

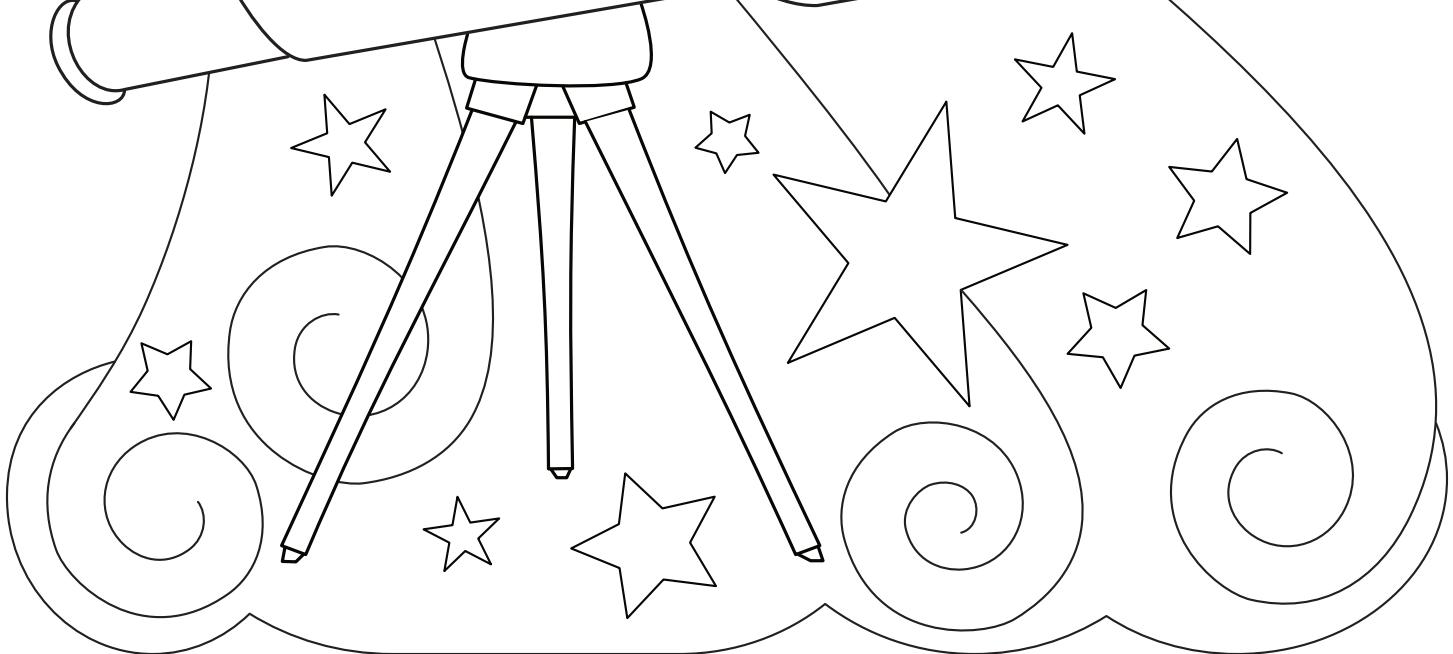
Astronomy

Earth and Our Solar System

Star Finding and Constellations

Galaxies and the Known Universe

Space Exploration



ASTRONOMY

Unit	Lesson	Date	Topic	Pages
Unit 1. Earth and the Moon	1	Mon, Jan 13	What Is Astronomy?	4-7
	2	Wed, Jan 15	Diurnal Motion	8-9
	3	Self paced lesson	Measure Your Latitude	10-13
		Mon, Jan 20	No Class (MLK day holiday)	
	4	Wed, Jan 22	The Seasons	14-15
	5	Self paced lesson	DIY Equatorial Sundial	16-17
	6	Mon, Jan 27	Lines of Latitude	18-19
	7	Wed, Jan 29	Our Moon	20-21
	8	Self paced lesson	Cookie Models and Journal	22-25
	9	Mon, Feb 3	Eclipsed	26-27
	10	Wed, Feb 5	Totality	28-29
	11	Self paced lesson	Earth and Moon Review/Assessment	30-33
	12	Mon Feb 10	EARTH & MOON QUIZ SHOW	
Unit 2. Our Solar System	13	Wed Feb 12	Our Solar System	34-35
	14	Self paced lesson	Step Scale Model of the Solar System	36-37
	15	Mon Feb 17	Inner vs Outer Planets	38-39
	16	Wed Feb 19	Planetary Motion	40-41
	17	Self paced lesson	Ellipses & Orbits	42-43
	18	Mon Feb 24	Dwarf Planets and Moons	44-45
	19	Wed Feb 26	Asteroids, Comets and Meteors	46-47
	20	Self paced lesson	Flour and Cocoa Craters	48-49
	21	Mar 3	Near Earth Objects	50-51
	22	Mar 5	SOLAR SYSTEM QUIZ SHOW	
	23	Self paced lesson	Solar System Review/Assessment	52-55
<i>Spring Break is March 10-15</i>				
Unit 3: Stars, Galaxies, and the Universe	24	Mar 17	The Sun as a Star	56-57
	25	Mar 19	Solar Weather	58-59
	26	Self paced lesson	Star Classification Poster	60-64
	27	Mar 24	The Scale of Space and Galaxies	65-66
	28	Mar 26	Main Sequence Stars	67-68
	29	Self paced lesson	Make a Constellation Viewer	69-70
	30	Mar 31	Supernovas and Black Holes	71-72
	31	Apr 2	Stargazing 101	73-74
	32	Self paced lesson	Stargazing Scavenger Hunt	75-78
	33	Mon, Apr 7	Constellations	79-80
	34	Wed, Apr 9	The Known Universe	81-82
	35	Self paced lesson	Stars & Universe Review/Assessment	83-88
	36	Mon, Apr 14	STARS & UNIVERSE QUIZ SHOW	

Unit	Lesson	Date	Topic	Pages
Unit 4: Space Exploration & Mysteries	37	Wed, Apr 16	The Tools of Astronomy	-
	38	<i>Self paced lesson</i>	Candy Bar Heat Shield	-
	39	Mon, Apr 21	Space Exploration 1: Lunar Missions	-
	40	Wed, Apr 23	Space Exploration 2: Beyond the Solar System	-
	41	<i>Self paced lesson</i>	Make a Cardboard Rover	-
	42	Mon, Apr 28	Space mysteries 1: Dark Matter & Dark Energy	-
	43	Wed, Apr 30	space mysteries 2: Quasars & More	-
	44	<i>Self paced lesson</i>	Review for Quiz Show	-
	45	Mon May 5	FINAL QUIZ SHOW	-

Supply List:

Lesson 3 - Measure Your Latitude

- Thread or string (about 15 cm long)
- Printable protractor OR standard protractor
- Pin OR a needle or nail
- Washer OR small object that can hang from string
- Straw
- Tape
- Tape measure

Lesson 6 - DIY Equatorial Sundial

- Inclinometer (made in lesson 3)
- Wooden Dowel
- Drill
- Cardboard or wood
- Sundial template
- Scissors

Lesson 8 - Make a Model of Earth & the Moon

- Dough OR modeling clay
- Ruler (optional)

Lesson 9 - Cookie Models and Journal

- Moon journal printout
- Binoculars (optional)
- Cookie and cream style sandwich cookies (optional)

Lesson 15 - Step Scale Model of Solar System

- Chalk or something else that can be used to mark position in an outdoor location
- Planet template OR modeling clay
- Yardstick or tape measurer (optional)

Lesson 18 - Ellipses and Orbits

- Thread OR string
- 2 pushpins OR small nails
- Marker OR pen
- Flat piece(s) of cardboard

Lesson 21 - Flour and Cocoa Craters

- 2 balls of different sizes such as small / large marbles
- Flour
- Cocoa powder
- Ruler
- A wide non-breakable container

Lesson 27 - Star Classification Poster

- Poster board or a large piece of paper
- Art supplies such as markers, crayons, or paint
- Objects to represent stars that are different sizes and colors such as:
 - Paper stars: use scissors to cut different colors of construction paper to different sizes
 - Balloon stars: inflate different-color balloons to different sizes
 - Papier-mâché stars: use a variety of bowls as molds to make hemispheres of different sizes

Lesson 30 - Make a Constellation Viewer

- Cylindrical cardboard container
- Constellation printout
- Nail or pin
- Phone (with a flashlight)

Lesson 32 - Stargazing Scavenger Hunt

- Stargazing scavenger hunt printout
- A pair of binoculars or telescope (optional)
- Stargazing app such as Sky Guide, Star Walk, Night Sky, Sky Safari, or Stellarium

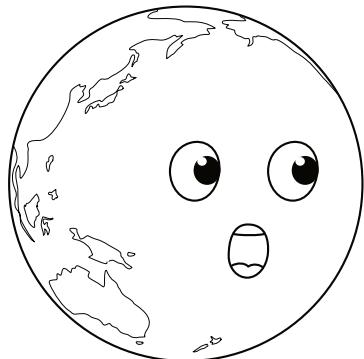
Lesson 39 - Candy Bar Heat Shield

- 4 paper cups
- Tongs
- Small candy bars
- Construction materials such as cotton balls, steel wool, newspaper, cardboard, or aluminum foil
- Electrical tape
- Hair dryer

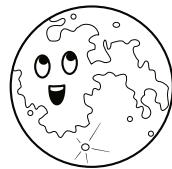
Lesson 42 - Make a Cardboard Rover

- Corrugated cardboard (enough to make several squares roughly 15 cm (6 in) across)
- 1 sharpened cylindrical pencil
- 2 pieces of hard candy with a hole in the middle
- Straw
- Rubber bands
- Ruler
- Tape OR a hot glue gun
- Scissors

Unit 1: Earth & the Moon



WOW MOON, YOU'RE
REALLY GLOWING!



THANKS, I'M JUST
REFLECTING ON
THINGS.

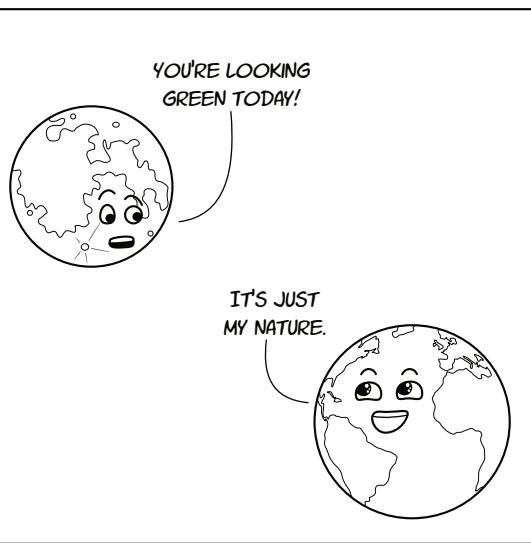
Words are more than tools for communication, they are the framework of knowledge! Without language to express and define new ideas, we wouldn't be able to learn.

To understand astronomy, it's essential to have the right **vocabulary**. The words you see on these pages are terms we will be using in our Earth and Moon unit.

Are you already familiar with some of these terms? If so, match them with the correct vocab cards.

If there are terms or words you don't know, don't worry! We'll be learning them in future lessons. As you learn new concepts, come back to these pages and label each card.

You can also become more familiar with these words by using flashcards or playing memory. The appendix has a printer-friendly set of all of the vocabulary terms.



APHELION

DIURNAL MOTION

ECLIPSE

ECLIPTIC

EQUATOR

HEMISPHERE

HORIZON

LATITUDE

LONGITUDE

ORBIT

PERIHELION

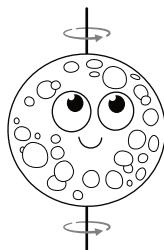
PRIME MERIDIAN

REVOLVE

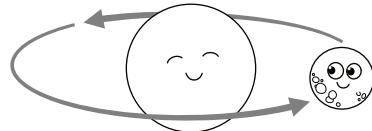
ROTATE

ZENITH

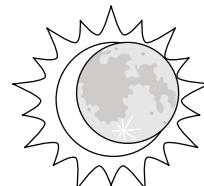
TO SPIN AROUND AN AXIS OR CENTER



TO MOVE IN A CIRCULAR PATH AROUND AN OBJECT; TO ORBIT AROUND SOMETHING



WHEN ONE OBJECT PASSES IN FRONT OF ANOTHER; WHEN ONE OBJECT PARTIALLY OR TOTALLY BLOCKS THE VIEW OF ANOTHER OBJECT



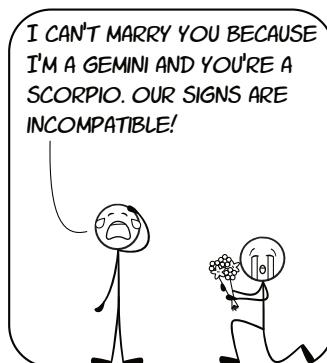
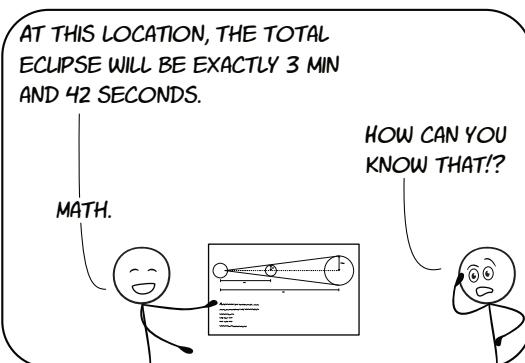
What is Astronomy?

People sometimes confuse astronomy and astrology. These two fields share a common history, but today they are very different!

Astronomy is: _____

Astrology is: _____

IS IT ASTRONOMY OR ASTROLOGY? Label each scenario below:



IS IT SCIENCE OR PSEUDOSCIENCE?

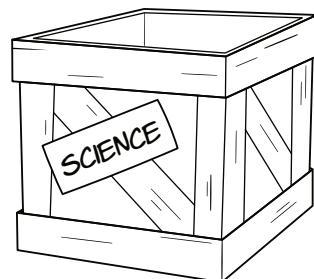
Match each characteristic with the appropriate box

Relies on anecdotal evidence

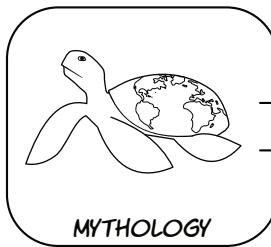
Relies on data, controlled studies, and reproducible observations

Responds to contradictions & criticism by gathering additional data or revising ideas

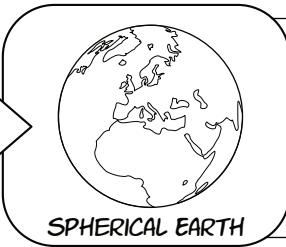
Responds to contradictions & criticism with denial, antagonism, or conspiracy theories



Concepts of Earth through Human History



MYTHOLOGY



SPHERICAL EARTH

In ancient times, many cultures had mythology depicting the Earth as being flat or being part of a giant tree or on the back of a large animal.

Using reason and mathematics, Greek philosophers proved the Earth was spherical. Some of them also recognized that Earth behaved like the other planets and orbited the Sun.

Aristotle

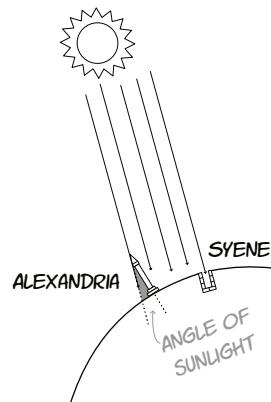
approximately 350 BCE

Eratosthenes

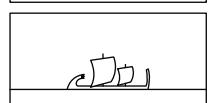
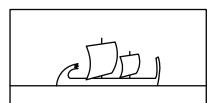
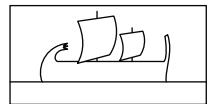
approximately 250 BCE

Ptolemy

approximately 150 CE



A SHIP DISAPPEARS HULL-FIRST WHEN IT SAILS OVER THE HORIZON



Our Current View of Earth:

LAND APPEARS "TOP FIRST" WHEN COMING HOME FROM SEA

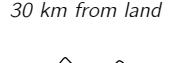
50 km from land



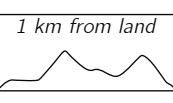
40 km from land



30 km from land



1 km from land

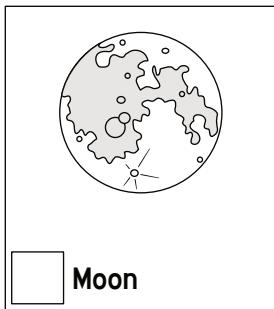
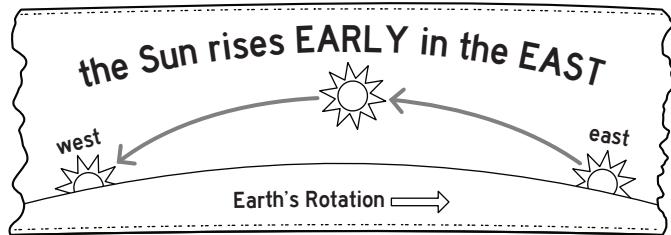




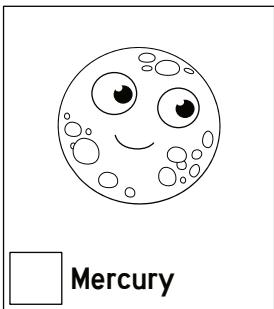
Diurnal Motion: resulting from the rotation of the Earth

From the perspective of an observer on Earth, the Sun moves in an arc across the sky each day from east to west.

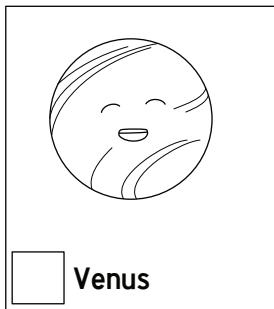
What other objects follow a similar path through the sky? Put a checkmark by all that apply:



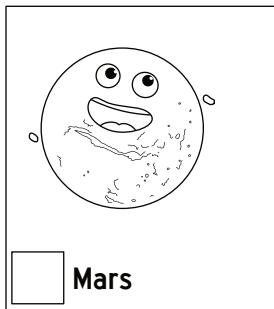
Moon



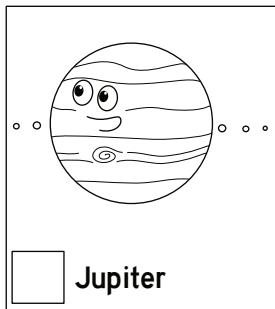
Mercury



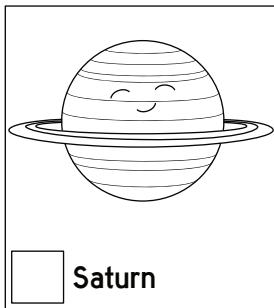
Venus



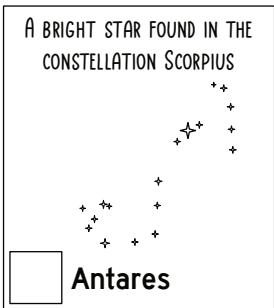
Mars



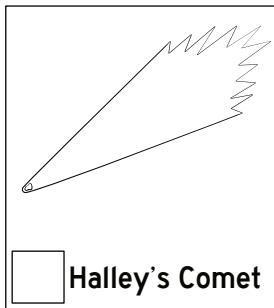
Jupiter



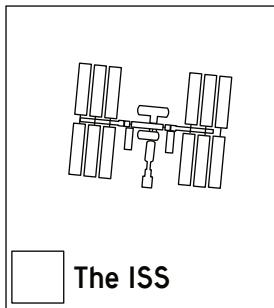
Saturn



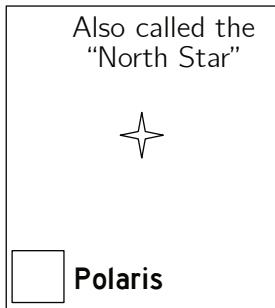
Antares



Halley's Comet



The ISS

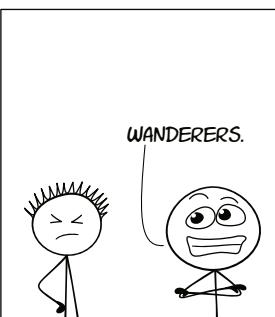
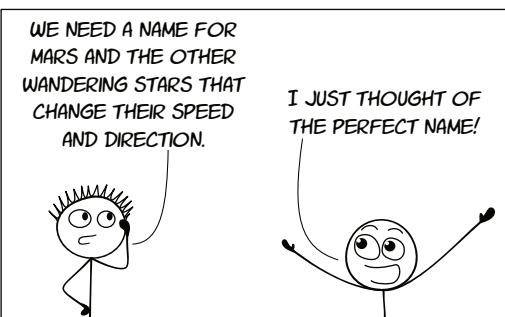
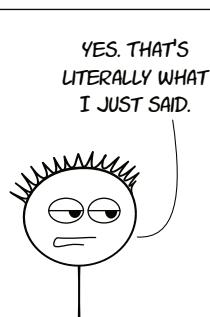
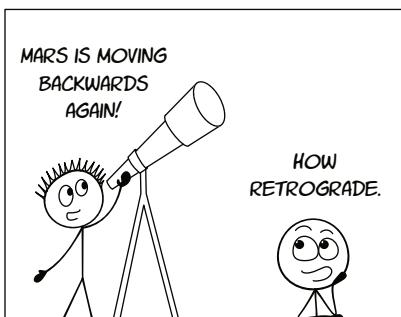
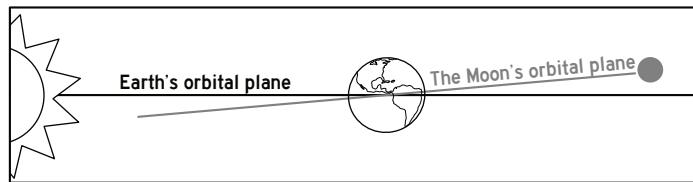
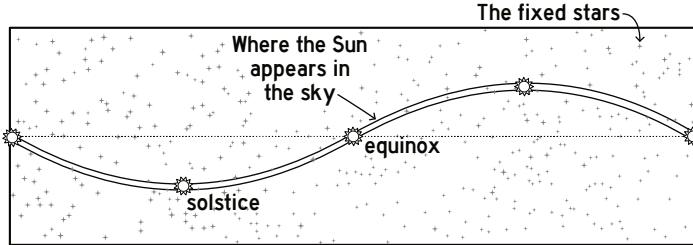


Polaris

Over the course of a year, the Sun appears to travel through the fixed stars, tracing a path called the **ecliptic**.

Early Greek astronomers named this line the **ecliptic** (Greek for “fail to appear”) because it was the only place where eclipses occurred.

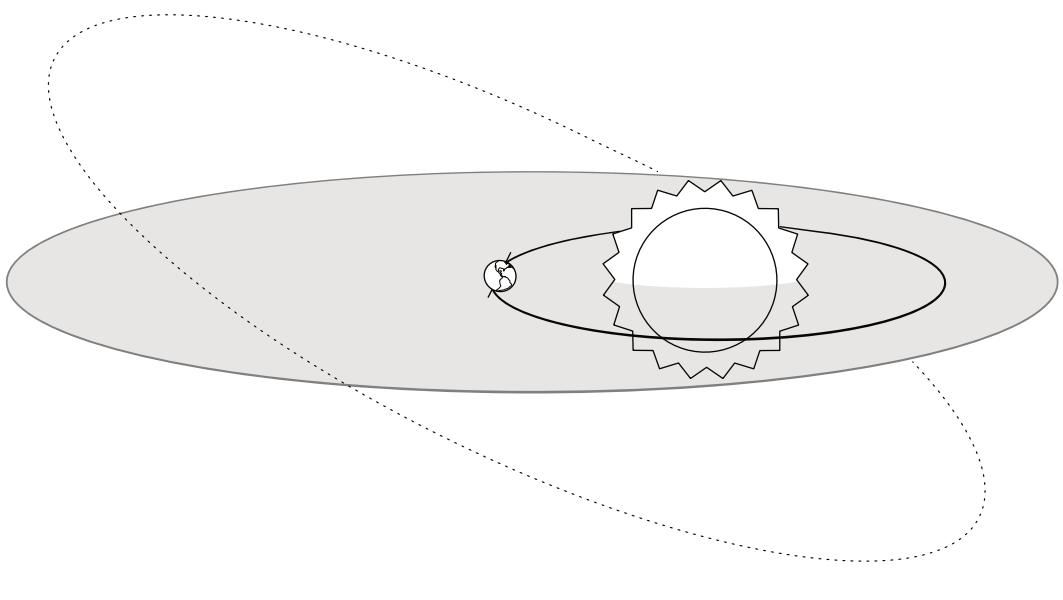
Another way to think about the ecliptic is from the perspective of an observer in outer space. In this case, the ecliptic is the plane of Earth’s orbit around the Sun.



The English word “planet” comes from the Greek word *planētēs* which means “wanderer.”

Label the diagram below with the following terms:

Earth Sun Ecliptic plane Equatorial plane



The poles, equator, lines of latitude, and lines of longitude are all defined in relation to how our planet **rotates**. Rotating is different than revolving!

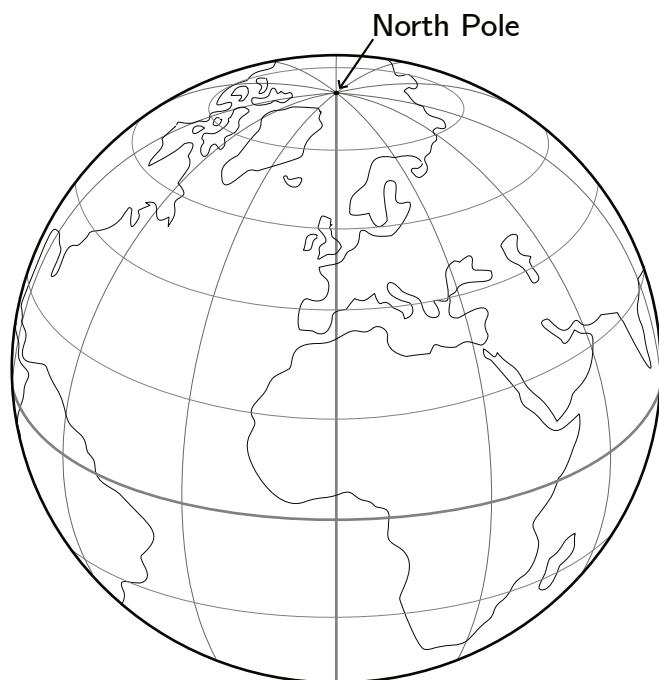
Define these terms and describe how long it takes the Earth to complete one of each:

Rotation: _____

Revolution: _____

Label the term for each definition and then identify them on the globe:

The first one has been done as an example



Pole (North or South Pole)

A point aligned with Earth's axis of rotation, or a point around which all the stars appear to rotate.

Equator

A line around the Earth that is equidistant from each pole. A circle that divides a sphere into northern and southern hemispheres.

Latitude

Parallel lines that measure distance from the equator.

Longitude

A line from the North Pole to the South Pole that passes through Greenwich, England.

Meridian

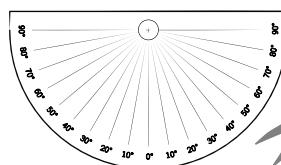
Lines that measure distance from the prime meridian.

Measure Your Latitude

MATERIALS



~15 cm
of thread
or string



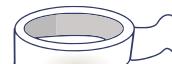
Protractor template and
scissors OR a standard
protractor



Pin



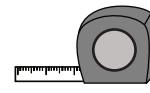
Washer or
other weight



Tape



1 straw



Tape measure

GOALS

★ Build a device to
measure the angle
of incline of a
distant object.

★ Find the latitude
of your current
location.

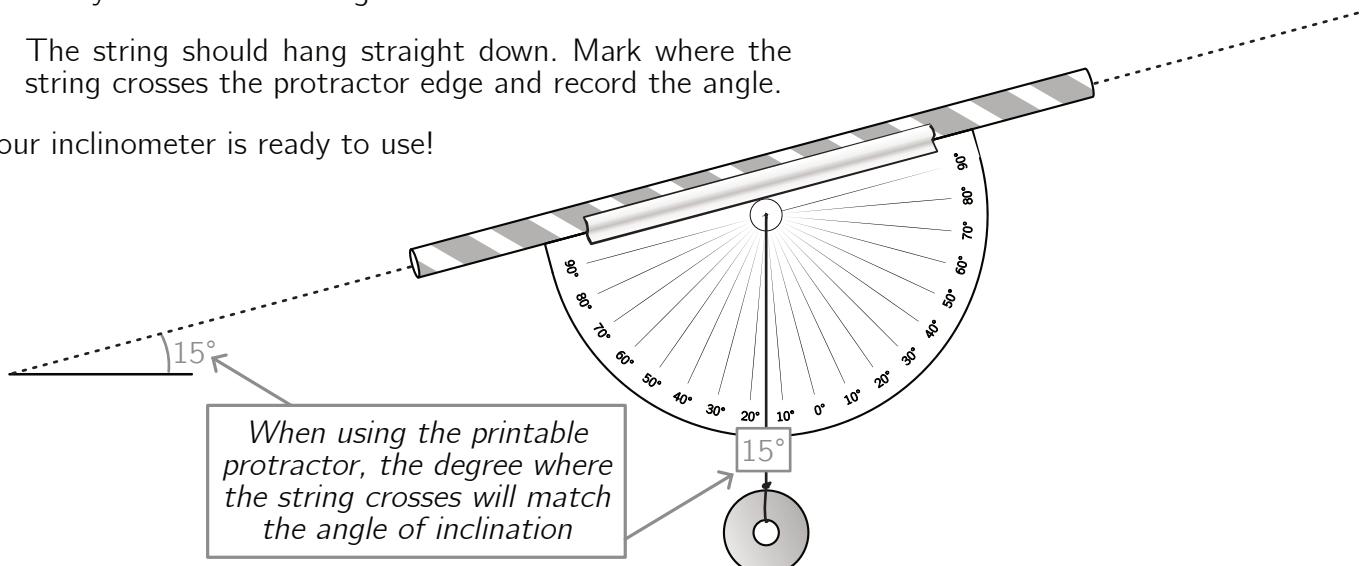
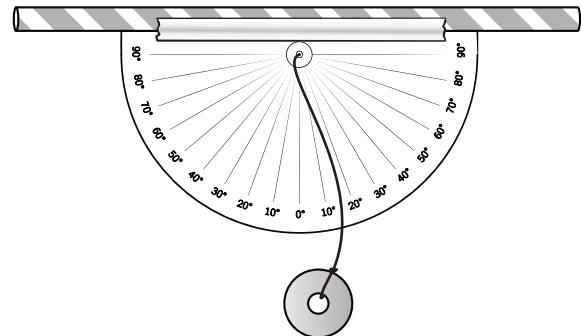
Purpose of an inclinometer

An inclinometer (sometimes called clinometer) is a tool that helps you to measure the angle or inclination of an object. With a little bit of geometry, inclinometers can be used to find the height of an object or the latitude of a person's current location.

How to make an inclinometer:

1. Use the protractor template from the appendix to make a printable protractor OR use a standard protractor. If using the printable version, be sure to cut it out carefully so that you get a straight edge on top. If necessary, glue it to cardstock or cardboard to make it more sturdy.
2. Use a pin to poke a hole in the center of the protractor template on the plus sign.
3. Feed some of the string through the hole and tape it in place on the back. If using a standard protractor, tape the string so that it hangs freely.
4. Tie the washer to the other end of the string.
5. Tape the straight edge of the protractor to the straw.
6. To use the inclinometer, close one eye and look at your target through the straw. Carefully adjust the angle so that you can see the target in the center of the straw.
7. The string should hang straight down. Mark where the string crosses the protractor edge and record the angle.

Your inclinometer is ready to use!

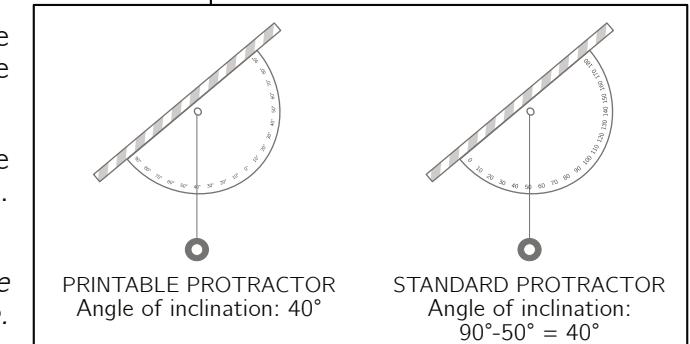
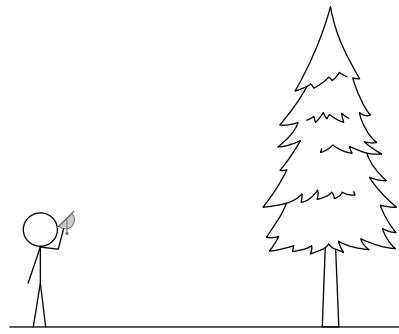


How tall is it?

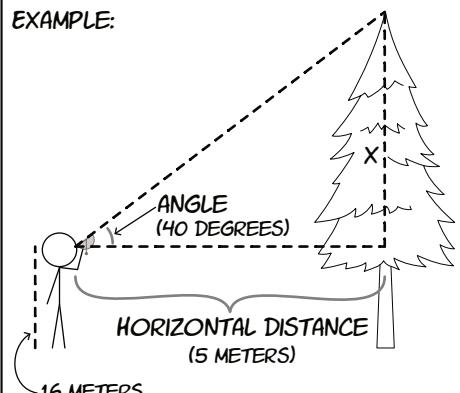
Before finding our latitude, it's important to understand how an inclinometer works by using it to find the height of an object.

1. Choose a tall object such as a tree, flagpole, or building that is located on flat ground.
2. Have a person (the observer) stand so that they have a clear line of sight to the object.
3. The observer should look through the straw of the inclinometer and hold it so that the top of the object is visible through the center of the straw.
4. Note where the string is hanging and record where it crosses the curved edge of the protractor. Record the angle.
 - If using the **printable protractor**, record the number seen where the string crosses the edge.
 - If using a **standard protractor**, subtract the angle measured on the protractor from 90° . This is your angle of inclination.
5. Measure the horizontal distance from observer to object.
6. Measure the eye height of the observer.
7. Now that you have both the angle and horizontal distance of a triangle, you can use trigonometry to find the length of the side opposite the angle. This distance (labeled x) is from the eye height of the observer to the top of the object. Use your angle and horizontal distance to find the value of x:

$$x = \tan(\text{angle of inclination}) \cdot \text{horizontal distance}$$
8. Add the height of the observer to x to find the total height of the object.



EXAMPLE:



$$x = \tan(40^\circ) \cdot 5$$

$$x = 4.2 \text{ meters}$$

$$\text{Tree height} = 4.2 + 1.6 = 5.8 \text{ meters}$$

What object did you choose to measure? How tall do you think it is? Before using the inclinometer, make a guess! What do you estimate for the height of the object?

Object: _____

$$x = \tan(\text{angle of inclination}) \cdot \text{horizontal distance}$$

Estimated height before measuring: _____

Horizontal distance (observer to object): _____

Eye level height of observer: _____

$$x + \text{eye level height of observer} = \text{object height}$$

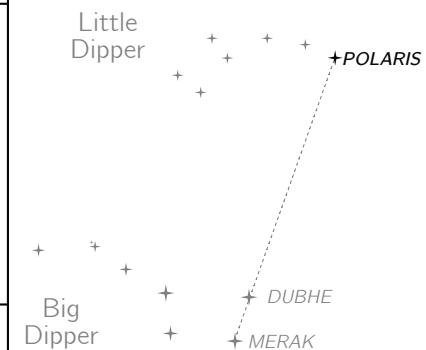
Angle of inclination: _____

Calculated height of the object: _____

Finding Your Pole Star: Northern Hemisphere

Locate Polaris (the North Star) by using an app such as Sky Guide or by using the asterism called the Big Dipper. The stars Merak and Dubhe in the Big Dipper point directly toward Polaris, which is the end of the "handle" in the Little Dipper.

To find your latitude with the inclinometer, look at Polaris through the straw. Hold the inclinometer steady with the string hanging freely down. Note where the string crosses the curved edge of the protractor.



Finding Your Pole Star: Southern Hemisphere

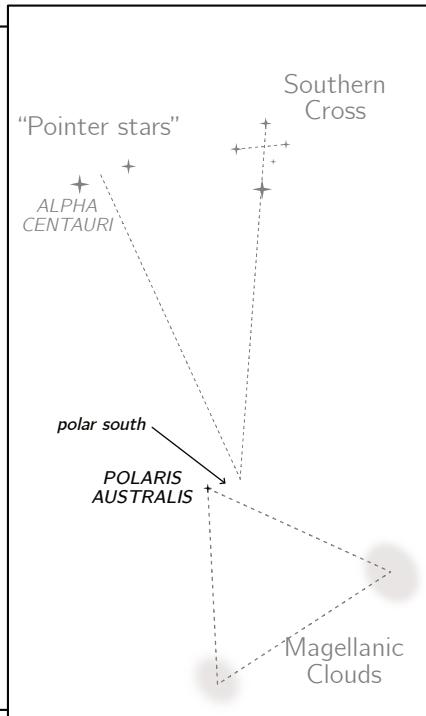
Use the inclinometer to find your latitude by locating Sigma Octantis (also called Polaris Australis or the Southern Star). It is not located exactly over polar south, but it's close! You can use an app such as Sky Guide or find it by using one of these approaches:

1. Southern Cross + 4 Lengths: Find the Southern Cross. Notice the length between the stars that form the "long" end of the cross. Polaris Australis is approximately 4 of these lengths away along the same line.

2. The "Pointer Stars" and the Southern Cross: The two brightest stars in the constellation Centaurus are near the Southern Cross. A line perpendicular to those stars can be used to intersect a line from the Southern Cross. Polaris Australis is very close to this intersection.

3. Magellanic Cloud Triangle: The large and small Magellanic clouds are two nearby galaxies that are visible as hazy spots in a dark night sky (similar in appearance to the hazy light of the Milky Way). A nearly equilateral triangle can be drawn between these and Polaris Australis.

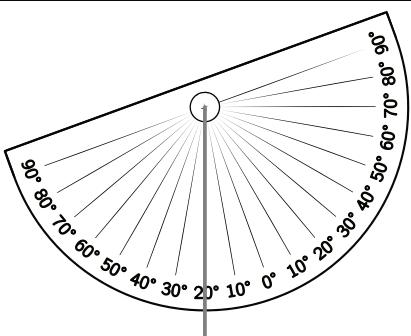
To find your latitude with the inclinometer, look at Polaris Australis, through your straw. Hold the inclinometer steady with the string hanging freely down. Note where the string crosses the edge of the protractor.



The **printable protractor** has angles labeled with $90^\circ - x$. Where the string crosses the edge will match the protractor's *angle of inclination*.

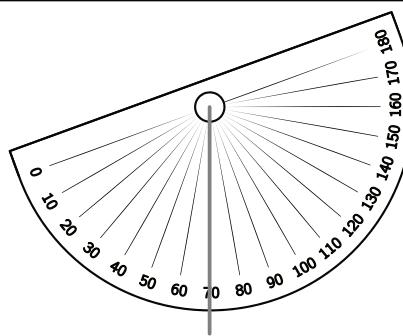
If using a **standard protractor**, take the angle where the string crosses the edge and then subtract it from 90° . Now you have found the *angle of inclination*.

EXAMPLE WITH PRINTABLE PROTRACTOR:



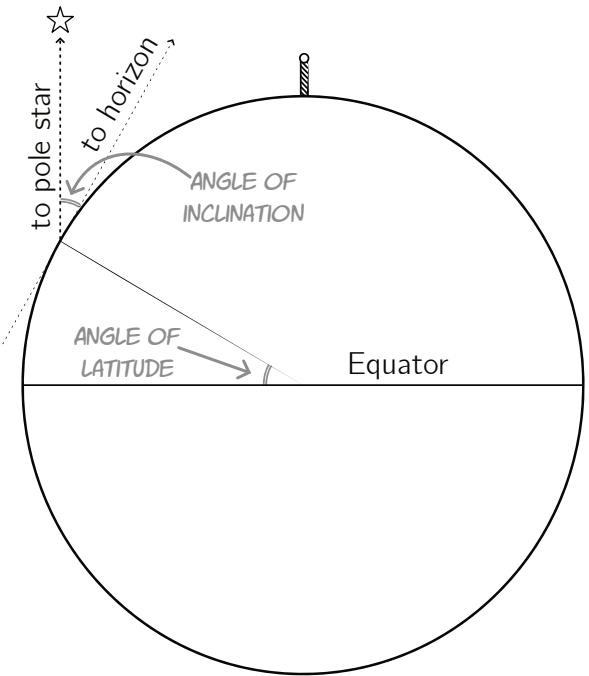
The string crosses at 20° , so the angle of inclination to the pole star and latitude are also 20° . If in the Northern Hemisphere, the latitude would be 20° North. In the Southern Hemisphere, the latitude would be 20° South.

EXAMPLE WITH STANDARD PROTRACTOR:



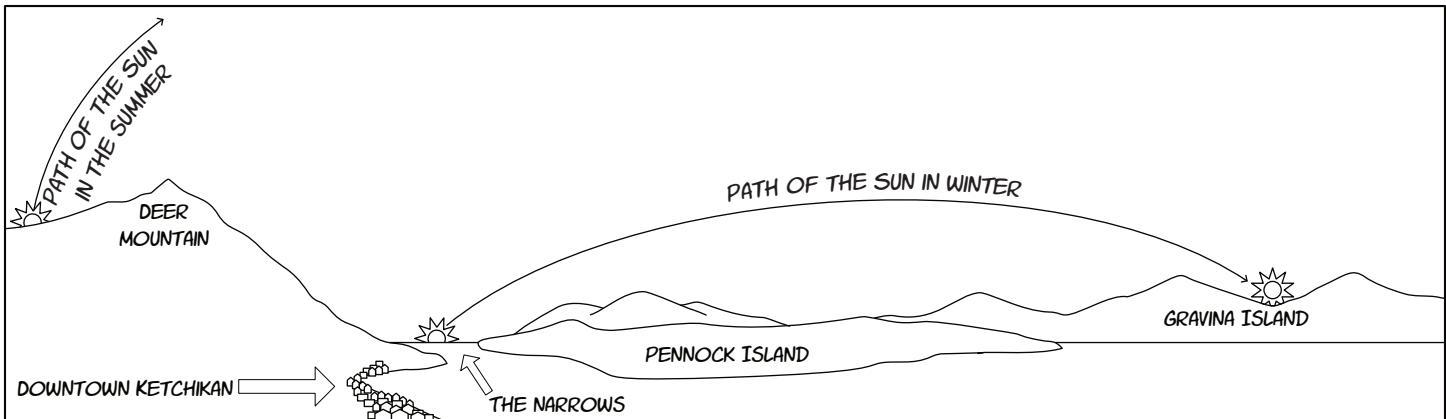
The string crosses at 70° , so the angle of inclination is $90^\circ - 70^\circ = 20^\circ$. If in the Northern Hemisphere, the measured latitude would be 20° North. If in the Southern Hemisphere, the latitude would be 20° South.

1. Why should the angle of inclination to the pole star be equal to an observer's latitude on Earth? Use the diagram if it is helpful to your answer.



2. At your location, what angle of inclination did you observe when sighting the pole star (Polaris or Polaris Australis)?
3. Look up your actual latitude. Did the angle of inclination match your latitude? If not, what do you caused the difference?
4. Siti lives on a small island in Indonesia located very close to the equator. Will she be able to use an inclinometer to find her latitude? Why or why not?

THE SEASONS: caused by Earth's axial tilt



During the winter in Ketchikan, Alaska, we watch the Sun rise over the Tongass Narrows. Sunset occurs over Gravina Island directly in front of our window. The Sun is low in the sky all day and never shines in our backyard.

During the summer, the Sun rises on the back side of Deer Mountain and our backyard has hours of sunshine. In the summer evenings, we can't see the sunset from our house. It's far to the right behind houses and mountains!

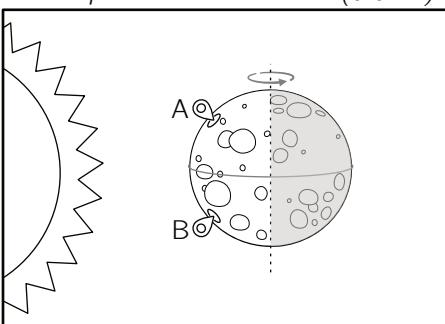
What seasonal differences in the position of the Sun have you observed where you live? When and where does the Sun rise and set? Where is the Sun in the sky at noon?

During winter: _____

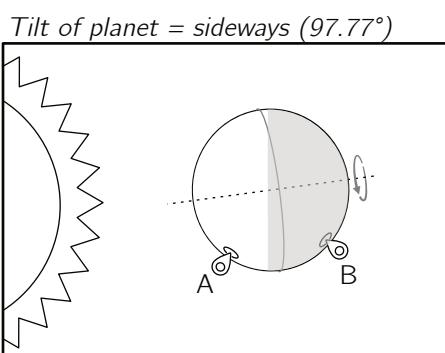
During summer: _____

How much sunlight in 1 day?

Tilt of planet = almost none (0.027°)

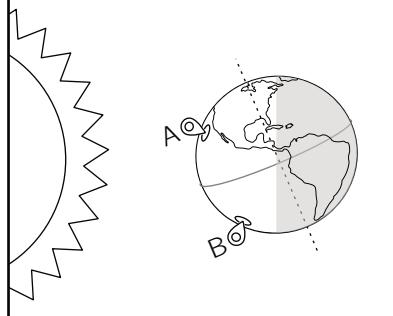


A planet with almost no tilt undergoes 1 complete rotation in 24 hours. During that time, will point A receive more, less, or the same amount of sunlight as point B? Point A and B are the same distance away from the equator.



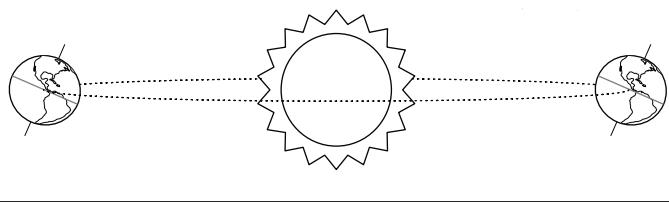
A planet with an extreme tilt of 97° undergoes 1 complete rotation in 24 hours. During that time, will point A receive more, less, or the same amount of sunlight as point B? Points A and B are the same distance away from the equator.

Earth is tilted at 23.5 degrees



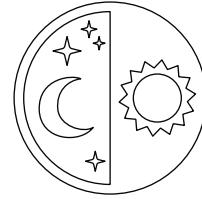
Earth has a tilt of 23.5° and completes 1 rotation every 23 hours and 56 minutes. During that time, will point A receive more, less, or the same amount of sunlight as point B? Point A and B are the same distance away from the equator.

Solstice



DEFINITION:

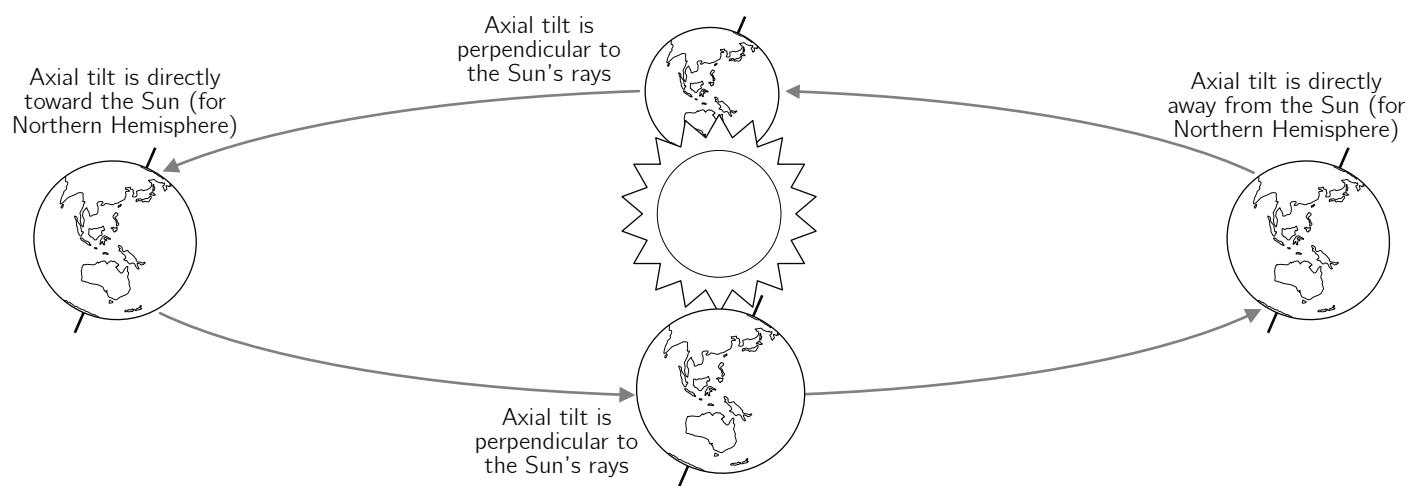
Equinox



DEFINITION:

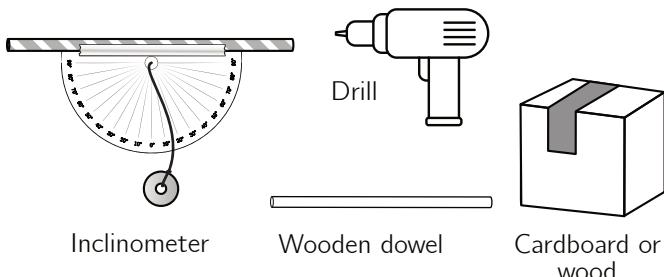
Four points in Earth's orbit are described in the diagram below. Label each with the correct equinox or solstice for the Northern and Southern Hemisphere. Also include the approximate date.

Note that distance and size are not to scale.

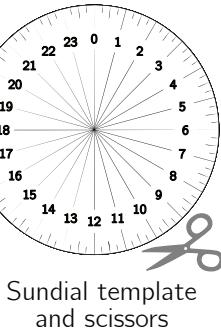


DIY Equatorial Sundial

MATERIALS



GOALS



★ Learn more about the Sun's path and Earth's orbit by building a working sundial.

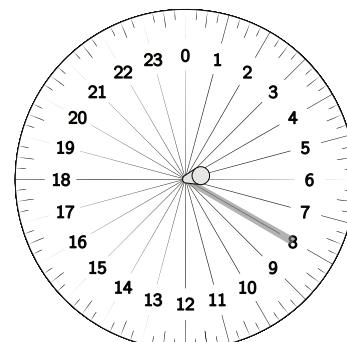
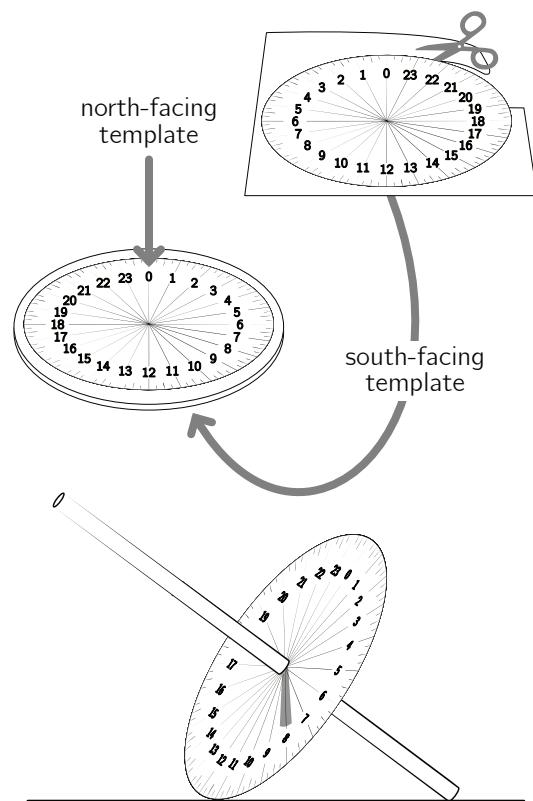
★ Adjust your sundial to give accurate time by considering various factors.

What's an Equatorial Sundial?

An equatorial sundial uses a shadow stick (gnomon) to cast a shadow on a circular dial. The dial is placed so that it's parallel to the Earth's equator. As long as it's properly aligned, it can be used anywhere on Earth!

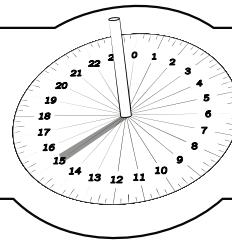
How to make an equatorial sundial:

1. Print both the north-facing and south-facing printouts from the appendix and cut them out.
2. Glue or tape them to a solid backing such as cardboard. The backing should be sufficiently thick and rigid so that it can hold a rod perpendicular to the face of the dial without tipping. Be sure that the 0s are aligned.
3. Drill a hole in the center of the dial so that the dowel fits snugly in the hole but can be slid in or out.
4. If you are in the Northern Hemisphere, point the dial so that the gnomon is pointed directly at Polaris. (If you are in the Southern Hemisphere, point the gnomon to Polaris Australis.) Secure the gnomon so it remains pointed toward a pole star. Note that geographic or true north/south is different than magnetic north or south which you would get from a compass.
5. Use your inclinometer to check that the angle of your gnomon matches your latitude.
6. Rotate the dial so that the center of the shadow shows the correct time on the sundial. For example, if it is 8 in the morning, rotate the dial so the shadow is over 8. If it is 2 in the afternoon, rotate your sundial so the shadow is over the 14. Be sure the gnomon remains pointed at geographic north/south as you make adjustments.
7. Observe the shadow on your sundial for one or more days. Does it continue to give the correct time?



Does the dial of a sundial need to be tilted?

It's possible to design a sundial that is flat on the ground, but it must be based on an elliptical shape, and the gnomon must be moved to a different location each day. To learn more about other sundials, look up "horizontal sundials" and "analemmatic sundials."



1. When you placed your sundial outside, did it accurately tell the time? Check on it over several days or weeks to see how it does. What factors might cause discrepancies between the sundial time and standard clock time?
2. Would your sundial work if located at the North Pole or South Pole? Why or why not?
3. Why does a sundial in the Northern Hemisphere need to be aligned with geographic north rather than magnetic north?
4. What was the most interesting thing you learned doing this project? OR What challenge or obstacles did you encounter making your sundial and how did you address them?

LINES OF LATITUDE: significant circles

On the December solstice, Earth is tilted so the South Pole is angled toward the Sun. Observers around the South Pole experience "polar day" or the "midnight sun."

The border of this region where the Sun does not set below the horizon on December solstice is called the **Antarctic Circle**.

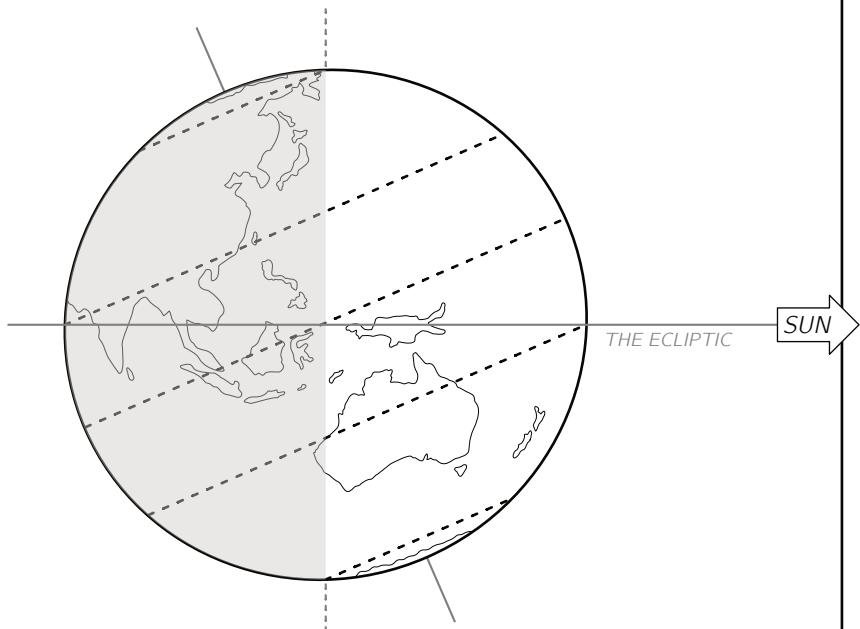
On the same day, observers in the region around the North Pole experience "polar night." The line of latitude surrounding this area is called the **Arctic Circle**.

These circles are defined as the latitudes where, during solstice, the center of the Sun remains continuously above or below the horizon for at least 24 hours.

On the December solstice, the latitude of 23.5° South intersects with the ecliptic. At this latitude, the Sun will be directly overhead. This southern most point where the Sun can appear directly overhead at noon is called the **Tropic of Capricorn** or "Southern Tropic." The word tropic comes from the Greek word *tropos*, meaning to turn.

DECEMBER SOLSTICE

Label the dotted lines of latitude



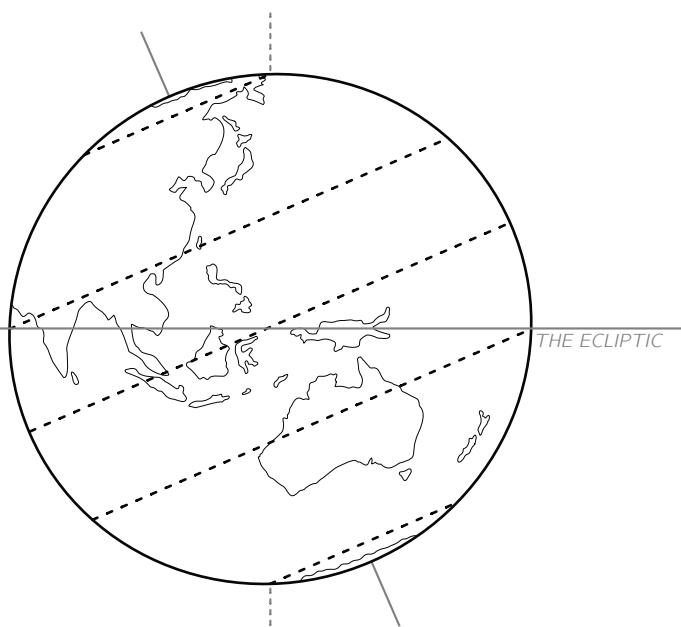
On the June solstice, what area of Earth will experience polar day?

On the June solstice, what area of Earth will experience polar night?

At the equator, will the Sun be directly overhead during either solstice? Why or why not?

JUNE SOLSTICE

Draw an arrow to indicate the direction of the Sun and shade the hemisphere that would experience night. Label the dotted lines of latitude.



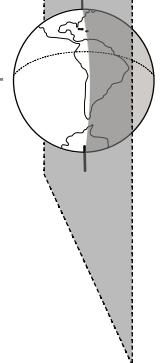
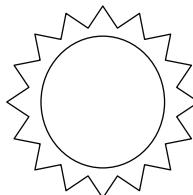
Fill in the blanks:

equal equinox location overhead perpendicular terminator

During each _____, the tilt of the Earth is _____ to the line between the Sun and Earth. Equinoxes are the only time of year when the Sun appears to be directly _____ at the equator.

When the solar _____ or “edge” between night and day is perpendicular to the equator, it causes a cool effect: Each equinox, almost every _____ on Earth experiences _____ hours of light and darkness.

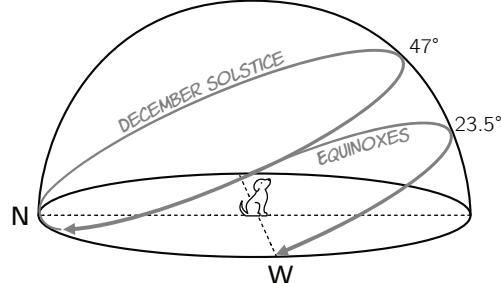
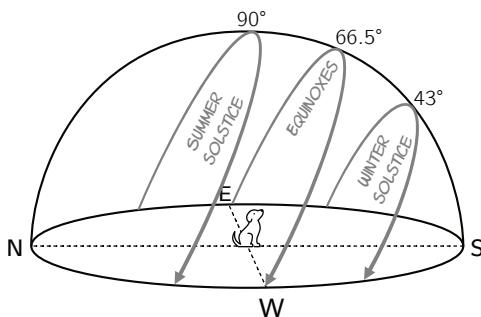
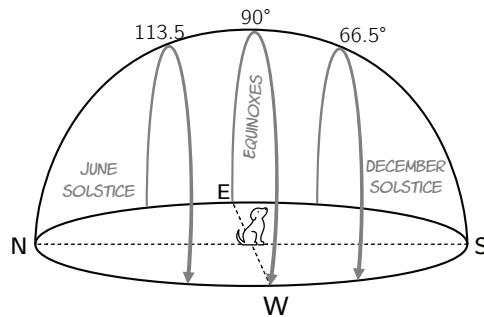
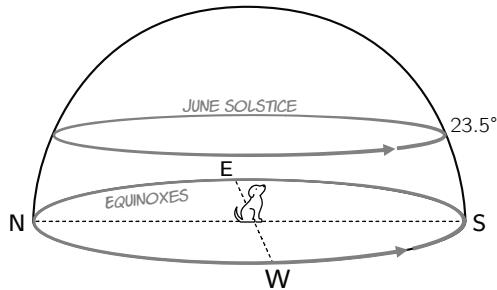
PLANE LINED UP WITH EARTH'S AXIS



SOLSTICE vs EQUINOX Views from the ground

The hemispheres below show the view of the Sun's path in the sky at solstices and equinoxes. Label each with the correct location for the observer.

Locations could be: Arctic Circle, Antarctic Circle, equator, North Pole, South Pole, Tropic of Cancer, or Tropic of Capricorn.



THE MOON: Earth's closest friend

Make a Model

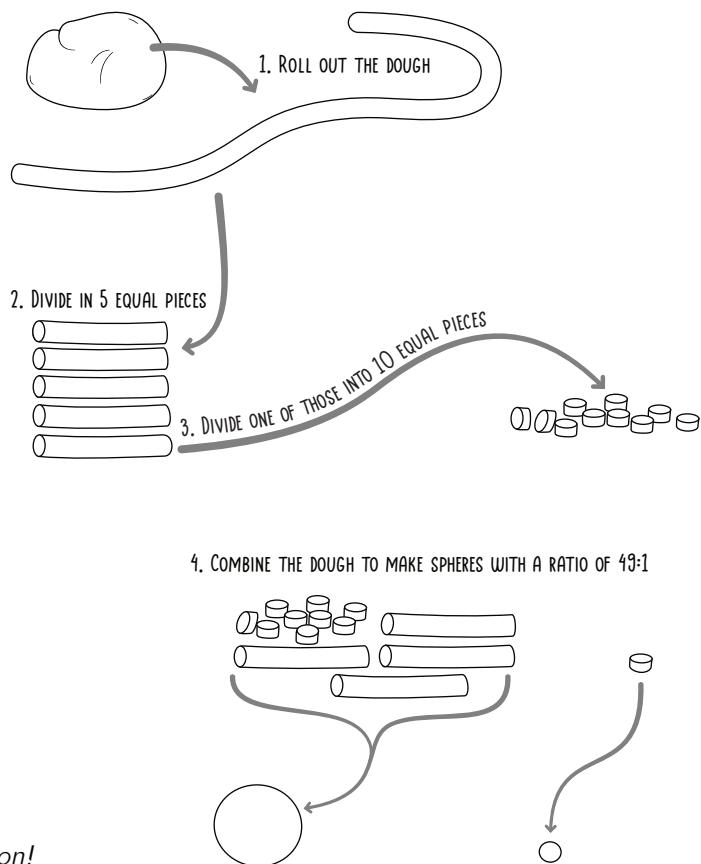
Earth and its moon are usually illustrated with their distance and size NOT to scale.

Here's a great modeling exercise to help you see how Earth and the Moon compare in size and how far apart they are from each other.

The only supplies you need are some clay or dough. A ruler or a piece of string might also be handy for estimating distance.

1. Roll the dough into a cylinder and divide it into five equally-sized portions.
2. Then divide one of those pieces into 10 equal size pieces.
3. Remove one of the small portions and roll it into a sphere. This sphere represents the Moon.
4. Combine the rest of the dough and roll it into a sphere. This sphere represents the Earth.
5. Measure the diameter of the model Earth. You can use a ruler or string or just take a visual estimate. Then place the Moon 30 "Earth diameter-lengths" away from your model Earth.

You now have a scaled model of the Earth and Moon!



Moons are natural satellites that orbit planets. Earth's moon, known simply as the Moon, is unusually large compared to the size of the Earth.

As it orbits Earth, different portions of its illuminated surface are visible from Earth; these are called the **phases of the Moon**. People have used them to measure the passage of time and other animals change or coordinate their activity based on the lunar cycle.

Draw a line to match each description with the correct term:

The illuminated portion of the Moon is getting bigger

○ → ○ → ⊙

The visible Moon is fully illuminated by sunlight

The near side of the Moon is becoming more shadowed

○ → ⊙ → ○

No sunlight is shining on the near side of the Moon

Half of the visible Moon is illuminated

WAXING

FULL MOON

WANING

FIRST QUARTER OR LAST QUARTER

NEW MOON

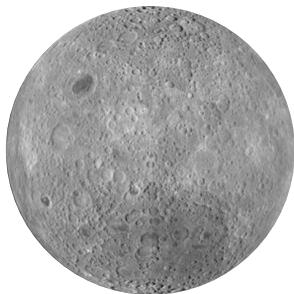
The Near & Far Sides of the Moon

The Moon is **tidally locked** with Earth, meaning that the same side is always facing Earth. The side of the Moon that we see from Earth has abundant craters, but there are also darker patches called **mare** (singular) or **maria** (plural). Formed by flood basalt, maria are lower in elevation than the lightly-colored lunar highlands.

What differences do you observe between the near side of the Moon (the side that faces Earth) and far side of the Moon? Does the Moon rotate? Why or why not?

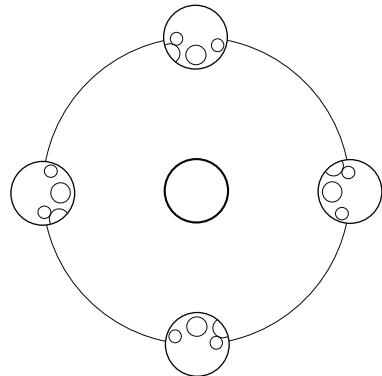


NEAR SIDE

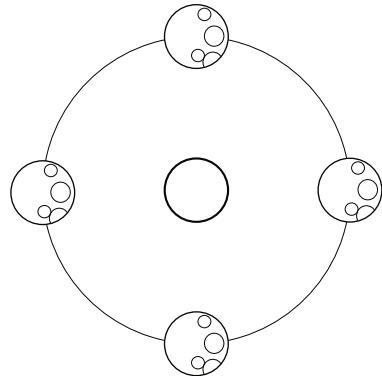


FAR SIDE

Image credits: NASA's Lunar Reconnaissance Orbiter/GSFC/Arizona State University



Tidally locked moon: the same side always faces the planet.



NOT tidally locked: the planet sees different sides of the moon.

Fact or Fiction?

Consider each statement, then write whether it is fact or fiction.

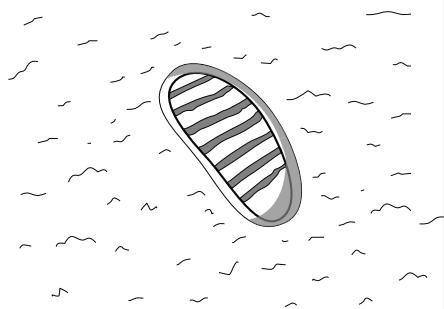
The Moon is a dwarf planet that came too close and was captured by Earth's gravity



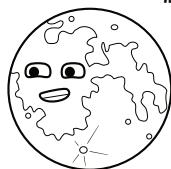
NEVER GONNA
GIVE YOU UP! ♪



Only 12 people have stepped on the Moon's surface. Their footprints are still visible today.



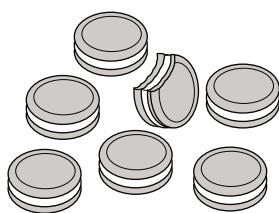
The Moon is drifting away from Earth at a rate of about 4 meters per year



MY ESCAPE IS
IMMINENT!

Cookie Models and Journal

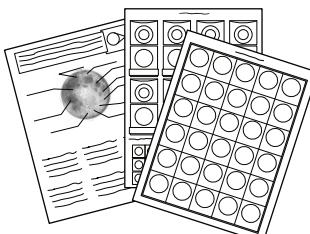
MATERIALS



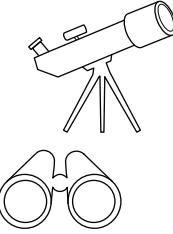
Sandwich style cookies with cream filling and a butter knife (optional)



Pencil, pen, or coloring supplies



Observe the Moon Page, Cookie Moon Phases Page, & Moon Journal Page,



Binoculars or telescope (optional)

GOALS

★ Become more familiar with the Moon and its phases.

★ Practice observing natural phenomena and keeping a detailed record of observations.

Complete the following 3 activities:

1. Observe the Moon & Label Famous Craters and Maria

You can observe the Moon during any of its phases, but craters will be more visible when the Moon is NOT in the full moon phase. The more pronounced shadows of a crescent or quarter moon make it easier to see craters. Observe the Moon without any tools or equipment (naked eye), with binoculars, or with a telescope.

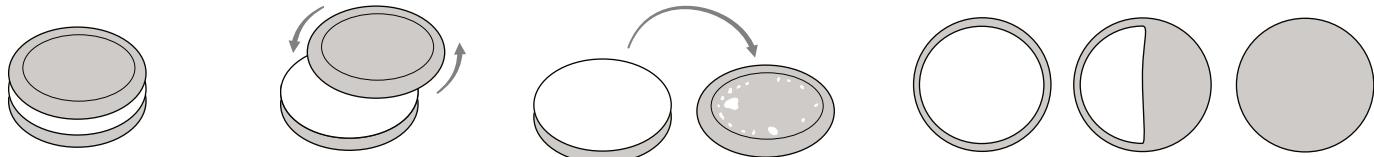
If you are unable to observe the Moon directly, you can explore virtually at <https://science.nasa.gov/moon/>

Use the descriptions of the craters and maria and online resources such as NASA to label the features on the **Observe the Moon** page. Then check the boxes next to each feature you're able to observe on the actual Moon.

Note: you may need to observe the Moon multiple times at different phases to be able to observe all 10 features.

2. Moon Phase Models

Fill out the chart on the **Cookie Moon Phases** page and check to be sure it's completed correctly. Then get 4 sandwich-style cookies. Carefully twist off the tops of each cookie. Use a butter knife to adjust the cream filling so that the cookie halves match the 8 phases of the moon. Once the cookies are complete, pick one at random. Can you place the remaining 7 phases in order? Complete this 3 times, with 3 different cookies as starting points. Bonus points if you can arrange the cookies in the correct order and name the phases without using the chart as a guide.



3. Observe moon for 30 days and draw/record phases

Observe the Moon daily for one month. Using the **Moon Journal Page**, record the date and the Moon's appearance by shading the portion that is shadowed or dark. If you are unable to observe the Moon due to clouds or other factors, write "no" (no observation) or "no data" in the circle.

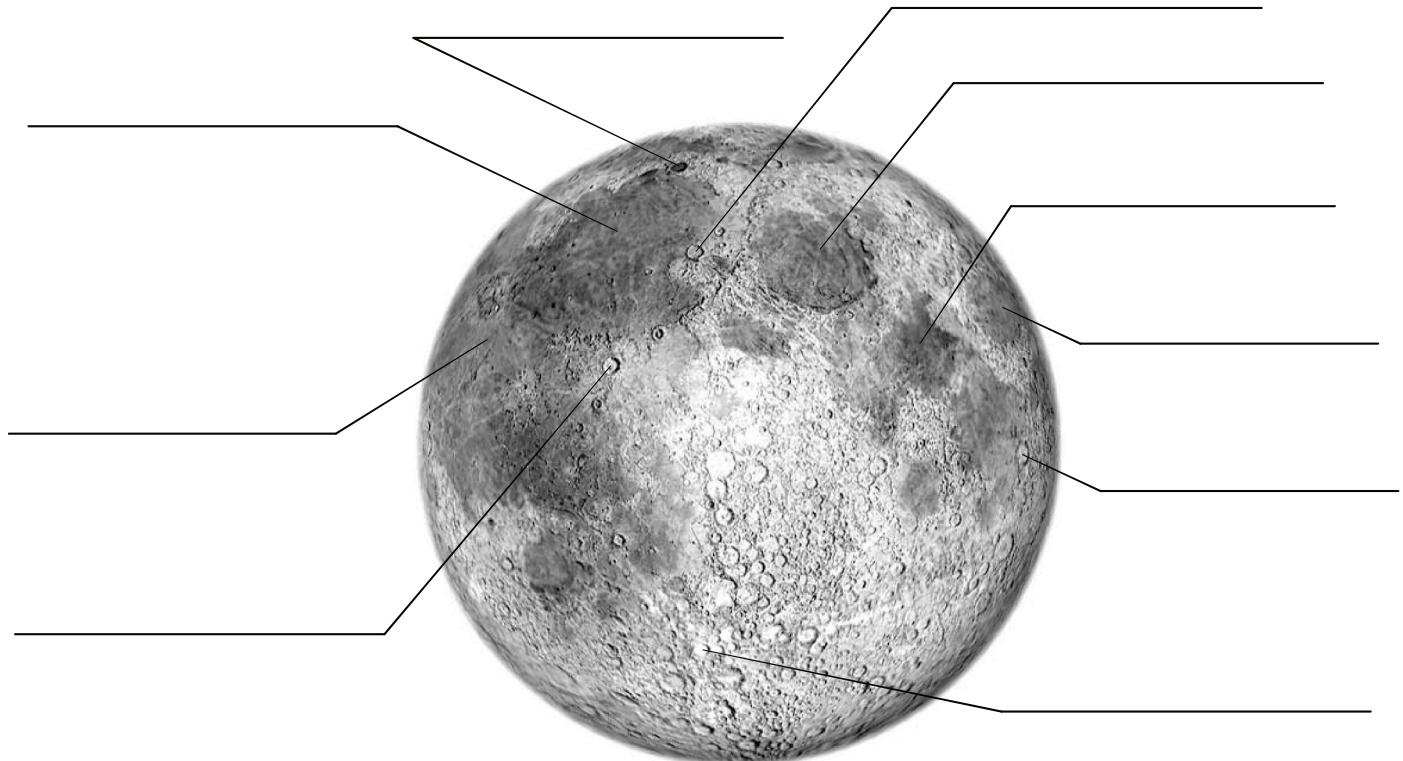
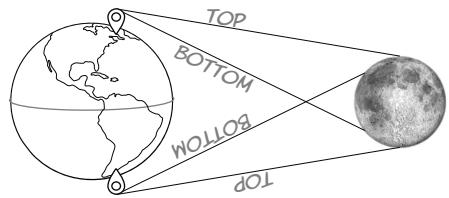
Did you observe the same phases during the 30 day time period?

Did you observe any differences in when and where you could see the Moon during this month?

Observe the Moon (and Label Famous Craters and Maria too!)

The Moon's orientation depends on where we observe it!

When viewed from the **Northern Hemisphere**, the Moon most often looks like the image below where the large maria are on "top" relative to the horizon. When viewed from the **Southern Hemisphere**, the orientation is reversed.



CRATERS Place a checkmark by each crater you are able to observe on the Moon:

Archimedes - In September of 1959 the Soviet probe Luna 2 crashed near this crater. It was the first craft to reach the Moon.

Diameter: 82 km

Copernicus - This crater has rays that extend for more than 850 km and overlap other craters. It also has several peaks in the center

Diameter: 93 km

Langrenus - This crater is on the eastern side of Mare Fecunditatis (south of Mare Crisium). Its central peak is about 3 km tall.

Diameter: 130 km

Plato - This lava-filled impact crater has a floor that is darker than the surrounding terrain and lacks a central peak.

Diameter: 101 km

Tycho - This distinctive bright white crater is surrounded by rays that extend outward in all directions. Some are over 1,500 km long!

Diameter: 85 km

MARIA Place a checkmark by each maria you are able to observe on the Moon:

Mare Crisium - This is one of the smaller lunar maria, being about the same size as as the country of Uruguay.

Diameter: 556 km

Mare Imbrium - This mare formed when lava flooded a giant crater. It's surrounded by mountains, more than 5 km tall.

Diameter: 1,145 km

Mare Serenitatis - This mare has a distinct circular shape. It has been visited by multiple lunar landers, including Luna 21 and Apollo 17.

Diameter: 674 km

Mare Tranquillitatis - The Apollo 11 spacecraft landed on the southwest shore of this mare in 1969. The site of the first Moon walk!

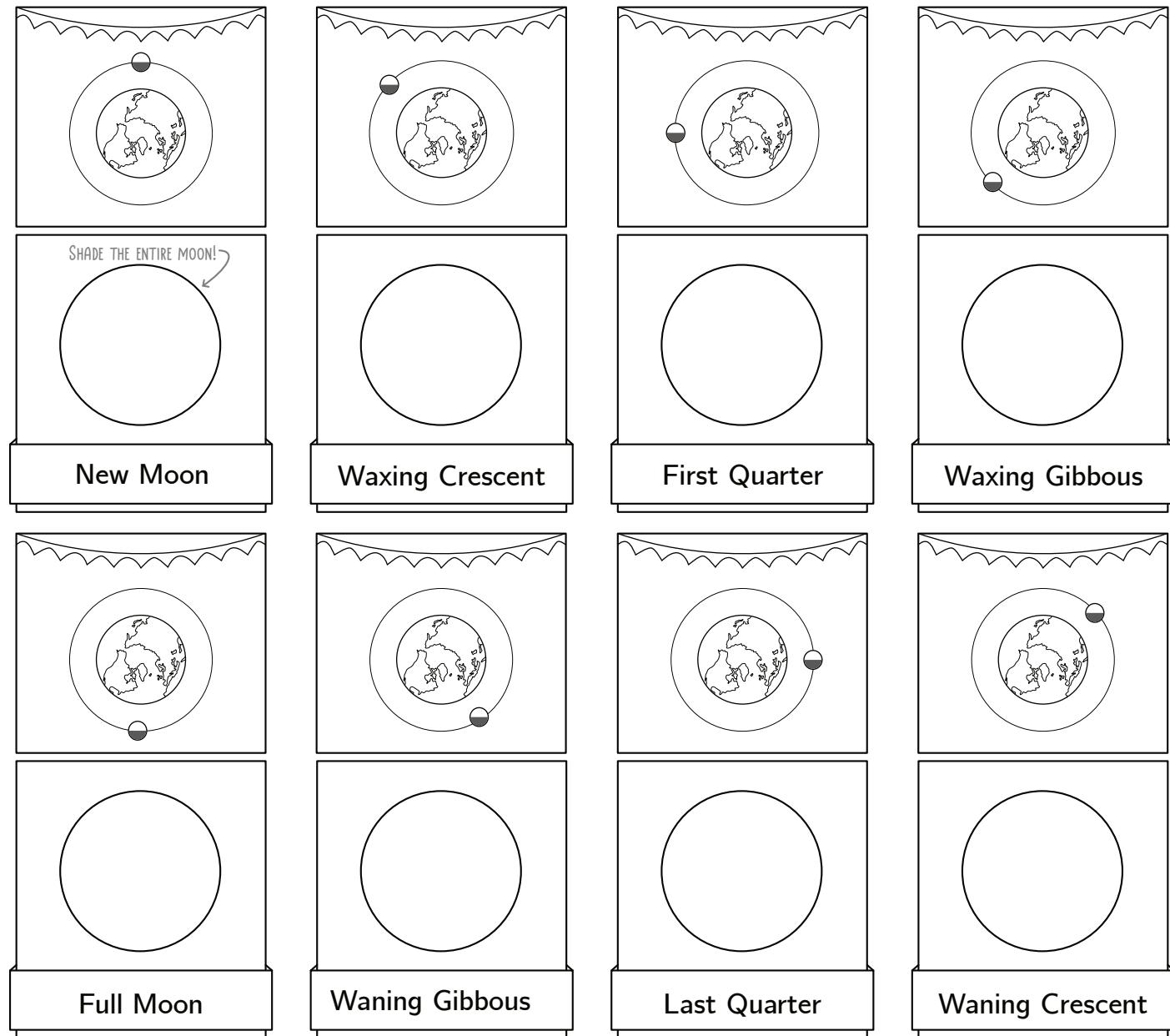
Diameter: 876 km

Oceanus Procellarum - This mare is called "oceanus" due to its large size. It is not associated with a crater or impact event.

Diameter: 2,000 - 3,000 km

Cookie Moon Phases

For each phase below, color in the part of the Moon that is in shadow. Note: whether the bright portion of the waxing crescent is on the right or left hand side depends on whether you're in the Northern or Southern Hemisphere.

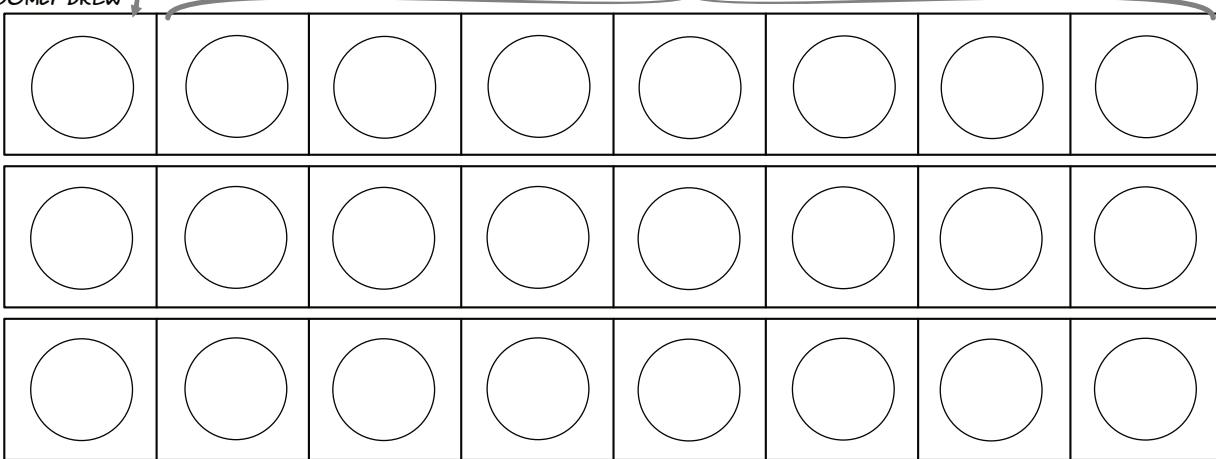


Arrange the Cookie Models at Least 3x

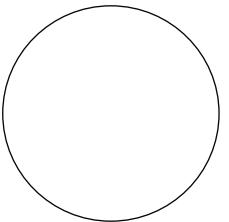
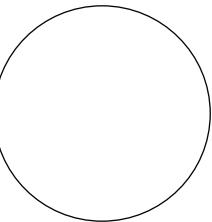
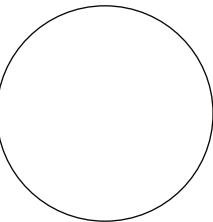
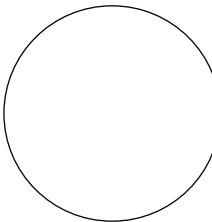
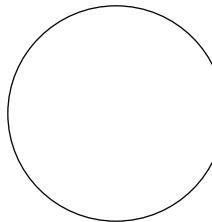
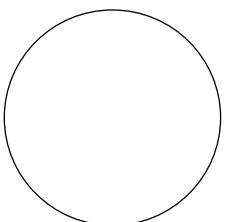
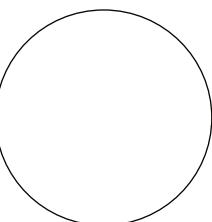
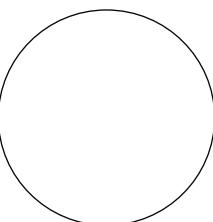
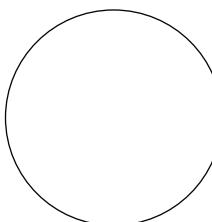
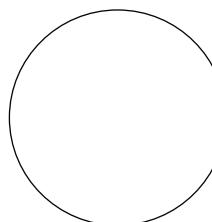
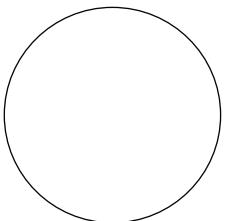
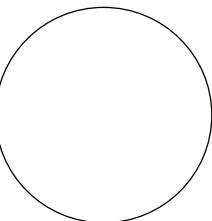
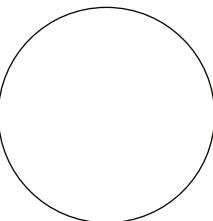
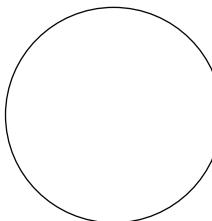
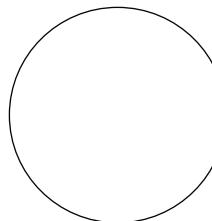
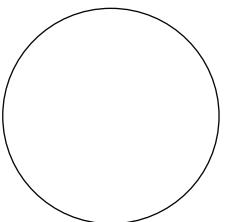
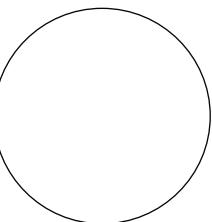
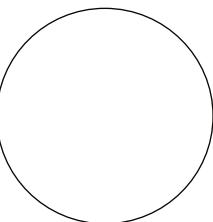
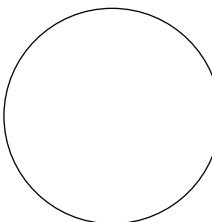
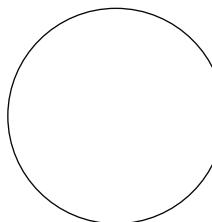
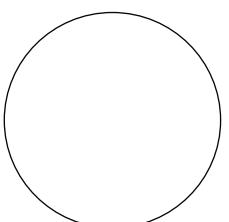
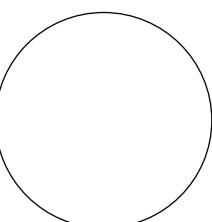
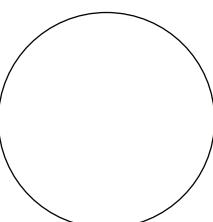
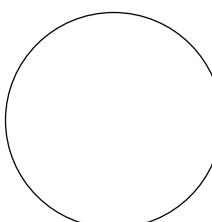
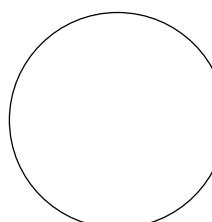
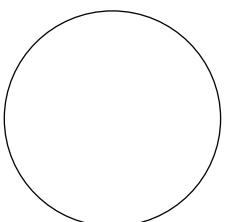
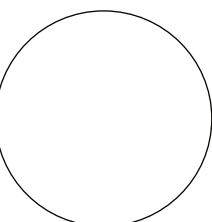
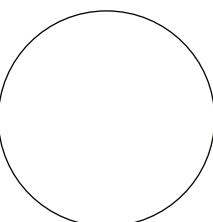
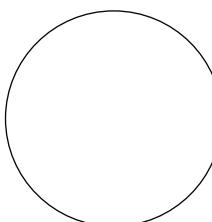
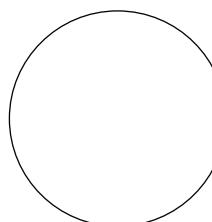
THE PHASE YOU
RANDOMLY DREW

THE OTHER 7 PHASES IN CORRECT ORDER:

ARRANGED
CORRECTLY WITHOUT
USING A REFERENCE?
BONUS POINTS!



Moon Journal

				
Date:	Date:	Date:	Date:	Date:
				
Date:	Date:	Date:	Date:	Date:
				
Date:	Date:	Date:	Date:	Date:
				
Date:	Date:	Date:	Date:	Date:
				
Date:	Date:	Date:	Date:	Date:
				
Date:	Date:	Date:	Date:	Date:

ECLIPSED

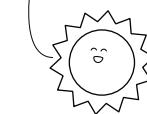


When 3 or more objects are arranged in a straight line, it's called **syzygy**. When an object that appears small (such as a distant planet) moves in front of an object that appears big (such as a large star) we call it a **transit**. If the objects are close enough that the shadow of one object covers another, it's called an **eclipse**.

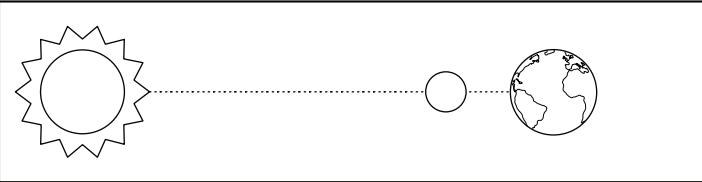
Transits and eclipses are incredible events that help astronomers discover many new things, from the size of the Moon in 300 BCE to the discovery of new exoplanets today.

SYZYGY

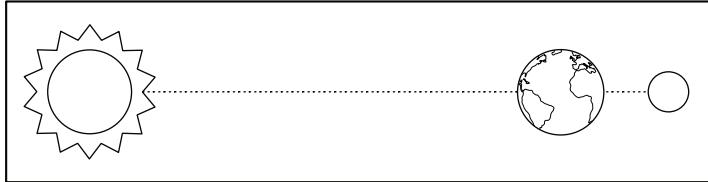
I LOVE IT WHEN PLANETS AND MOONS ALIGN WITH ME!



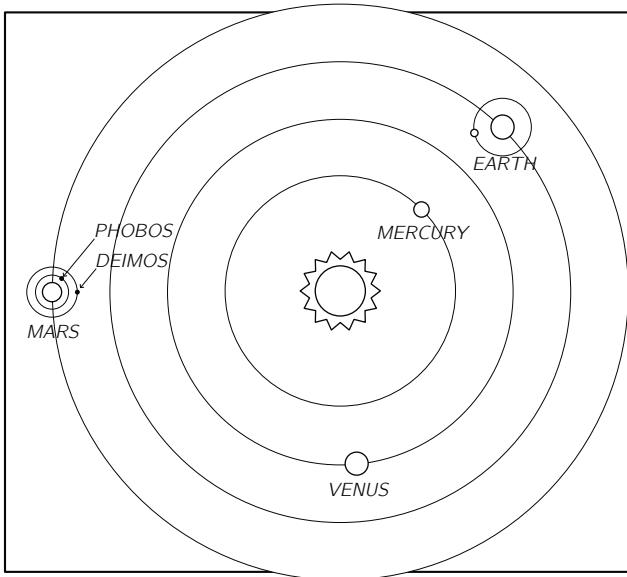
HEY, I CAN'T SEE THE SUN!



When the Moon passes between the Earth and Sun, it's a _____ eclipse.

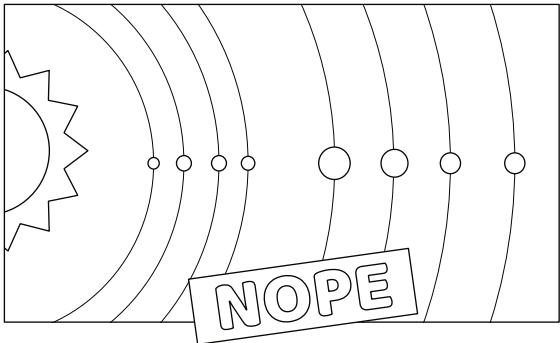


When the Earth passes between the Sun and Moon, it's a _____ eclipse.



Which planets or moons are in syzygy with the Sun?

All 8 planets won't ever line up perfectly, but sometimes multiple planets are visible in the same area of the night sky.



When two or more planets come close together in the sky it's called a **conjunction**. When multiple planets are visible it might also be called a "parade of planets" or a large alignment.

MARS

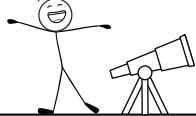
JUPITER

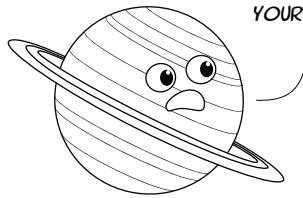
VENUS

NEPTUNE

SATURN

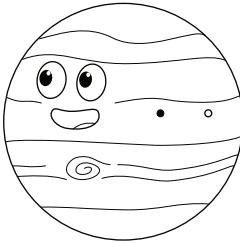
WOW! I CAN SEE 5 PLANETS AT THE SAME TIME!





JUPITER, I DON'T WANT TO SCARE YOU,
BUT YOU HAVE A BIG BLACK DOT ON
YOUR FACE. AND IT'S MOVING!

DON'T WORRY! IT'S JUST A SHADOW
FROM ONE OF MY MOONS!



Discoveries Due to Eclipses

Jupiter has 4 moons large enough to cause solar eclipses. When their orbits take them between the Sun and Jupiter, they cast distinct shadows that can be viewed from Earth. How did observing the eclipses of Jupiter's moons inspire the first calculation of the speed of light?

First calculation of the speed of light:

What other discoveries came from observing eclipses?

Solar eclipse or lunar eclipse? Draw lines to match each description with the best fit.

The Moon is positioned directly between the Sun and the Earth

The Earth is positioned directly between the Sun and the Moon

Usually visible in a narrow area between 100 to 200 km wide

Usually visible in a large area such as an entire hemisphere of the Earth

Shadow falls on the Moon

SOLAR ECLIPSE

LUNAR ECLIPSE

Can only occur during the FULL MOON phase

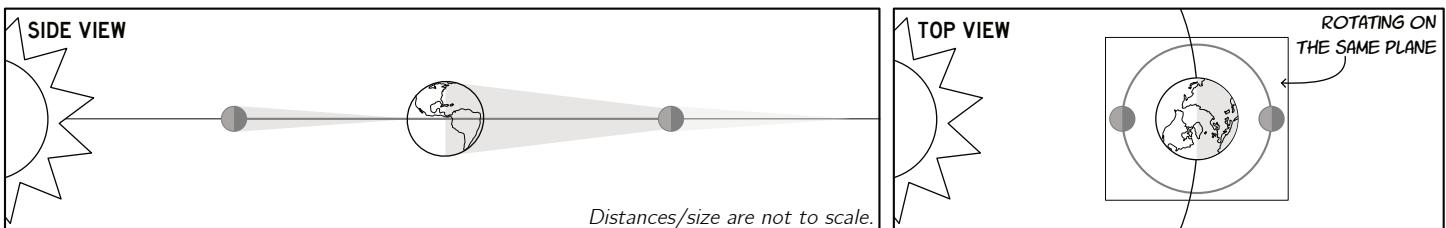
Can only occur during the NEW MOON phase

Usually lasts for a couple of minutes

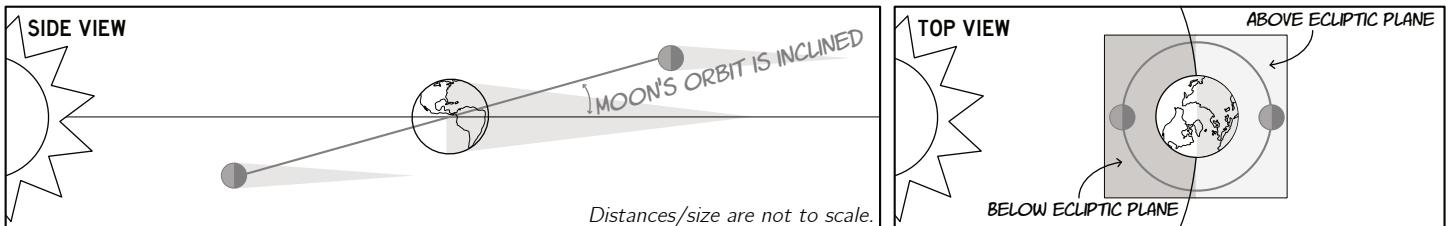
Shadow falls on the Earth

Usually lasts for a couple of hours

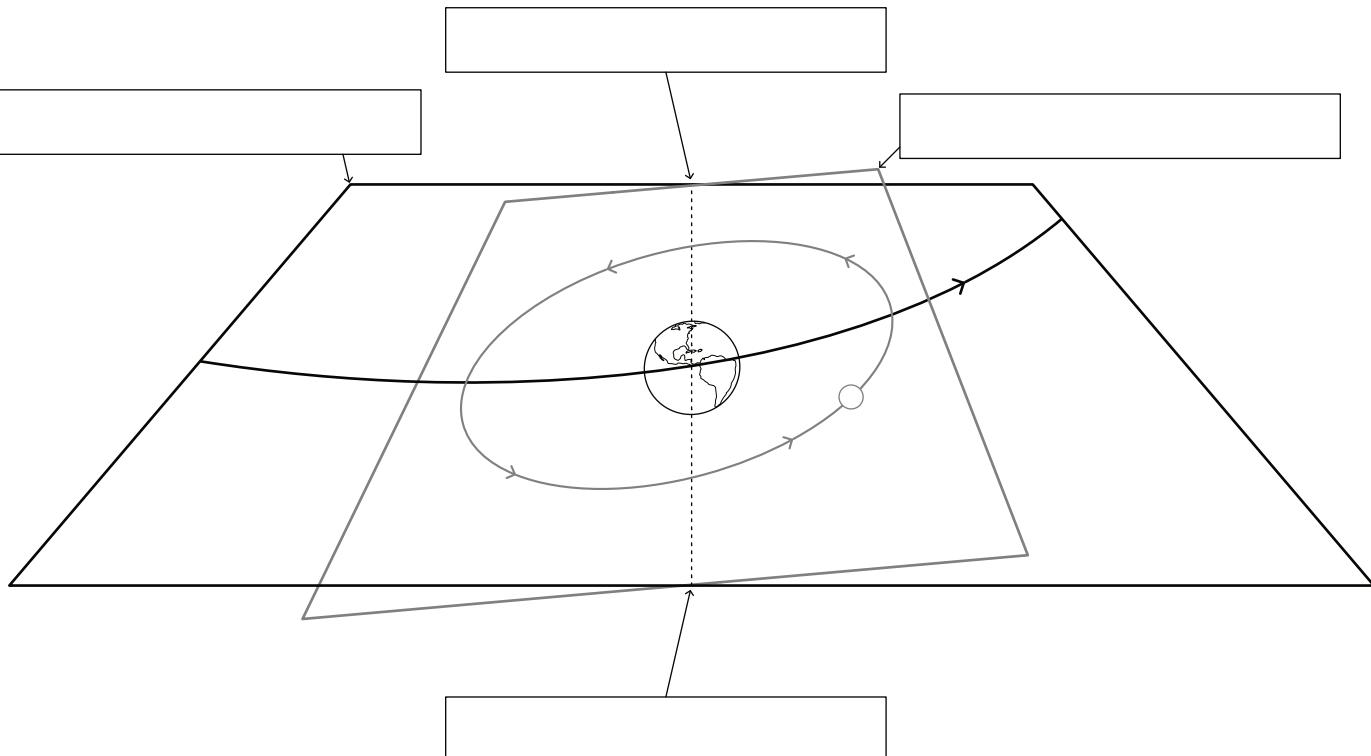
TOTALITY: a closer look at solar & lunar eclipses



If the Moon, Earth, and Sun were all on the exact same plane, when would we see solar and lunar eclipses?



If the Moon, Earth, and Sun were NOT on the same plane, when would we see solar and lunar eclipses?



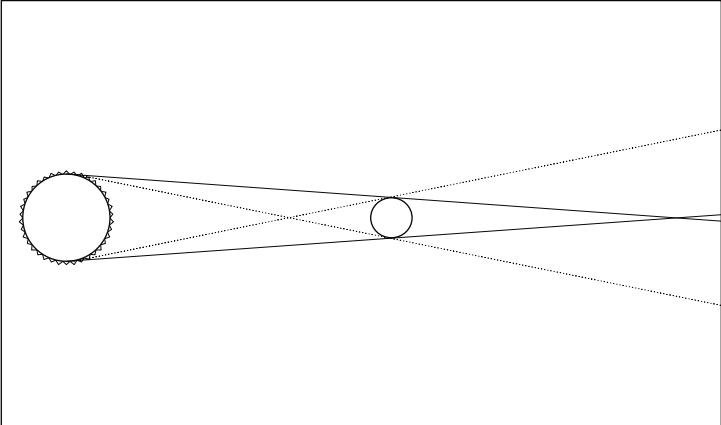
When sunlight shines on an opaque object, it casts a shadow. Most shadows have 3 parts:

Umbra: _____

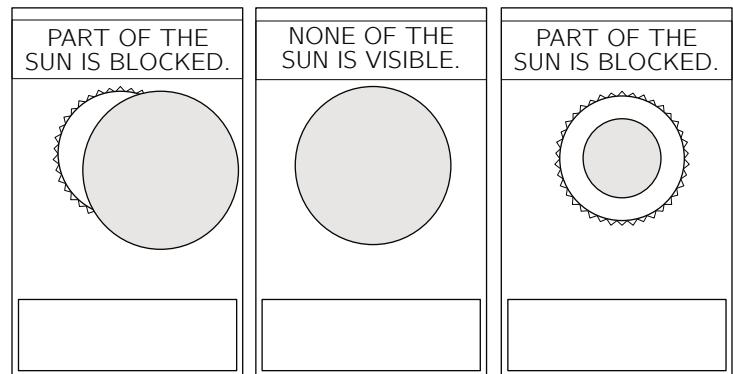
Penumbra: _____

Antumbra: _____

Color in and label the umbra, penumbra, and antumbra:



Where is the Sun being observed from? The umbra, penumbra, or antumbra?



Fact or Fiction?

Consider each statement, then write whether it is fact or fiction.

During a total lunar eclipse, the Moon appears red in color

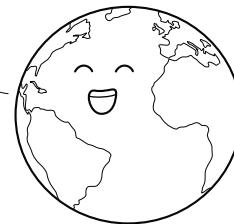


CAN WE GET 2 OTHER MOONS THAT TURN GREEN AND YELLOW FOR A FULL STOPLIGHT?



Earth is the only planet in the solar system with a moon that causes total solar eclipses.

TOLD YOU I WAS UNIQUE!



Every 12,000 years, a solar eclipse and a lunar eclipse will happen at the same time.



Earth & Moon Review

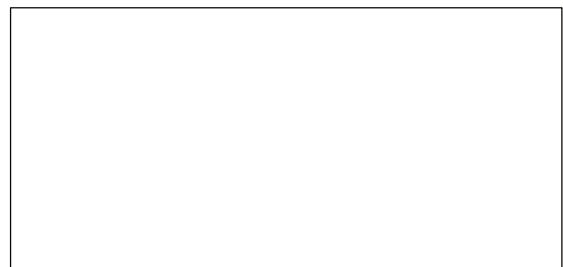
IN YOUR OWN WORDS!

Learning and understanding new words is an important part of astronomy! Define each of the following terms in your own words. Use the space in the box to draw and label a diagram.

APHELION: _____



PERIHELION: _____



EQUATOR and PRIME MERIDIAN: _____



EQUINOX: _____



SOLSTICE: _____



MATCH THE WORD WITH THE CORRECT DEFINITION

ECLIPTIC

The angle between the direction of gravity and the plane of the Earth's equator; measures the distance north or south of the equator

LATITUDE

Measures the east-west position of a point on Earth's surface

LONGITUDE

A repeating path that one object in space takes around another object, usually following an elliptical shape

ORBIT

The Sun's apparent path across the sky; the plane that contains both the Sun and Earth's orbit

REVOLVE

To spin or move around an axis or center

ROTATE

When three or more objects are in a straight line

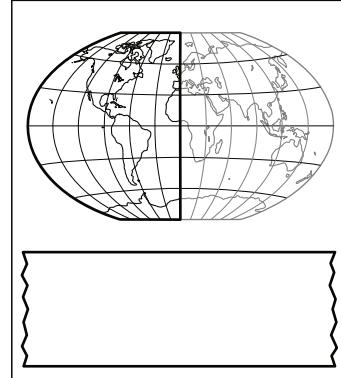
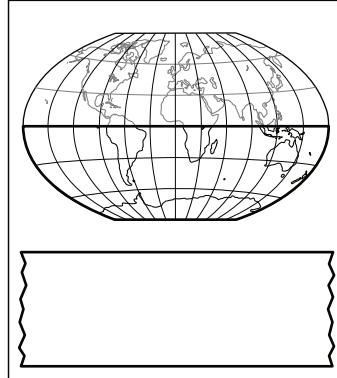
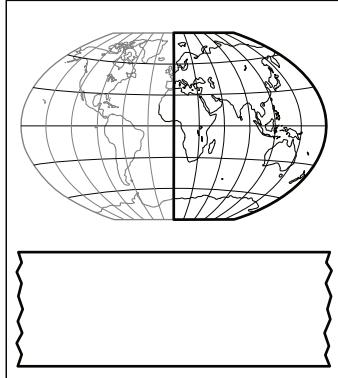
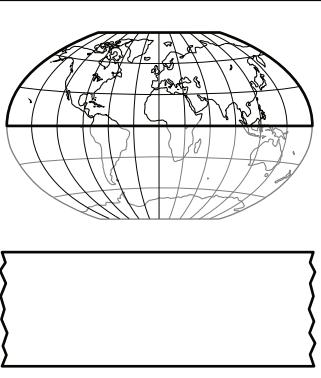
SYZYGY

The highest point

ZENITH

To move in a circular path around an object; to orbit around something

LABEL THE HEMISPHERES



Earth & Moon Review

1 What is true about **astronomy**? (mark all that apply)

- A. It is considered to be one of the branches of modern science
- B. It is used to produce daily horoscopes
- C. It relies heavily on mathematics and physics
- D. It is used to study the physical properties of stars and planets

2 What is true about **astrology**? (mark all that apply)

- A. It has lore and traditions surrounding the constellations that lie along the ecliptic
- B. It relies heavily on mathematics and physics
- C. It is considered to be one of the branches of modern science
- D. It is used to produce daily horoscopes

3 If a star sets during the night, in which direction will it fall below the horizon?

- A. North
- B. East
- C. South
- D. West

4 If the Sun is observed daily from the *Tropic of Capricorn*, in which direction does it most often reach its highest point or zenith?

- A. North
- B. East
- C. South
- D. West

5 What is the reason Earth has seasonal variations in daylight and temperature? In other words, what is the primary cause of spring, summer, autumn and winter?

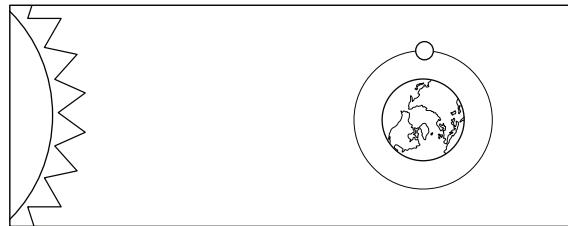
- A. Earth has an elliptical orbit
- B. Earth rotates on a tilted axis
- C. The Moon causes changes as it orbits
- D. The Sun varies in brightness over the course of a year

6 The Sun is observed from a location north of the Tropic of Cancer. In which direction (relative to the viewer) will it reach its highest point in the sky?

- A. North
- B. South
- C. Directly overhead (at the zenith)

7 Which of the following statements about the Moon are true?

- A. It rotates faster than the Earth
- B. On average, the far side of the Moon receives as much sunlight as the near side
- C. The darker patches on the face of the Moon have higher elevation than the lighter patches
- D. The moon does not rotate



8 What phase of the Moon is visible if the Sun, Moon, and Earth are positioned as pictured above?

- A. Full moon
- B. Crescent or gibbous
- C. Quarter
- D. New moon

9 The Moon goes through a complete cycle of its phases approximately:

- A. Daily
- B. Weekly
- C. Monthly
- D. Yearly

10 A **lunar eclipse** can only occur during which Moon phase?

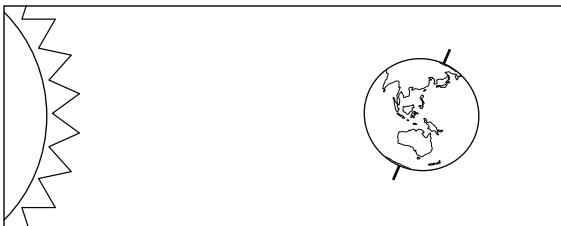
- A. New moon
- B. Crescent moon
- C. Quarter moon
- D. Full moon

11 What is the term for the line of latitude at 23.5° North?

- A. Arctic Circle
- B. Antarctic Circle
- C. Tropic of Cancer
- D. Tropic of Capricorn

12 When is the autumn equinox in the *Southern Hemisphere*?

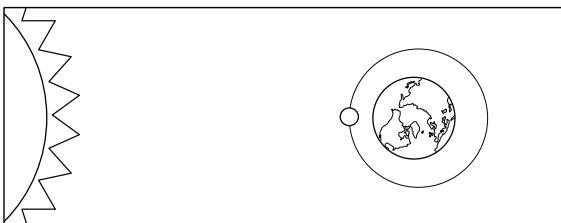
- A. December
- B. March
- C. September
- D. June



- 13** In the illustration above, is the Southern Hemisphere experiencing winter or summer?
- Winter
 - Summer
 - Neither

- 14** A **solar eclipse** can only occur at what phase of the Moon?
- New moon
 - First quarter
 - Full moon
 - Last quarter

- 15** The dark areas on the Moon's surface are best described as:
- Craters
 - Lava plains
 - Mountains
 - Oceans



- 16** What phase of the Moon is visible if the Sun, Moon, and Earth are positioned as pictured above?
- Full moon
 - Crescent or gibbous
 - Quarter
 - New moon

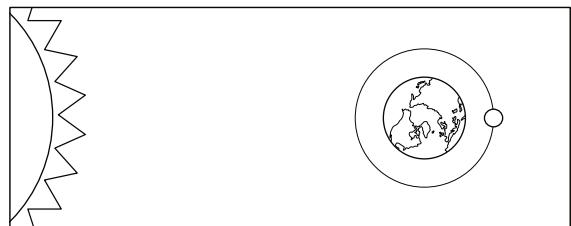
LABEL EACH DESCRIPTION WITH THE CORRECT TYPE OF ECLIPSE (Annular, partial, or total and either lunar or solar)

The type of eclipse that occurs when the Moon is too far from Earth to completely cover the Sun, leaving a "ring of fire."

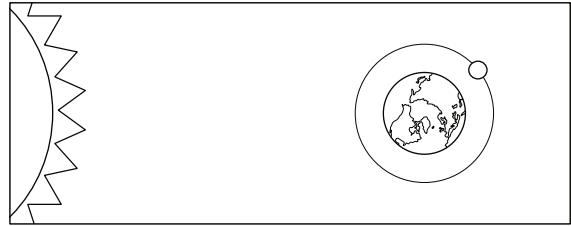
Also called a "Blood Moon," this eclipse occurs when the Earth moves directly between the Sun and the Moon.

This type of eclipse produces crescent-shaped shadows on the ground.

- 17** What is the name for the lighter outer part of a shadow?
- Umbra
 - Penumbra
 - Antumbra



- 18** What phase of the Moon is visible if the Sun, Moon, and Earth are positioned as pictured above?
- Full moon
 - Crescent or gibbous
 - Quarter
 - New moon



- 19** What phase of the Moon is visible if the Sun, Moon, and Earth are positioned as pictured above?
- Crescent
 - Full moon
 - Gibbous
 - Quarter

- 20** The gnomon on a sundial is:
- The curved part where the time is marked
 - The shadow-casting bar or post
 - The compass used to align the sundial
 - The base of the sundial

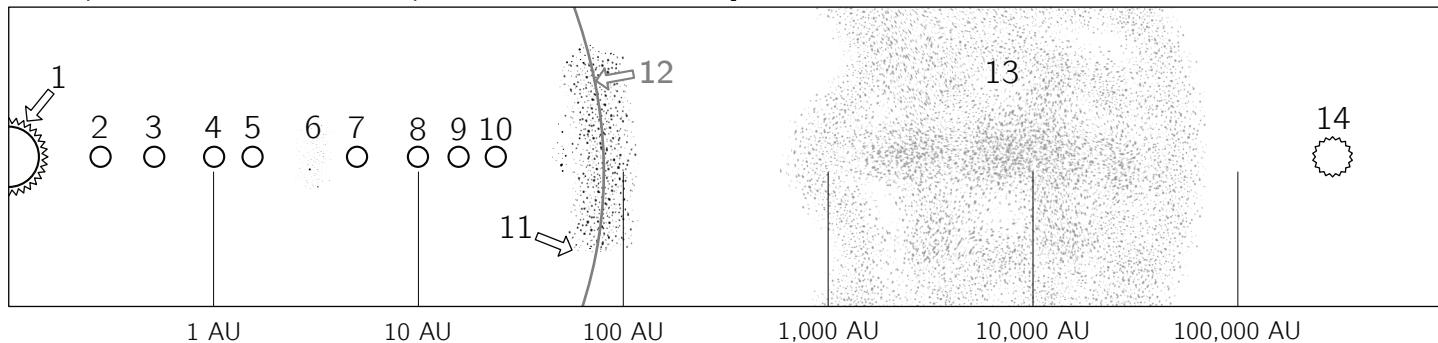
Our Solar System: scope and story

Fill in the blanks (words may be used more than once)

planets Sun dwarf asteroids comets moons

Our solar system includes the _____ and all of the objects that orbit around it. In addition to 8 _____, there are also 5 _____, hundreds of _____, and over 1 million _____ and _____. The _____ contains more than 99% of the total mass of the solar system.

A logarithmic scale diagram of our solar system (and its closest neighbor)



Each distance is the number of astronomical units from the Sun.

Label and briefly describe the features in the diagram above:

1 _____

8 _____

2 _____

9 _____

3 _____

10 _____

4 _____

11 _____

5 _____

12 _____

6 _____

13 _____

7 _____

14 _____

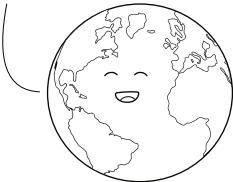
In the logarithmic scale diagram, each distance is TEN TIMES further than the previous one. An Astronomical Units (AU) is the average distance from Earth to the Sun (150 million kilometers). Artwork is modeled after a diagram from NASA/JPL: <https://photojournal.jpl.nasa.gov/catalog/PIA17046>

Fact or Fiction?

Consider each statement, then write whether it is fact or fiction.

Earth is the only place in the solar system with liquid water

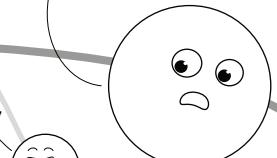
I'M THE ONLY ONE!



Neptune is sometimes further from the Sun than Pluto

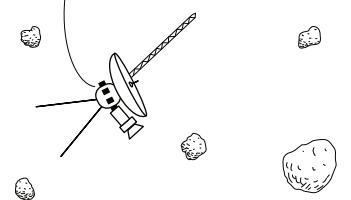
HOW DID THIS HAPPEN?!

BWAHAHA!



Spacecraft traveling through the asteroid belt are at high risk of collisions

WATCH OUT FOR THE ASTEROIDS!



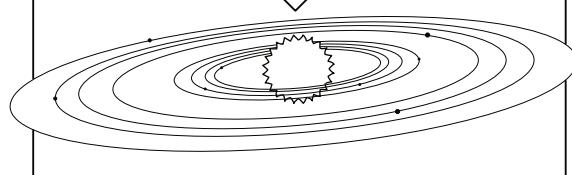
Why do the planets all rotate in the same plane?

Why not perpendicular to each other or random orientations?
Consider and then write down a few of your thoughts.

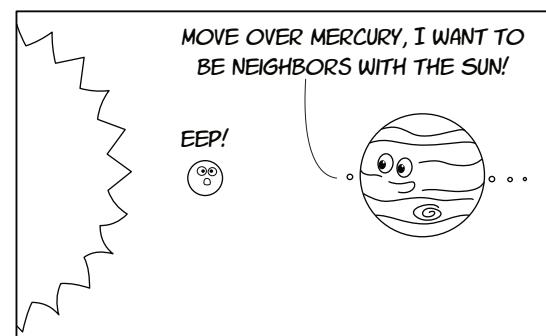
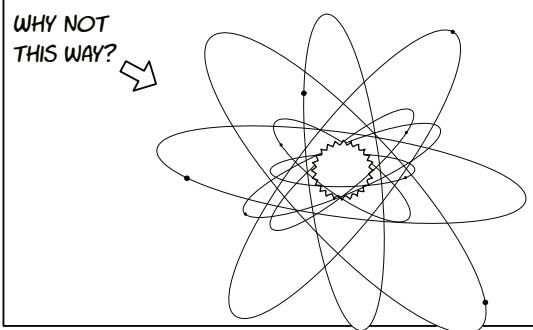
Why rocky, then gassy, then icy?

Why aren't the planets arranged from largest to smallest or in some other order instead? Consider and write a few ideas.

THIS IS THE WAY ↓



WHY NOT THIS WAY? ↗

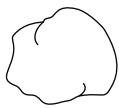


The Scale of the Solar System

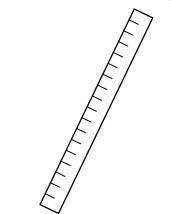
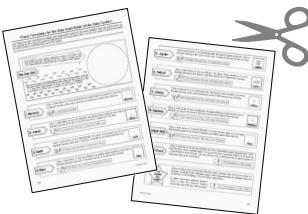
MATERIALS



Chalk or something to mark a location



Modeling clay/dough for sculpting
OR the printable planet templates from the appendix and scissors



A yardstick or tape measure (optional)

GOALS

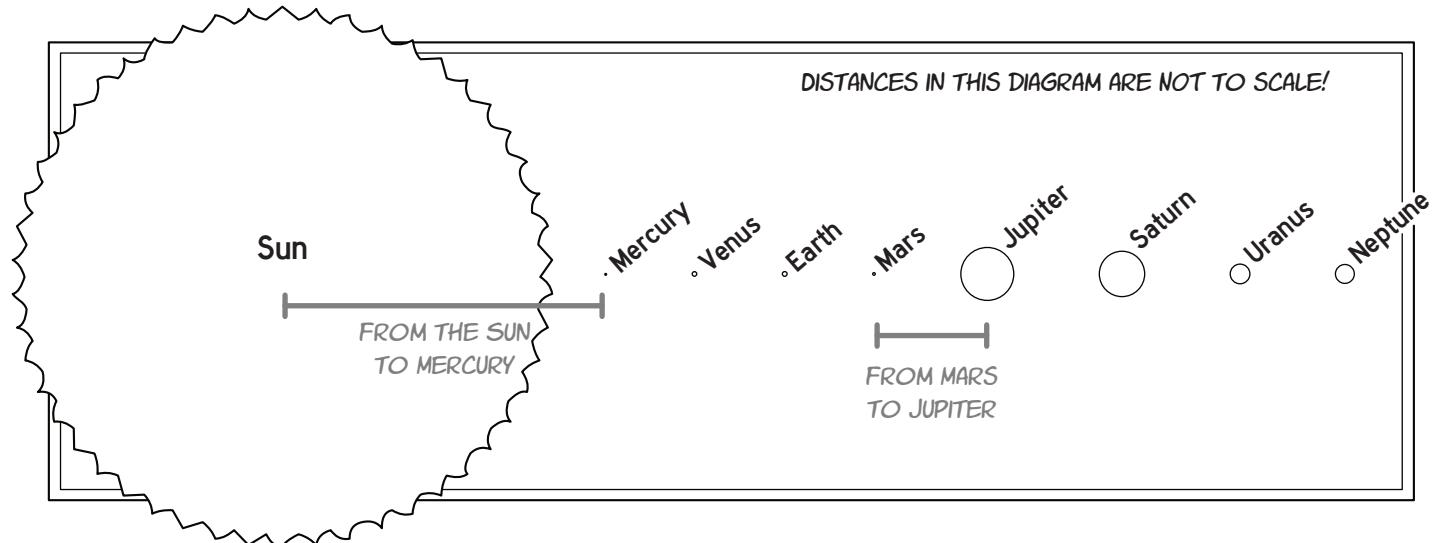
★ Create a scale model of the planets.

★ Create a scale model of the solar system distances.

In most of the pictures or diagrams of the solar system, the planets and distances are not to scale. In this activity we'll build a scale model of the planets and the distances between them using a scale factor of one to ten billion.

If we apply that scale to the objects in the solar system, the Sun and 8 planets look like this:

The Sun and Planets (at a scale factor of 1/10,000,000,000)



The distances above are not accurate for the size of the Sun and planets. But what if they were? If the Sun had a diameter of 70 mm (that's about as wide as a dollar bill in US currency), then how far would Mercury be from the Sun? What about Jupiter from Mars? Take a guess!

Your guess or estimate:

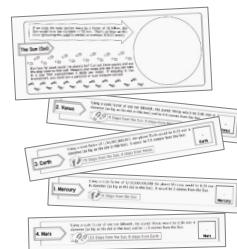
1. From the Sun to Mercury: _____

2. From Mars to Jupiter: _____

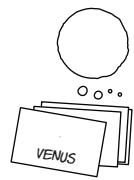
Now that you've made your guesses, it's time to make a scaled model and find out the answer!

Walking the Solar System

1. Make models of the objects in our solar system either by cutting out the printable scaled planets in the appendix OR by making them with clay or dough (note: if using clay, the inner planets will be almost too small to pick up! You could place them on index cards for easier handling.)
2. Find a long straightaway on a non-busy street, sidewalk, or flat open area. Ideally, find a distance that is the length of two football fields or longer.
3. Choose a location on the ground for the Sun. Have a person stand there to mark the spot OR place the paper or clay/dough model of the Sun there OR mark the location with chalk.
4. Use the Step-Scale chart below to find the distance to Mercury in steps. Pace the distance or use a tape measure if you prefer to measure meters. (To convert steps to meters, just divide the number of steps by 2)
5. Continue the same process with the remaining planets. Take a picture or your solar system model when you get to significant milestones like Earth or Neptune.



OR



I SHALL STAND HERE WITH MY BALL OF CLAY
AND REPRESENT OUR FABULOUS STAR SOL!



20, 21, 22, 23...



Step-Scale Solar System Distances

	Distance from Sun	Distance from last planet
Sun	0 steps	0 steps
Mercury	6 steps	6 steps
Venus	11 steps	5 steps
Earth	15 steps	4 steps
Mars	23 steps	8 steps
Jupiter	78 steps	55 steps
Saturn	143 steps	65 steps
Uranus	287 steps	144 steps
Neptune	451 steps	164 steps
Pluto	591 steps	140 steps

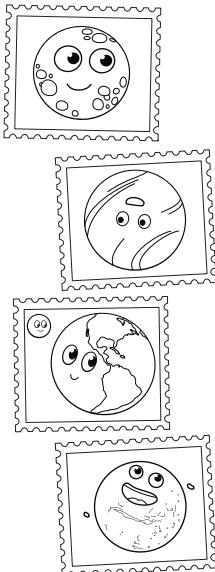
This chart assumes each step is half a meter in length.

What surprised you about this activity? Did you run into any challenges while doing it?

The Inner and Outer Planets

The inner planets are the 4 planets closest to the Sun: Mercury, Venus, Earth, and Mars. These planets are also called ROCKY or TERRESTRIAL planets because they have solid surfaces. They each have iron cores, a high amount of silicate minerals in their crusts, and all of them have been volcanically active.

Fill in the chart below for the inner planets:

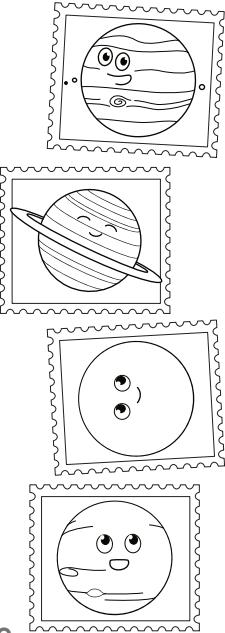


	Distance from the Sun AU	Solid surface Y or N	Number of moons	Atmosphere	Average surface temperature Celsius	Volcanism in present or past Y or N
Mercury						
Venus						
Earth						
Mars						

The outer planets are the 4 planets furthest away from the Sun: Jupiter, Saturn, Uranus, and Neptune. These large planets have no solid surface. Their dense atmospheres get thicker and more dense until they become liquid. Deep within each giant outer planet is a solid core.

Jupiter and Saturn are called GAS GIANTS because apart from their solid core, they are almost entirely made of hydrogen and helium. Uranus and Neptune are called ICE GIANTS because they are mostly made of water, methane, and ammonia.

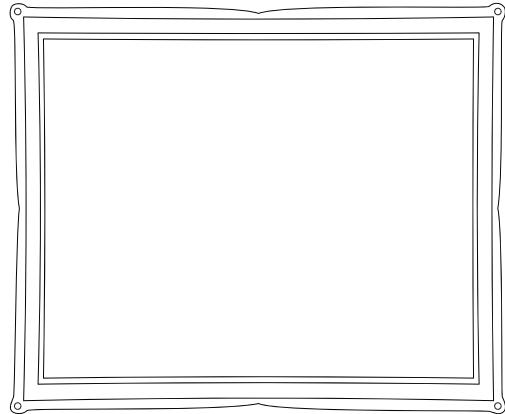
Fill in the chart below for the outer planets:



	Distance from the Sun AU	Solid surface Y or N	Number of moons	Most abundant elements outside of the small rocky core	Temperature at 1 atm of pressure in Celsius	Does the planet have rings? Y or N
Jupiter						
Saturn						
Uranus						
Neptune						

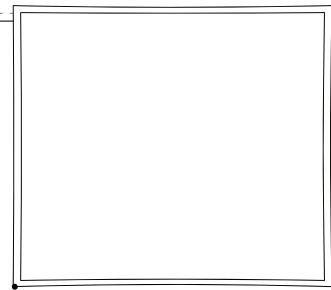
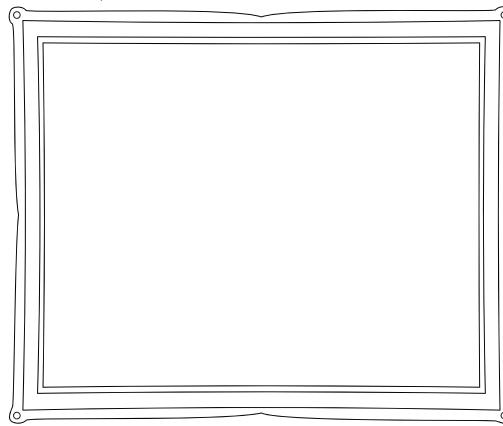
\\\\\\\\ Draw pictures or diagrams in each frame to illustrate the formation of the solar system //

- 1 A large **nebula** exists in space, made of hydrogen, dust, and some heavier elements. A distant supernova sends a shockwave through the cloud and the gas begins to collapse inward.

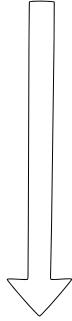


The inner region of the disk is very hot. Rocky materials are solid but materials like water, methane, and ammonia only exist as gasses. In this region, accretion only occurs with rocky materials. Small pieces combine to form larger bodies called planetesimals.

- 2 The material in the nebula starts contracting and swirling around until it forms a **protoplanetary disk**. The material at the center of the disk is called a **protostar**. The protostar is growing in mass and very hot and bright, but it hasn't started fusion yet.

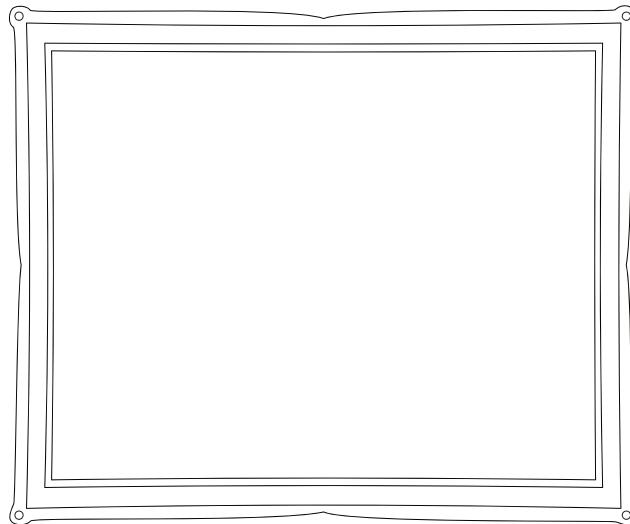


The outer region of the disk is cooler. Rocky materials are solid but so is water, methane, and ammonia. Here, accretion occurs with both rocky materials and frozen ices like water and methane.



- 3 When the protostar becomes large enough, pressure at its center is large enough that hydrogen atoms begin to fuse, forming helium. It's now a real star!

The solar wind produced by the star blows away the remaining gas and dust. The planets and moons are now clearly visible.



Planetary Motion

Fill in the blanks _____

orbits Latin ecliptic direction elliptical appear retrograde

Viewed from a fixed point in outer space, the planets move around the Sun in predictable _____. These paths aren't perfectly circular, they are _____. Planets always travel in the same _____. Viewed from Earth, the planets usually appear to move east to west along the _____. But sometimes they _____ to move backwards. Ancient astronomers called this _____ motion. The word "retrograde" comes from the _____ words retro (backward) and gradus (step).

How are a planet's speed (year length) related to the distance from the Sun?

- A Planets closer to the Sun orbit at the **same speed** as those further away
- B Planets closer to the Sun orbit **faster** than those further away
- C Planets closer to the Sun orbit **slower** than those further away

Why is this the case?

Fact or Fiction?

Consider each statement, then write whether it is fact or fiction.

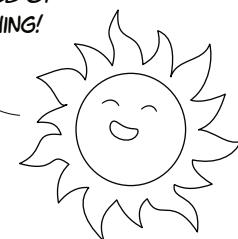
If the Sun disappeared, the planets would keep moving in their same orbits.

IT'S DARK NOW, BUT THAT'S THE ONLY REAL CHANGE.



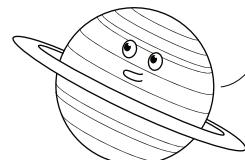
The Sun is at the exact center of each planet's orbit.

I REALLY AM AT THE MIDDLE OF EVERYTHING!

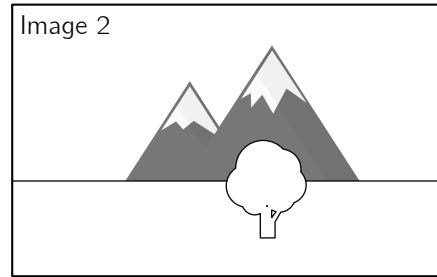
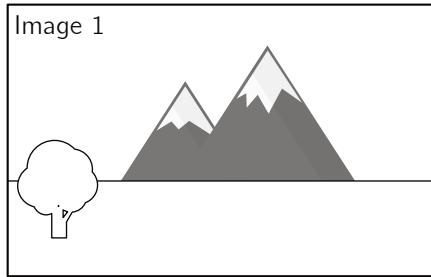


Gravity is the primary force keeping the planets in orbit around the Sun.

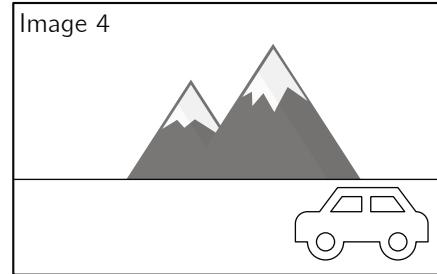
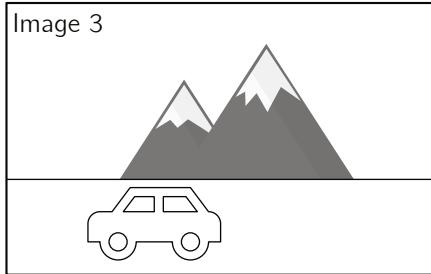
HOW COULD I CONSIDER LEAVING WHEN THE SUN IS SO ATTRACTIVE?



Parallax



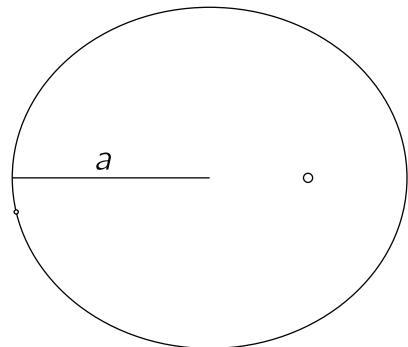
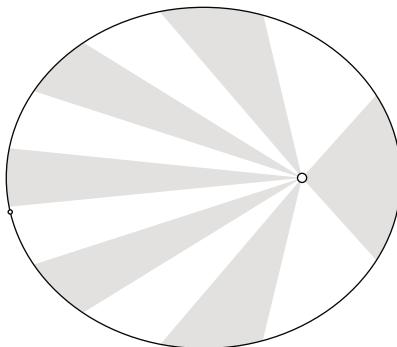
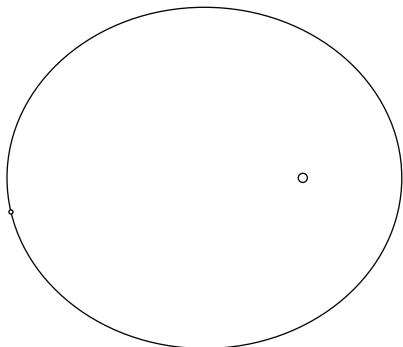
Bob looks out the car window and sees image 1. A few seconds later, he looks out the window and sees image 2. Is Bob traveling to the left or to the right? Explain.



Bob looks out the car window and sees image 3. A few seconds later, he looks out the window and sees image 4. Is Bob traveling to the left or to the right? Explain.

Kepler's Laws

1. Planets move in elliptical orbits with the Sun as a focus.
2. A line that joins a planet to the Sun sweeps equal areas of space in equal time intervals.
3. A planet whose semi major axis has length of a AU will complete a full orbit in $T = \sqrt{a^3}$ Earth years.



Ellipses and Orbits

MATERIALS



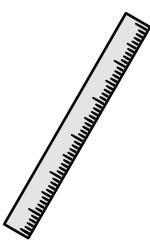
String



2 pins



Marker or pen



Ruler



Flat piece(s) of cardboard

GOALS

★ Construct elliptical orbits using geometry.

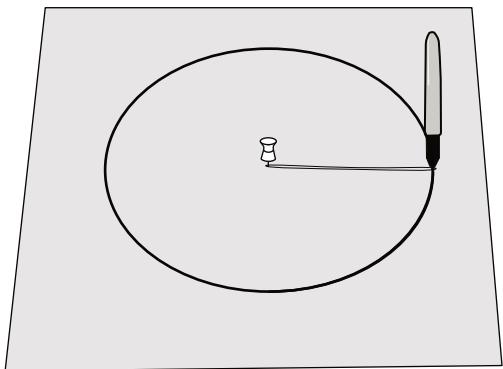
★ Calculate the eccentricity of orbits.

★ Calculate orbital periods.

Kepler's 1st Law states that planets follow an elliptical orbit with the Sun at a focus point of the ellipse. In this activity we'll learn how to construct an ellipse and what a focus point is.

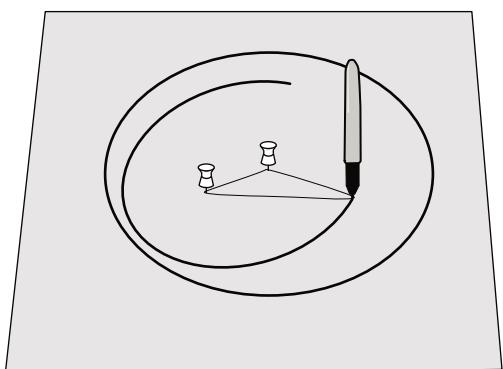
Constructing a Circle.

1. Cut about a foot of string, and tie a knot so that the string makes a big loop.
2. Place a dot near the center of the cardboard and label it "Sun".
3. Place a push pin into the center of the Sun. Place padding under the cardboard if needed.
4. Place the loop around the pin, and insert the pen into the loop as well. Pull the string taut as you draw a shape as far from the pin as the loop of string will allow.
5. The resulting shape is a circle, which has a mathematical definition of "the set of points in a plane that are all the same distance from a central point." The string keeps the distance constant.



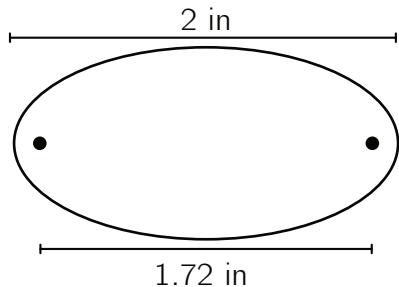
Constructing an Ellipse.

1. Now place a second pin into the cardboard. Each pin will be the focus of our ellipse.
2. You may reuse the string or make one of a different length.
3. Place the loop around both pins, and insert the pen into the loop as well. Pull the string taut as you draw a shape as far from the pins as the loop of string will allow.
4. The resulting shape is an ellipse, which has a mathematical definition of "the set of points in a plane that are the same total distance away from two points when you add the distances." Note that the length of string between the pins stays constant and doesn't play any role in the definition.
5. Keep the Sun in the same position, but move the other pin around and use loops of different lengths to create more ellipses.

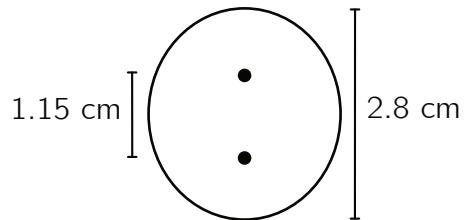


Eccentricity

A long, narrow ellipse is said to be highly eccentric, while a circle has no eccentricity (or 0 eccentricity). To calculate the eccentricity, we divide the distance between the dots by the length of the major axis (the widest distance).



$$e = \frac{1.72}{2} = 0.86$$



$$e = \frac{1.15}{2.8} = 0.41$$

Find the eccentricity of each of your ellipses.

1. Measure the distance between the two focus points.
 2. Divide it by the total width of the ellipse.
- Were any of your ellipses more eccentric than Mars? ($e = 0.0934$)
 - Were any of your ellipses more eccentric than Pluto? ($e = 0.25$)
 - Were any of your ellipses more eccentric than Halley's Comet? ($e = 0.967$)

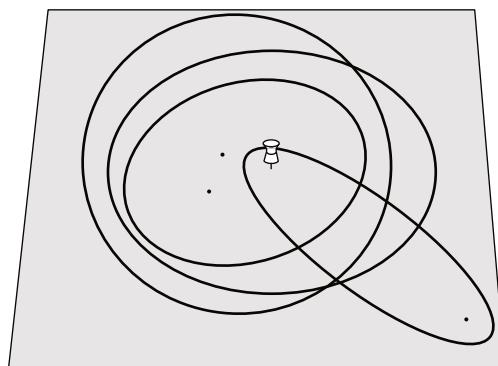
Orbital Period

We can calculate the number of Earth years it takes for an object to complete a full orbit by measuring the semi major axis (half of the total widest distance) in AU's and then plugging that value a into the formula:

$$T = \sqrt{a^3}$$

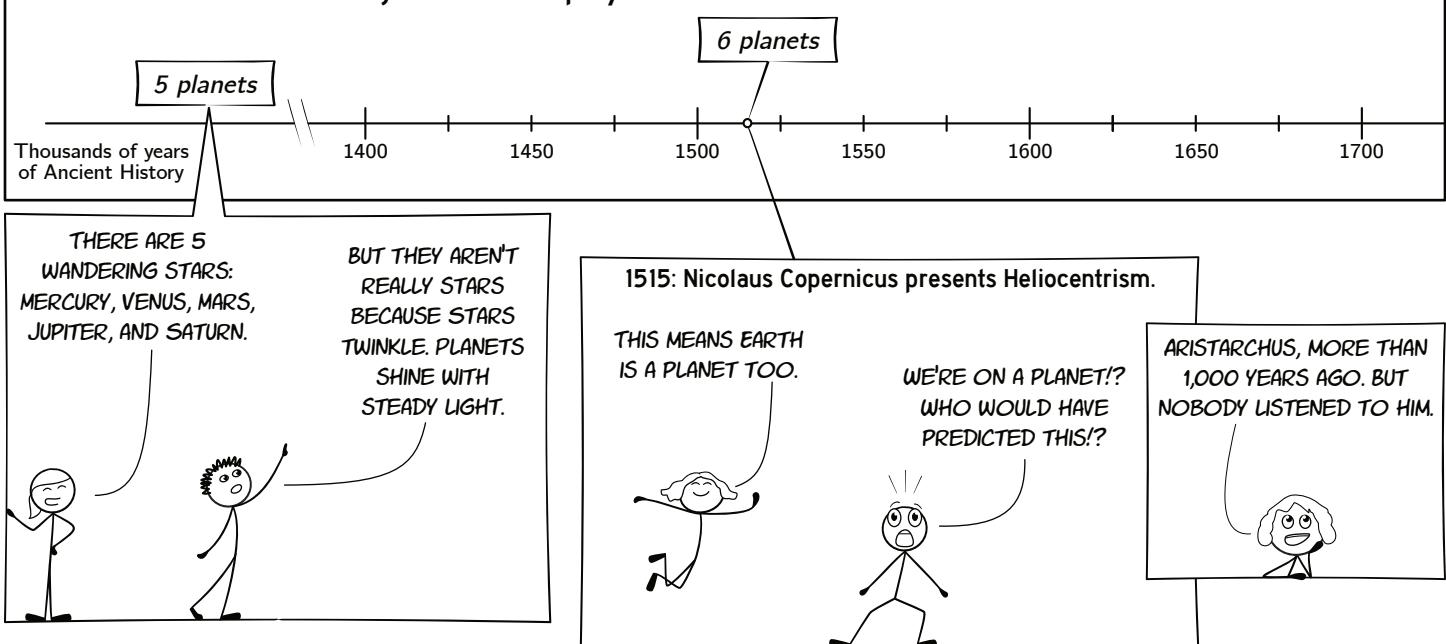
Suppose the solar system whose orbits you designed is scaled so that 1 inch equals 1 AU. Find the orbital period for each planet or satellite in your solar system.

1. Measure the full width of each ellipse in inches and divide that number in half to get the length of the semi major axis.
 2. Plug that value into the formula $T = \sqrt{a^3}$ in place of a to get the number of Earth years, T . (A calculator will come in handy.)
- Which of your orbits has the longest transit time?
 - Were you surprised by any of the results?

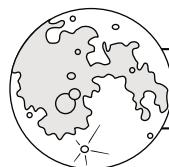
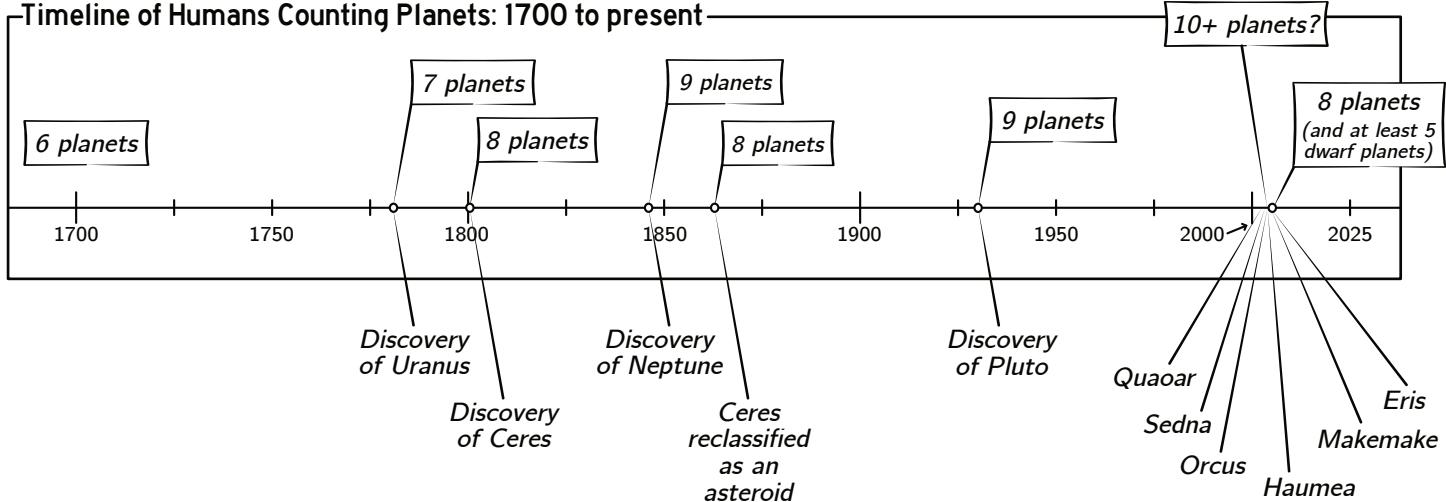


Dwarf Planets and Moons

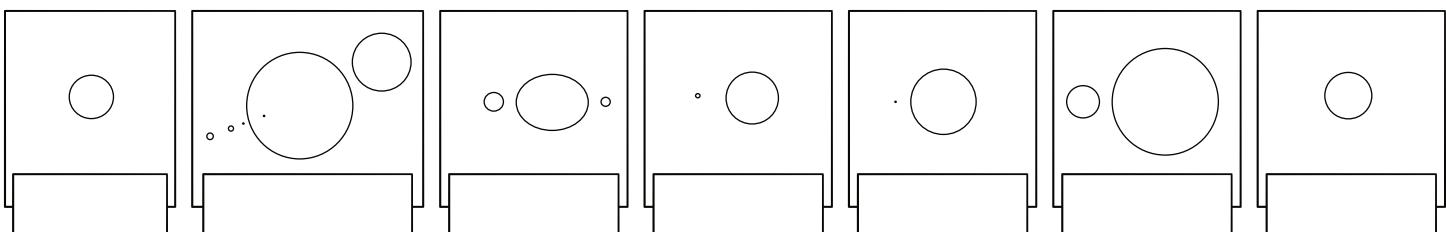
Timeline of Humans Counting Planets: antiquity to 1700



Timeline of Humans Counting Planets: 1700 to present



Fill in the name of each dwarf planet or Trans-Neptunian Object (TNO):
Earth's moon (diameter 4,567 km) is shown here at the same scale as the objects below



952 km diameter
2.8 AU from Sun
No moons
Discovered 1801

2,376 km diameter
39 AU from Sun
5 moons
Discovered 1930

1,740 km diameter
43 AU from Sun
2 moons
Discovered 2004

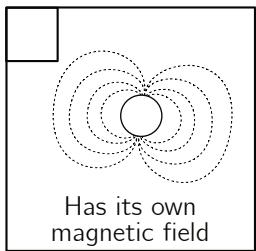
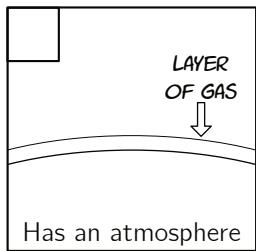
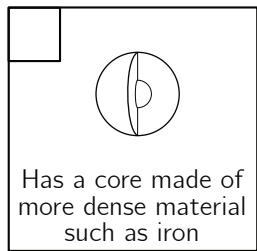
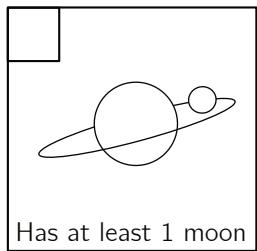
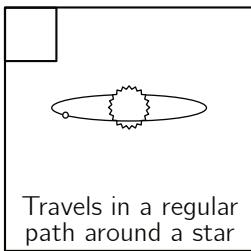
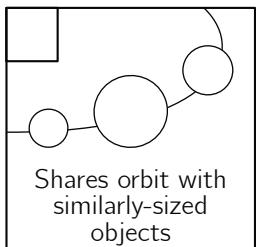
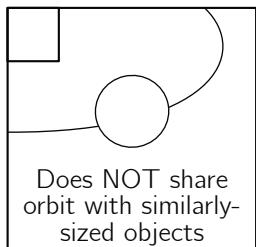
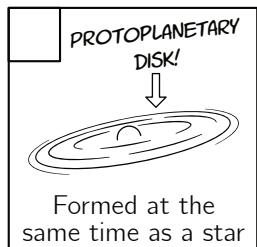
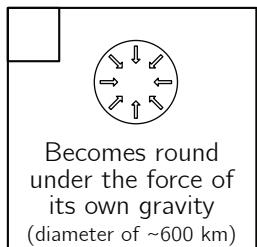
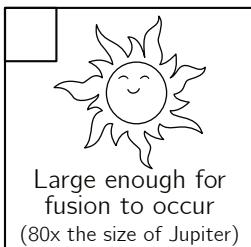
1,100 km diameter
43.7 AU from Sun
1 moon
Discovered 2002

1,430 km diameter
45.8 AU from Sun
1 moon
Discovered 2005

2,400 km diameter
68 AU from Sun
1 moon
Discovered 2005

900 km diameter
83.55 AU from Sun
No moons
Discovered 2003

Characteristics of things in space:



What is your opinion about the definition of a planet? Put a checkmark by each characteristic you think should be included from the boxes above. Then explain and defend your definition.

Moons to know in our solar system

Io	Europa	Ganymede	Callisto
<i>The Galilean Moons of Jupiter</i>			

2 moons of Saturn	Titan	Enceladus
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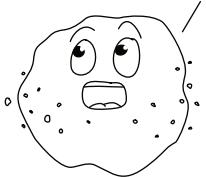
Asteroids, Comets, and Meteors

Billions of years ago, a group of planetesimals considered becoming a planet.

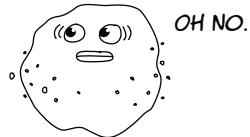
FORM A PLANET? GREAT!
LET'S SMASH TOGETHER.



NO! WE NEED TO
GRADUALLY GROW IN SIZE.
IT'S CALLED ACCRETION.

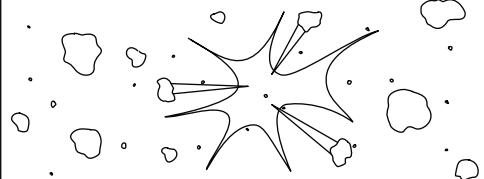


SMASHING
TIME!



OH NO.

More than 99% of the mass was ejected from the solar system.



What remains is known as the asteroid belt.



Asteroid Facts:

Total mass of main asteroid belt is: _____

Most of that mass is contained in: _____

Number of asteroids larger than 1 km: _____

Outside the main belt, asteroids are found: _____

Match the Terms with the correct definition:

ASTEROID

COMET

METEOR

METEORITE

METEOROID

A SMALL TO LARGE
ROCKY OBJECT
ORBITING THE SUN.
HAS NO ATMOSPHERE.

A ROCK IN
OUTER SPACE,
USUALLY OF
SMALLISH SIZE.

AN ICY OBJECT ORBITING
THE SUN THAT FORMS A
TAIL WHEN WARMED BY
SOLAR RADIATION.

A ROCK FROM SPACE
THAT HAS ENTERED
EARTH'S ATMOSPHERE
AND IS BURNING UP.

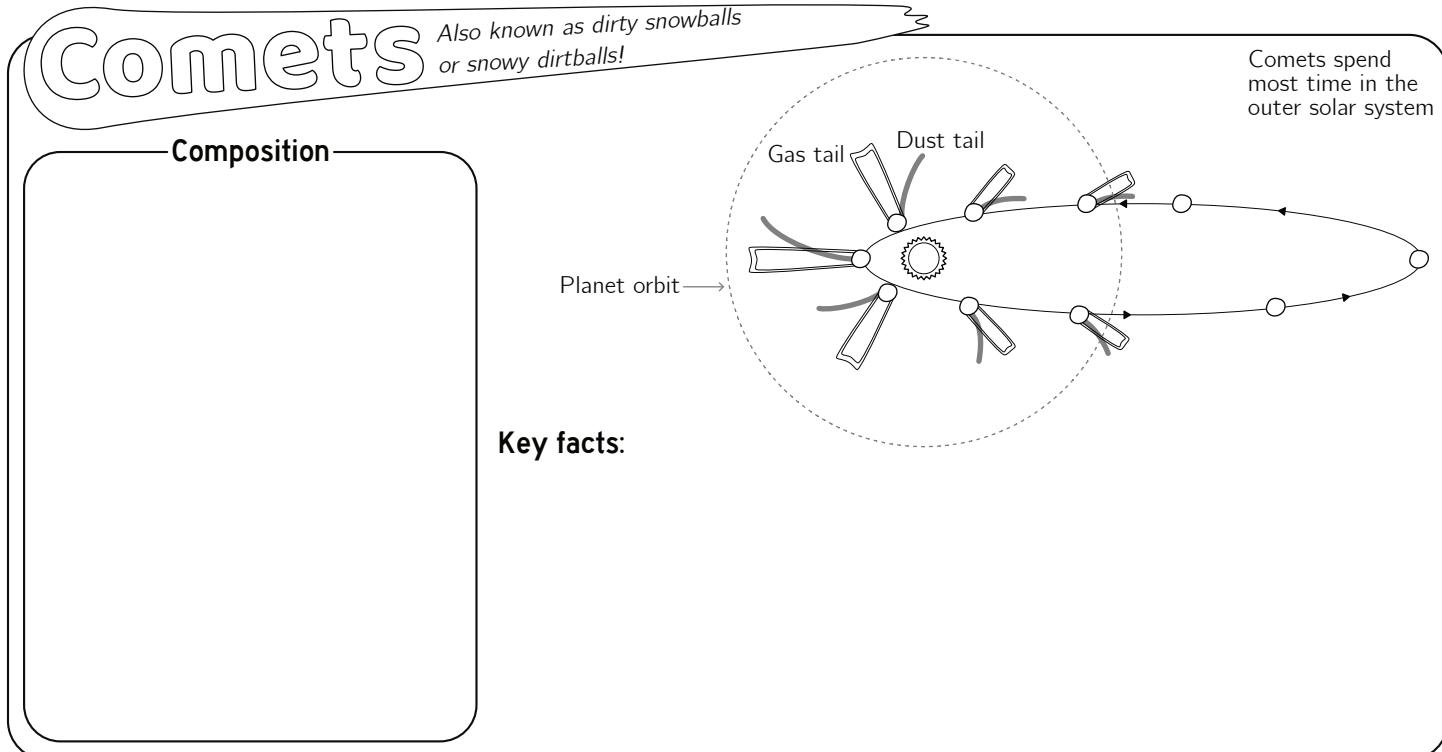
A ROCK FROM SPACE
THAT WENT THROUGH
EARTH'S ATMOSPHERE
AND HITS THE GROUND.

Meteorite or a meteorwrong?

Finding a meteorite is exciting because they are quite rare. Since 1900, fewer than 2,000 meteorites have been found in all of North America. Here are 3 questions to ask if you think you've found a meteorite:

- **Does it have a fusion crust?** Falling through the atmosphere forms a paper-thin glassy crust over the rock.
- **Does it feel heavy for its size?** Meteorites tend to be dense. Up to 95% of their mass can be iron, nickel, and cobalt.
- **Is it magnetic?** Stony meteorites are weakly magnetic. Stony-iron or iron meteorites are strongly magnetic.

Also, a meteorite will not have quartz crystals, bubbles or vesicles, or leave a streak when scraped across a ceramic surface.

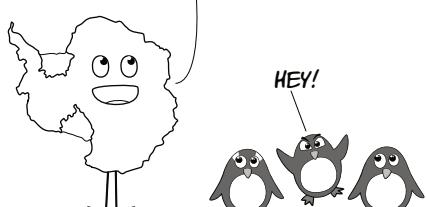


Fact or Fiction?

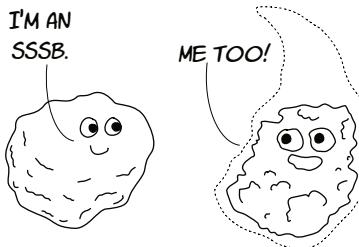
Consider each statement, then write whether it is fact or fiction.

Approximately 60% of all meteorites discovered have been found in Antarctica.

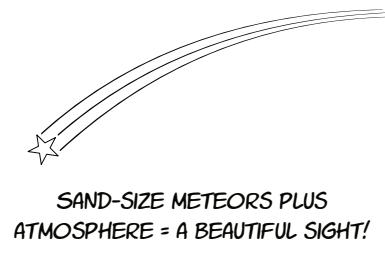
TRULY AMAZING
GIVEN THAT NO
ONE LIVES HERE!



The term the IAU prefers for both asteroids and comets is small Solar System bodies (SSSB)

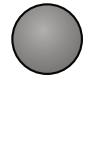


Every one of Earth's annual meteor showers are caused by our planet passing through the debris trails of comets



Crater Creator

MATERIALS



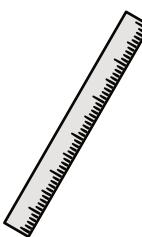
Two marbles or ball bearings of different size.



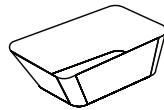
Flour



Cocoa powder



Ruler



A wide non-breakable container

GOALS

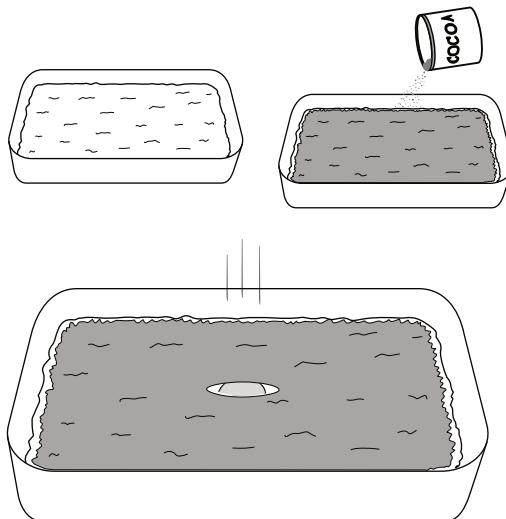
★ Simulate meteors colliding with the ground.

★ Formulate and test a hypothesis about meteor collisions.

How does the mass and velocity of an object affect the crater size? Design an experiment to find out!

How a Flour-Marble Model Works:

- Pour flour into the container to a depth of three to four inches. Flatten it out by shaking or jostling the container.
- Spread a layer of cocoa powder on the top of the flour. For best results, the layer should entirely cover the flour.
- Drop a marble into the flour to simulate a meteor colliding with the ground.
- Observe the impact site.
- When the surface gets overcrowded with craters, smooth it over for another round of tests. Just apply another layer of cocoa powder before dropping more marbles.

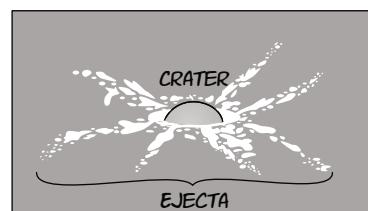


Design Your Experiment

There are at least three things you can measure with each strike:

- The diameter of the crater.
- The depth of the crater, measured from flour surface to the bottom of the marble.
- The diameter of the ejecta blanket (the white flour that has blasted out around the crater and covered the cocoa layer).

Come up with a hypothesis you would like to test. Then decide how to test the hypothesis, and carry out the test. Write up your conclusion.



Here are potential questions to help in developing a hypothesis:

- Does the speed at impact affect the depth of the craters? If yes, how? Does doubling the speed double the depth?
- Does marble mass affect the size of the craters? Does doubling the mass double the size of the crater or the ejecta?
- Does changing the mass have a bigger or smaller impact than changing the speed? In other words, what would form bigger craters, doubling the mass or doubling the speed?
- Is the crater size or ejecta blanket affected by how compact the flour is?

Note that to double the speed of the marble, you need to multiply the drop height by 4. In general, to multiply the speed by n you need to multiply the drop height by n^2 .

Hypothesis

Write out your hypothesis. This is the specific claim you want to test:

Methods

Describe how you will test your hypothesis. What will be measured? How will those measurements help you determine whether your hypothesis is true?

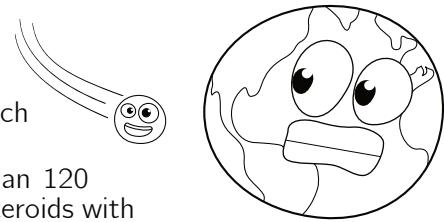
Gather Data

Record your data on another piece of paper. Organize and label it neatly.

Conclusions

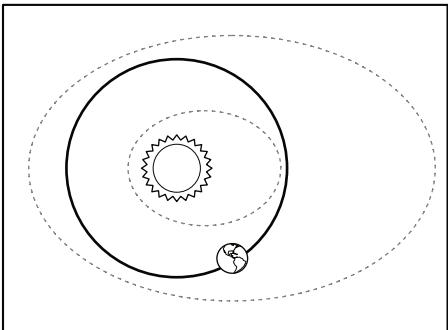
Were you able to confirm or disconfirm your hypothesis? What follow-up questions or tests do you recommend?

Near Earth Objects

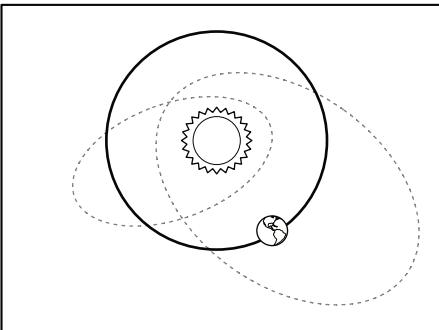


Near-Earth Objects (NEOs) are small Solar System bodies orbiting the Sun which have a perihelion approach of 1.3 AU or less.

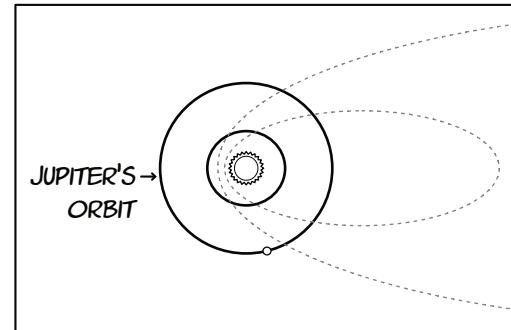
There are more than 34,000 known near-Earth asteroids (NEAs) and more than 120 near-Earth comets. Some have orbits that are outside or inside Earth's orbit. Asteroids with Earth-crossing orbits are more likely to be classified as PHAs (Potentially Hazardous Asteroids).



NEAs with orbits entirely within Earth's orbit are called Atiras. Amor asteroids have orbits between Earth and Mars.



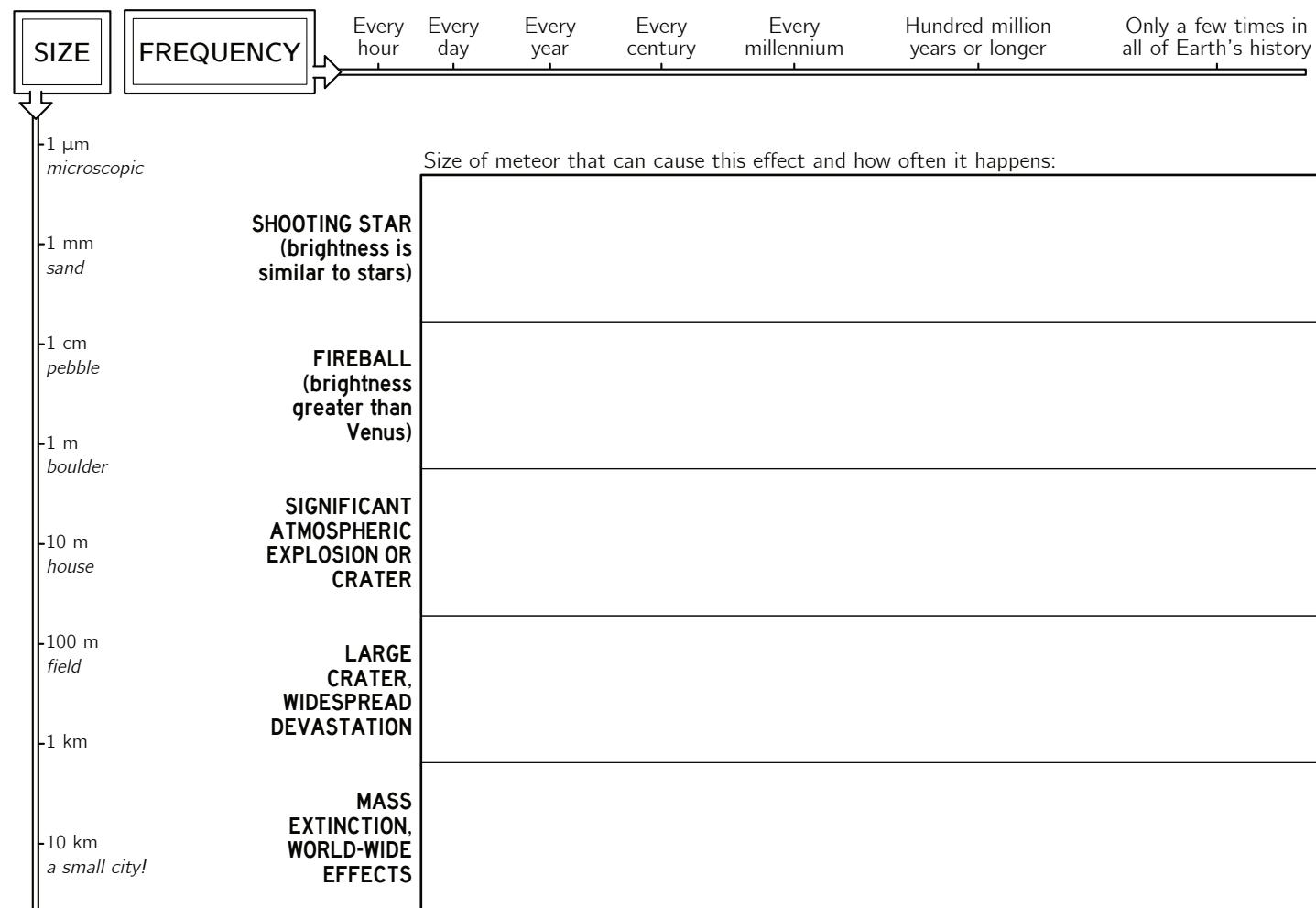
NEAs with Earth-crossing orbits can have axes either smaller (the Atens) or larger (the Apollos) than Earth's.



Near-Earth Comets either come from the Kuiper belt (short-period) or the Oort cloud (long-period comets with an orbit of more than 200 years).

Meteor & Meteorite size, impact, and frequency

Describe the size and frequency of the meteors that cause the effects listed below:



Meteor Shower	Peak viewing*	Rate per hr [†]	Parent Body	Length of Orbit measured in Earth years	Next Perihelion
Quadrantids	Early January	120	Asteroid 2003 EH ₁ [‡]	5.53 years	2025
Lyrids	End of April	18	Comet C/1861 G1 Thatcher	~416 years	2283 ± 5 yrs
Eta Aquarids	Beginning of May	50	Comet 1P/Halley	76 years	2061
Southern Delta Aquarids	End of July	25	Comet 96P/Machholz	5.28 years	2028
Perseids	Mid August	100	Comet 109P/Swift-Tuttle	133 years	2125
Orionids	End of October	20	Comet 1P/Halley	76 years	2061
Leonids	End of November	15	Comet 55P/Tempel-Tuttle	33 years	2031
Geminids	Mid December	150	Asteroid (3200) Phaethon [§]	1.44 years	2025
Ursids	End of December	10	Comet 8P/Tuttle	13.61 years	2035

* Exact timing changes every year and also depends on which hemisphere the viewer is in.

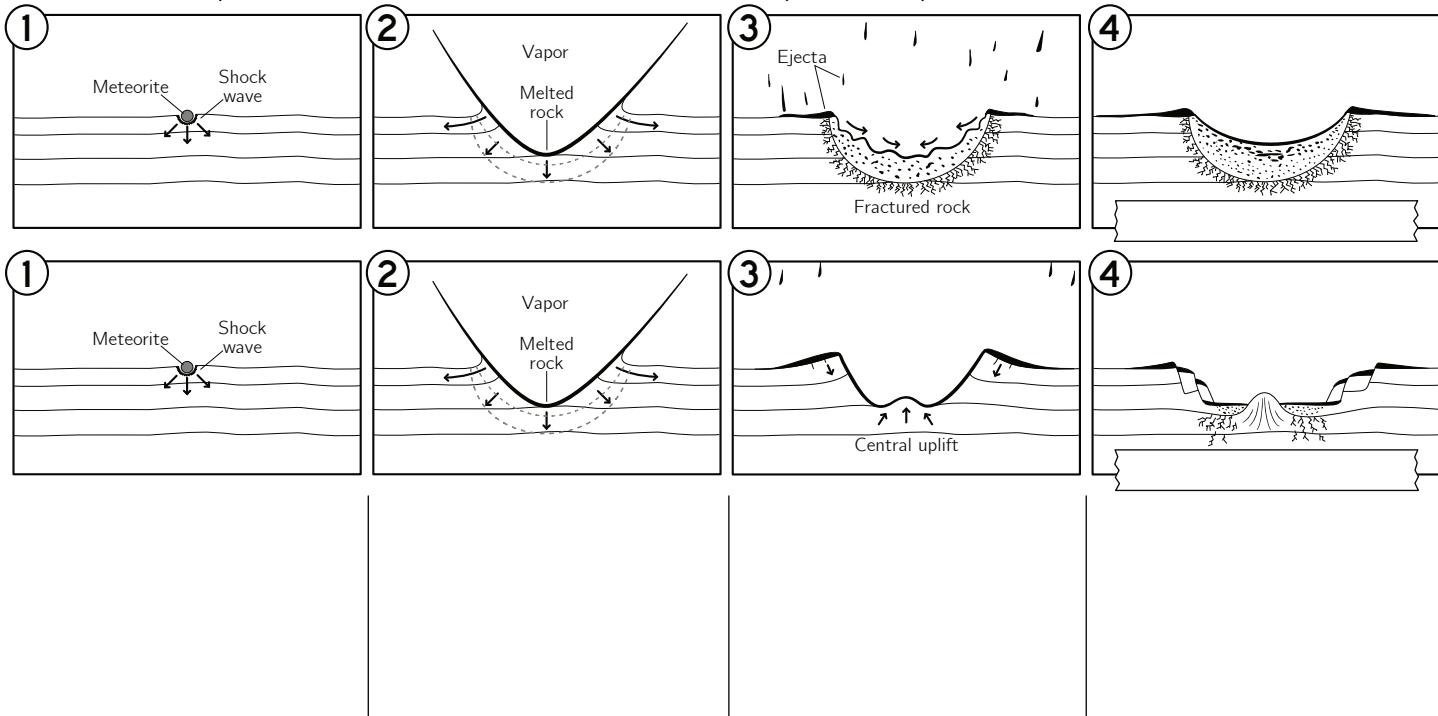
† Rate per hour estimates from NASA. Note that meteor rate is highly variable, even for predictable showers.

‡ A paper in the *Astronomical Journal* in 2004 called 2003 EH₁ an intermittently active comet. In other sources, it's called an asteroid.

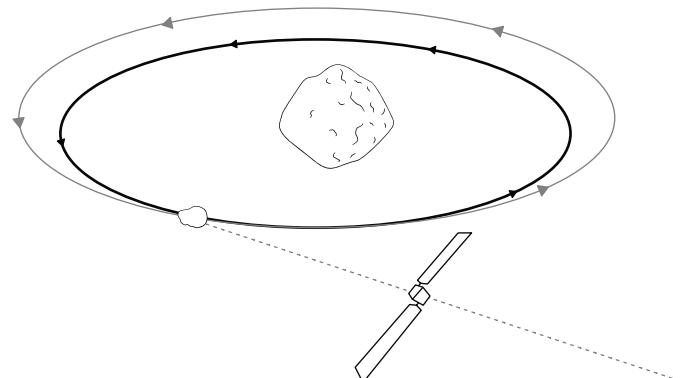
§ Phaethon acts like a comet, brightening and forming a tail when it's near the Sun. But this tail seems to be mostly sodium gas.

What happens on impact?

Describe the steps of crater formation and label which is complex vs simple.



PanSTARRS and DART



Solar System Review

IN YOUR OWN WORDS!

Learning and understanding new words is an important part of astronomy! Define each of the following terms in your own words. If the word has a box next to it, use that space to draw and label a diagram.

ASTEROID: _____

BOLIDE: _____

COMET: _____

ELIPSE: _____

FIREBALL: _____

METEOR: _____

METEORITE: _____

NEBULA: _____

PARALLAX: _____

PROTOPLANETARY DISK: _____

- 1** Which planet has the highest density in our solar system?
A. Jupiter
B. Earth
C. Mars
D. Venus
- 2** The asteroid belt is primarily located between which two planets?
A. Mars and Jupiter
B. Earth and Mars
C. Jupiter and Saturn
D. Venus and Earth
- 3** Which planets have a stronger magnetic field than Earth?
A. Mercury
B. Venus
C. Mars
D. Jupiter
E. Saturn
F. Uranus
G. Neptune
- 4** Which statement about the Sun is FALSE?
A. It contains about 99.86% of the solar system's mass
B. It is classified as a red giant star
C. It produces energy through nuclear fusion
D. Its core temperature is about 15 million degrees Celsius
- 5** The Great Red Spot is a feature found on which planet?
A. Mars
B. Venus
C. Jupiter
D. Saturn
- 6** Which of the following are dwarf planets?
A. Ceres
B. Pluto
C. Eris
D. Hale-Bopp
E. Makemake
- 7** What is the primary component of Saturn's rings?
A. Rocky debris
B. Ice particles
C. Metallic dust
D. Frozen methane
- 8** Which planet rotates "backwards" compared to most other planets?
A. Uranus
B. Venus
C. Neptune
D. Mars
- 9** The Kuiper Belt is primarily composed of:
A. Metallic asteroids
B. Gas clouds
C. Icy bodies
D. Dust particles
- 10** How many Earth years long would a year be on a planet with a circular orbital radius of 4 AU?
A. 2 Earth years
B. 4 Earth years
C. 8 Earth years
D. 16 Earth years
- 11** What is the name of Mars' largest moon?
A. Ganymede
B. Phobos
C. Deimos
D. Io
- 12** Olympus Mons, the largest known volcano in the solar system, is located on:
A. Venus
B. Mars
C. Mercury
D. Io
- 13** What phenomenon causes the appearance of Saturn's rings to change as viewed from Earth?
A. Saturn's rotation
B. Saturn's orbital tilt
C. Solar wind
D. Atmospheric distortion
- 14** Which planet's atmosphere contains the highest percentage of carbon dioxide?
A. Mercury
B. Venus
C. Earth
D. Mars
E. Jupiter
F. Saturn

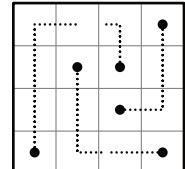
- (15)** What is the approximate time it takes for sunlight to reach Mars?
- 1.5 minutes
 - 6 minutes
 - 12.5 minutes
 - 20 minutes
- (16)** The Cassini Division is:
- A gap in Saturn's rings
 - A region of the asteroid belt
 - A crater on Mercury
 - A zone in Jupiter's atmosphere
- (17)** Which planet was discovered through mathematical calculations before it was observed?
- Uranus
 - Neptune
 - Saturn
 - Mars
- (18)** The surface of Venus is obscured by clouds primarily composed of:
- Water vapor
 - Methane
 - Sulfuric acid
 - Ammonia
- (19)** The orbits are shown for objects A, B, C, and D. Place them in order from shortest year (full orbit) to longest year.
-
- (20)** Four different points are shown along the orbit of a planet, labeled A, B, C, and D. At which point is the planet moving fastest?
- A
 - B
 - C
 - D
 - The planet is always moving the same speed along the orbit.
- (21)** Mercury's "day" (one full rotation on its axis) is approximately how long compared to its "year" (one orbit around the Sun)?
- 1/4 of a Mercurial year
 - 2/3 of a Mercurial year
 - 2 Mercurial years
 - 3 Mercurial years
- (22)** What causes the blue color of Neptune?
- Water reflection
 - Methane in its atmosphere
 - Surface ice
 - Nitrogen compounds
- (23)** Which moon is the only one known to have a thick atmosphere?
- Europa
 - Callisto
 - Ganymede
 - Titan
- (24)** The Galilean moons are associated with which planet?
- Saturn
 - Jupiter
 - Uranus
 - Neptune
- (25)** Which planet has the shortest day (rotation period)?
- Mercury
 - Venus
 - Mars
 - Jupiter
- (26)** Mark each statement as true or false.
- | | | |
|---|---|---|
| T | F | Half of the Moon never receives sunlight. |
| T | F | The same side of the Moon is always facing the Earth. |
| T | F | Mercury is the hottest planet in the solar system. |
| T | F | The asteroid belt contains more total mass than Earth's moon. |
| T | F | Venus rotates in the opposite direction compared to most other planets. |
| T | F | Uranus has the greatest tilt in its orbit of any planet. |
| T | F | A day on Mars is about the same length as a day on Earth. |
| T | F | Saturn is less dense than liquid water. |

Pipe Flow Matching - Moons

	D			E
5	1			2
	A			
	B			4
	3	C		

Rank the planets below by number of moons and join the corresponding letter and number with a continuous stroke. Each square in the grid should be visited by exactly one pipe as in the example grid shown below.

- | | |
|------------|----------------------|
| 1. Mars | A. Most moons |
| 2. Earth | B. Second most moons |
| 3. Saturn | C. Third most moons |
| 4. Jupiter | D. Fourth most moons |
| 5. Venus | E. Fewest moons |

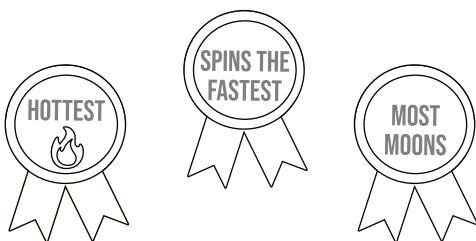


Pipe Flow Matching - Planet Facts 1

		1		
	D	E		4
	A			
C	B	2	3	5

Which planet is the hottest, spins the fastest, and is the most in other categories? Join each planet with its corresponding award with a continuous stroke (pipe). Each square in the grid should be visited by exactly one pipe.

- | | |
|------------|----------------------|
| 1. Jupiter | A. Spins the fastest |
| 2. Earth | B. Strongest winds |
| 3. Venus | C. Most dense planet |
| 4. Mars | D. Largest volcano |
| 5. Neptune | E. Hottest planet |



Pipe Flow Matching - Planet Facts 2

	A	1		E
			4	
		3		
	B	2		D
		C		5

Which planet rotates sideways? Which one has moons that can be seen with binoculars? Join each planet with its corresponding award with a continuous stroke (pipe). Each square in the grid should be visited by exactly one pipe.

- | | |
|------------|--------------------------------------|
| 1. Uranus | A. Shortest year |
| 2. Mercury | B. Is closest to Earth |
| 3. Jupiter | C. Moons visible with binoculars |
| 4. Mars | D. Has snow (made of carbon dioxide) |
| 5. Venus | E. Rotates sideways |

