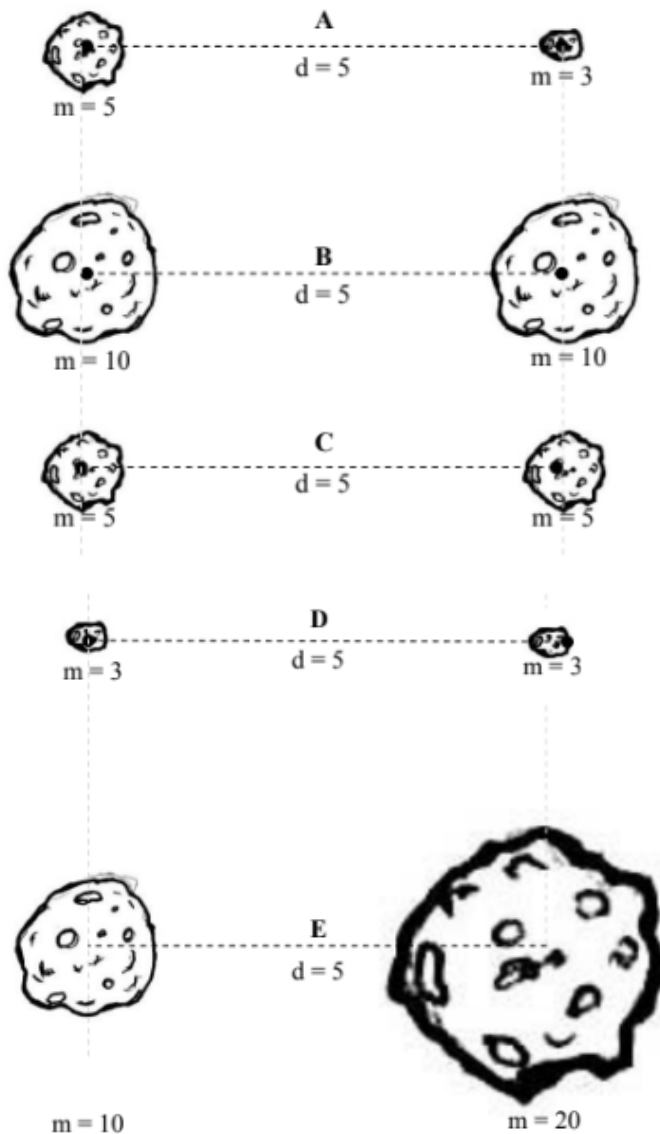
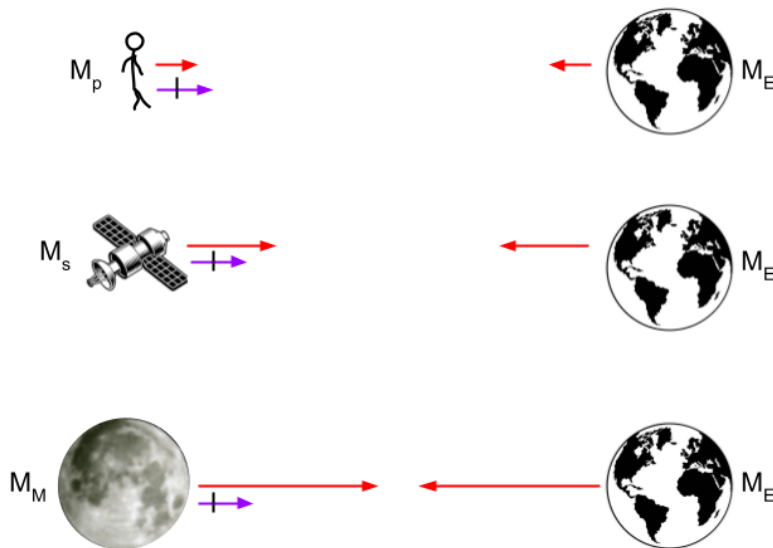


Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

2.1.3 Force and Motion

Model

In the model below, the force of gravity and acceleration of gravity are shown for three objects. On each object, the top arrow represents the force of gravity that we just explored. The bottom arrow represents the acceleration of the object, which represents how the motion changes based on the force of gravity.



Earth and three objects showing varying gravity force arrows and equal acceleration arrows.

1. For each Earth–object pair, how does the force of gravity on the object compare to the force of gravity on the Earth?
2. Compare across objects. Rank the forces of gravity that each object experiences.

Same F for all Objects OR Greatest _____ **Least**

3. Based on your responses, predict how the masses of the three objects (not Earth) compare.

Same M for all Objects OR Greatest _____ **Least**

4. Compare across objects. Rank the acceleration of gravity that each object experiences.

Same a for all Objects OR Greatest _____ **Least**

5. Use your responses to make a connection between force, mass, and acceleration. Circle the statement that best matches the patterns you see:
 - Mass does not affect acceleration.
 - With more mass you need more force to get the same acceleration.
 - With more mass you need less force to get the same acceleration.

Summary

The net force (ΣF) acting on an object is equal to the product of the mass of the object and the object's acceleration. This relationship is called **Newton's Second Law**.

$$\Sigma F = ma$$

The net force causes this acceleration. When objects have more mass, they experience less acceleration for the same net force. You can say this another way by rearranging the equation:

$$a = \frac{\Sigma F}{m}$$

To get the same acceleration, you need more force on objects with more mass. For curved motion, acceleration points inward toward the center of the curve.

With gravity, more mass leads to more force, so the mass of the object ends up canceling out. The acceleration is only based on the mass of the other object and the distance between the two objects.

$$F_g \propto \frac{m_1 \times m_2}{d^2}$$

$$a_1 \propto \frac{m_2}{d^2}$$

2.1.4 Multiple Forces

Model

In this model, there are three objects that exert gravitational forces on each other.

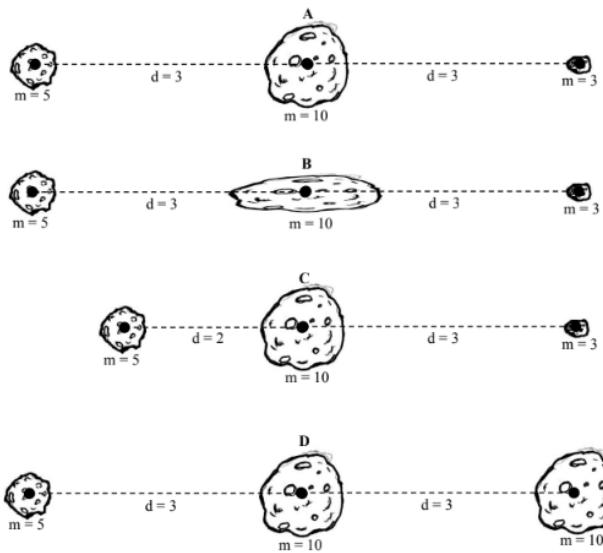


Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

1. Draw a force arrow on each middle object. Make the length represent the strength of the force, so if the force to the left is greater than to the right, make the arrow to the left longer than the arrow to the right.
2. Next to each object, write what direction it will change its motion.
3. Next to the objects on the left, draw an arrow to represent the force from both the middle and right-most object. Scale them to show which force is bigger.
4. Next to the objects on the right, draw an arrow to represent the force from both the middle and left-most object. Scale them to show which force is bigger.
5. When an object interacts with two other objects, do you simply add the forces together? If not, explain how you identify the change in motion of an object when there is more than one force acting on that object.

Summary

Forces have _____ and _____. When adding two or more forces together, you need to take both into account.

The change in motion of the object is based on the _____ force acting on that object.

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2.2: Tides

Tides from the Earth-Moon System

Recall the relationships we found for the force of gravity and the acceleration due to gravity:

$$F_g \propto \frac{m_1 \times m_2}{d^2}$$

$$a_1 \propto \frac{m_2}{d^2}$$

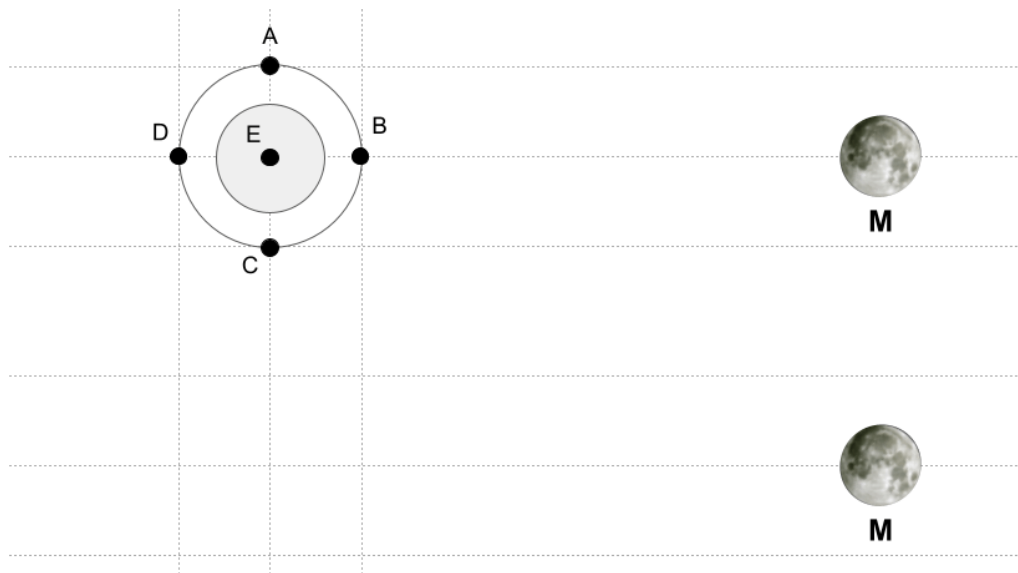
In this activity, we will focus on the effect of gravity, which means focusing on acceleration. Use this proportionality to determine relative amounts of motion in this activity:

$$a_1 \propto \frac{m_2}{d^2}$$

2.2.1 The Gravitational Pull of the Moon

Model

The Earth is shown as a gray circle below. The ring around the Earth represents the ocean. The diagram is not to scale. The Moon exerts a gravitational force on both the Earth and its oceans.



Earth and surrounding ocean ring with labeled points showing Moon's gravitational effect.

1. Compare the mass of the Moon for all lettered points.

Same M for all Points OR Greatest _____ **Least**

2. Compare the distance between the Moon and each of the lettered points.

Same d for all Points OR Greatest _____ **Least**

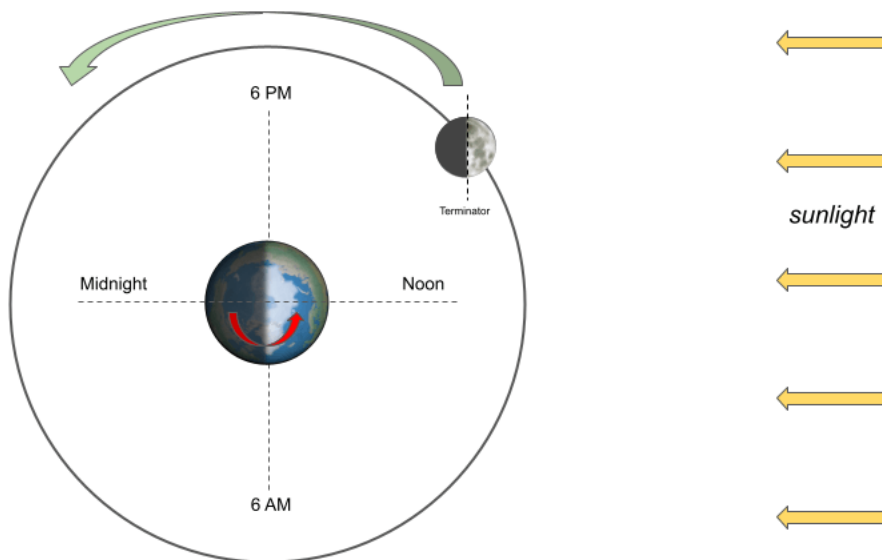
3. How should the acceleration (g) compare for each of the lettered points?

Same a for all Points OR Greatest _____ Least

4. Based on your responses, construct a new model below the first that shows how the Earth and oceans respond to the Moon's gravitational pull:
 - Draw arrows on each point to show the direction of the acceleration. Make the size of the arrows match what you said in the previous question.
 - On the lines below the original image, shift the points based on the length and direction of the arrows. They might not all shift the same amount.
 - Draw a new Earth circle centered around the E dot. Be sure to draw it the same size as the model above.
 - Use curved lines to connect dots A–D to make a new circle/oval. This represents the surface of the oceans.
5. Examine the sea level compared to the Earth. Label portions of the Earth **High Tide** and **Low Tide**.
6. Summarize: Where on Earth do high tides occur?

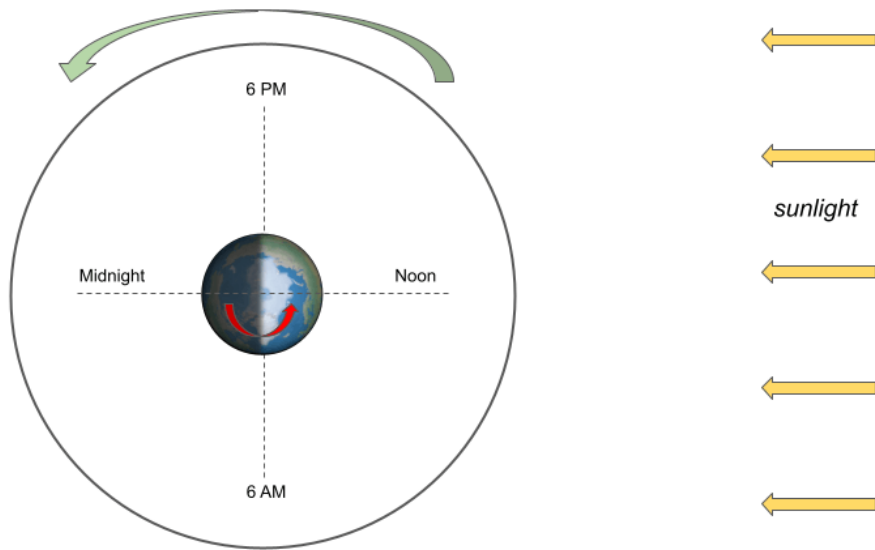
2.2.2 Tide Schedule

Model



Earth–Moon–Sun system used to model high tides, low tides, and tidal timing.

1. Draw in the ocean to show what you learned about high and low tides, based on the position of the Moon.
2. Label the time(s) of day that correspond to high tide.
3. For the Earth on the diagram below, there is a high tide that occurs at 9 PM.
 - Draw in the ocean to show high and low tides.
 - Draw the position of the Moon to make this occur.
 - Draw the phase of the Moon when it is in this position.



2.3: Kepler Orbits

2.3.1 Exploring Orbits

Model

Go to the simulation: <https://tinyurl.com/mysolarsystemPHET>

Make adjustments and click the options to show the velocity and force. Before running the simulation, always click the button to **"Follow Center of Mass"**.

Pay attention to:

- Orbital Shape
- Orbital Velocity (Green Arrow)
- Gravitational Force (Purple Arrow)
- Orbital Period

Complete the table to record what you observe:

Exploring Orbits Observations

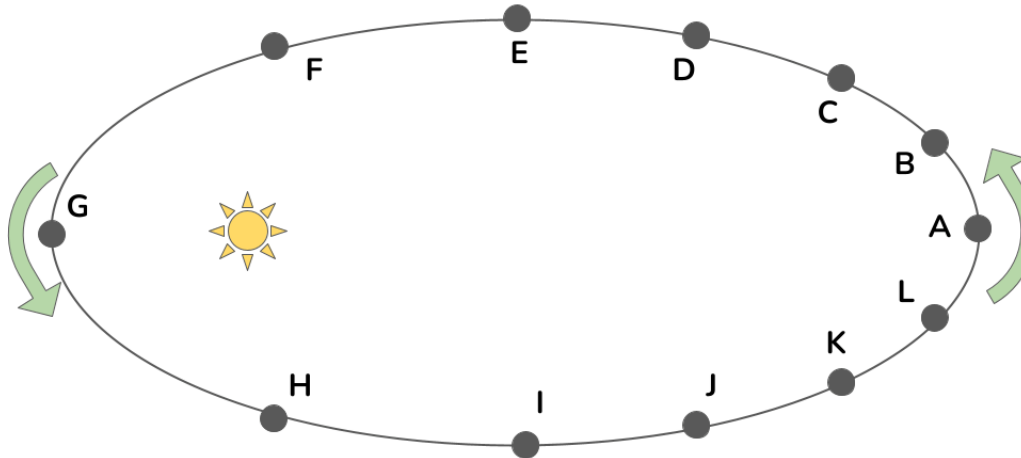
We Will Change...	We Predict...	We Observed...

1. **Summarize:** Construct one or more CERs to identify patterns or summarize what determines the orbits of a two-body system.
-

2.3.2 Kepler Orbits

Model

The model below shows a planet at different positions in it's orbit around a star. The same amount of time elapses between successive letters (A to B, B to C, etc.).

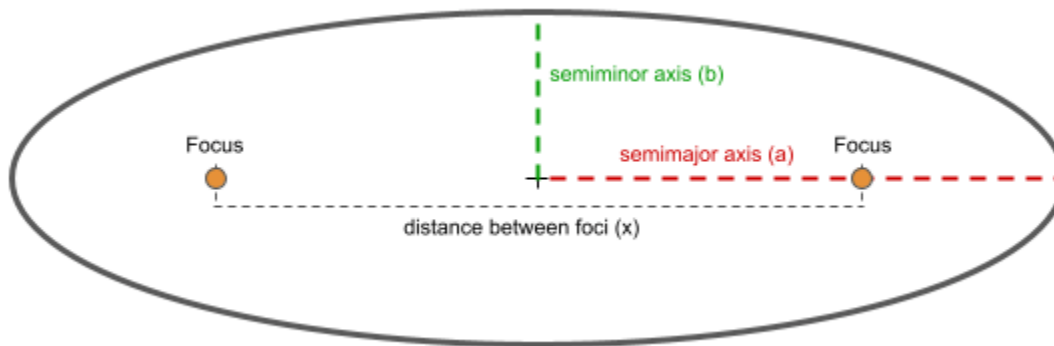


Adapted from Lecture-Tutorials for Introductory Astronomy, Second Edition

Planet orbit with labeled positions showing changing orbital speed around a star.

1. Does the planet appear to travel the same distance each month?
2. At which positions is the planet moving the fastest? The slowest? Explain.
3. At position D, is the speed of the planet increasing or decreasing? Explain.
4. Draw a line between each lettered position of the planet and the center of the star. Describe how the wedges that form between planet positions compare.
5. Create a concise statement that describes the relationship between a planet's orbital speed and its distance from its companion star.

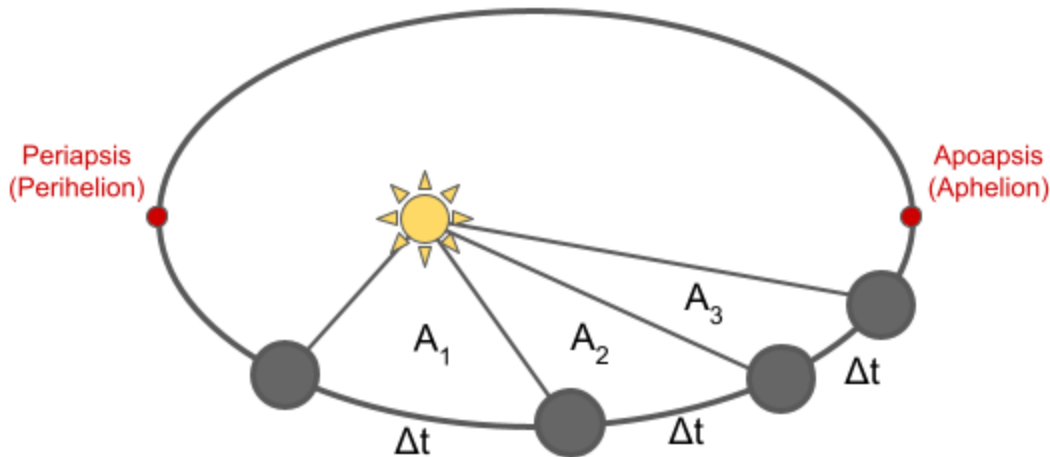
Summary



eccentricity

$$e = \frac{x}{2a}$$

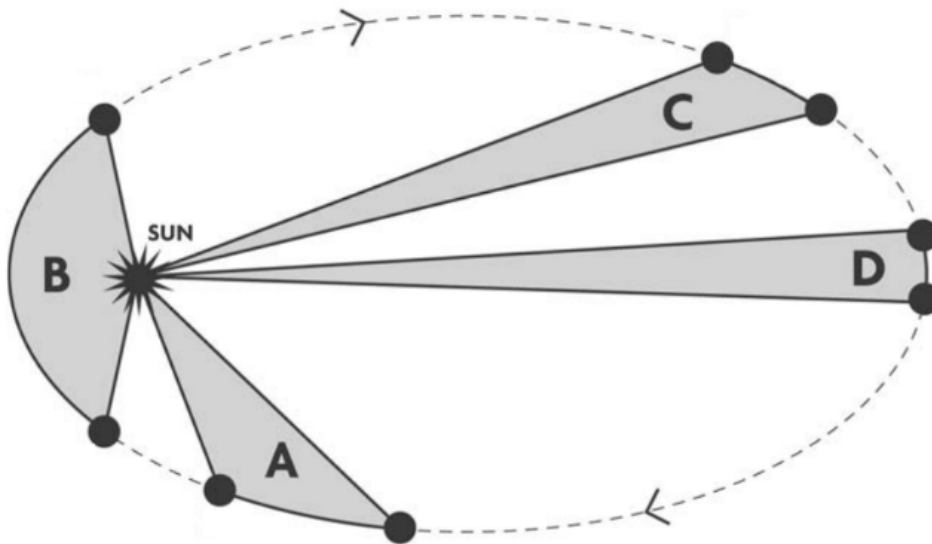
Kepler's First Law states that the orbital path of planets trace out an **ellipse** which has two foci. The star (or other parent body) is at one focus and the other focus is empty. The **eccentricity** of the ellipse is the distance between each focus divided by twice the semimajor axis. A circle has an eccentricity of zero.



As objects travel in their orbit, they trace out **Equal Area** wedges in **Equal Amounts of Time**. This relationship is known as **Kepler's Second Law**.

2.3.3 Arcs and Areas in an Orbit

Model



Elliptical orbit divided into wedges showing orbital arcs and equal-area sectors.

Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

Information Processing

1. Identify some evidence (No CER needed)
 1. Which wedge is the widest (biggest angle)? Is the planet close or far from the star in that portion?
 2. Which wedge is the narrowest (smallest angle)? Is the planet close or far from the star in that portion?

- How do the areas of each wedge (approximately) compare?

Critical Thinking: Write a CER response:

- How do you think the length of time it takes for the planet to traverse the arc of each wedge compares?

2.3.4 Orbital Period

Model

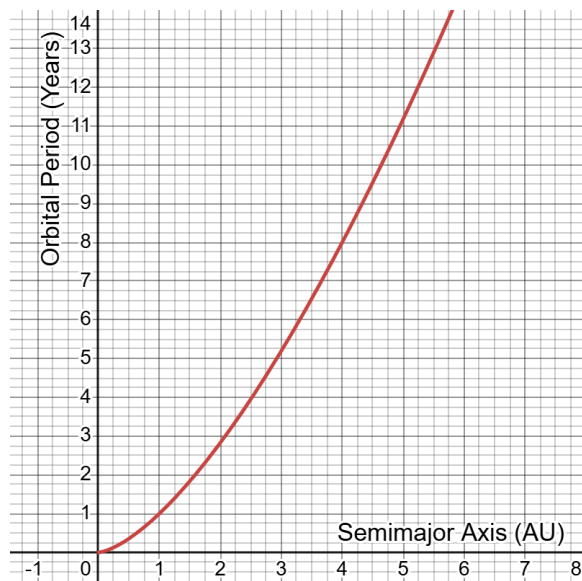
In a **Planetarium** or using planetarium software (eg, [World Wide Telescope](#)), view the orbits of planets in our solar system. All planets orbit the same object (the Sun) but their orbits are different.

- What planet is traveling the fastest? Is it close or far from the Sun?
- What planet is traveling the slowest? Is it close or far from the Sun?
- What planet takes the most time to complete an orbit (Period)? Is it close or far from the Sun?
- What planet takes the least time to complete an orbit (Period)? Is it close or far from the Sun?

2.3.5 Kepler Law 3

Model

This graph shows how the orbital period (time to complete one orbit) of an object in our solar system varies with distance. An AU is an Astronomical Unit and is equal to the average distance between the Earth and the Sun. This graph was created using [Desmos](#).



- When satellites are closer to the object they orbit, is the orbital period longer or shorter?
- If I double the size of the orbit (orbital distance), does the orbital period double? If not, is it more than double or less than double? Cite examples from the graph.

Summary

The relationship between the orbital distance and orbital period is given by the equation:

$$P^2 \propto a^3$$

This equation is known as **Kepler's 3rd Law**. The symbol $\propto$ means “proportional to” and shows a general trend relationship. The exact equation was determined later by Isaac Newton.

Kepler's third law becomes an equality when used for objects in our solar system if the period is measured in years and the semimajor axis is measured in Earth–Sun distances, which are called Astronomical Units (AU).

Apply

The table below provides a partial list of the orbital periods (in years) and orbital distances (in AU) for six planets orbiting a one solar-mass star. The mass of each planet is also provided (in Earth masses). Rank the orbital periods of the planets. It might help to determine some of the unknown values.

Activity Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

Planet	Orbital Distance (AU)	Orbital Period (Years)	Mass (Earth Masses)
A		20	500
B	0.8		375
C	3.0		100
D		2.0	50
E	5.0		3
F		3.5	0.5

2.3.6 Orbital Speed

Model

The equations below identify an approximate average speed by using Kepler's Third Law ($P^2 = a^3$) and assuming a circular orbit. They originate by taking the circumference of that orbit ($2\pi a$) and dividing by the time (period, P).

These equations are only valid for objects orbiting a solar-mass star and the units are in Astronomical Units per Year (AU/year).

$$v_{avg} = \frac{2\pi a}{P}$$

$$v_{avg} = \frac{2\pi}{P^{1/3}}$$

$$v_{avg} = \frac{2\pi}{a^{1/2}}$$

1. Use the equations, along with Kepler's 3rd Law, to complete this table for the planets in our solar system.

Orbital Speed Table

Planet	Orbital Distance	Orbital Period	Orbital Speed
Mercury	0.4 AU		
Venus	0.1 AU		
Earth	1.0 AU		
Mars	1.5 AU		

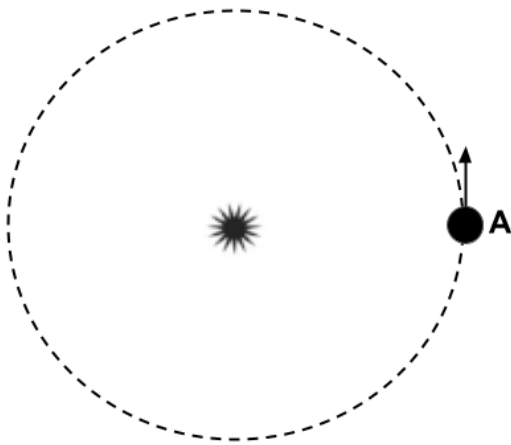
Planet	Orbital Distance	Orbital Period	Orbital Speed
Jupiter	5.2 AU		
Saturn	9.6 AU		
Uranus	19.2 AU		
Neptune	30 AU		

2.4: Transfer Orbits

2.4.1 Speeding Up

Model

Observe the simulation at <https://tinyurl.com/mysolarsystemPHET> to see how changing the speed of an orbiting object changes the orbit itself. An object makes a circular orbit around a star. At point A, the speed of the object increases from that circular orbit speed.

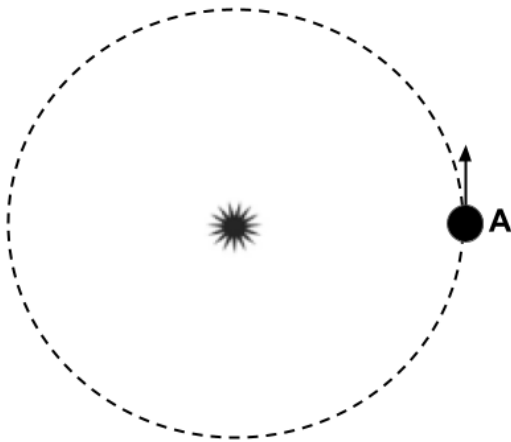


1. Draw out the new orbit as a dashed line.
2. Put a dot at the point on the orbit that is directly on the other side of the star as Point A. Label it B.
3. Is Point B a periapsis or apoapsis? Is the object moving faster or slower at Point B than at Point A?
4. Does increasing the speed of an object in circular orbit push the other side of the orbit further from the star or does it pull the other side of the orbit closer in to the star?

2.4.2 Slowing Down

Model

Observe the simulation at <https://tinyurl.com/mysolarsystemPHET> to see how changing the speed of an orbiting object changes the orbit itself. An object makes a circular orbit around a star. At point A, the speed of the object decreases from that circular orbit speed.

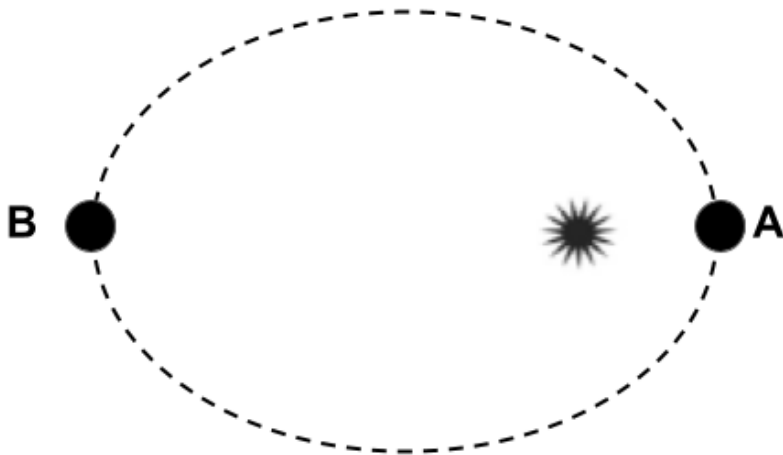


1. Draw out the new orbit as a dashed line.
2. Put a dot at the point on the orbit that is directly on the other side of the star as Point A. Label it C.
3. Is Point C a periapsis or apoapsis? Is the object moving faster or slower at Point C than at Point A?
4. Does increasing the speed of an object in circular orbit push the other side of the orbit further from the star or does it pull the other side of the orbit closer in to the star?

2.4.3 Adjusting to Circular Orbits from Elliptical Orbits

Model

The model below shows an elliptical orbit of a satellite around a star. Points A and B are the periapsis and apoapsis of the orbit.

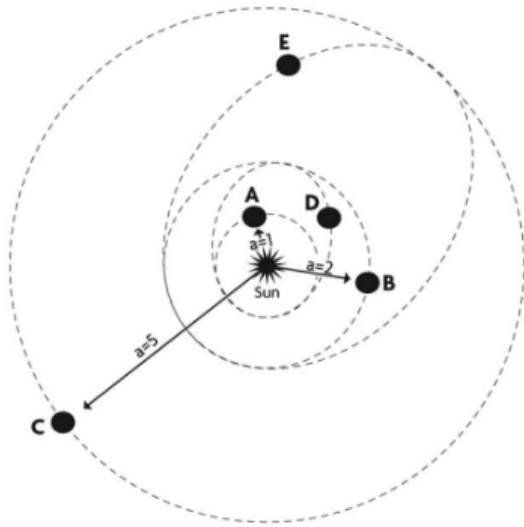


1. Is the planet moving faster at point A or B? Explain how you know.
2. In order to turn the orbit into a circular orbit that includes point A, should the satellite speed up or slow down at point A? Explain your reasoning.
3. In order to turn the orbit into a circular orbit that includes point B, should the satellite speed up or slow down at point A? Explain your reasoning.

4. What should be at the center of both circular orbits?
 5. Draw both circular orbits.
-

2.4.4 Many Orbits

Model



Multiple circular orbits A–E around a star used to compare orbital speeds.

Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

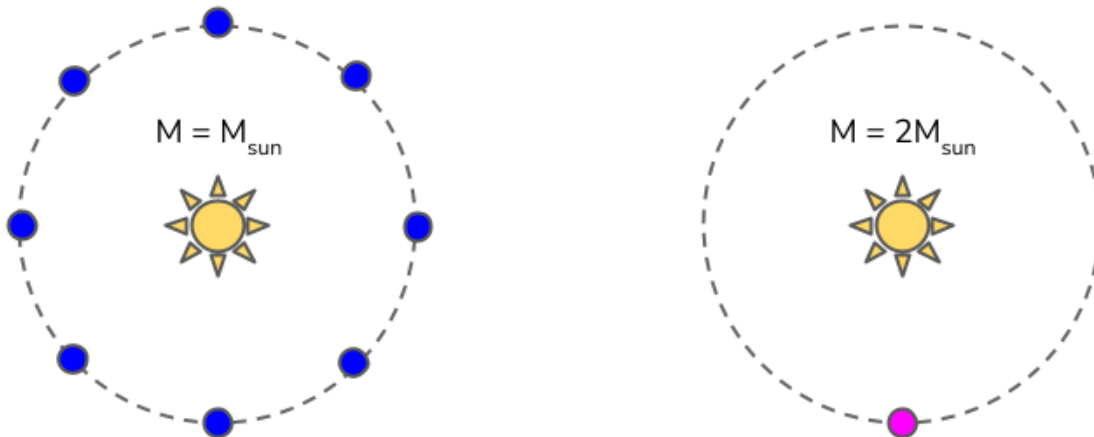
1. Which orbit (A–E) is the fastest? How do you know?
 2. Which orbit (A–E) is the slowest? How do you know?
 3. Describe the process (speeding up / slowing down) to get from circular orbit A to circular orbit B.
 4. Describe the process (speeding up / slowing down) to get from circular orbit C to circular orbit B.
 5. In general, what is the process to change the size of a circular orbit?
-

2.5: Newtonian Orbits

2.5.1 Circular Orbital Speed

Model

This model shows two gravitational orbits of an object around a star. The stars have different masses, as shown. Assume the orbiting object is the same object in both systems.



Two different star–planet orbit systems with different star masses for comparing orbital speed.

1. Which orbiting system (left or right) will have a stronger force of gravity? Explain your reasoning.
2. Which orbiting system (left or right) do you think will have a faster moving planet? Explain your reasoning.
3. Based on your response above, draw additional dots for the system on the right around the orbit. Assume the same amount of time between dots as the model on the left, so decide if they should be further apart or closer together. Explain your reasoning.

Summary

The speed of a circular orbit does not depend on the mass of the orbiting object (for example, a planet). It depends on the mass of the object being orbited (for example, a star) and the distance between the planet and the star.

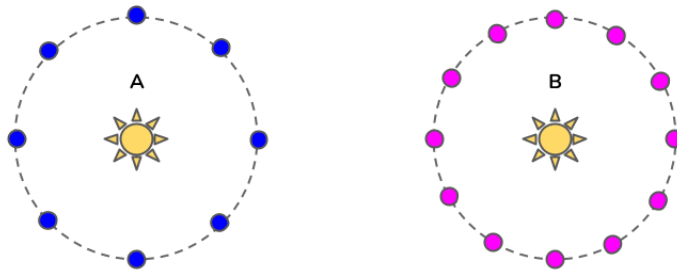
It is based on the strength of gravity and follows the relationship:

$$v_{\text{circular orbit}} \propto \sqrt{\frac{M}{r}}$$

2.5.2 Weighing a Star

Model

The model below shows two orbits of planets around different stars. Assume the same amount of time elapses between each dot in the orbit.



Two planetary orbits with equal time markers used to compare star masses.

1. Which orbit has a faster moving planet? Explain how “speed” can be determined on these dot models of an orbit.
2. Which orbit must have a more massive star? Explain your reasoning.
3. Explain how we can use measurements of a satellite orbit to determine (or at least compare) the mass of the central body that satellite orbits.

Summary

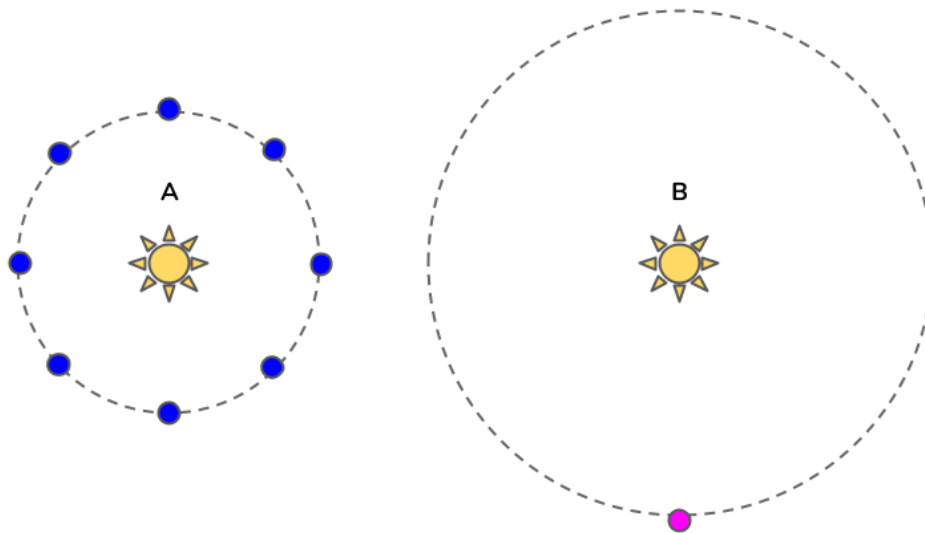
We can rearrange the same equation from earlier to show that the mass of the central body can be determined by the relationship:

$$M_{\text{central body}} \propto v^2 r$$

2.5.3 Speed on an Orbit

Model

In the model below, the speed of the satellite is the same for both objects.



Two satellite orbits of different sizes with equal orbital speed for comparison.

1. Which orbit (A or B) is a bigger path?
2. If the satellites travel at the same speed, how will the length of time needed for each satellite to complete one orbit compare?
3. If we put dots at equal intervals of time, which orbit will have more dots? Explain your reasoning.
4. Draw the dots to show the orbit for the satellite on the right. Make sure they represent the same amount of time between dots as the orbit on the left.

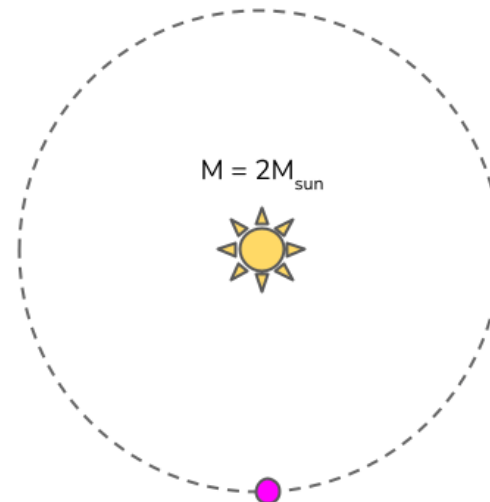
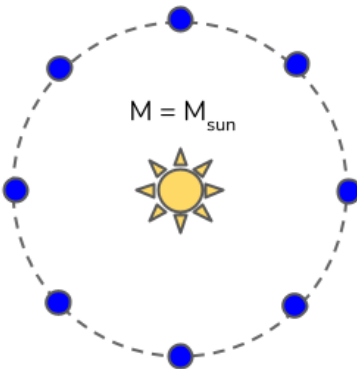
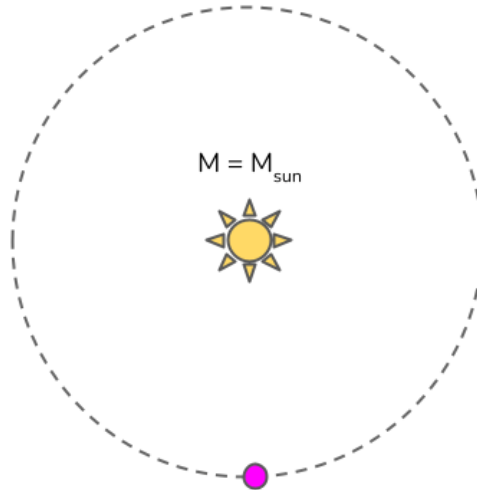
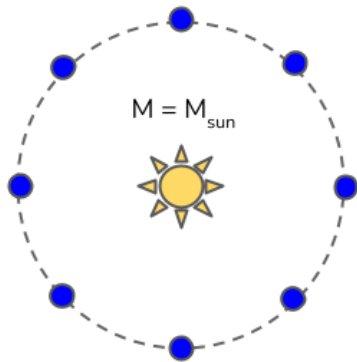
Summary

The speed of the orbiting satellite is represented in this model by the spacing between the dots.

Apply

Use the orbit on the left to complete the model for the orbit on the right, based on the values given for M and r .

Explain your reasoning for each model based on how the speed of each satellite should compare. Then identify which orbit takes longer to complete.



Radius is
Double

Summary

The time it takes for a satellite to complete one orbit is called the **orbital period**.

It depends on the radius of the orbit and the mass of the central body and is related by the equation:

$$P_{\text{satellite}} \propto \sqrt{\frac{r^3}{M_{\text{central body}} + m_{\text{satellite}}}}$$

We will not use this equation much, but the powers in the equation show that the period increases with radius and decreases with mass.

The radius plays a bigger role than mass because it is raised to the third power.

This equation can be thought of as:

$$P_{\text{satellite}} \propto \sqrt{\frac{\text{radius} \times \text{radius} \times \text{radius}}{M_{\text{central body}} + m_{\text{satellite}}}}$$

2.6: Tour of the Solar System and Space Missions

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3: LIGHT AND ASTRONOMICAL MEASUREMENTS

- 3.1: Electromagnetic (EM) Radiation
- 3.2: Measuring Light
- 3.3: Luminosity Plots
- 3.4: Determining Speed with the Doppler Method
- 3.5: Detecting Exoplanets with the Doppler Method
- 3.6: Detecting Exoplanets with the Transit Method
- 3.7: Spectroscopy
- 3.8: Applications of Spectroscopy

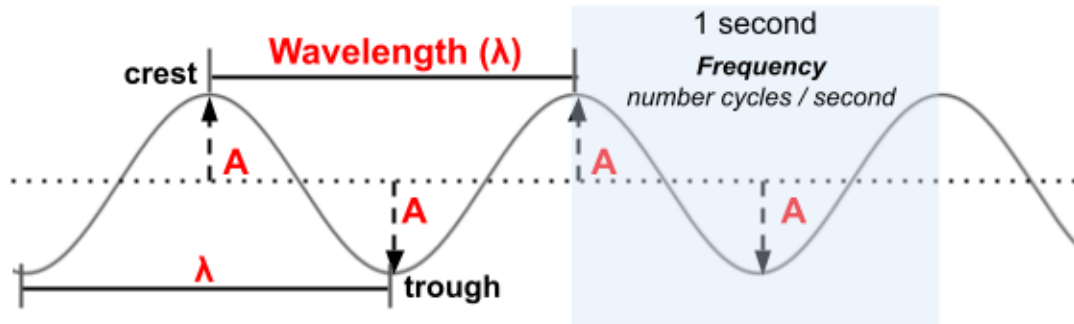
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3.1: Electromagnetic (EM) Radiation

1. Electromagnetic Radiation

1.1 Wavelength Model

Model



Wavespeed Equation

$$v = \lambda f$$

For light, $v = c = 3 \times 10^8 \text{ m/s}$ in a vacuum

$$\lambda = c/f \quad \text{and} \quad f = c/\lambda$$

Wave diagram showing wavelength, amplitude, and frequency for comparing wave properties.

1. What is the difference between wavelength (λ) and amplitude (A)?
2. How would a wave look if it had a higher frequency?
3. Two waves are traveling at the same speed, but one has a higher frequency. Will it have a longer or shorter wavelength? Explain your reasoning and then draw both waves.

Student Drawing Area

1.2 Colors of Light

Model

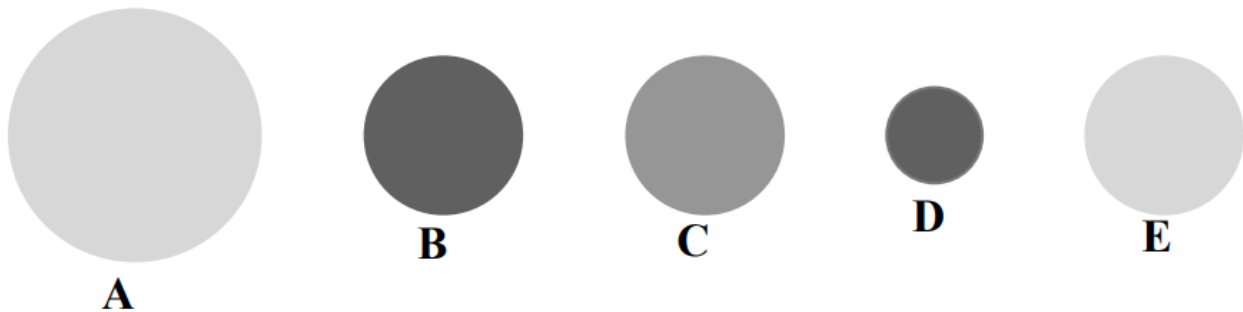
Image needed here with Alt Text: Visible light spectrum showing colors arranged by wavelength and frequency.

1. What is different about the different colors of light?
2. Compare violet (purple) light and red light: Which has a longer wavelength and which has a shorter wavelength?
3. If violet and red light travel past you at the same speed, which color will have more crests pass by you in a given amount of time (frequency)?
4. Identify a pattern: For light, when wavelength increases, frequency:

1.3 Blackbody Radiation

Model

The model below shows different size hotplates. The hotplates that are a lighter color are hotter. Imagine you place a pot with the same amount of water on each burner and heat it up until it boils.



Hotplates of different sizes and temperatures used to compare heating and luminosity.

Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

1. Which burner will boil the water fastest? Explain your reasoning.
2. Which burner will boil the water slowest? Explain your reasoning.
3. If two burners are the same size, what determines which burner will boil a pot of water faster? Explain your reasoning.
4. If two burners are the same temperature, what determines which burner will boil a pot of water faster? Explain your reasoning.
5. If you use two burners of different sizes, can you assume that the burner that boils water faster is at a higher temperature? Explain your reasoning.

Summary

Luminosity is based on temperature and size. Overall luminosity follows the pattern:

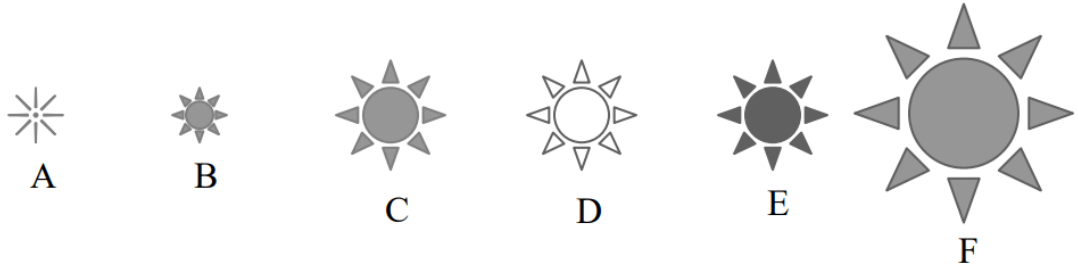
$$L \propto AT^4$$

This is equivalent to:

$$L \propto A \times T \times T \times T \times T$$

Apply

1. Compare the luminosity of the stars shown below. Explain your reasoning.



Star	A	B	C	D	E	F
Surface Area	1	1	2	2	2	4
Temperature	1000 K	2000 K	2000 K	3000 K	1000 K	2000 K

Stars of different sizes and temperatures used to compare luminosity.

Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

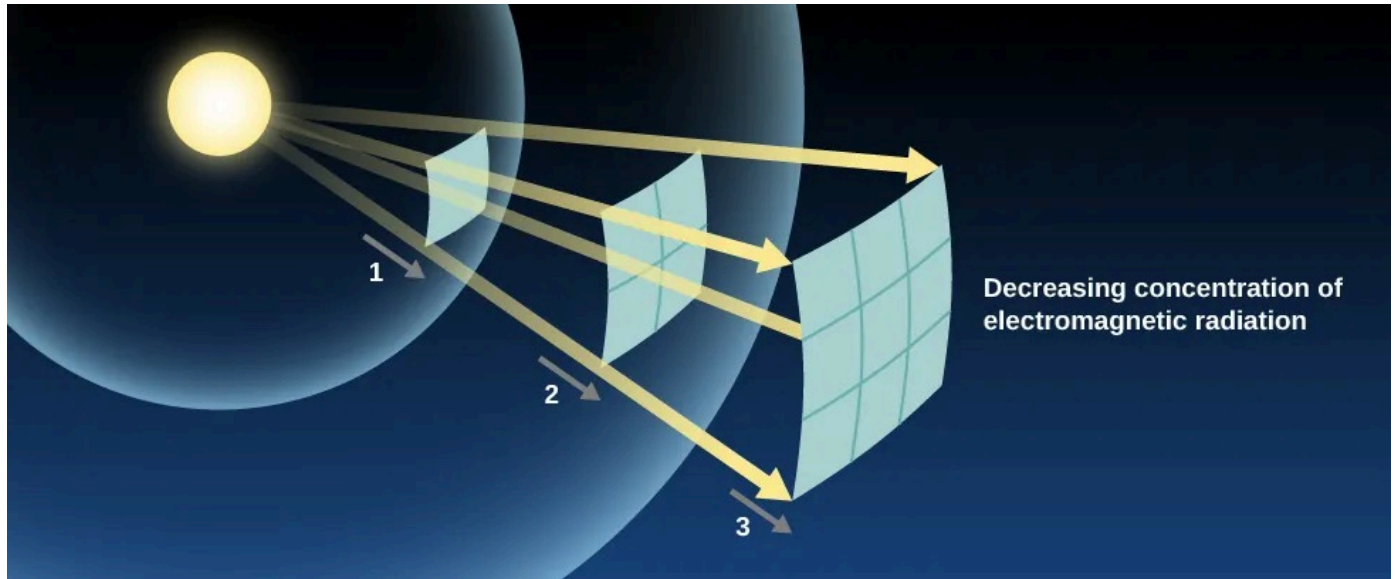
3.2: Measuring Light

1. Measuring Light

1.1 Inverse Square Law of Light

Model

The model below shows how light spreads out with distance. Each **single grid square** is the same size.



Light source illuminating expanding square regions at increasing distances from the source.

Image Credit: OpenStax Astronomy 2e (<https://openstax.org/details/books/astronomy-2e>)

- Identify answers to the following:
 - How should the total amount of light that is spread across the full square at each letter compare?
 - As distance from the source increases, does this light spread over a smaller or larger area?
- Construct a CER: How should the amount of light that is spread across **a single grid square** at each distance?
- The amount of light in a single grid square is the **brightness / intensity of light**. As you get farther from a source, does that brightness / intensity increase or decrease? Explain your reasoning.

Summary

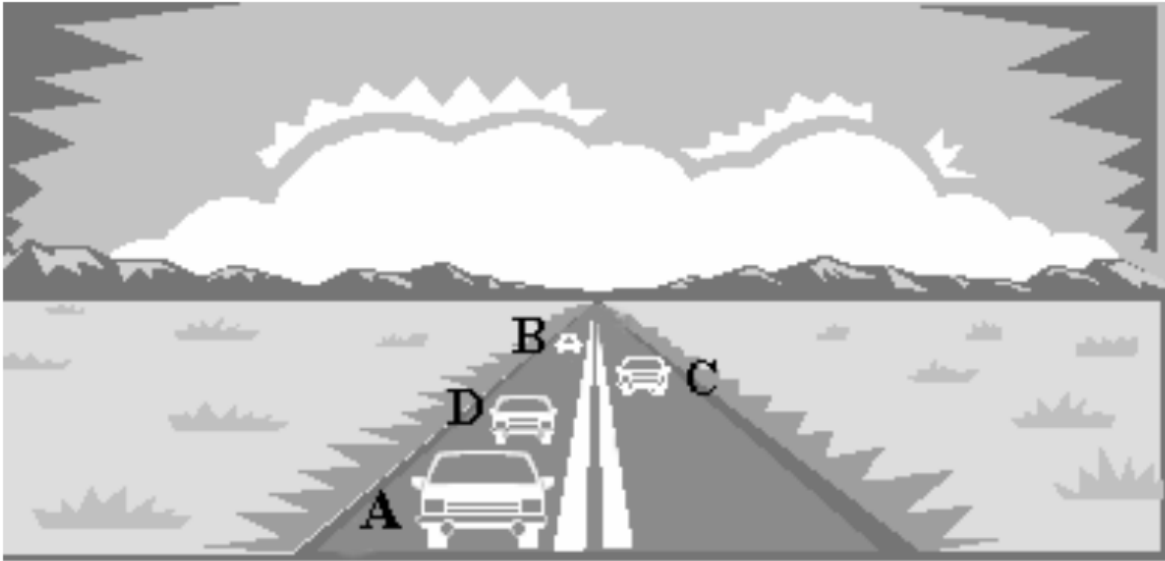
As you get farther from a light source, the brightness / intensity of the light:

Doubling the distance results in _____ of the brightness / intensity. This is called the _____.

1.2 Absolute and Relative Brightness

Model

On the road you see a number of identical cars with their headlights on.



Identical cars with headlights at different distances demonstrating apparent brightness.

Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

1. How do you think the amount of light given off by the headlights (Luminosity) compares for the different cars? Explain.
2. How do you think the brightness / intensity of the light as interpreted by your eye compares for the different cars? Explain.
3. If the road is really dark and you cannot see which car is farther and which car is closer, how could you figure out which car is farthest away?

Summary

Relative Magnitude refers to:

Absolute Magnitude refers to:

Absolute Magnitude is a standardization tool to compare stars regardless of their distance. The absolute magnitude of a star is its apparent magnitude when it is a distance of 10 parsecs away.

1.3 Measuring Distance Using Brightness

Model

The image below shows the apparent brightness of 5 stars from Earth. The darker shades represent dimmer stars.

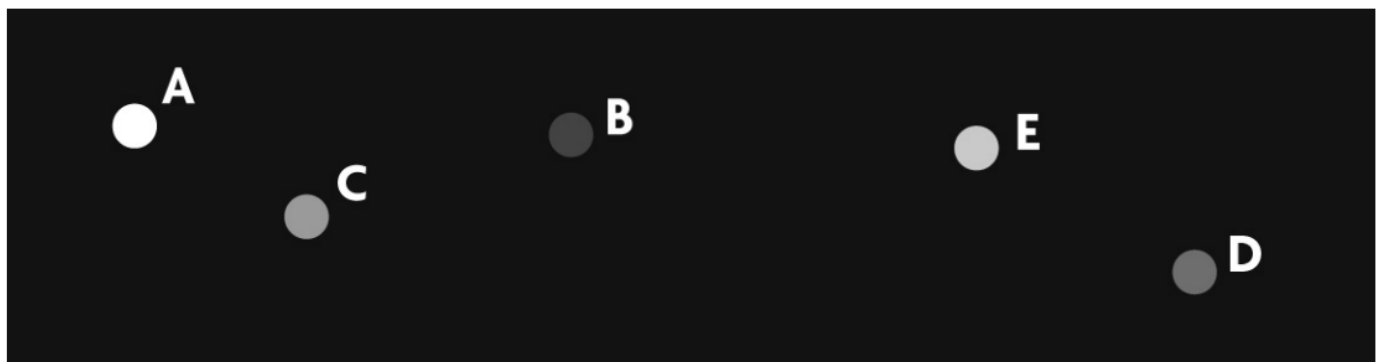


Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

The image below shows the absolute magnitude (luminosity) of the different stars. Lower numbers (including more negative values) mean greater luminosity.

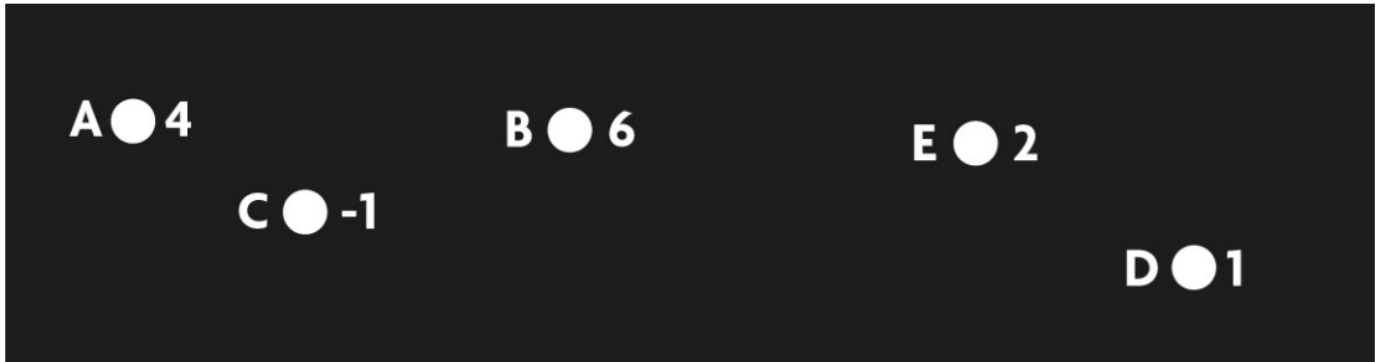


Image Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

1. Which star appears the brightest?
2. Which star has the greatest luminosity?
3. Which star appears the dimmest?
4. Which star has the least luminosity?
5. Rank the stars from closest to farthest away. Explain your reasoning.

Summary

If an object has a lower (more negative) absolute magnitude but appears dimmer, that means the object is _____ away.

1. Fill in the blanks in the table to identify the fraction of light received at each distance. Explain your reasoning below the table.

Activity Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

Fraction of Light Received at Different Distances

Distance	Fraction of Light Received
	1
	1/9
4	

Distance	Fraction of Light Received
1	
	1/4
3	

Reasoning

- Fill in the blanks in the table to identify how distance, luminosity, and apparent brightness are related.

Activity Credit: Astronomy Interactives from the Astronomy Education Department at the University of Nebraska-Lincoln (<https://astro.unl.edu/interactives/>)

Distance, Luminosity, and Apparent Brightness Relationships

Distance	Luminosity	Apparent Brightness
1		1
	2	2
2	4	
2		3/4
3	6	
	3	1/3

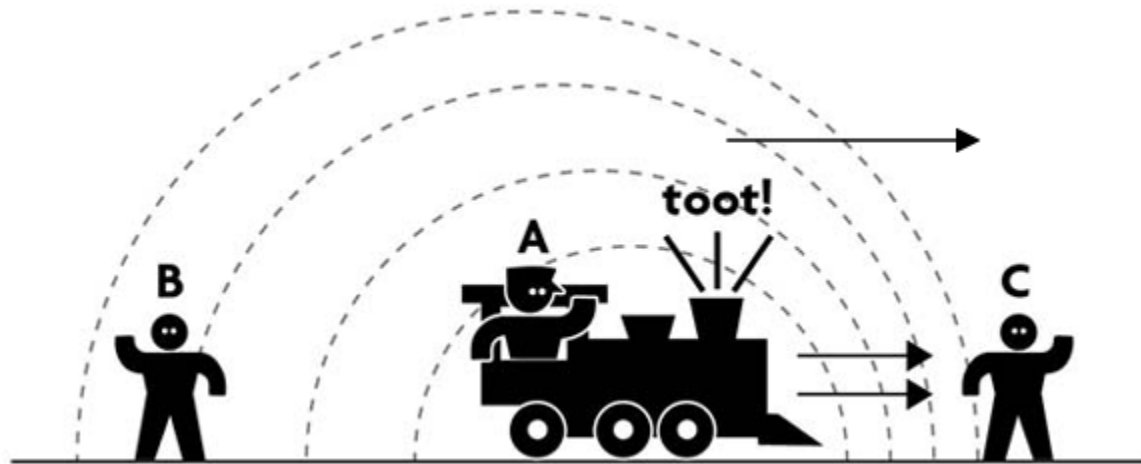
3.3: Luminosity Plots

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3.4: Determining Speed with the Doppler Method

3.4.1 Doppler Shift

Model



1. Which person (A, B, or C) is moving with the source of the sound?
2. Is the source of sound moving towards or away from person B? Is the wavelength of the waves bigger or smaller for that person?
3. Is the source of sound moving towards or away from person C? Is the wavelength of the waves bigger or smaller for that person?
4. Rank the wavelength of the waves that each person experiences from smallest to greatest.

Summary

When an object is moving towards you the wavelength is shifted to be _____ and the frequency is shifted to be _____.

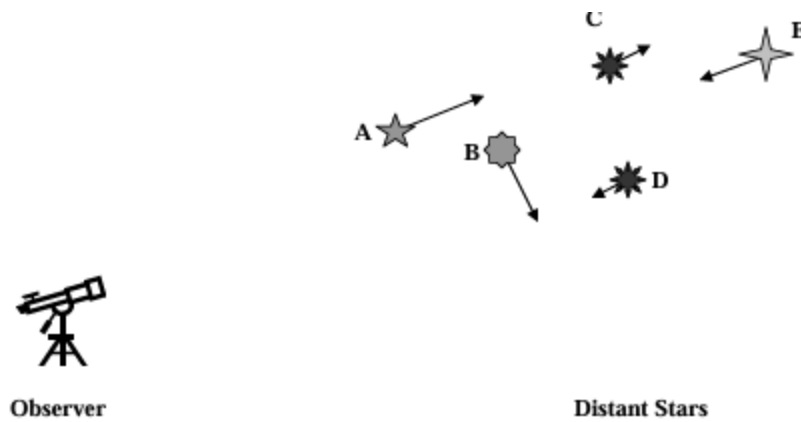
When an object is moving away from you the wavelength is shifted to be _____ and the frequency is shifted to be _____.

For light, shorter wavelengths mean bluer light and longer wavelengths mean redder light. We can then say the light is **blueshifted** or **redshifted**.

3.4.2 Predicting Shifted Light

Model

An observer looks at 5 stars with relative motion shown by their arrows.

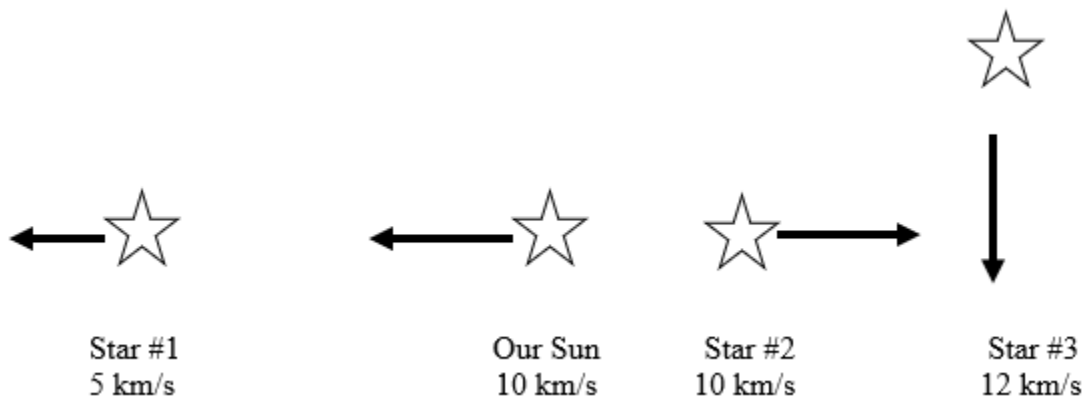


1. Which objects are moving towards the observer?
2. Which objects are moving away from the observer?
3. Are any objects not moving towards or away (even if they are moving)? If so, identify them and explain your thinking.
4. Label each letter as **redshifted**, **blueshifted**, or **no shift** based on the motion and the patterns we discovered earlier. Explain how you determined these labels here.

3.4.3 Determining Relative Speed

Model

We move with our sun and do not notice our own motion. Consider relative velocity as **towards you** if you get closer to that object over time and **away from you** if you get farther from that object over time.



1. Which star(s) ended up closer to our Sun than they started?
2. Which stars ended up farther away from our Sun than they started?
3. Use your responses to come up with a definition of **relative velocity**.
4. Using your definition, identify if the relative velocity of each star is towards or away from us.
5. Based on the relative velocity of each star, label each star as **redshifted**, **blueshifted**, or **no shift** based on the motion and the patterns we discovered earlier. Explain how you determined these labels here.

Summary

The relative velocity of a star is based on how it moves relative to us. We can simply subtract our velocity from the velocity towards or away from us for each star to figure out the relative velocity, but we have to do so using vectors, which can make the calculation more challenging when we have a two-dimensional problem like this.

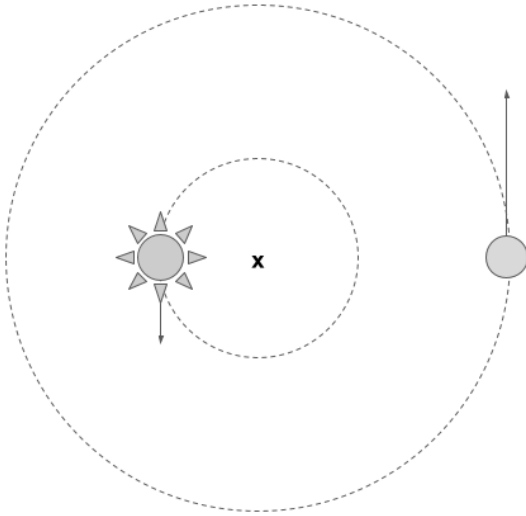
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3.5: Detecting Exoplanets with the Doppler Method

3.5.1 Orbital Velocity: Top Down

Model

This model shows a **top-down** view of a planet and star in their orbit around the center of mass of the system. The arrows represent the velocities of each object at that moment in time.

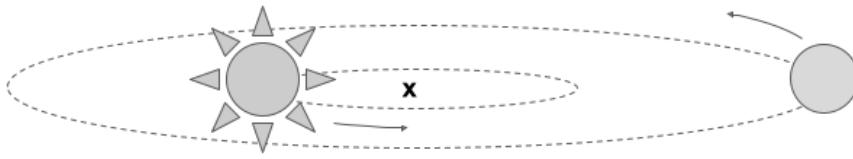


- What is at the center of the two orbits?
 - The Star
 - The Planet
 - The Center of Mass
- Compare the size of the orbit for each object:
 - The Star has a bigger orbit than the planet.
 - The Planet has a bigger orbit than the star.
 - The Planet and the Star have the same size orbit.
- How do you think the orbital periods of the two objects compare? Select one and explain your reasoning.
 - The planet will take longer to complete one orbit than the star.
 - The star will take longer to complete one orbit than the planet.
 - The star and the planet will complete one orbit in the same amount of time.
- Based on your answers to the last two questions, compare the speed of the planet and the star. Explain your reasoning.
- At the instant shown on the model, compare the direction that the planet and star are moving.
- Would either present a Doppler shift if you are viewing them from this perspective? If so, would the light be blue- or redshifted? Explain your reasoning.

3.5.2 Orbital Velocity: Edge On

Model

This model shows an **edge-on** view of a planet and star in their orbit around the center of mass of the system. The arrows represent the direction that each object moves around its orbit.



1. From this perspective, is the star moving towards you, away from you, or neither at this moment in time?
2. Based on your response above, would this light present a Doppler shift if you are viewing the star from this perspective? If so, would the light be blue- or redshifted? Explain your reasoning.
3. From this perspective, is the planet moving towards you, away from you, or neither at this moment in time?
4. Based on your response above, would this light present a Doppler shift if you are viewing the star from this perspective? If so, would the light be blue- or redshifted? Explain your reasoning.
5. Which object are we more likely to see the light from, the star or the planet? Explain your reasoning.

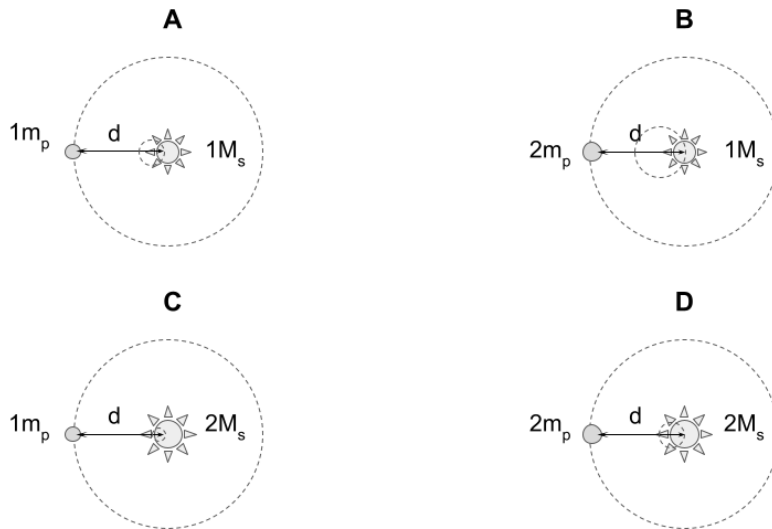
3.5.3 Comparing Doppler Orbits

Model

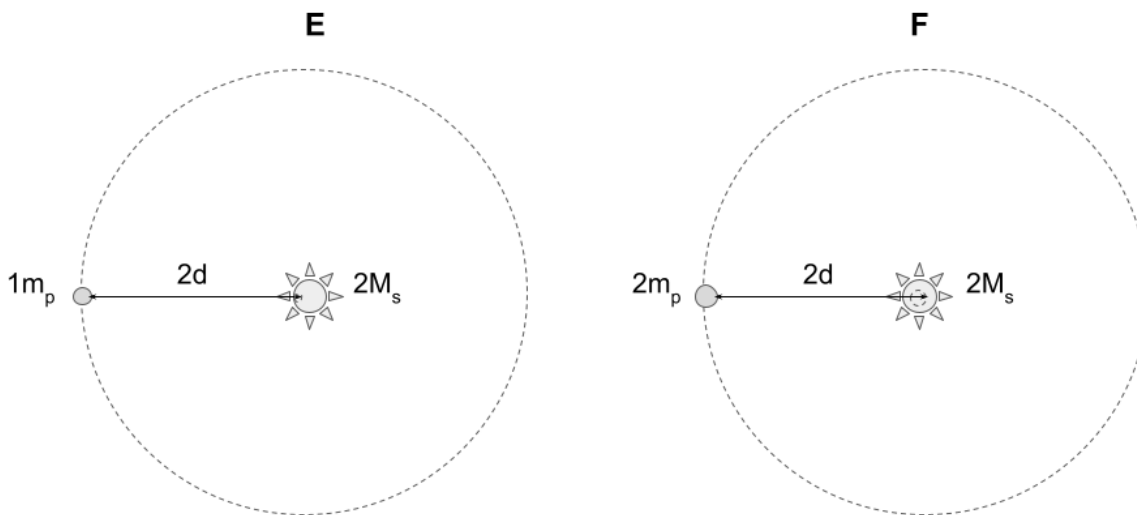
The speed of the star is based on the mass of the star and planet, as well as the distance between them. A greater speed causes a greater Doppler shift. The Doppler shift is given by the following proportional relationship:

$$\Delta\lambda \propto \frac{m_{\text{planet}}}{\sqrt{M_{\text{star}} \times d}} \quad (3.5.1)$$

1. Based on the equation, should there be a larger or smaller Doppler shift ($\Delta\lambda$) if the planet has a larger mass? Explain your reasoning.
2. Based on the equation, should there be a larger or smaller Doppler shift ($\Delta\lambda$) if the star has a larger mass? Explain your reasoning.
3. Based on the equation, should there be a larger or smaller Doppler shift ($\Delta\lambda$) if the distance between the planet and star is greater? Explain your reasoning.
4. Which has a larger effect on the Doppler shift, the mass of the planet or the mass of the star?
5. Rank the Doppler shift of the following orbits. Explain your reasoning.



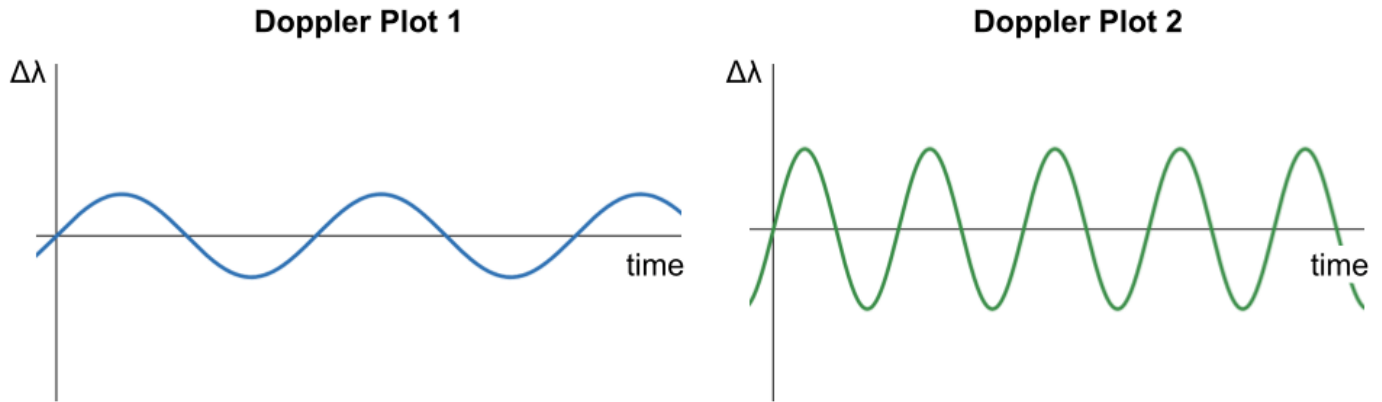
6. How do the Doppler shifts from orbits E and F compare to the previous orbits? Explain your reasoning.



3.5.4 Doppler Plots

Model

The two Doppler plots represent the Doppler shift from two different star-planet systems. Positive Doppler shifts represent a shift in wavelength to a longer wavelength and negative Doppler shifts represent a shift in wavelength to a shorter wavelength.



Two Doppler shift graphs showing wavelength changes over time for star systems.

1. Place a dot on the most positive readings. At those points, is the star moving towards you or away from you? Explain.
2. Place a dot on the most negative readings. At those points, is the star moving towards you or away from you? Explain.
3. Which orbit has a faster moving star? How can you tell?
4. What else is different about these plots? What do you think might cause this difference?
5. Create a plot to match the six orbits A–F from the previous model.





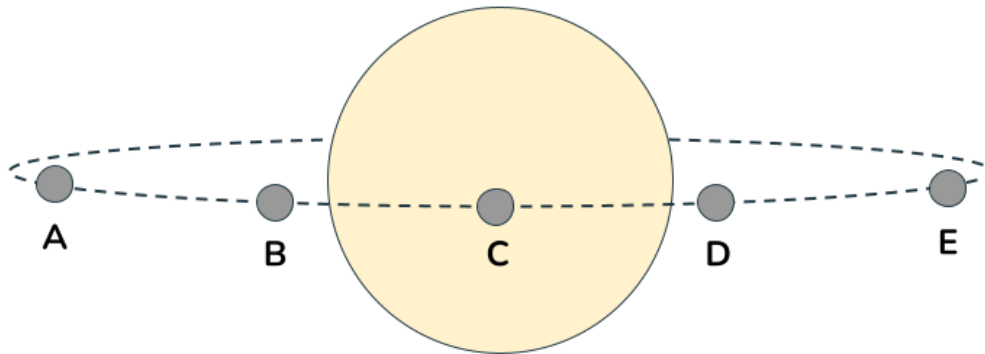


3.6: Detecting Exoplanets with the Transit Method

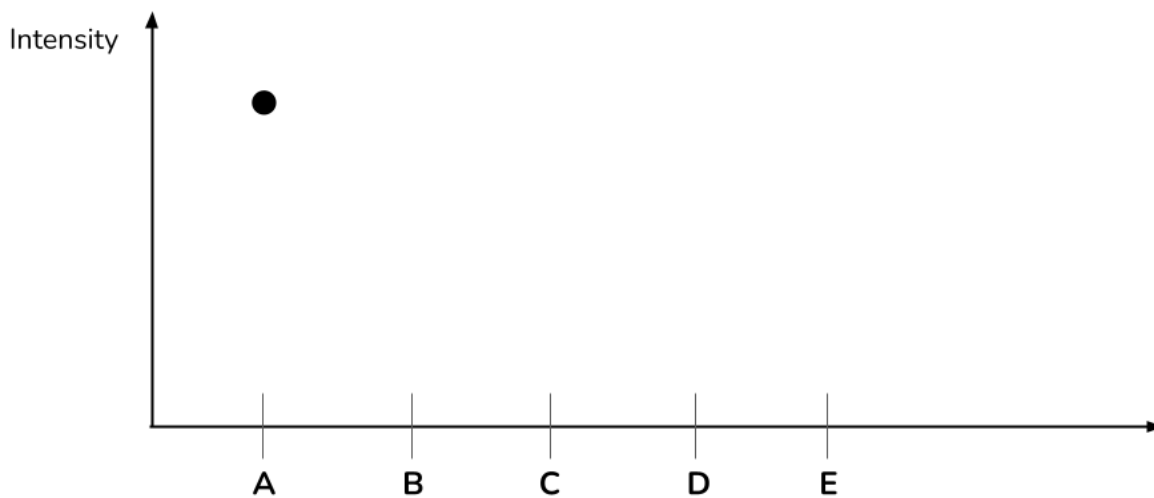
3.6.1 Transit and Light

Model

The model below shows the same planet at multiple positions in its orbit around a star. Consider how much light you would receive from the star if you look at it from this configuration (edge-on).



1. Identify the intensity of total light based on how much the star is blocked or not blocked by the planet and place a dot to represent the measured intensity.



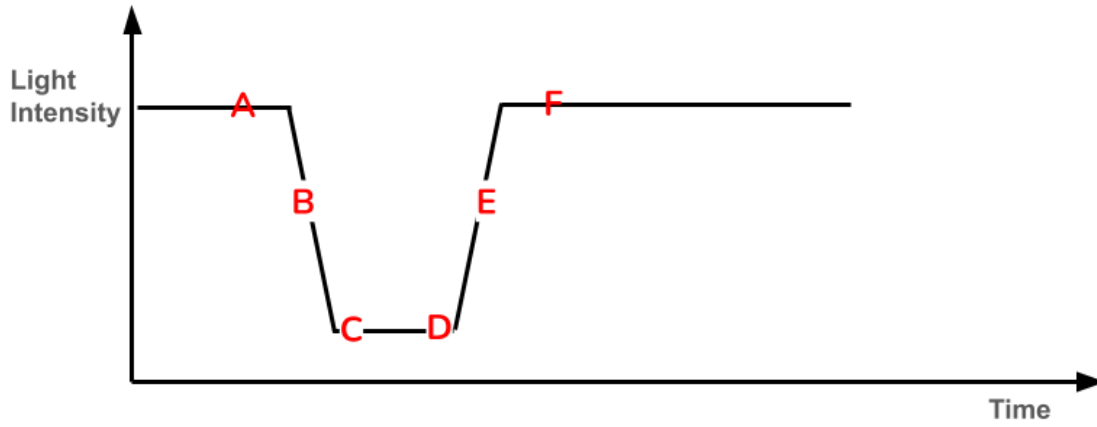
Light curve plot of intensity vs position

1. Connect the dots on your graph.
2. Describe the shape of the graph.

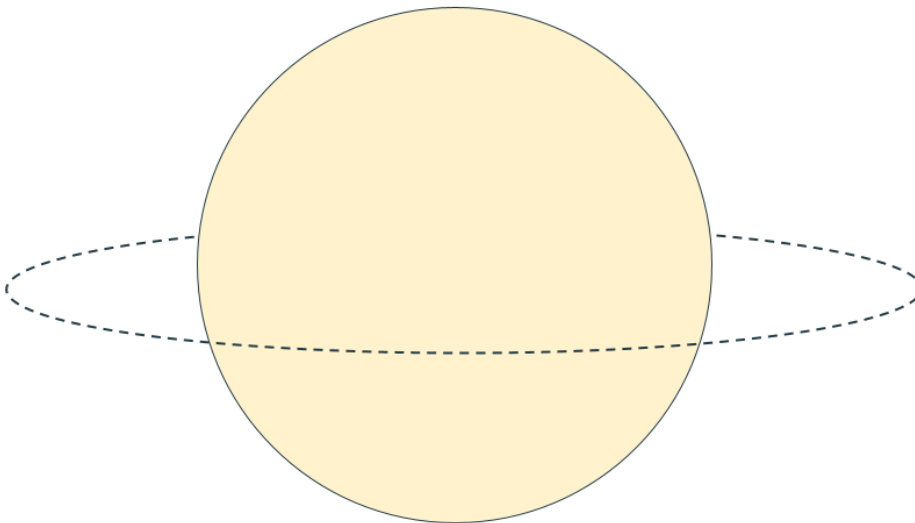
3.6.2 Transit Light Curve

Model

This model is a light curve plot for a new planetary system.



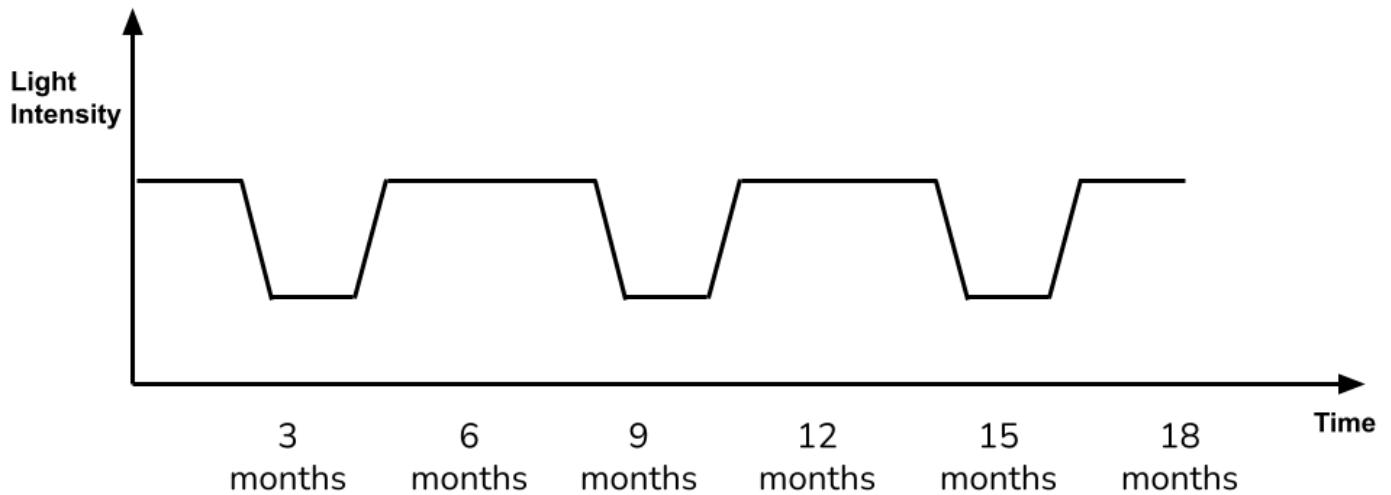
1. At what point(s) do we receive the most light?
2. At what point(s) do we receive the least light?
3. At what point(s) do we receive an amount of light between these maxima and minima?
4. Draw a possible location of the planet for each letter on the light curve. Label the planet positions with those letters.



3.6.3 Periodic Light Curves

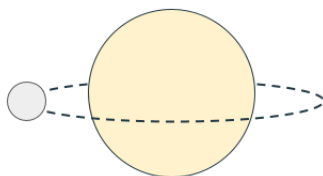
Model

The plot below is the continuation of the light curve plots from the previous models.

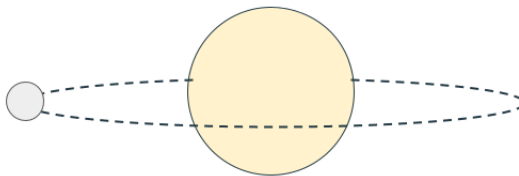


1. Why do you think the pattern repeats?
2. What part of the pattern do we see for more time, the part with more light or the part with less light? Why does that make sense?
3. Why is the “dip” a flat portion and not a single point?
4. What is the period (time to orbit once) for this orbit? Give an approximate answer.
5. How do you think the light curve would be different if the planet was larger (that is, had a larger radius)? Explain your reasoning.
6. How do you think the light curve would be different if the star was larger (that is, had a larger radius)? Explain your reasoning.
7. How do you think the light curve would be different if the period of the planet was greater (that is, it takes more time to complete one orbit)? Explain your reasoning.
8. Draw what the light curves might look like for the following planet–star systems.

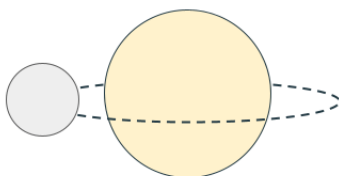
System A



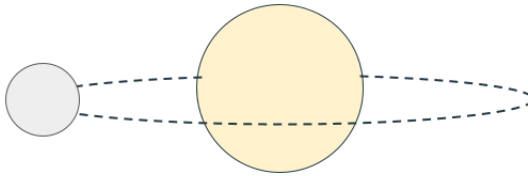
System B



System C



System D



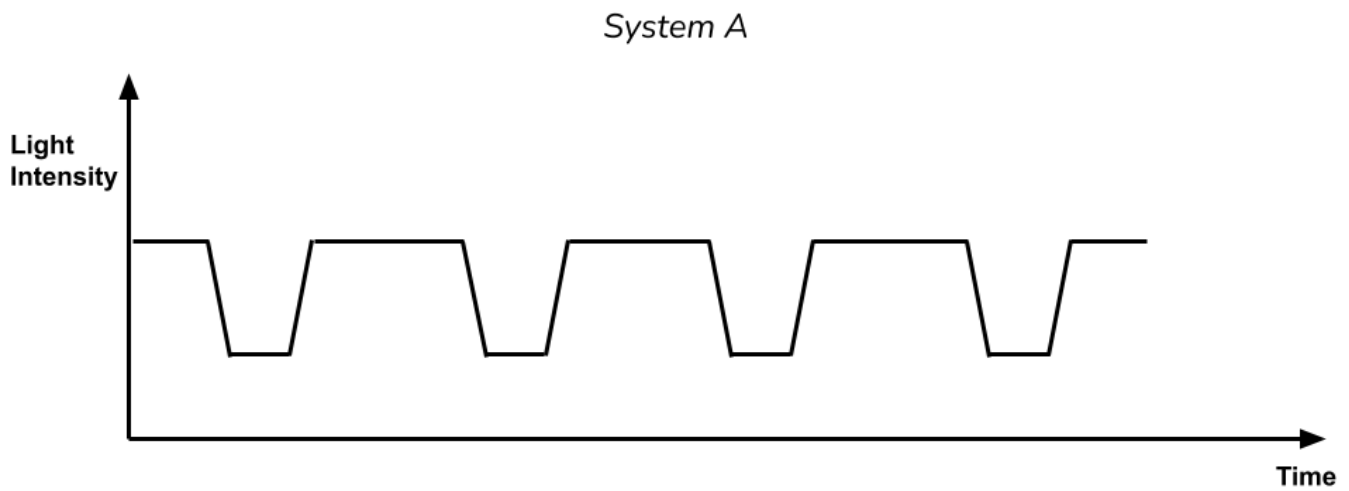




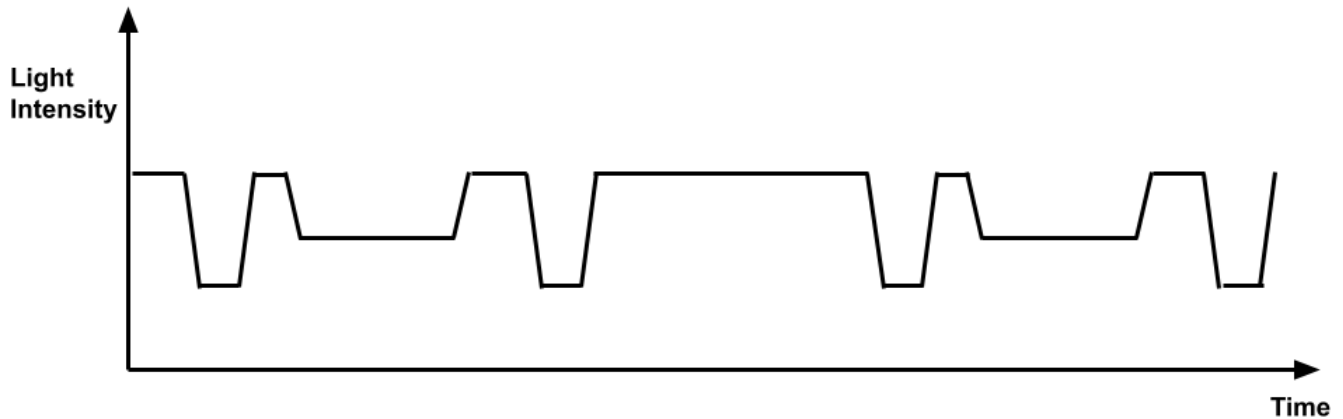
3.6.4 Multi-planet Systems

Model

Systems A and B below show light curves that may include more than one planet.

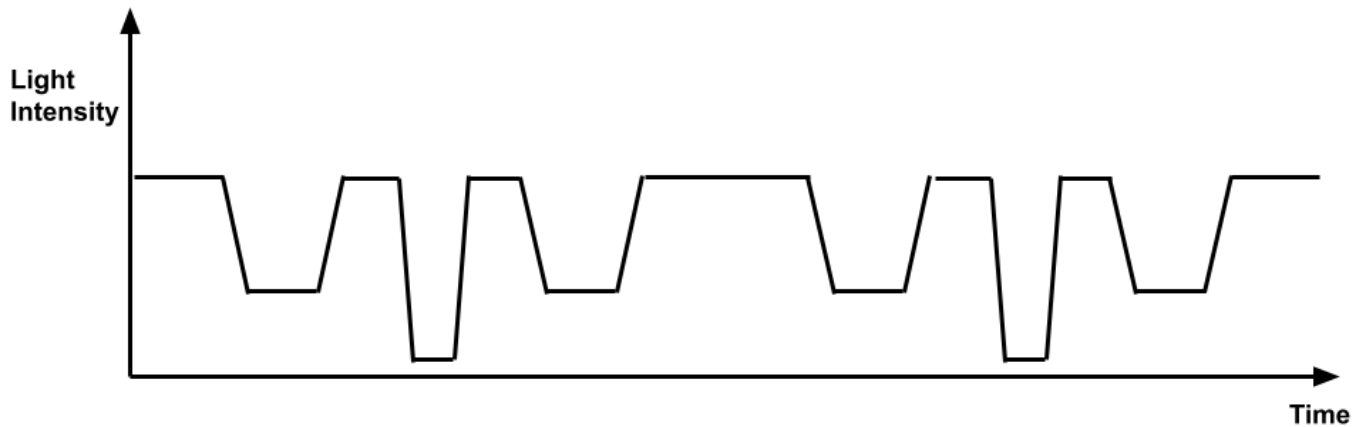


System B



1. Which star system appears to only have one planet in orbit? How do you know?
2. Which star system appears to have more than one planet in orbit? How do you know?
3. How many planets are orbiting this star system? Label them on the diagram (for example, A, B, C, and so on).

System C



1. Which planet is larger? How do you know?
2. Which planet has a longer period (time to orbit once)? How do you know?

3.7: Spectroscopy

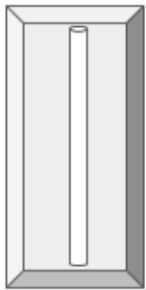
3.7.1 Discrete Spectra

Model

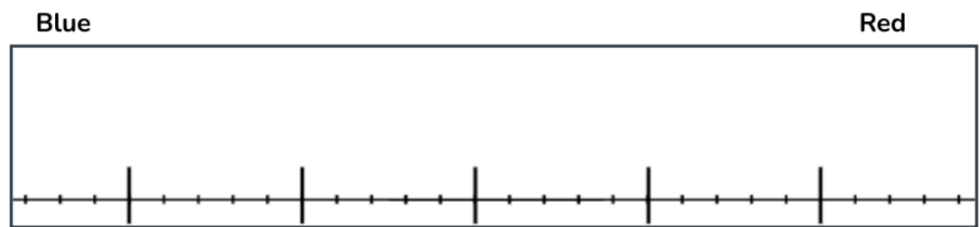
Shade in the spectrum tube based on the color without using the diffraction grating. Then, sketch the spectrum of the light using the diffraction grating. If you do not have physical tools, you can do this using the Spectroscopy Simulator from the Foothill AstroSims website: <https://foothillastrosims.github.io/Spectroscopy-Demonstrator/>

Hydrogen

Tube Color



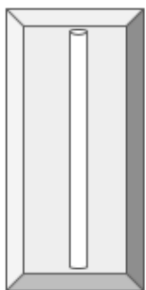
Spectrum



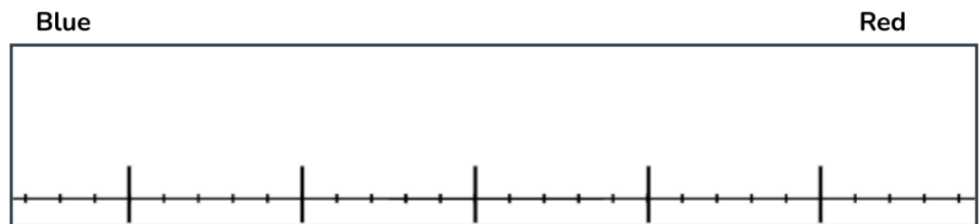
Hydrogen discharge tube and observed emission spectrum through a diffraction grating.

Helium

Tube Color



Spectrum



Helium discharge tube and observed emission spectrum through a diffraction grating.

1. Does the light from these tubes contain all of the colors?
2. Are the lines from each source the same or different?
3. How many lines did each source emit?

Summary

The emission spectrum that you observed is different from the blackbody spectrum that we explored earlier:

An emission spectrum contains _____.

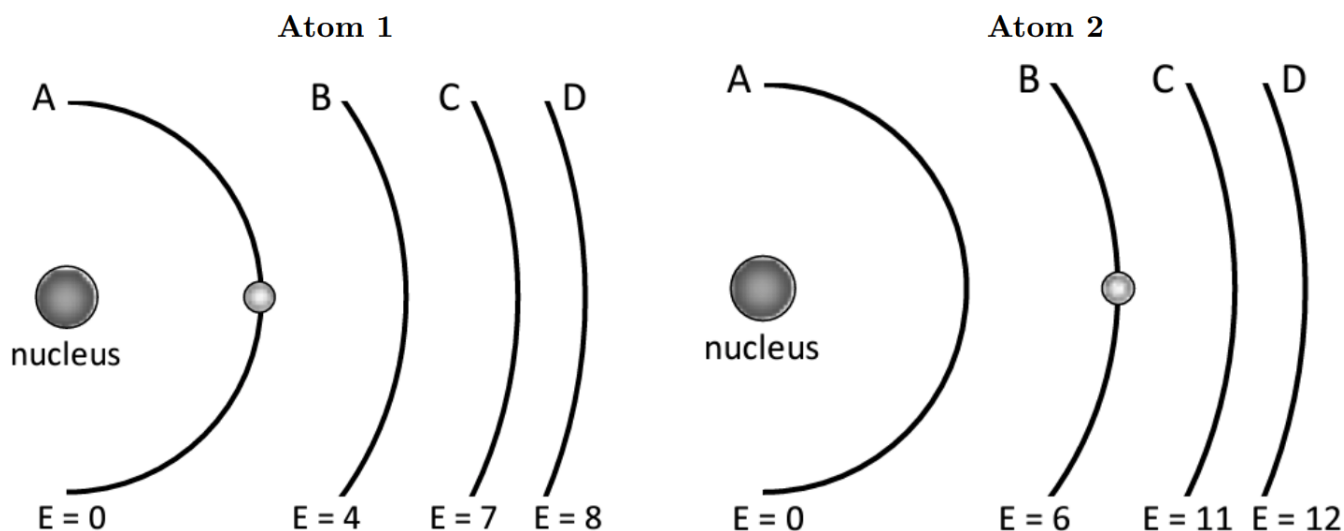
An emission spectrum depends on the _____ of the object and does not depend on the _____ of the object.

A blackbody spectrum contains _____.

A blackbody spectrum depends on the _____ of the object and does not depend on the _____ of the object.

3.7.2 Atomic Orbitals

Model



Two atoms showing electron energy levels and orbital transitions for comparison.

Image Credit: Astronomy Ranking Task from Rica Sirbaugh French at MiraCosta College (<https://home.miracosta.edu/rfrench/facultyshare/RTs.html>)

1. Is the lowest energy state near the nucleus of the atom or far away from the nucleus of the atom?
2. Which atom will need to absorb more energy to transfer an electron from its ground state (lowest energy state) to the first excited state? How much energy does this process take in each atom?
3. How much energy is gained or lost (identify one) when an electron transitions from C to B in each atom?
4. When atoms lose energy, they give off light with a wavelength determined by the amount of energy lost. Will these two atoms have the same spectral lines? Explain your thinking.

Summary

The ground state is the _____.

The first excited state is _____.

When atoms absorb photons, electrons transition closer to / farther from the ground state: _____.

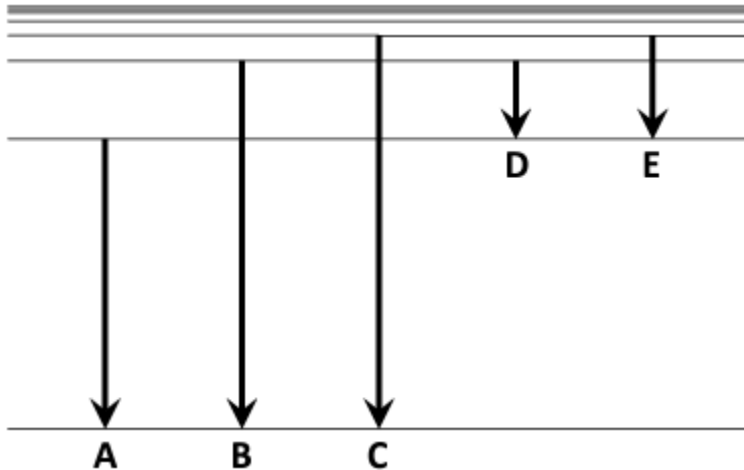
When atoms emit photons, electrons transition closer to / farther from the ground state: _____.

The energy levels are _____ for different atoms, which is why atoms have _____ spectra.

3.7.3 Emission

Model

The lines below represent similar energy levels as the previous model. The bottom line is the ground state, closest to the nucleus of the atom. The length of the arrows represents the amount of energy released by the atom as a photon.



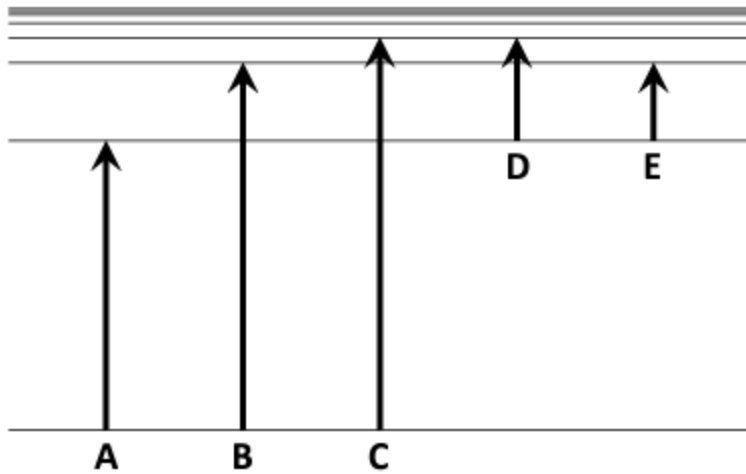
Electron energy level diagram showing emission transitions and photon energies.

Image Credit: Astronomy Ranking Task from Rica Sirbaugh French at MiraCosta College (<https://home.miracosta.edu/rfrench/facultyshare/RTs.html>)

1. As you get farther from the ground state (bottom), are the lines closer together or farther apart?
 2. Which transitions end on the ground state?
 3. Which transitions end on the first excited state?
 4. Which transitions are the largest?
 5. Complete the sentence: Higher energy photons are released for transitions that end at the _____ state.
-

3.7.4 Absorption

Model



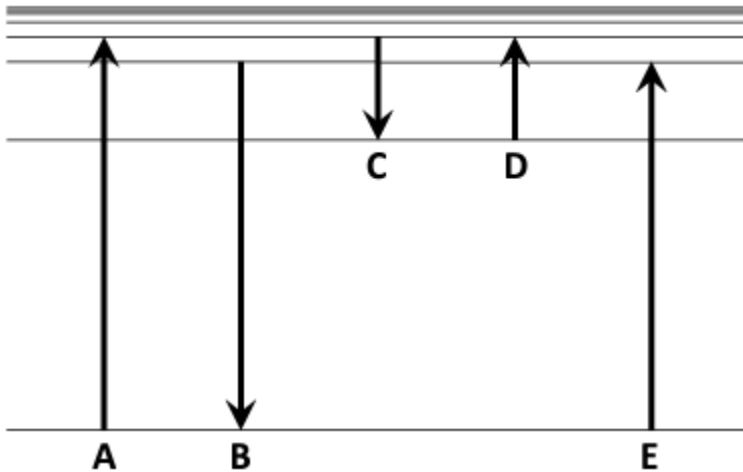
Electron energy level diagram showing absorption transitions to higher states.

Image Credit: Astronomy Ranking Task from Rica Sirbaugh French at MiraCosta College (<https://home.miracosta.edu/rfrench/facultyshare/RTs.html>)

1. Are these transitions to lower or higher energy states?
2. If an atom absorbs a low-energy photon, what transitions might occur?
3. If an atom absorbs a high-energy photon, what transitions might occur?
4. Electrons typically remain at the ground state. If that is the case, which transition would represent the minimum amount of energy needed to change the state of the electron?

3.7.5 Electron Transitions

The models below represent different transitions within a single atom.



Electron transition diagram with labeled paths for absorption and emission analysis.

Image Credit: Astronomy Ranking Task from Rica Sirbaugh French at MiraCosta College (<https://home.miracosta.edu/rfrench/facultyshare/RTs.html>)

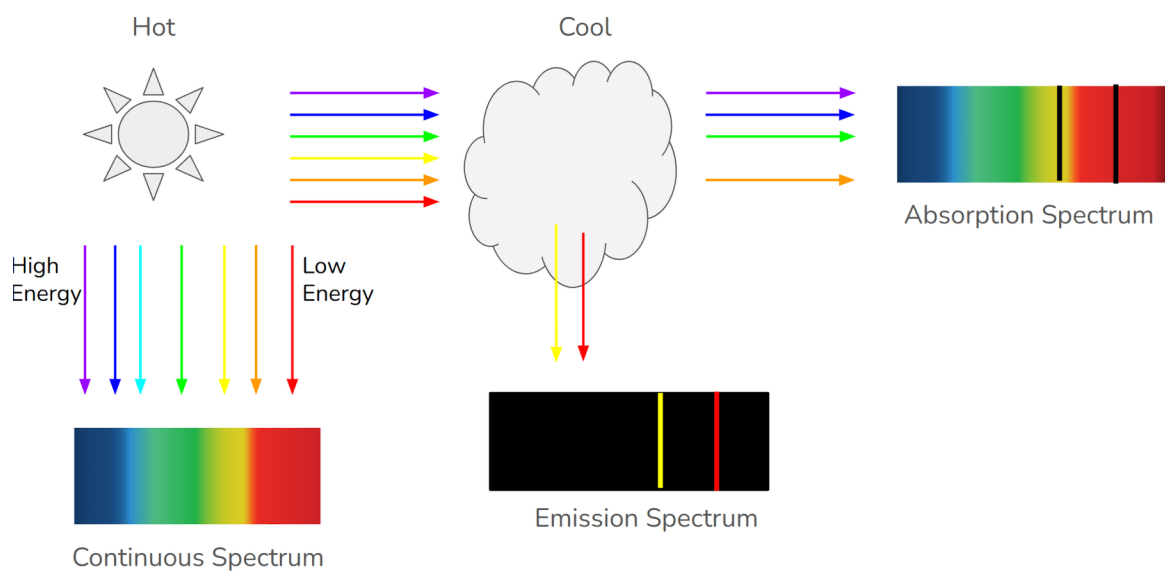
1. Which letters represent absorption of light? Rank them from largest to smallest amount of energy gained.
2. Which letters represent emission of light? Rank them from largest to smallest amount of energy gained.

3.8: Applications of Spectroscopy

3.8.1 Types of Spectra

Model

The model below shows the three types of spectra



Hot star, cool gas cloud, and resulting continuous, emission, and absorption spectra.

1. What colors of light are given off by the star?
2. Do all of those colors pass through the cool cloud? If not, what happens to those colors?
3. When a hot object radiates light due to its temperature, what type of spectrum does it give off?
4. When light passes through a cold gas, what type of spectrum do you see if you are looking at the light that passes through the gas from the source?
5. When light passes through a cold gas, what type of spectrum do you see if you are looking at the light emitted from that gas, not the original source?
6. Use the model images in class to match the spectrum to the Energy Output Plot on the next page.

3.8.2 Blackbody Radiation Plots

Model

The simulation below shows the amount of light each section (power) for each wavelength of light. The peak of the red curve shows which wavelength is emitted the most. Explore the simulation below:

- Change the temperature to see how the red curve changes up/down and left/right
- Zoom in or out as needed to see the data
- Examine the star color, which is right next to the B, G, R circles above the graph

Simulation Source: https://phet.colorado.edu/sims/html/blackbody-spectrum/latest/blackbody-spectrum_all.html

1. When the temperature increases, does the curve get taller/shorter? Does it get wider/narrower?

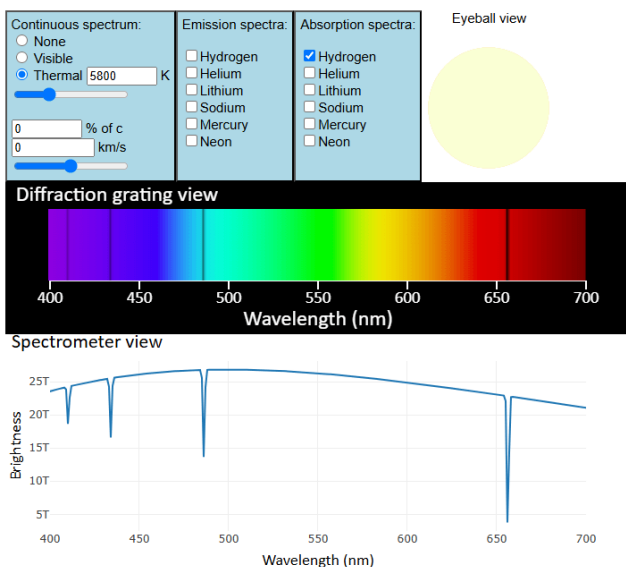
- When the temperature increases, does the peak of the curve move left or right? Is this towards a higher or lower wavelength?
- Are all visible wavelengths emitted at any temperature? You might need to zoom in to check if some are nonzero.
- Is this a **continuous spectrum**, **emission spectrum**, or **absorption spectrum**? Explain how you know.
- If you saw two curves, how could you tell which one represented a hotter star? Be specific.

1.3 Radiation Plot with Absorption and Emission Spectra

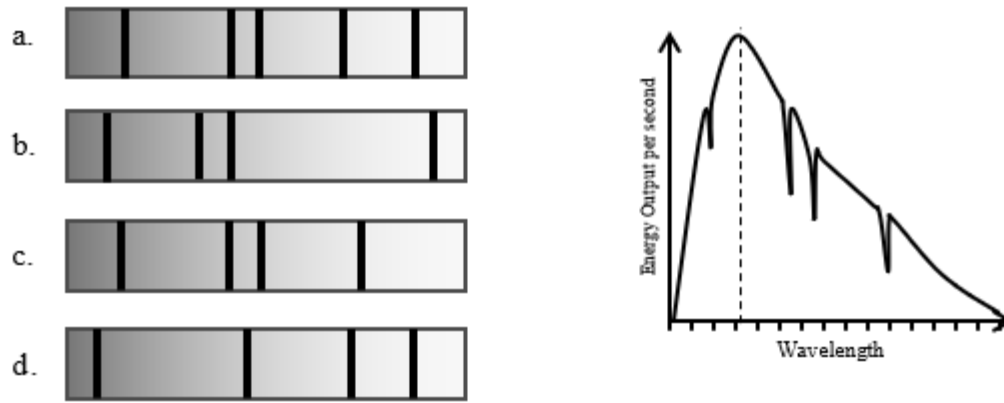
Model

Go to the Spectrum Constructor from Foothill AstroSims: <https://foothillastrosims.github.io/...m-Constructor/>

- Select **Thermal** and adjust the temperature. This is a zoomed in (flatter) plot of what you explored in the PhET Radiation Plot simulator
- Reset the temperature 5800K. This is the surface temperature of our sun
- Select **Hydrogen** on the **absorption spectra** panel.
- Explore other elements one at a time in the absorption spectra panel

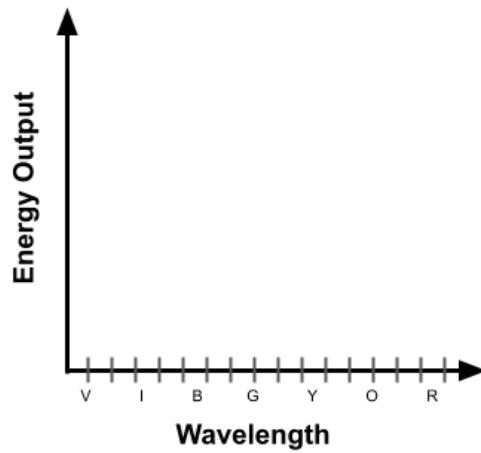


- How does the Diffraction Grating image compare to the Spectrometer View graph?
- Choose an element and compare its **Emission Spectrum** to its **Absorption Spectrum** (only have one checked at a time). Describe similarities and differences between the two spectra
- Four different reference spectra are shown for different elements (a-d). On the right, there is a blackbody radiation plot.
 - Which spectrum do the lines on the radiation plot match? Explain your thinking.
 - Is the plot an **emission** or **absorption** plot? Explain your reasoning.
 - How would the energy output look different for the opposite (absorption or emission) of light at those wavelengths? Explain your reasoning and draw it on the blank template below.



Four reference spectra and a blackbody radiation plot with absorption features.

Image Credit: Center for Astronomy Education (CAE) (https://www.as.arizona.edu/cae/materials_resources/)



4: SOLAR SYSTEM FORMATION

- 4.1: Birth of a Solar System
- 4.2: Tour of Our Solar System
- 4.3: Planetary Formation 1- Planetesimals
- 4.4: Non-planetary Bodies
- 4.5: Planetary Interiors
- 4.6: Magnetic Fields
- 4.7: Planetary Surface Changes

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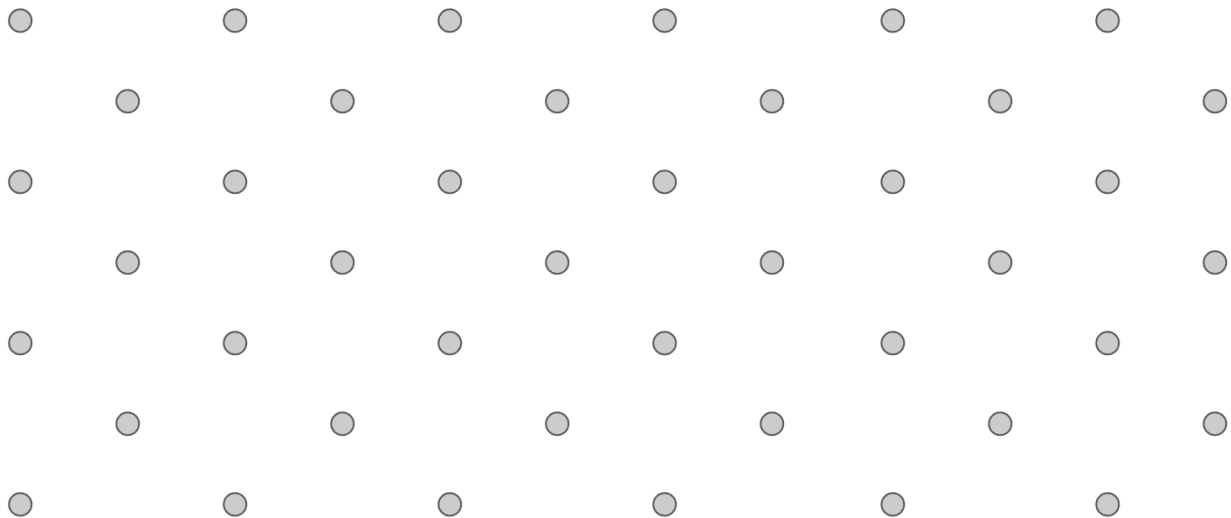
4.1: Birth of a Solar System

4.1.1 Gravitational Collapse in the Solar Nebula

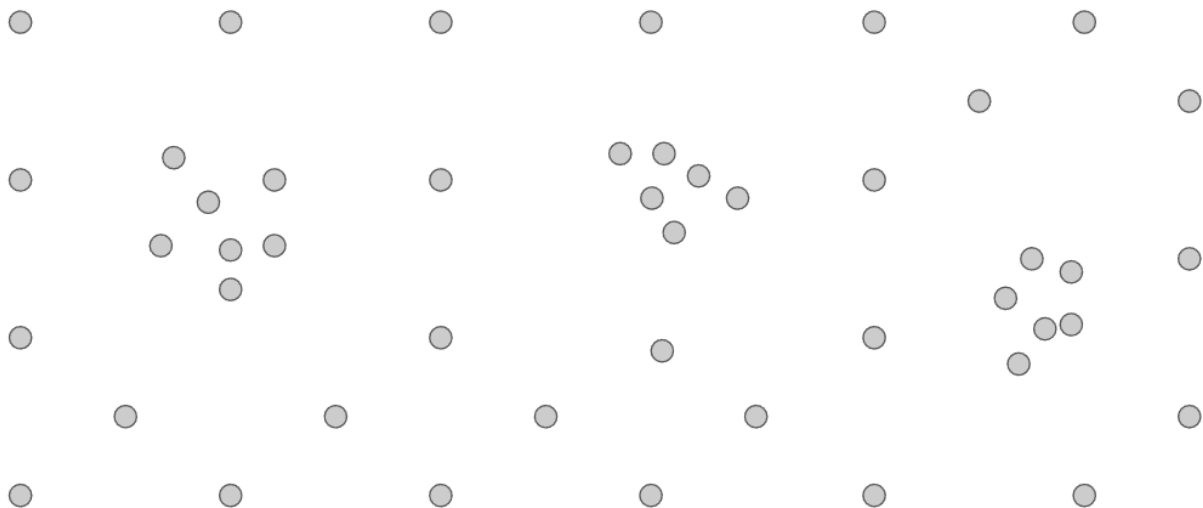
Model

Solar systems form from giant clouds of gas and dust. The initial gas is cool and not moving very fast. Two models below show possible solar nebula states: One with constant density and one with denser pockets. The grey dots represent gas/dust particles in the nebula.

Constant Density



Dense Pockets

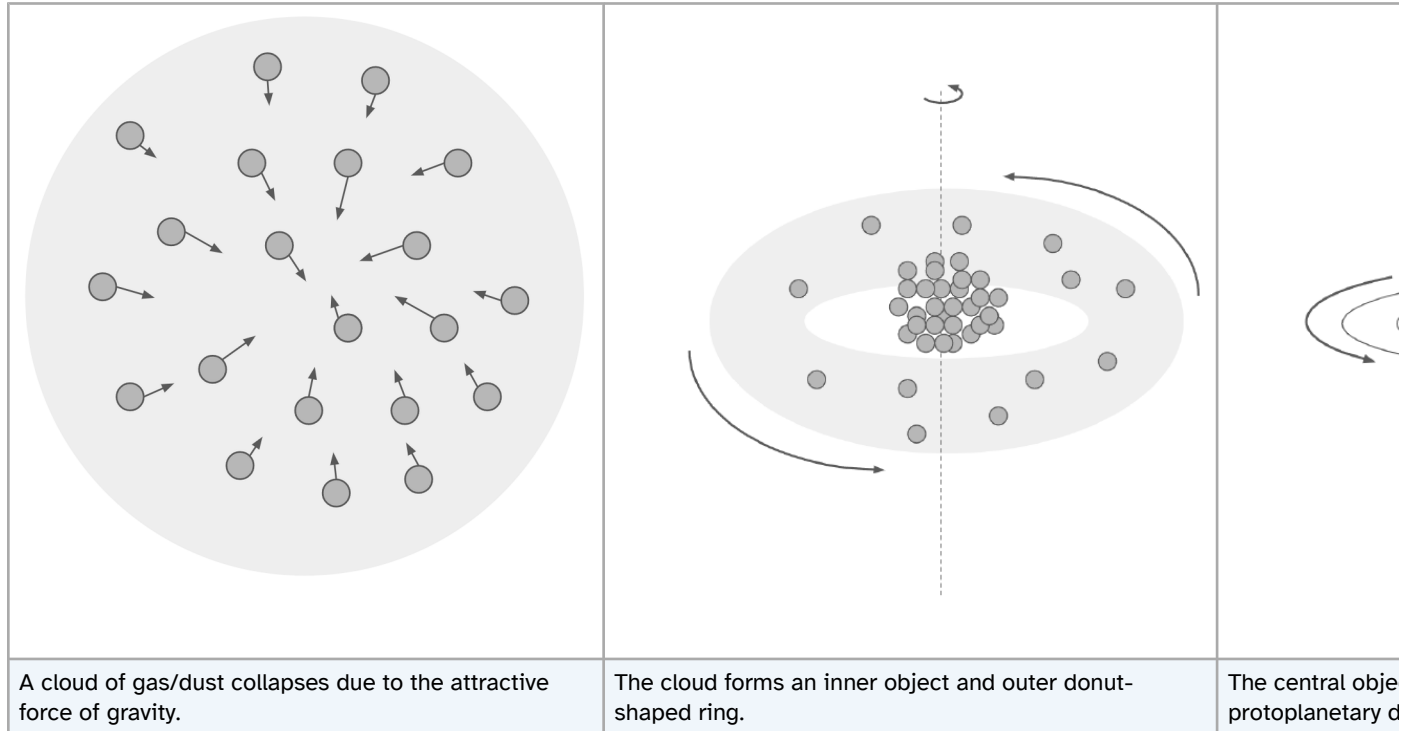


Recall that gravity is stronger between objects that are closer together. In both model images:

1. Put an X over any dots that should have an equal gravitational pull in all directions. Ignore the dots on the very edge.
2. On the dots that remain, draw an arrow in the direction of the **net gravitational force**. This does not need to be exact.
3. Circle any regions where all of the dots will fall towards one another. These are regions of star formation.
4. **Summarize:** In a nebula (cloud of gas/dust), what is necessary for stars to form and where do they form? Cite examples (evidence) from the models and your annotations.

4.1.2 Formation of a Star and Protoplanetary Disk

Model



1. As the nebula becomes a solar system, does the overall cloud of gas/dust get flatter or more 3-dimensional?
2. Does most of the mass (gas/dust) end up in the central object or the outer ring? Does your answer become a star or planets?
3. Examine the arrows in all three panels. How does the motion of the gas/dust particles change over time?
4. Does the ring rotate in the same or opposite direction that the central object spins?

4.1.3 Gas Pressure and Temperature

Model

Interact with the Gas Properties simulation from PhET to explore how temperature and volume (size) relate in gases. Select the **Explore** simulation.

- Add 100 light particles. Do not change this number.
- Note the temperature and pressure of the gas
- Grab the handle on the left side of the container and push the container in to **decrease the volume** of the gas. Note the temperature and pressure of the gas.

Make some claims about a collapsing gas. Use before/after screenshots or data as evidence for your claims.

1. As a gas collapses, the temperature
2. As the gas collapses, the pressure ...

Reset the simulation with the same 100 light particles at the initial size and temperature. Now keep the size of the container the same and **add heat** instead. Reset but **cool the gas**. Make a claim about temperature and pressure.

1. As the temperature of a gas increases, the pressure ...
2. As the temperature of a gas decreases, the pressure ...

4.1.4 Hydrostatic Equilibrium

Model

The model below shows two forces that are present on all particles in a star.

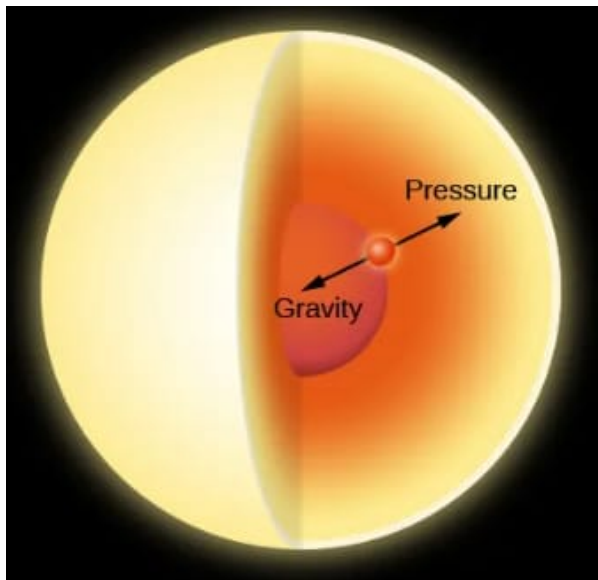
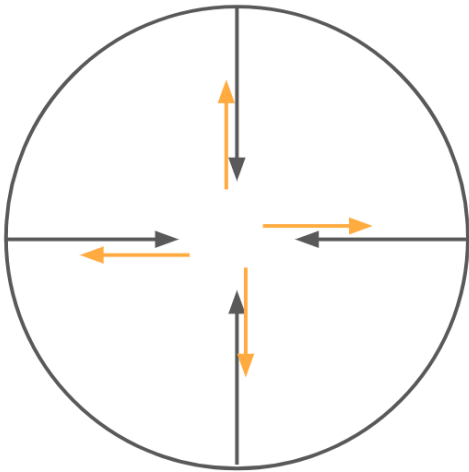


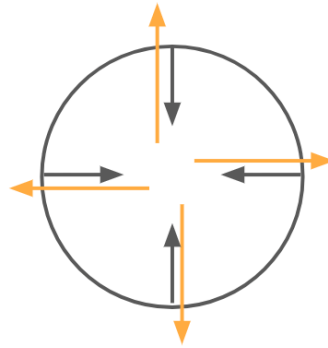
Image Credit: OpenStax Astronomy 2e (<https://openstax.org/details/books/astronomy-2e>)

1. What force pulls a particle inward? What force pushes a particle outward?
2. What would have to be true about the forces of gravity and pressure if the particles do not fall inward or get pushed outward?
3. Two stars are shown below with their inward and outward arrows (forces). Label each star as either **Gravity Wins** or **Pressure Wins** and then make a claim about whether the star will get bigger, smaller, or remain the same size. Provide clear evidence and reasoning.

Star A



Star B



4.2: Tour of Our Solar System

Introduction

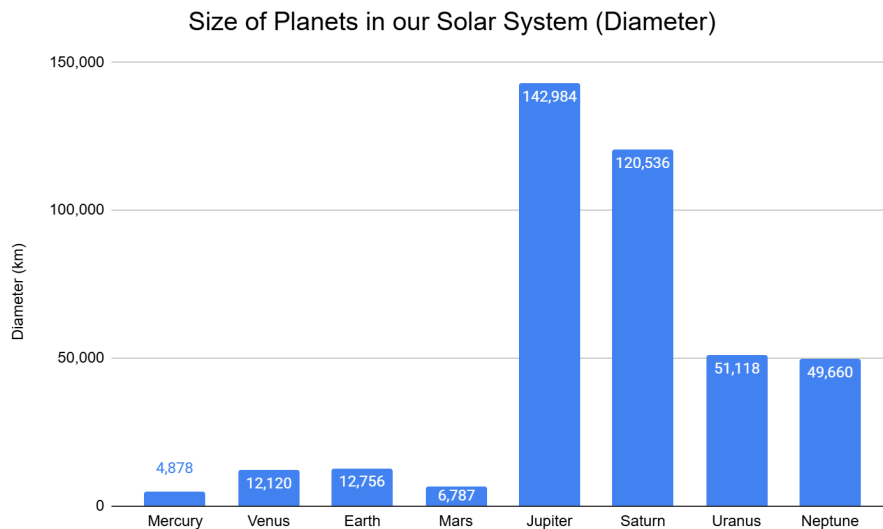
Our solar system contains 8 planets. The table below lists a few key measurements about each planet. The activities that follow will examine a few select measurements using bar charts to provide a visual comparison of the values in the table.

Planets in our Solar System

Name	Distance from Sun (AU) ²	Revolution Period (y)	Diameter (km)	Mass (10 ²³ kg)	Density (g/cm ³)
Saturn	9.54	29.46	120,536	5686	0.7
Jupiter	5.20	11.86	142,984	18,991	1.3
Uranus	19.18	84.07	51,118	866	1.3
Neptune	30.06	164.82	49,660	1030	1.6
Mars	1.52	1.88	6,787	6.4	3.9
Venus	0.72	0.62	12,120	48.7	5.2
Mercury	0.39	0.24	4,878	3.3	5.4
Earth	1.00	1.00	12,756	59.8	5.5

4.2.1 Size

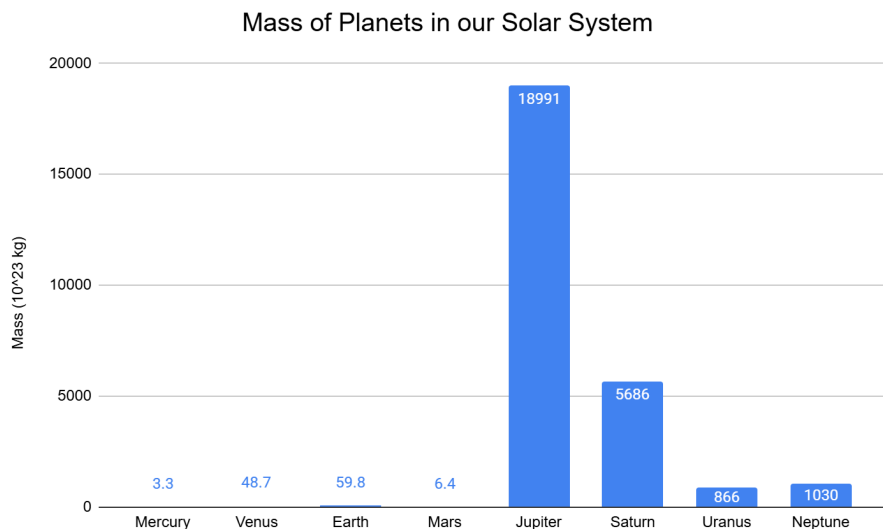
Model



- Using just the data above (Size), create 2-4 groups of planets that have similar size.
 - If you made four groups, see if you can identify a **super group** that represents two groups that are more similar to each other than the other groups
 - If any group has four or more planets, see if you can identify **1-2 sub groups** within that group
- Give a name/label to each group (as well as any super groups or sub groups) and explain the criteria for that group to be used for sorting exoplanets that we discover.

4.2.2 Mass

Model

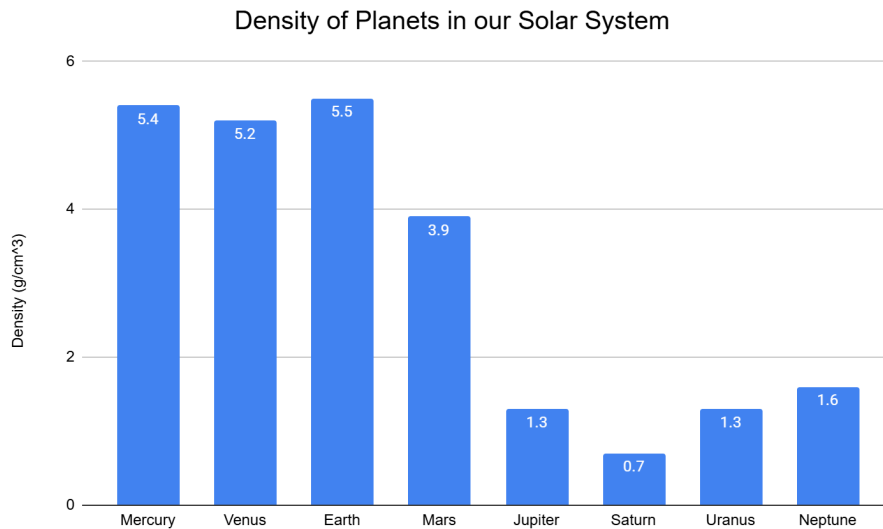


- Using just the data above (Mass), create 2-4 groups of planets that have similar mass.

1. If you made four groups, see if you can identify a **super group** that represents two groups that are more similar to each other than the other groups
2. If any group has four or more planets, see if you can identify **1-2 sub groups** within that group
2. Give a name/label to each group (as well as any super groups or sub groups) and explain the criteria for that group to be used for sorting exoplanets that we discover.

4.2.3 Density

Model



1. Using just the data above (density), create 2-4 groups of planets that have similar density.
 1. If you made four groups, see if you can identify a **super group** that represents two groups that are more similar to each other than the other groups
 2. If any group has four or more planets, see if you can identify **1-2 sub groups** within that group
2. Give a name/label to each group (as well as any super groups or sub groups) and explain the criteria for that group to be used for sorting exoplanets that we discover.

4.2.4 Overall Groups

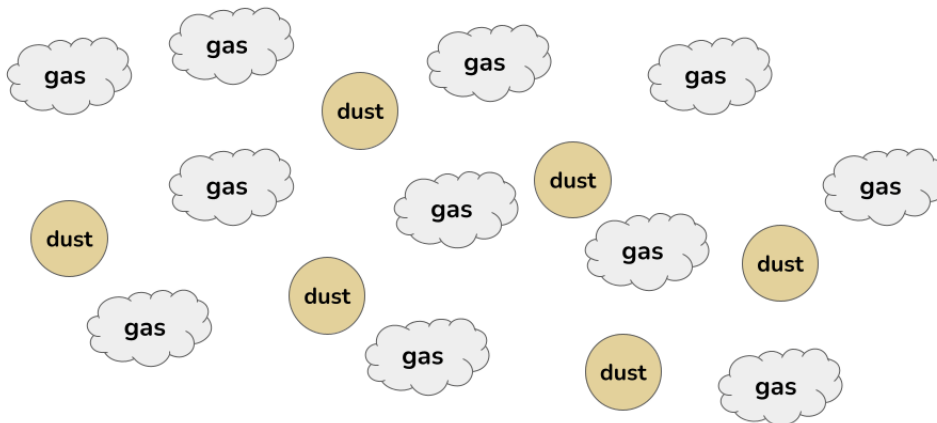
1. Using all of the data (size, mass, and density), create 2-4 groups of planets
 1. If you made four groups, see if you can identify a **super group** that represents two groups that are more similar to each other than the other groups
 2. If any group has four or more planets, see if you can identify **1-2 sub groups** within that group
2. Give a name/label to each group (as well as any super groups or sub groups) and explain the criteria for that group to be used for sorting exoplanets that we discover.

4.3: Planetary Formation 1- Planetesimals

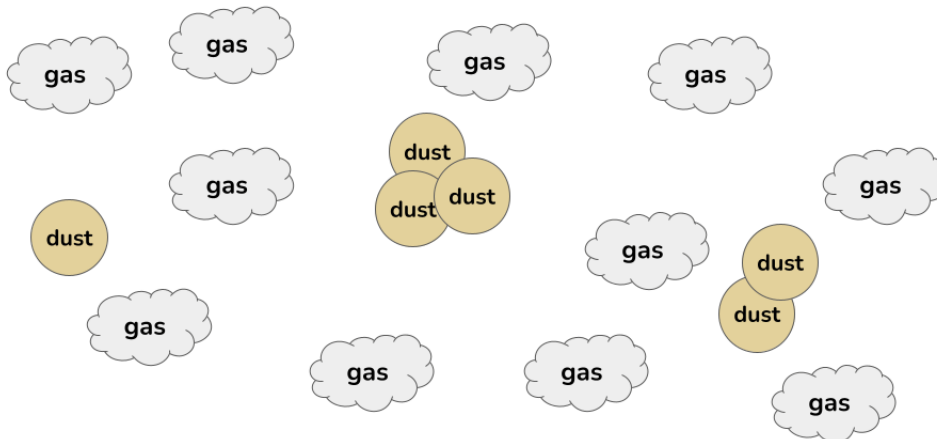
4.3.1 Planetesimal Formation

Model

Early Protoplanetary Disk



As time goes on...

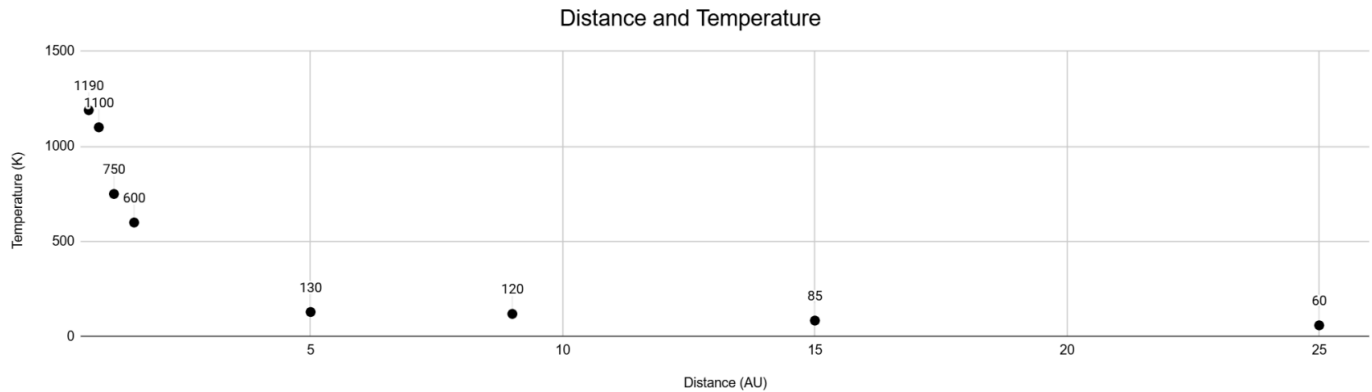


1. What are the two types of matter in the protoplanetary disk?
2. Which type of matter sticks together?
3. If the protoplanetary disk is a higher percent dust than gas, are planets more or less likely to form?
4. If the protoplanetary disk is a higher percent dust than gas, are planets more or less likely to form?

4.3.2 Temperature and Types of Material

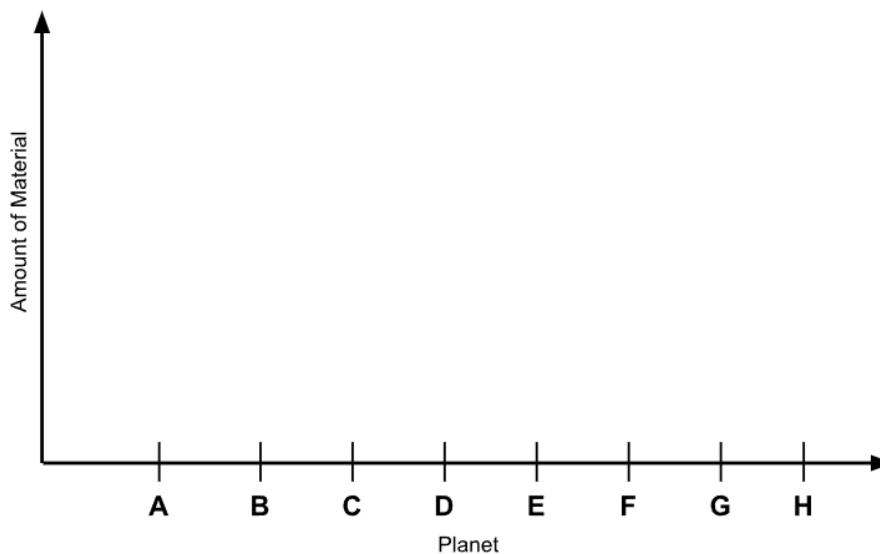
Model

The models below provide some data on the temperature at the time of formation at the location of several planets in a planetary system. This planetary system has 8 planets, A-H, with Planet A the closest to the star (smallest distance).



Material	Condensation Temperature
Metal	1300K
Rock	1200K
Water	140K
Methane/Ammonia	90K
Hydrogen	N/A - Always gas in space

- Based on the temperature of each planet, decide which substance(s) that planet it made up of. For each type of material that each planet is made up, draw a dot and stack them on top of each other to make a vertical column for each planet. Use a different color for each different substance. Start with metal on the bottom and work up to lower condensation temperature substances.



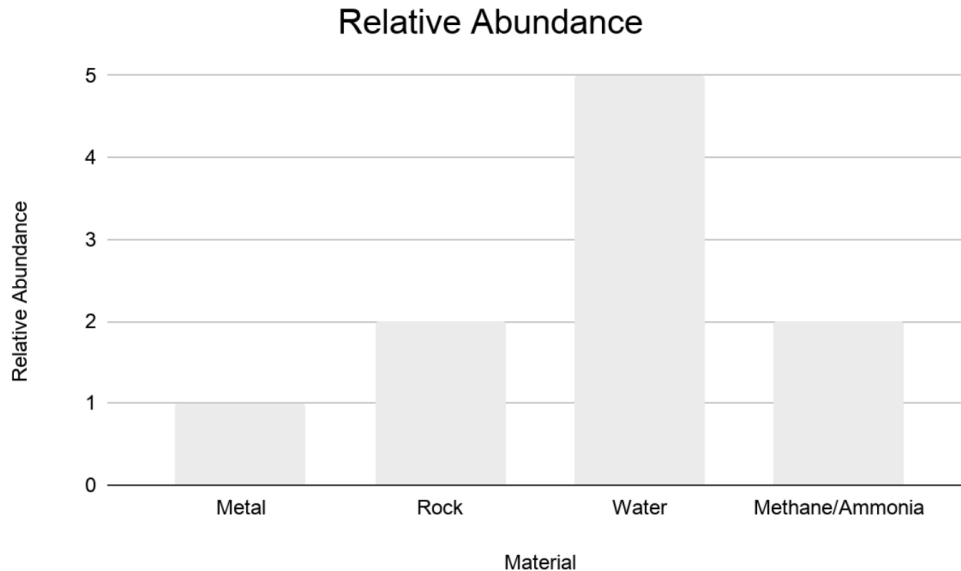
- Identify patterns between planetary formation location (ie, proximity to the star) and diversity of planet material.

2. According to these data, which planet(s) should be the largest (most mass) and which should be the smallest (least mass)? Why?

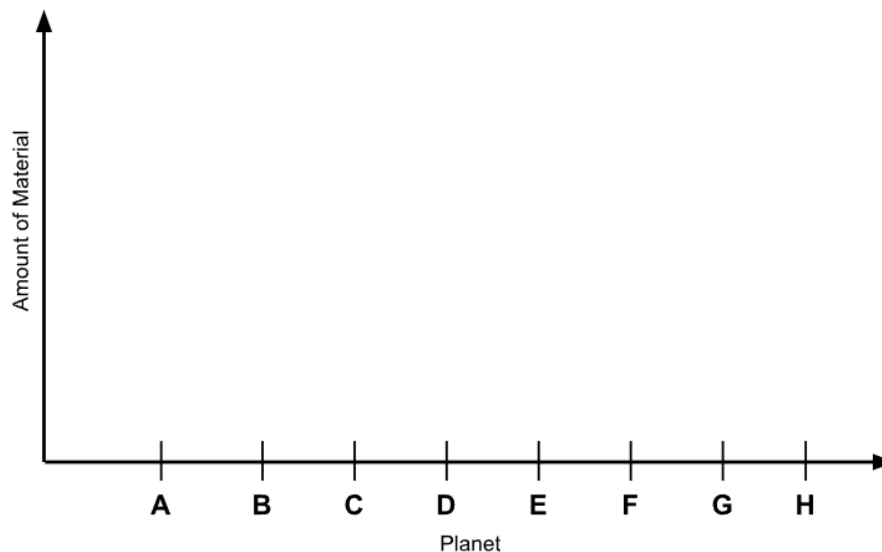
4.3.3 Types of Materials + Relative Abundance

Model

The **Relative Abundance** chart tells you how the amount of metal, rock, water, and methane/ammonia compare in the protoplanetary disk.



1. For each type of material that each planet is made up, draw dots to make a new set of vertical columns. This time, draw as many dots as match the relative abundance (eg, if the planet is formed from water, place 5 water dots). Start with metal on the bottom and work up to lower condensation temperature substances.



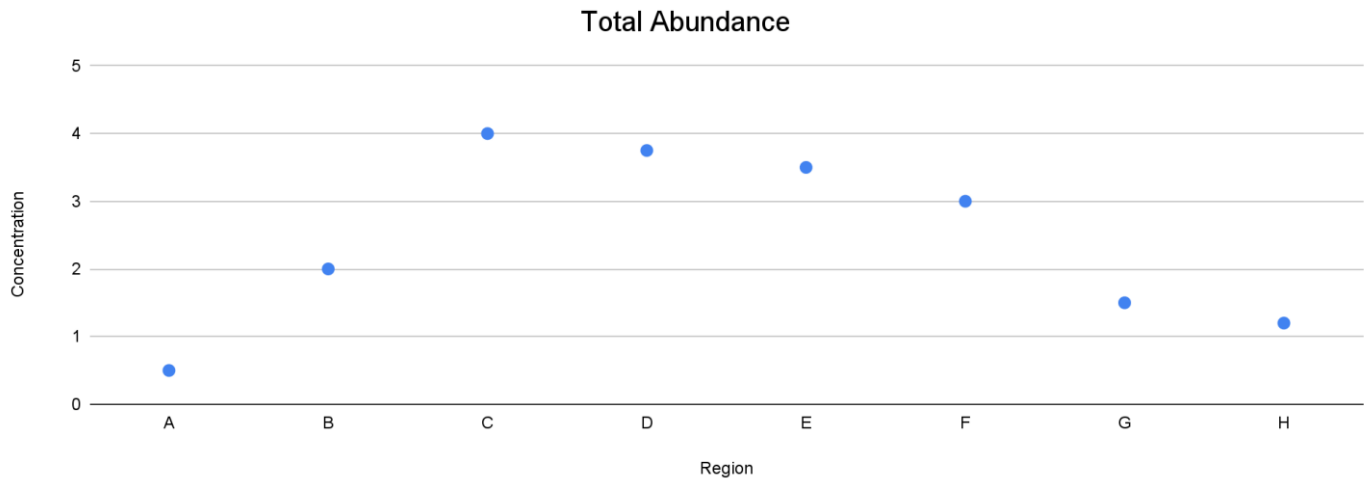
1. According to these data, which planet(s) should be the largest (most mass) and which should be the smallest (least mass)? Why?
2. **Generalize a pattern:** Where in this solar system do small, medium, and large planets form? Why does this happen?
3. What separates the big planets from the small planets? Where in space would this line separating the two groups of planets

be?

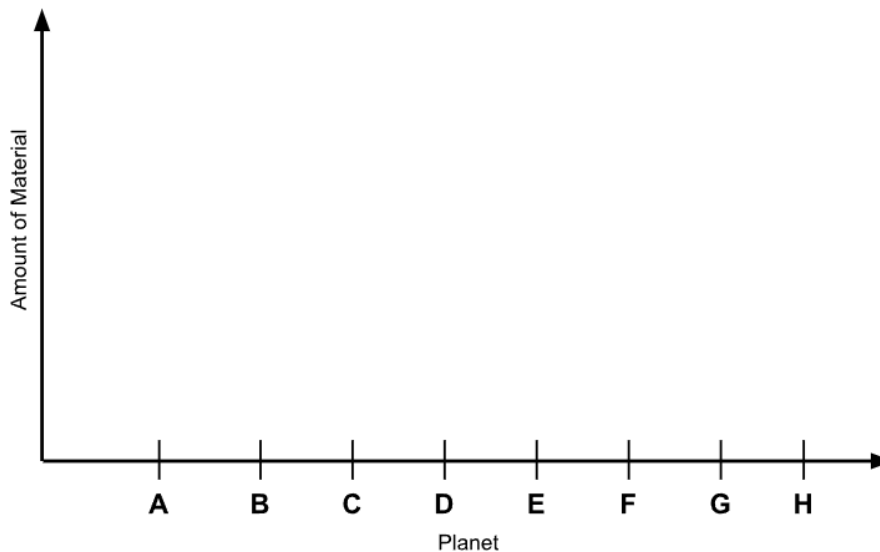
4.3.4 Types of Materials + Total Abundance

Model

The **Total Abundance** chart tells you how the amount of metal, rock, water, and methane/ammonia compare in the protoplanetary disk **at different distances in that disk**.



1. Take the amount of dots you used in the **Types of Materials + Relative Abundance** activity and **multiply by the total abundance value** at the location of each planet. Round answers to the nearest integer. Draw dots to match those numbers. Start with metal on the bottom and work up to lower condensation temperature substances.



1. According to these data, which planet(s) should be the largest (most mass) and which should be the smallest (least mass)? Why?
2. **Generalize a pattern:** Where in this solar system do small, medium, and large planets form? Why does this happen?

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4.4: Non-planetary Bodies

Introduction

Scientists use specific criteria to distinguish planets from other objects in our solar system. In this activity, you will examine characteristics such as mass, radius, orbit, neighborhood clearing, and shape to determine what defines a planet.

4.4.1 Comparing Mass and Radius

Model

Mercury, Earth, and Titan



Mercury

Mass: 0.33×10^{24} kg

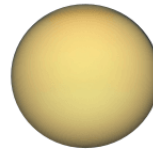
Radius: 2,439.7 km



Earth

Mass: 6×10^{24} kg

Radius: 6378 km



Titan

Mass: 0.14×10^{24} kg

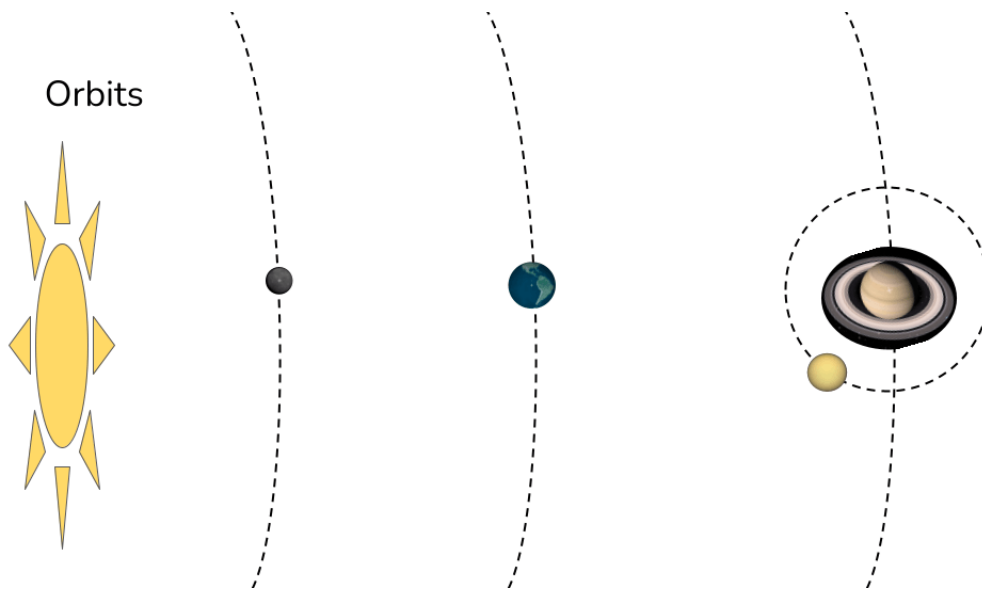
Radius: 2574.8 km

Mercury, Earth, and Titan compared by size and mass

1. Rank the objects in terms of size (radius) from smallest to biggest.
2. Rank the objects in terms of mass from smallest to biggest.
3. Titan is not a planet, but the other objects are. Do you think radius is an appropriate criterion to distinguish planets and non-planets? Explain.
4. Do you think mass is an appropriate criterion to distinguish planets and non-planets? Explain.

4.4.2 Comparing Orbits

Model

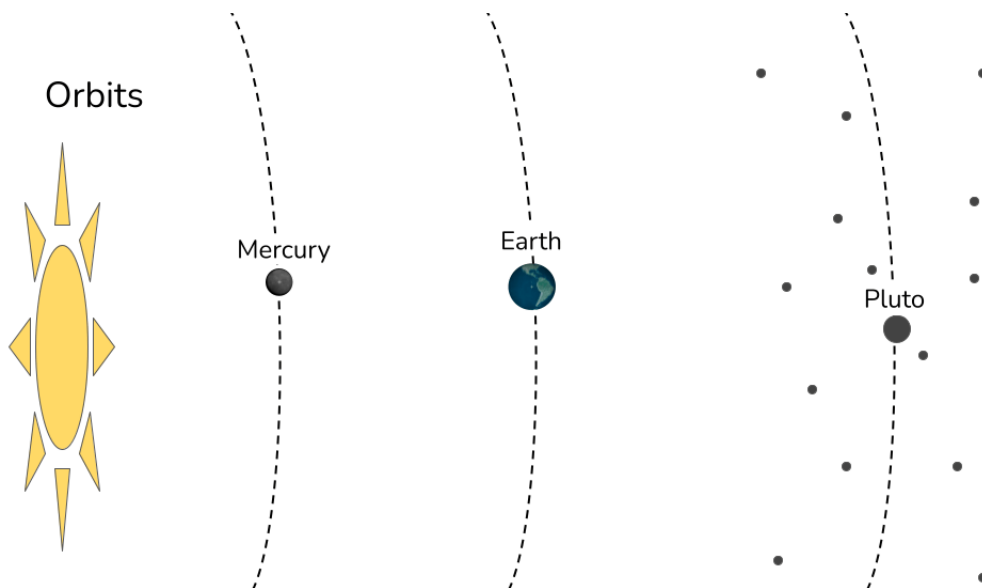


Solar system objects show Mercury and Earth in orbit around the sun and Titan in orbit around Saturn

1. What object do each of these bodies orbit?
2. Based on your responses above, what might be a useful criterion to distinguish between planets and non-planets? Explain.

4.4.3 Clearing the Neighborhood

Model



Mercury and Earth have clear orbits while Pluto is surrounded by debris

1. Which object(s) have a relatively empty neighborhood around their orbit?
2. Which object(s) have a “crowded” neighborhood around their orbit?
3. Pluto is not a planet, but the other objects are. What distinguishes Pluto from the two planets in this model?
4. Based on the distinction between Pluto and planets, do you think the asteroids in the asteroid belt are planets? Explain why or why not.

4.4.4 Shape

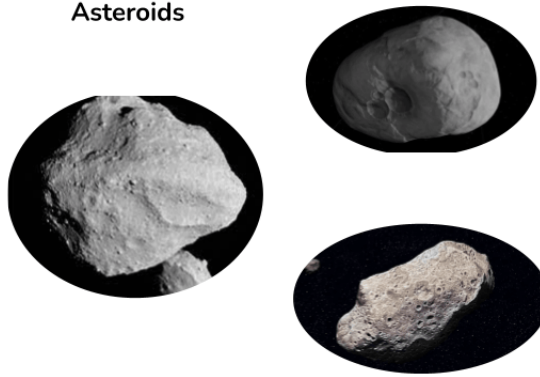
Model

Shape of Objects

Planets



Asteroids

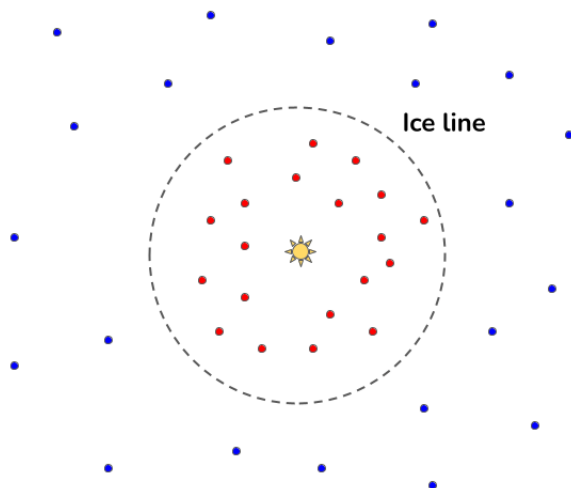


Comparison of spherical planets and irregularly shaped asteroids.

1. How do planets differ from asteroids in terms of shape?
2. Using only this criterion, would you sort Pluto into the planet category or the asteroid category? Explain.

4.4.5 Asteroids vs Comets

Model



Condensation Temperature	Substance(s)
1,300K	Iron
1,200K	Silicates (Rock)
140K	Water Ice
90K	Methane & Ammonia Ices
N/A	Hydrogen & Helium

1. What substances do you think the dots inside the circle are made of?
2. What substances do you think the outside the circle are made of?
3. Asteroids are small objects (failed planets) that are made mostly of rock. Where do you think asteroids

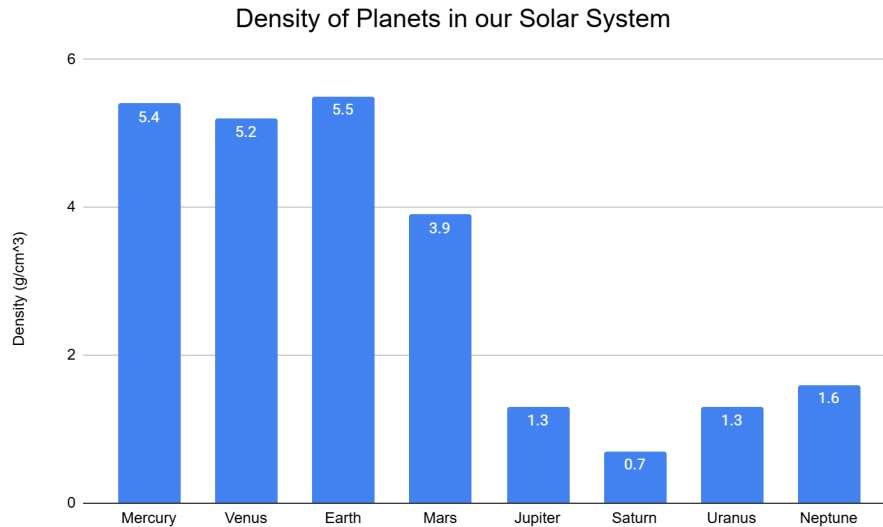
can be found?

4. Comets are small objects (failed planets) that are made mostly of ice. Where do you think comets can be found?

4.5: Planetary Interiors

4.5.1 Density

Model



Mean density of planets in our solar system displayed at bar chart

1. How do the densities of the terrestrial planets compare?
2. Draw a horizontal line at the density of each material found in the protoplanetary disk (metal, rock, water, methane/ammonia, hydrogen)

Material	Density
Metal	7.9 g/cm ³
Rock	3.0 g/cm ³
Water Ice	1.0 g/cm ³
Methane and Ammonia Ice	0.9 g/cm ³
Hydrogen	0.5 g/cm ³

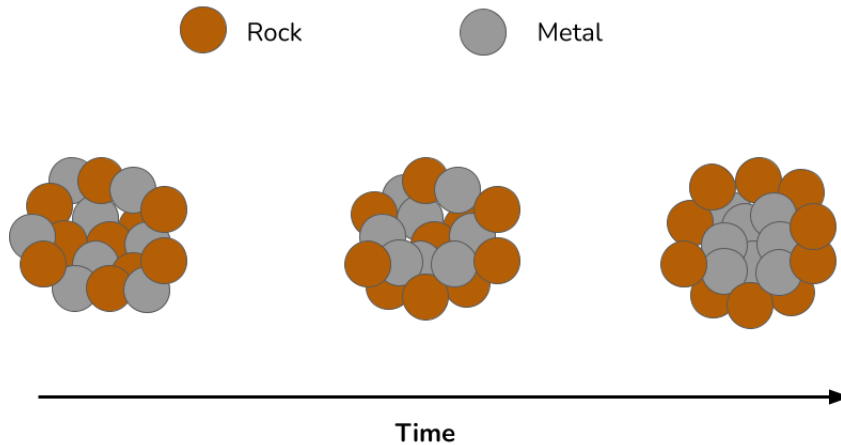
1. Fill in the table with your prediction for the density of a planet that is made from each percent composition

Composition	Density
100% Metal	
100% Rock	
100% Water Ice	
50% Metal and 50 % Rock	
70% Water and 30% Rock	
30% Iron and 70% Rock	

- Based on their densities:
 - What do you expect the terrestrial planets (Mercury, Venus, Earth, Mars) are made of?
 - What do you expect the Jovian planets (Jupiter, Saturn, Uranus, and Neptune) are made of?
- What do you think is different about Mars compared to the other four terrestrial planets? Explain your reasoning.
- Which Jovian planet do you think is the largest percent hydrogen? Explain your reasoning.

4.5.2 Differentiation

Model

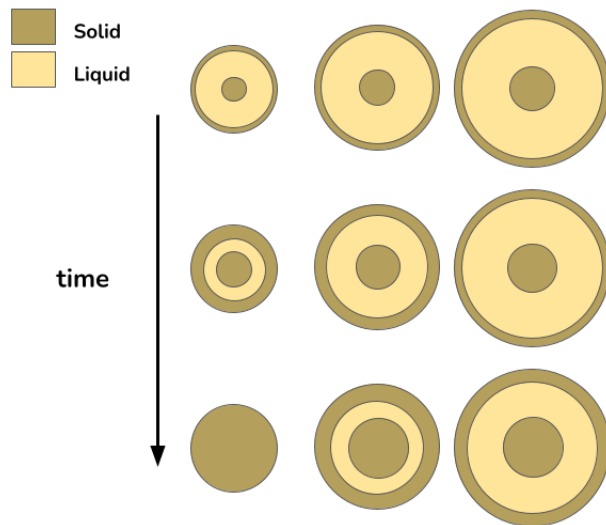


Early and late stages of planetary differentiation showing metal and rock separation.

- At an early stage (early in time), is the rock and metal mixed together or are they separated into groups?
- At a late stage (late in time), is the rock and metal mixed together or are they separated into groups?
- In the end, where is the iron? Where is the rock?
- Metal is more dense than rock. Based on the end model (late in time), which part of the planet has material with the highest density?
- Based on your response, do denser materials rise to the surface or sink to the core?
- Recall that Earth is made of metal and rock. Where on Earth is the metal and where on Earth is the rock? Explain why this makes sense.

4.5.3 Terrestrial Solidification

Model



Comparison of planetary cooling and solidification rates for different-sized terrestrial planets.

1. Do bigger or smaller planets solidify more quickly?
2. Based on your answer, do you think bigger or smaller planets cool down more quickly?
3. Which planet would you expect to have more of a liquid core, Earth or Mercury (Earth is much bigger)?

Apply

Predict the interior structure of the terrestrial planets based on their size. Choose different colors/patterns for different phases/substances and fill those colors/patterns into the key.

Mercury

Venus

Earth

Mars

☐	Solid Metal
☐	Liquid Metal
☐	Solid Rock
☐	Liquid Rock

Substance(s)	Density
Iron	7.9 g/cm ³
Silicates (Rock)	~3 g/cm ³

4.5.4 Jovian Layers

Model

The following materials have different densities:

Material Densities

Material	Density
Metal	7.9 g/cm ³
Rock	3.0 g/cm ³
Water Ice	1.0 g/cm ³
Methane and Ammonia Ice	0.9 g/cm ³
Hydrogen	0.5 g/cm ³

1. Use the previous table to predict which materials are present in each layer of the Jovian planets by drawing circles and color-coding substances in the circles to represent different layers. Make a key. Recall that Jupiter and Saturn have a lot more hydrogen than Uranus and Neptune. You might need to look back at your earlier work to recall what each planet is made of.

Jupiter	Saturn
Uranus	Neptune

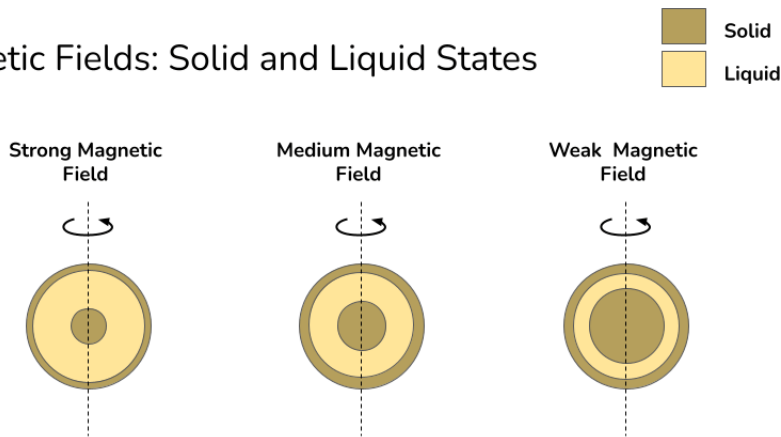
1. What is similar about the structure of these planets?
2. How do these layers differ from the terrestrial planets (for example, Earth)?
3. You might identify two different groups for these four planets. Which pairs of planets would you group together? Explain your thinking.

4.6: Magnetic Fields

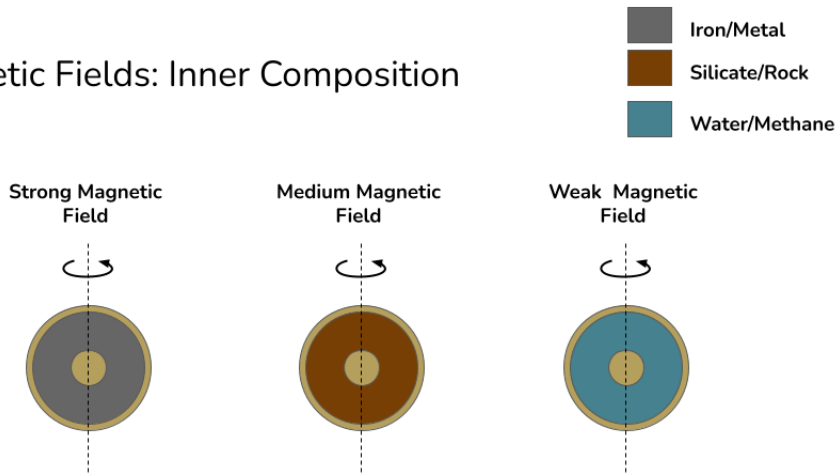
4.6.1 Terrestrial Magnetic Fields

Model

Magnetic Fields: Solid and Liquid States



Magnetic Fields: Inner Composition



1. What phase of matter (solid or liquid) might be the source of the magnetic field?
2. Identify the pattern:
When there is more solid / liquid in a planet's interior, there is a stronger magnetic field.
3. What type of material (metal, rock, or ice) creates the strongest magnetic field?
4. What type of material (metal, rock, or ice) creates the weakest magnetic field?
5. Mercury has a much larger iron (metallic) core than Earth and Mercury's core is all solid. Earth has a smaller iron core, and some of it is solid and some of it is liquid. Which planet do you think has a larger magnetic field? Explain.
6. Mars has almost no magnetic field. Based on this information, do you think Mars' interior is more liquid or more solid?

compared to Earth? Explain your thinking.

4.6.2 Terrestrial Magnetic Field Comparisons

Model

The table below lists the four terrestrial planets in our solar system along with their magnetic field strength and rotational period.

Terrestrial Planet Magnetic Fields and Rotational Periods

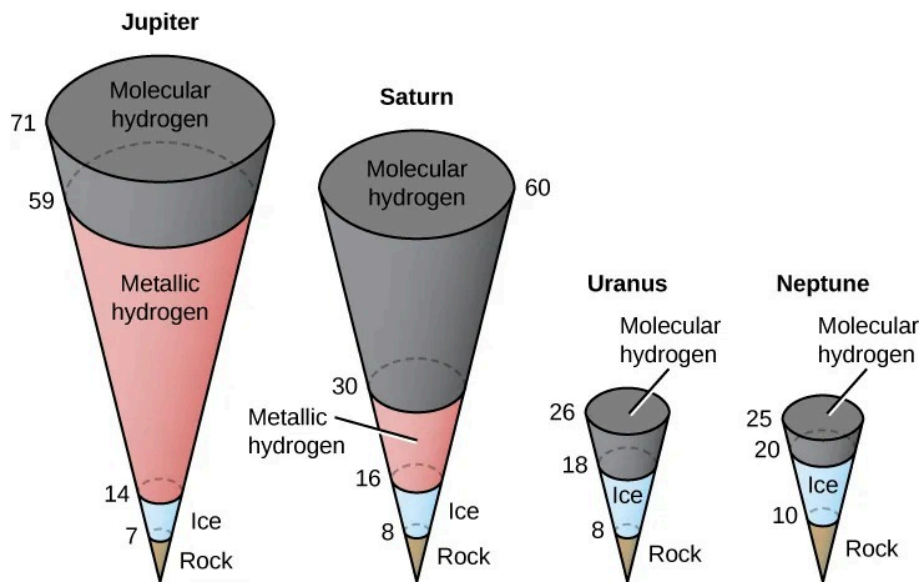
Planet	Magnetic Field	Rotational Period
Mercury	0.006 B_{Earth}	58 days
Venus	0	243 days
Earth	1 B_{Earth}	1 day
Mars	0	1.04 days

1. Recall that Mercury has a large iron core. Why is the magnetic field of Mercury so much less than Earth?
2. Venus is similar to Earth in terms of its composition (both substance and amount of liquid). Why doesn't it have a magnetic field?
3. Mars has almost the same rotational period as Earth. Why doesn't it have a magnetic field?

4.6.3 Jovian Magnetic Fields

Model

The model below shows the composition of the Jovian planets and includes a table of their magnetic fields and rotational periods.



Jupiter and Saturn are composed primarily of hydrogen and helium (but hydrogen dominates), but Uranus and Neptune consist in large part of compounds of carbon, nitrogen, and oxygen.

Image Credit: OpenStax Astronomy 2e (<https://openstax.org/details/books/astronomy-2e>)

Planet	Magnetic Field	Rotational Period
Jupiter	20,000 B_{Earth}	~10 hours
Saturn	570 B_{Earth}	~10 hours
Uranus	48 B_{Earth}	~12 hours
Neptune	28 B_{Earth}	~16 hours

1. Why do you think Jupiter and Saturn have such strong magnetic fields? What do they have that might contribute a strong field that Uranus and Neptune do not have?
2. Why are the magnetic fields of Uranus and Neptune so much stronger than Earth? There might be more than one reason. Explain your thinking.

4.6.4 Magnetic Field Protection

Model

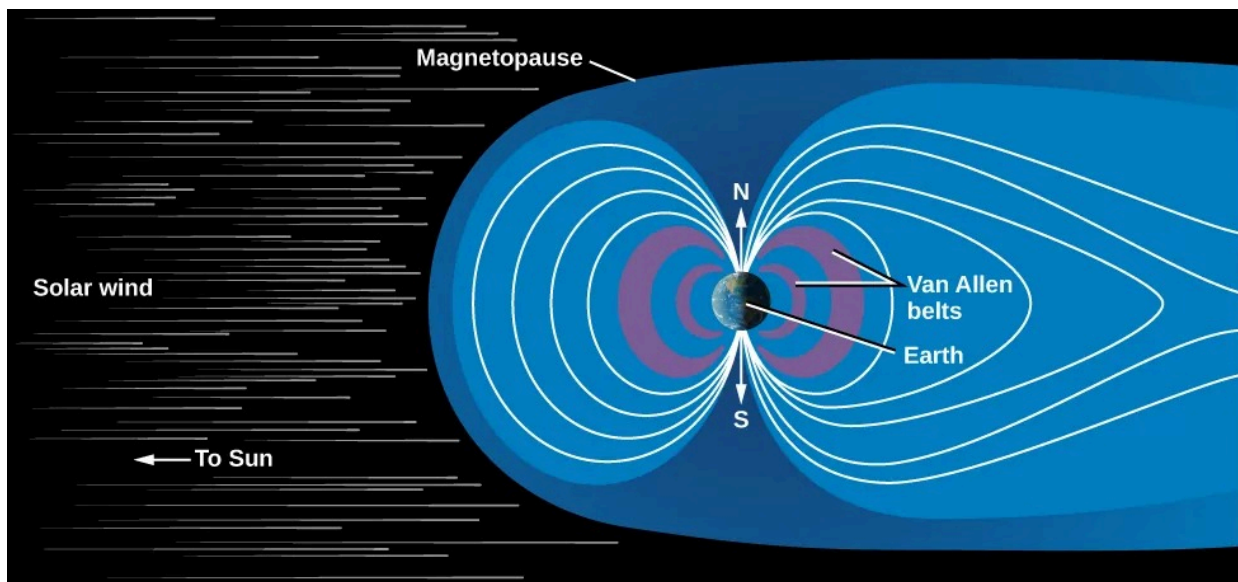


Image Credit: OpenStax Astronomy 2e (<https://openstax.org/details/books/astronomy-2e>)

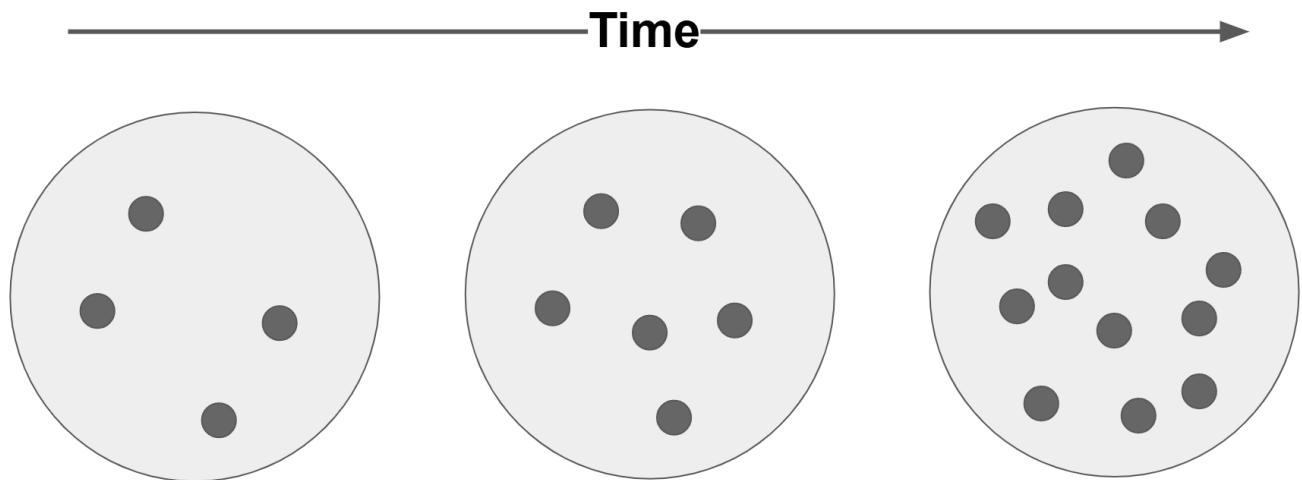
1. Solar wind particles travel along magnetic field lines but do not cross them. What will happen to the particles that are heading straight to Earth?
2. Could some of the solar wind get deflected to Earth? If so, where does it end up on Earth?
3. Solar wind can involve very high-energy radiation, which is dangerous to humans (and other life). Why might it be more dangerous to travel to the Moon? Hint: It might help to imagine where the moon would be relative to the magnetic field line diagram.
4. Why might it be even more dangerous to travel to Mars?

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4.7: Planetary Surface Changes

4.7.1 Impact Cratering

The model below shows snapshots of the same planet at different moments in time. The dark circles represent impact craters on the surface of the planet.



1. In each image, circle the impact craters that are **new**
2. Write the number of **new craters** and **total craters** underneath each image
3. **Identify a pattern and provide reasoning for why the pattern makes sense:**

As time goes on, the number of impact craters ...

This makes sense because ...

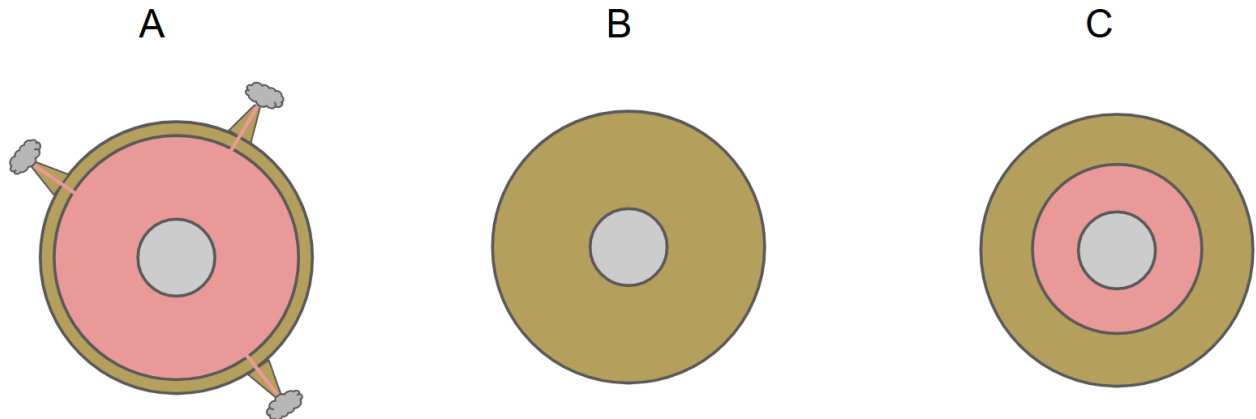
4.7.2 Volcanism

The model below shows three different planets (or the same planet at different times) with different proportions of solid/liquid interior layers.

■ Solid crust

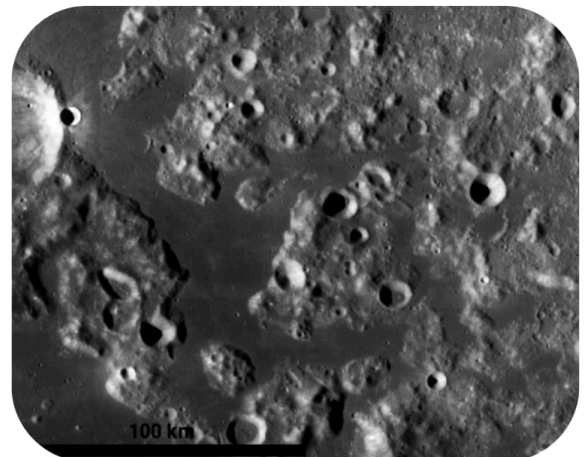
■ Liquid Mantle

■ Solid/Liquid Core



1. **Compare planet A and B:** What is different about planet A that might be the reason it has volcanic activity?
2. **Compare planet A and C:** What is different about planet A that might be the reason it has volcanic activity?
3. **Summarize:** What needs to be true about a planet for volcanic activity to occur?
4. Recall that planets are initially nearly all liquid and solidify as they cool down. What is more likely? Make a claim and provide evidence and reasoning:
 1. A planet has volcanic activity in the past but loses that volcanic activity.
 2. A planet did not have volcanic activity in the past but will gain it in the future.
5. Suppose a planetary system has two planets, a large planet and a small planet.
 1. If the small planet has active volcanoes, will the large planet necessarily also have active volcanoes? Explain your reasoning.
 2. If the large planet has active volcanoes, will the small planet necessarily also have active volcanoes? Explain your reasoning.

4.7.3 Volcano vs Crater



1. Imagine the volcano and crater in the model are near each other. What might happen to the crater after many eruptions?
2. If we look at the planet after many eruptions, which will we most likely see evidence of, volcanism or impacts?
3. Lava flows create a smooth surface that can look like oceans. For this reason, they are called “Mares” (which means oceans) on some bodies. Identify the mares (circle or label them) on the model image on the right.

4. Which parts of the image on the mare and crater landscape do you think represent older rock (ie, rock that formed/solidified a long time ago) and which part represent newer rock (rock that formed/solidified more recently)? Label these parts “older” and “younger”
5. **Make a claim and back it up with evidence and reasoning:** Does volcanism lead to older or younger surfaces?
6. Examine the circled crater in the flat mare in the image below. Do you think that impact occurred before or after the mare was created? Explain your reasoning.



Image Credit: OpenStax Astronomy 2e (<https://openstax.org/details/books/astronomy-2e>)

Note: Mares are often from lava seeping up out of the ground as areas of the crust are broken up by impact craters. They are not always caused by mountainous volcanoes with eruptions like the model picture.

5: WATER AND LIFE

5.1: Atmospheres

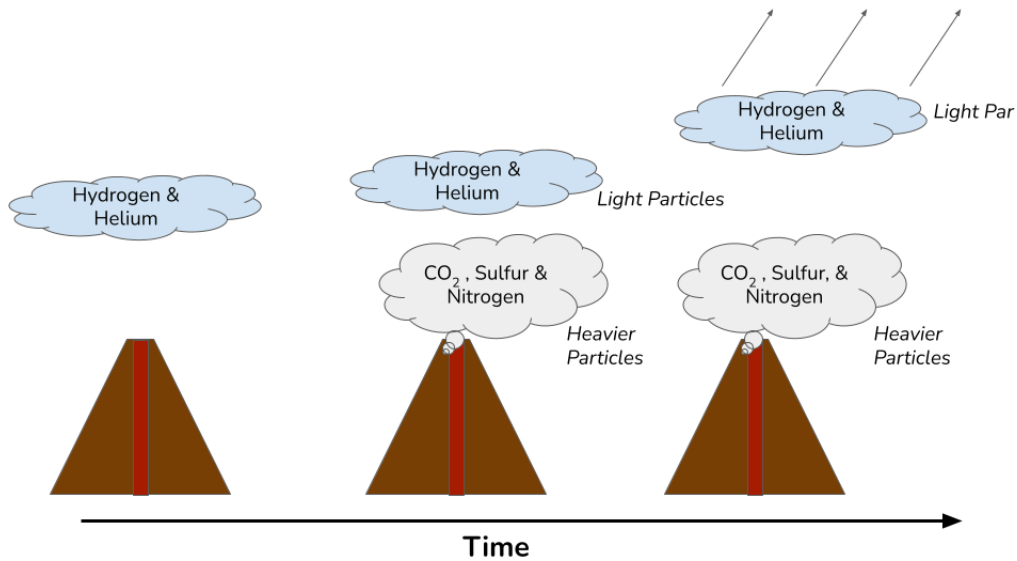
5.2: Habitable Zones

5.3: Life in the Universe

5.1: Atmospheres

5.1.1 Primary and Secondary Atmospheres

Model

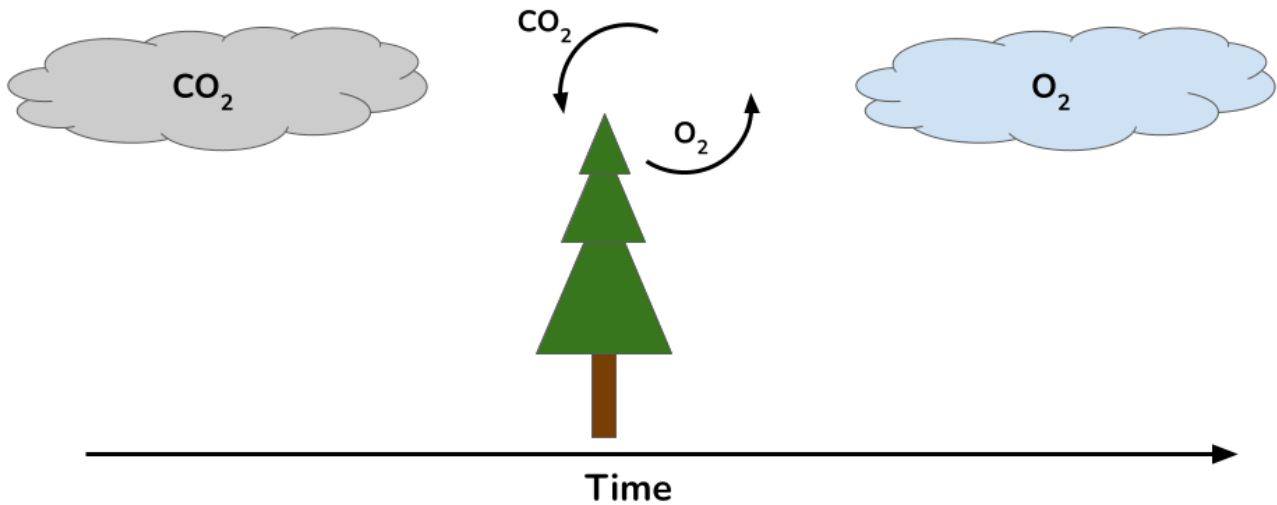


Evolution of a planet's atmosphere from primary gases to a secondary atmosphere.

1. What was the atmosphere originally made of? Where did that come from?
2. What new molecules were added to the atmosphere? Where did they come from?
3. Which atoms/molecules eventually drifted away?
4. What was different about the atoms/molecules that drifted away over time and the atoms/molecules that remained?

5.1.2 Earth's Tertiary Atmosphere

Model

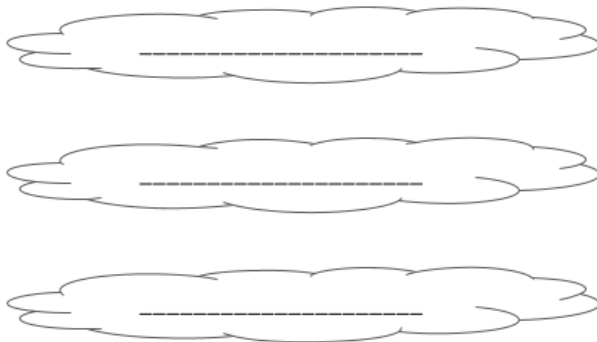


Timeline showing changes in Earth's atmosphere and the rise of oxygen.

1. What was the atmosphere made up of at the start of this timeline? Based on the previous activity, do you think this was the primary or secondary atmosphere?
2. What new molecules were added to the atmosphere? Where did they come from?
3. Which atoms/molecules eventually went away? Where did they go?
4. If you see a planetary atmosphere that is full of oxygen, what does that tell you about what you might find on the planet?

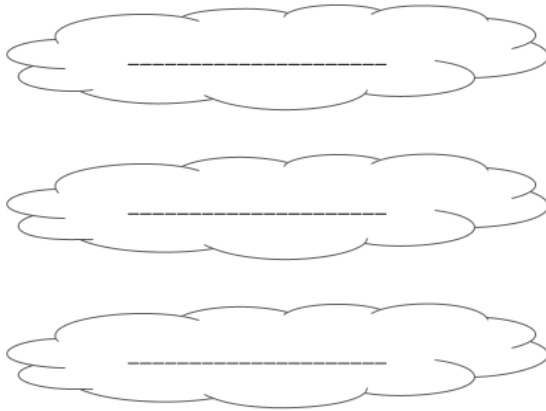
5.1.3 Cloud Bands of Jupiter and Saturn

Model

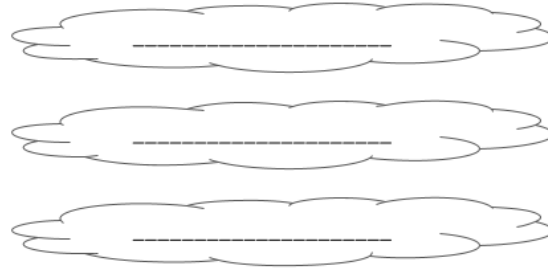


Ammonium Hydrosulfide Ice	Middle Density
Ammonia Ice	Least Dense
Water Ice	Most Dense

1. **Recall:** Do denser materials sink or rise? Based on what you know about density, label the layers of Jupiter and Saturn.
2. Jupiter has **much more gravity** than Saturn. Identify which planet you think is which, based on the atmospheres shown.



Jupiter or Saturn



Jupiter or Saturn

5.1.4 Condensation in the Atmosphere of Uranus and Neptune

Uranus and Neptune have methane in addition to the compounds found in the atmosphere of Jupiter and Saturn.

Model

Relative Density of Atmospheric Ices

Substance	Relative Density
Water Ice	Most Dense
Ammonia Ice	Second Most Dense
Ammonium Hydrosulfide Ice	Second Least Dense
Methane Ice	Least Dense

Create a structure for that atmosphere based on the given density comparison.

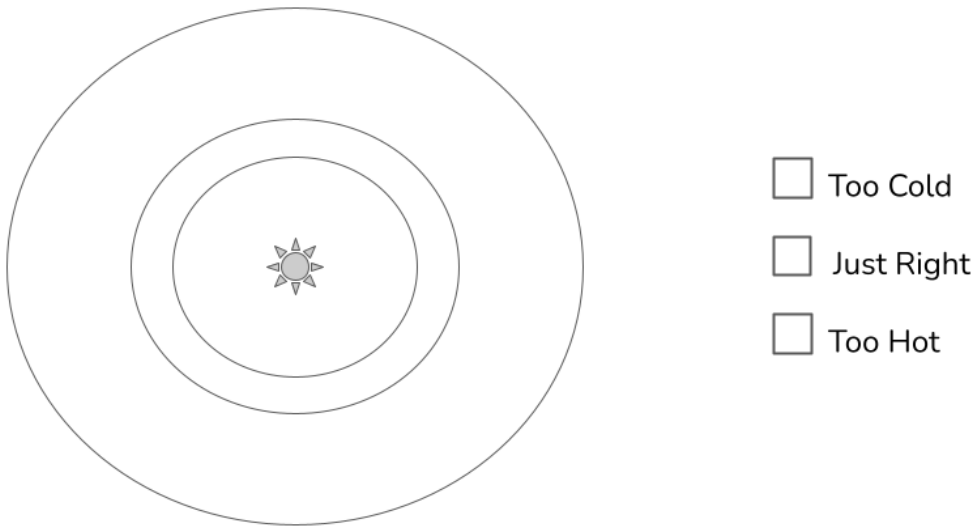
On Uranus and Neptune, the low temperature causes the more dense layers to condense (become solid), fall lower, and even drop out of the atmosphere entirely. Only one layer remains. What substance will be in the atmosphere of Uranus and Neptune? Draw and label that cloud.

1. Why do Jupiter and Saturn have stripes but Uranus and Neptune do not?
2. **Summarize:** How does density affect the atmospheres of the Jovian planets (Jupiter, Saturn, Uranus, and Neptune)? Discuss density in terms of layers as well as what happens to those layers in colder planets

5.2: Habitable Zones

5.2.1 Goldilocks and the Search for Water

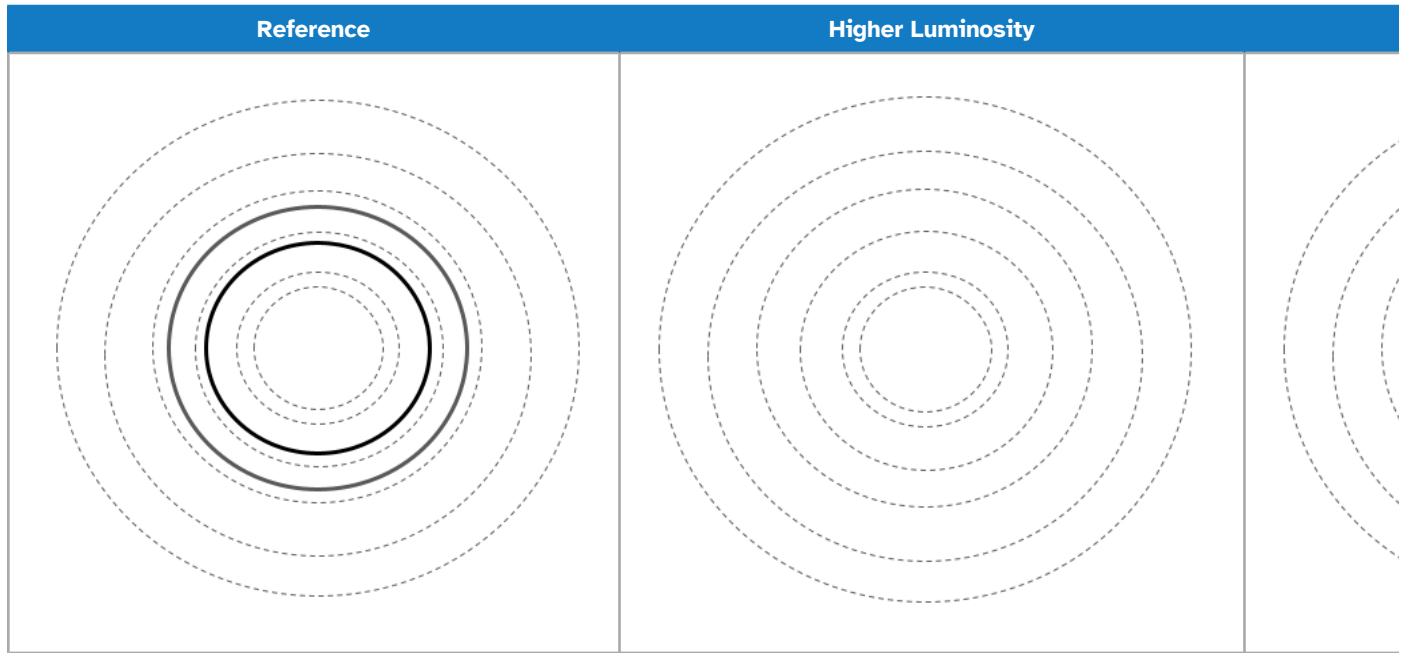
Model



Habitable zone diagram around a star showing too hot, just right, and too cold regions.

1. Where is it “too hot” for liquid water? What do you think happens to liquid water in that region?
2. Where is it “too cold” for liquid water? What do you think happens to liquid water in that region?
3. Which region do you think Earth is in? Why do you think that?
4. How might these circles change if the star gives off more light? Draw new versions based on the reference.

Comparison of habitable zones for different stellar luminosities

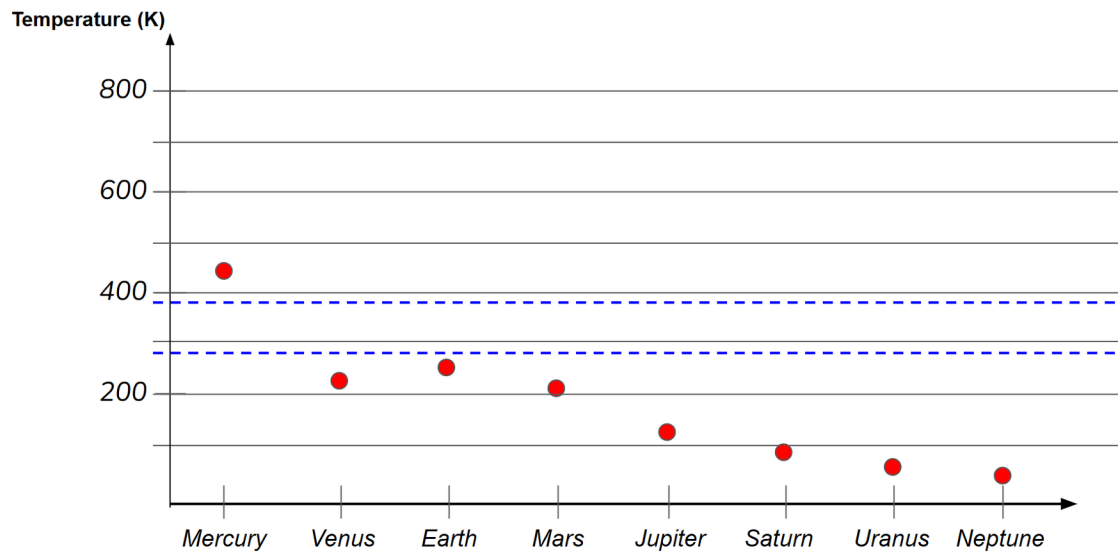


- For lower luminosity stars, is the liquid water zone (“just right”) closer or farther from the star?
- For higher luminosity stars, is the liquid water zone (“just right”) closer or farther from the star?

5.2.2 Surface Water without an Atmosphere

Model

The data below show the predicted surface temperature of the planets in our solar system **without atmospheric effects** based on the size of the planets and their distance from the sun. The dashed blue lines represent the temperature range where water is liquid at one atmosphere of pressure.



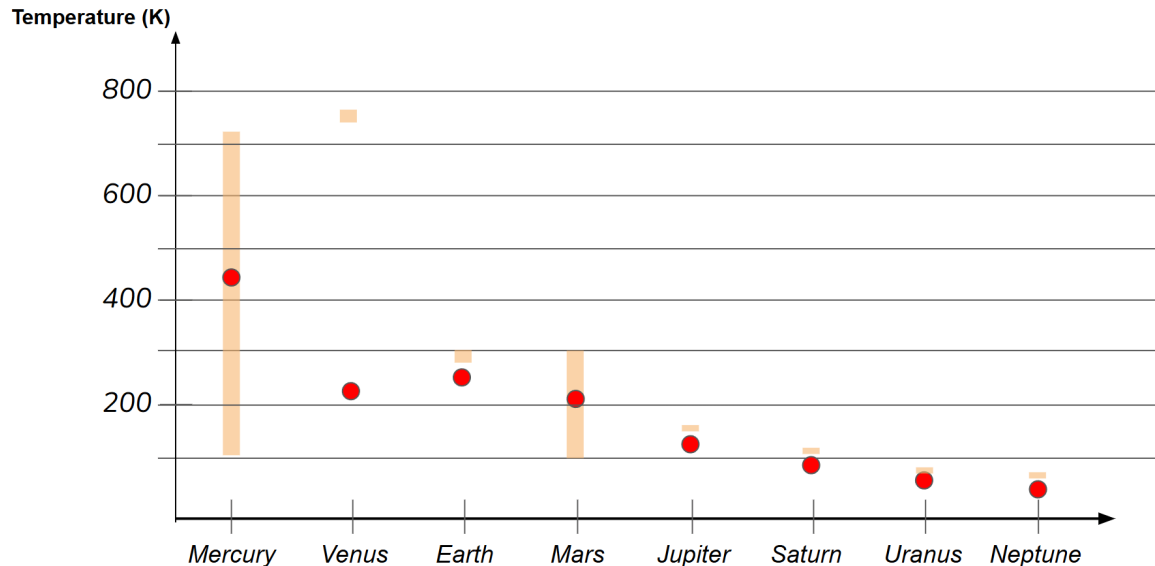
- Which planet(s) in our solar system would you expect to find liquid water on the surface?
- Which planets in our solar system have a surface that is “too hot” for liquid water?

- Which planets in our solar system have a surface that is “too cold” for liquid water?

5.2.3 Atmosphere and Temperature

Model

The data below show the predicted surface temperature of the planets in our solar system **without atmospheric effects** based on the size of the planets and their distance from the sun as red dots. The **orange bars show the actual range of temperature** (averaged over latitude) for these same planets.



- Which planets have a measured temperature range (orange) that is entirely above the predicted temperature (red dot)?
- Which planets have a measured temperature range (orange) that is both above and below the predicted temperature (red dot)?
- A thicker atmosphere raises the overall temperature of a planet and reduces the range in temperature of the planet. Which planets do you think have a thick atmosphere? Explain.
- Why do you think some planets have a large temperature range?

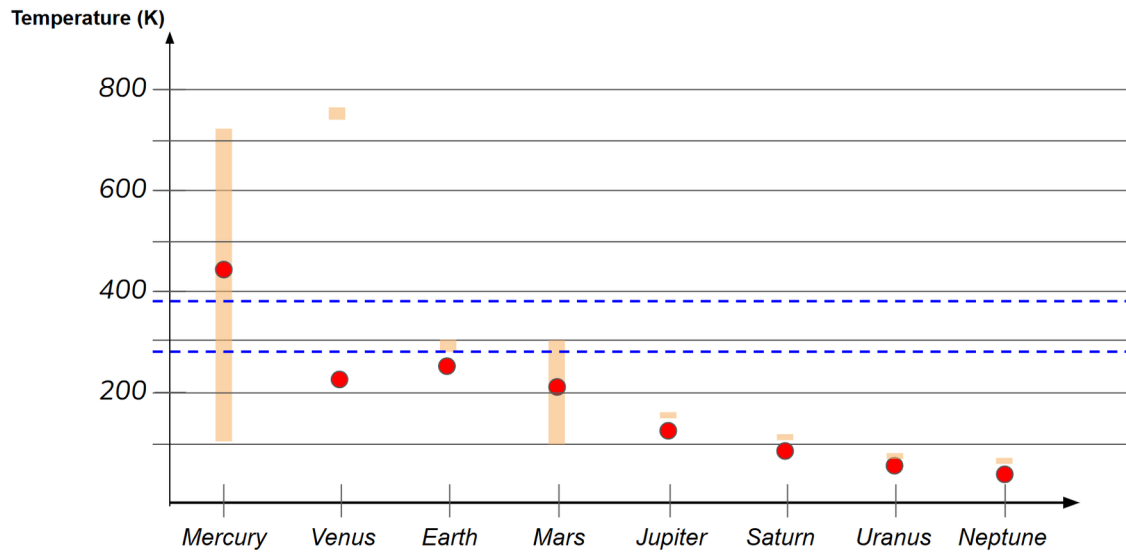
Summary

Atmospheres act like a blanket to the overall temperature and the range in temperature. This process is called the **greenhouse effect**.

5.2.4 Surface Water with an Atmosphere

Model

The data below show the predicted surface temperature of the planets in our solar system **without atmospheric effects** based on the size of the planets and their distance from the sun as red dots. The orange bars show the actual range of temperature (averaged over latitude) for these same planets. The **dashed blue lines represent the temperature range where water is liquid** at one atmosphere of pressure.



1. Which planet(s) have a black dot (predicted temperature) that is in the liquid water zone ("just right")?
2. Which planets could have a temperature in the liquid water zone if they had more of a greenhouse effect?
3. Water freezes at 273 K. Would you expect to find a Jovian planet that has liquid water on its surface? Explain why or why not.

5.3: Life in the Universe

5.3.1 Exoplanet Sample

Model

One way to group our planets is by size, which can then be used to compare exoplanets to planets in our solar system. Our solar system has two small terrestrial planets (Mercury and Mars) and two larger terrestrial planets (Venus and Earth). The Jovian planets are also grouped by size and composition with smaller ice giants (Uranus and Neptune), which are much larger than terrestrial planets, and larger gas giants (Jupiter and Saturn). Below this grouping is a histogram of the exoplanets that have been discovered and their size relative to the size of Earth.

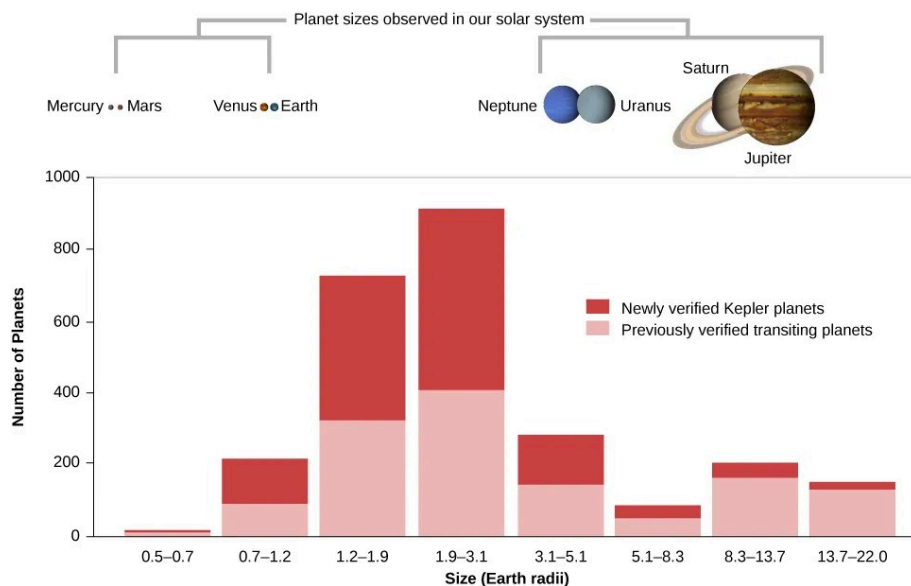


Image Credit: OpenStax Astronomy 2e (<https://openstax.org/details/books/astronomy-2e>) modification of work by NASA

1. Use the diameter column on the planetary properties table to identify ranges for **sub-Earths** (like Mercury and Mars), **Earth-like** (Venus and Earth), **Neptunian** (Uranus and Neptune), and **Jupiters** (Jupiter and Saturn). Put those bold labels on top of the columns in the model that most fit those categories.

Planet Classification Data

Planet	Density (g/cm ³)	Mass (Earth = 1)	Diameter (Earth = 1)
Mercury	5.43	0.055	0.383
Earth	5.51	1.000	1.000
Mars	3.93	0.107	0.532
Jupiter	1.33	317.8	10.97
Uranus	1.27	14.5	3.98
Saturn	0.69	95.2	9.14
Neptune	1.64	17.1	3.86
Venus	5.24	0.815	0.949

1. Examine the size of that bar relative to the others: Are **Earth-like planets** very common, somewhat common, or very rare?

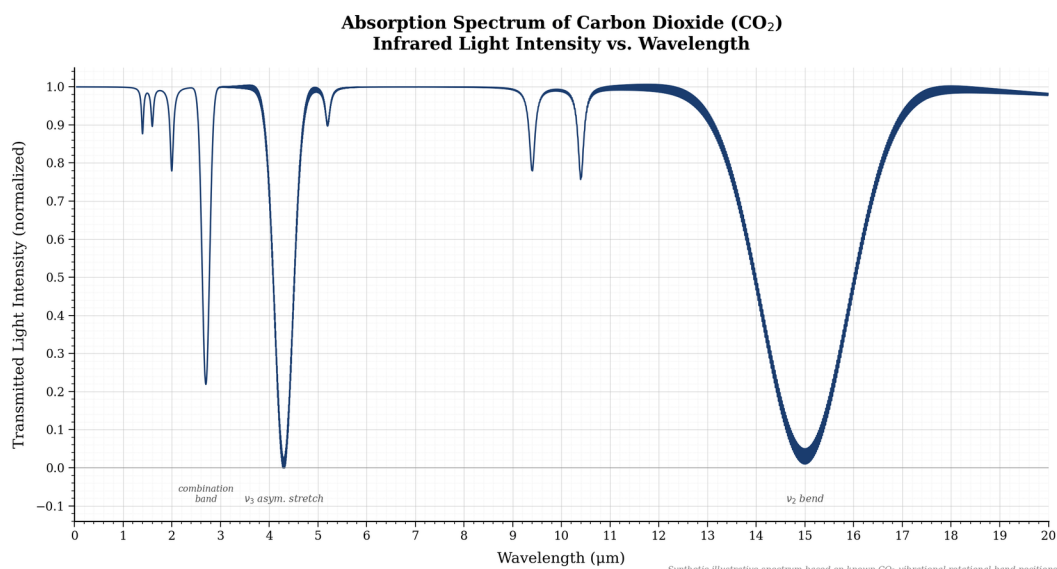
- Astronomers define a category of planets with diameters from 1.25 - 2 Earth diameters as **Super Earths**. Label this bar on the chart. Are **Super Earths** very common, somewhat common, or very rare?
- What is the most common planet size according to the exoplanets we have discovered? Do we have planets like that in our solar system?

5.3.2 Bio-signatures

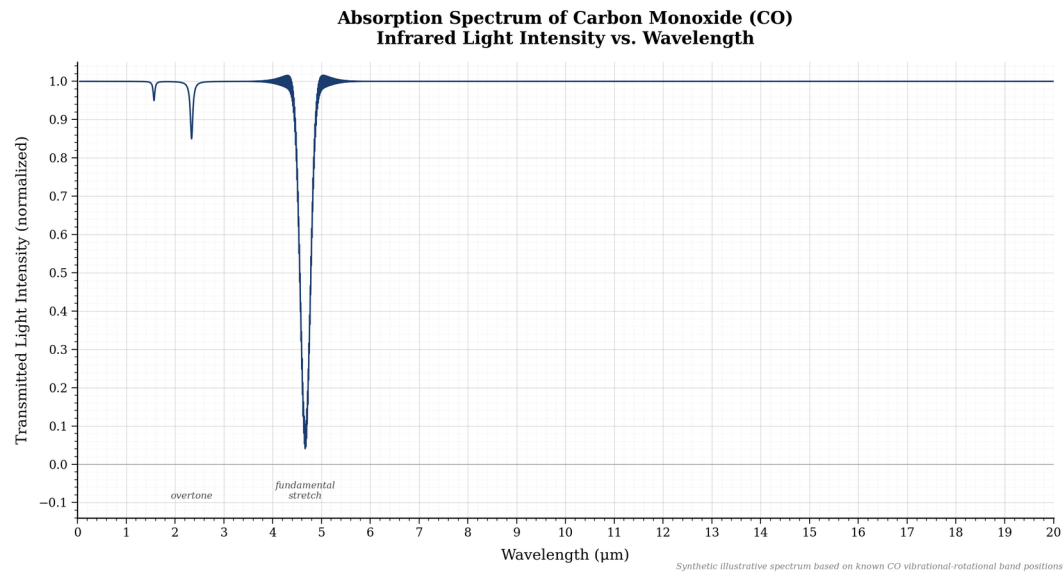
Model

The plots below show the **absorption plots** for common atmospheric molecules. These are similar to the absorption spectra we explored for atoms, but there are more ways molecules can interact with light so there are sometimes wide bands, rather than individual wavelengths that are absorbed. These plots are generated from data, not exact values from measurements.

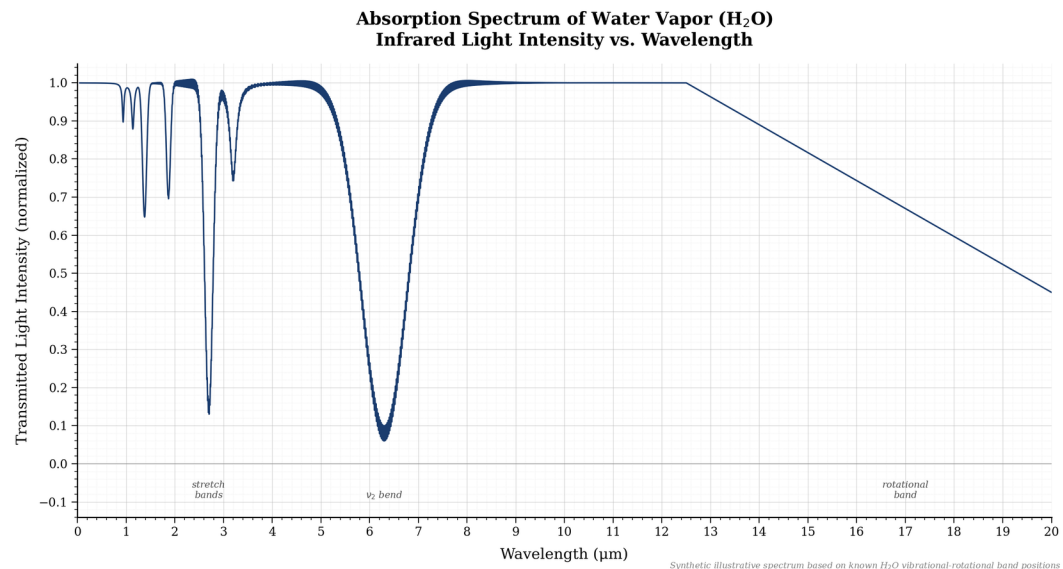
Carbon Dioxide (CO₂)



Carbon Monoxide (CO)



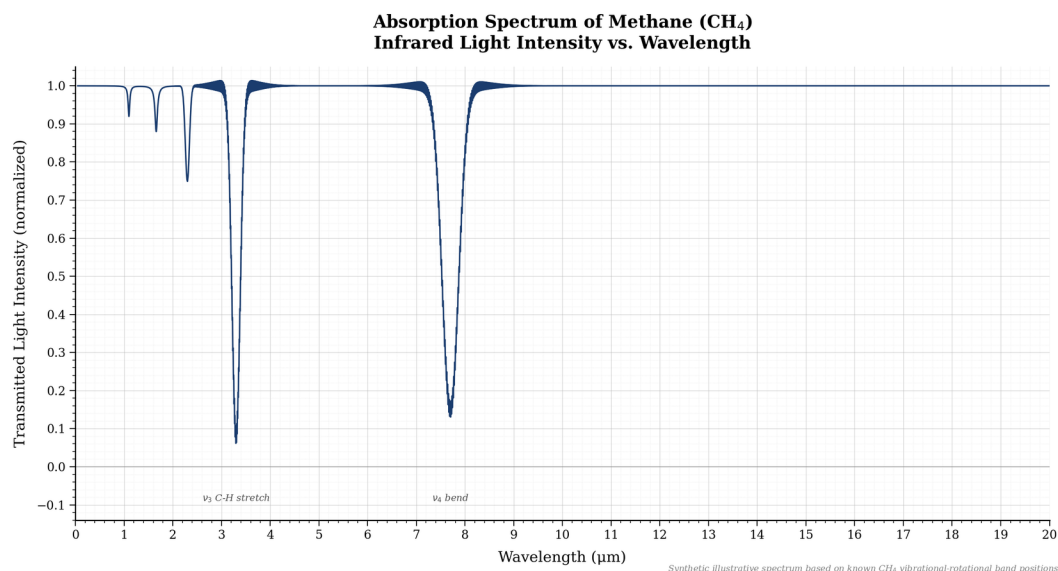
Water Vapor (H₂O)



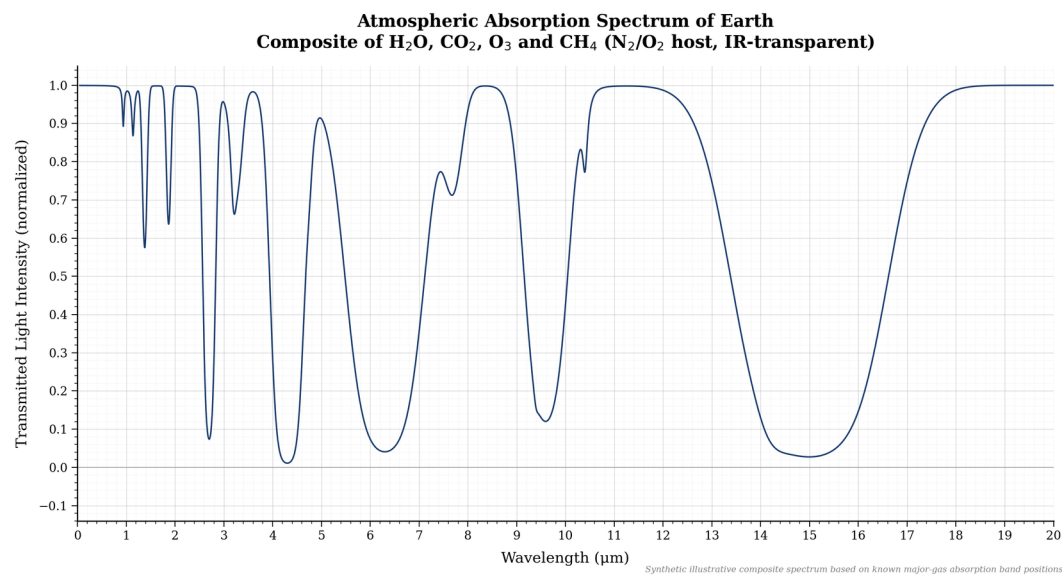
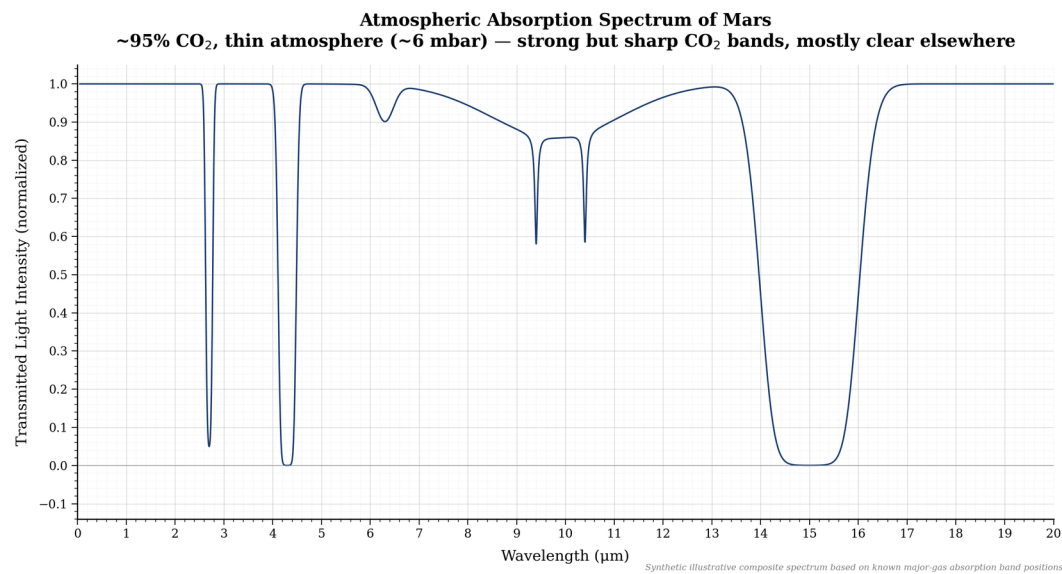
Ozone (O₃)



Methane (CH₄)



1. Do the different molecules have sufficiently different absorption bands (dips) or are they similar/overlapping?
2. Examine the absorption plots for the atmospheres of Earth and Mars:
 1. Identify the molecules on the plots, then use those to identify the molecular signature of the groups you made
3. Earth has life. What molecules were in the Earth's absorption plot that might be indicators of life? Astro-biologists and alien searchers call these **bio-signatures**.



5.3.3 Nearby Stars and the Radio Bubble

Model

The table below estimates the number of star systems (some of which have more than one star), total number of planets, and approximate number of planets in the habitable zone at different distances from Earth. These are estimates based on predicted density from data, not actual discoveries of star systems/planets.

Estimated Star Systems and Planets Within 100 Light-Years of Earth

Distance from Earth (light-years)	Approximate Star Systems	Approximate Total Planets	Approximate Habitable-Zone Planets
10	15	30	4
20	100	225	30
30	320	720	95
40	760	1,700	225

Distance from Earth (light-years)	Approximate Star Systems	Approximate Total Planets	Approximate Habitable-Zone Planets
50	1,400	3,200	420
60	2,400	5,500	720
70	3,700	8,500	1,100
80	5,600	13,000	1,700
90	7,900	18,500	2,400
100	11,000	26,000	3,300

Note: Values are cumulative and include all star systems within the stated distance from Earth.

1. Approximately what percent of star systems have a planet in the habitable zone?
2. The fastest people have traveled through space is about 25,000 miles per hour. At that rate, it would take over 26,000 years to travel one light year. Would we be able to travel to a distant exoplanet if there was life on it?
3. The first radio signals on Earth were sent out in 1906. Approximately how many habitable planets could have received that signal by now?
4. Radio signals to space peaked in the 1970's-1980's. Approximately how many habitable planets could have received those higher signals by now?
5. Imagine you had a cosmic phonebook and we assume all habitable planets have intelligent life. How many times over the rest of your life (estimate it) could you send and receive a messages (send one, then receive one) with:
 1. 4 planets?
 2. 25 planets?
 3. 100 planets?
6. What would your first message be to those groups of planets? It could be the same or differ based on the number of interactions you know are possible.

5.3.4 Drake Equation

Model

The Drake Equation is a probabilistic formula developed by astronomer **Frank Drake** in 1961 to estimate the number of detectable, communicating extraterrestrial civilizations in the Milky Way galaxy.

$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

Variables in the Drake Equation

Variable	Meaning
N	The number of detectable communicating civilizations currently in the Milky Way.
R^*	The average rate at which new stars form in the Milky Way (stars per year).
f_p	The fraction of stars that have planetary systems.
n_e	The average number of planets per planetary system that could potentially support life.
f_l	The fraction of habitable planets on which life actually develops.
f_i	The fraction of planets with life where intelligent life evolves.
f_c	The fraction of intelligent civilizations that develop technology capable of communicating across interstellar space.
L	The average length of time (in years) that a communicating civilization remains detectable.

- Astronomers estimate 2-3 stars form in the Milky Way per year. Pick one and write it below for your estimate.

$R^* =$

- We previously identify the fraction of star systems that have planets in the habitable zone, which is the product of the fraction of stars with planetary systems and the average number of planets that can support life. Rewrite this below:

$$f_p \times n_e =$$

- In our solar system, Venus, Earth, and Mars are all potentially habitable depending on atmospheric effects, but only Earth has life. What should the fraction that life develops be?

$$f_l =$$

- We only have Earth as our sample for the next few, so we can be optimistic and assume:

$$f_i = 1.0$$

$$f_c = 1.0$$

- We have emitted radio since 1906. Determine **L** and estimate the number of intelligent life in our Galaxy

$$L =$$

$$N =$$

- Are you surprised by the number of intelligent, technological alien worlds in our galaxy or does this number feel right?
- The last number, L, is based on our current amount of time as a radio-sending civilization. Many systems were created long before us, so astronomers actually estimate how long the civilization will last (ie, how long before we wipe ourselves out). Choose a new number based on how long you think humanity has left before we result in our own extinction. **Boundaries:**
 - We haven't died yet, so the number must be higher than the previous calculation
 - Our Earth will not exist in about 5 billion years, so lets cap it at that.

$$L =$$

$$N =$$

INDEX

No index terms found.

GLOSSARY

S

Sample Word 1 | Sample Definition 1

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