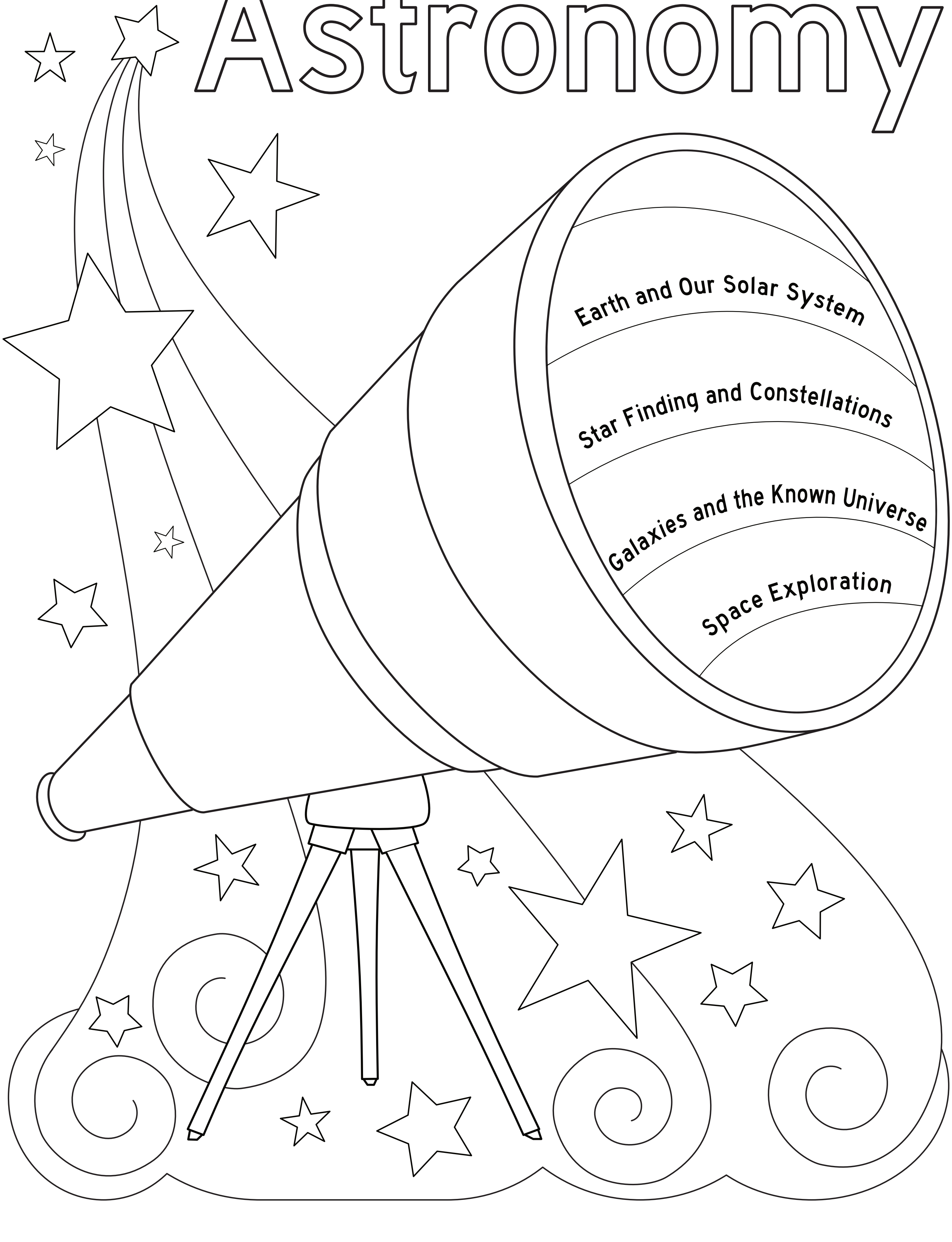
Astronomy


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
	4	Mon, Jan 20	No Class (MLK day holiday)	
	5	Wed, Jan 22	The Seasons	14-15
	6	Self paced lesson	DIY Equatorial Sundial	16-17
	7	Mon, Jan 27	Lines of Latitude	18-19
	8	Wed, Jan 29	Our Moon	20-21
	9	Self paced lesson	Cookie Models and Journal	22-25
	10	Mon, Feb 3	Eclipsed	26-27
	11	Wed, Feb 5	Totality	28-29
	12	Self paced lesson	Earth and Moon Review/Assessment	30-33
	13	Mon Feb 10	EARTH & MOON QUIZ SHOW	
Unit 2. Our Solar System	14	Wed Feb 12	Our Solar System: Scope and Story	34-35
	15	Self paced lesson	Step Scale Model of the Solar System	36-37
	16	Mon Feb 17	Inner vs Outer Planets	38-39
	17	Wed Feb 19	Planetary Motion	40-41
	18	Self paced lesson	Ellipses & Orbits	42-43
	19	Mon Feb 24	Dwarf Planets and Moons	44-45
	20	Wed Feb 26	Asteroids, Comets and Meteors	46-47
	21	Self paced lesson	Flour and Cocoa Craters	48-49
	22	Mar 3	Near Earth Objects	50-51
	23	Mar 5	SOLAR SYSTEM QUIZ SHOW	
	24	Self paced lesson	Solar System Review/Assessment	52-55
Spring Break is March 10-15				
Unit 3: Stars, Galaxies, and the Universe	25	Mar 17	The Sun as a Star	-
	26	Mar 19	Solar Weather	-
	27	Self paced lesson	**Star Classification Poster**	-
	28	Mar 24	The Scale of Space and Galaxies	-
	29	Mar 26	Main Sequence Stars	-
	30	Self paced lesson	Make a Constellation Viewer	-
	31	Mar 31	Supernovas and Black Holes	-
	32	Apr 2	Stargazing 101	-
	33	Self paced lesson	**Stargazing Scavenger Hunt**	-
	34	Mon, Apr 7	Constellations	-
	35	Wed, Apr 9	The Known Universe	-
	36	Self paced lesson	Stars & Universe Review/Assessment	-
	37	Mon, Apr 14	STARS & UNIVERSE QUIZ SHOW	-

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

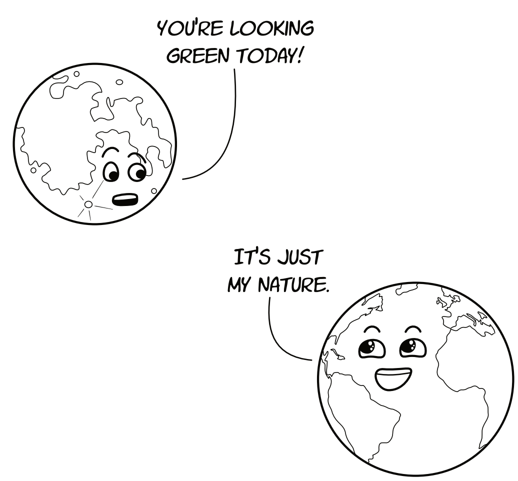
Words are more than tools for communication, they are the framework of knowledge! Without language to express and define new ideas, we wouldn't be able to learn.

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.

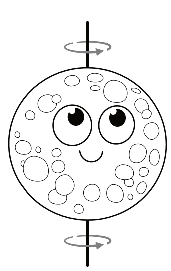
If there are terms or words you don't know, don't worry! We'll be learning them in future lessons. As you learn new concepts, come back to these pages and label each card.

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.



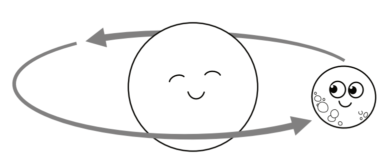
APHELION   DIURNAL MOTION   ECLIPSE   ECLIPTIC   EQUATOR
HEMISPHERE   HORIZON   LATITUDE   LONGITUDE   ORBIT
PERIHELION   PRIME MERIDIAN   REVOLVE   ROTATE   ZENITH

TO SPIN AROUND AN AXIS OR CENTER



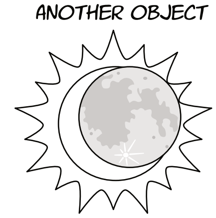
ROTATE

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



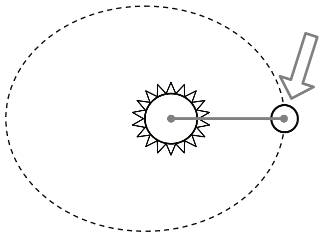
REVOLVE

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



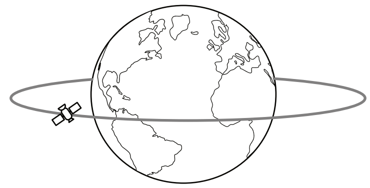
ECLIPSE

THE POINT WHERE AN ORBITING OBJECT IS CLOSEST TO THE SUN



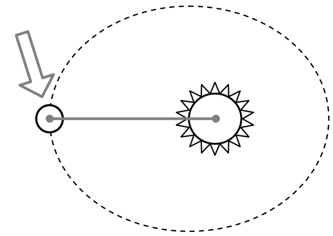
Perihelion

THE CURVED PATH AN OBJECT TAKES AROUND A STAR, PLANET, OR MOON



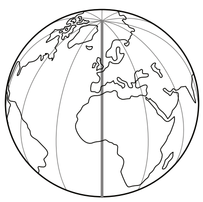
Orbit

THE POINT WHERE AN ORBITING OBJECT IS FURTHEST FROM THE SUN



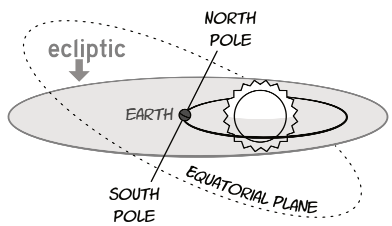
Aphelion

A LINE FROM NORTH TO SOUTH POLE THAT PASSES THROUGH GREENWICH, ENGLAND



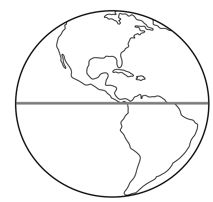
Prime Meridian

THE APPARENT PATH OF THE SUN ACROSS THE SKY OVER A YEAR



Ecliptic

A LINE AROUND THE EARTH THAT IS EQUALLY DISTANT FROM THE NORTH / SOUTH POLES.

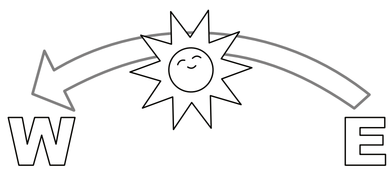


Equator

PARALLEL LINES THAT MEASURE DISTANCE FROM THE EQUATOR

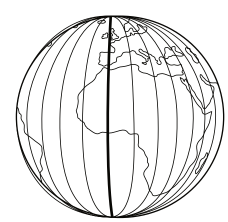
Latitude

THE REPEATED DAILY MOVEMENT OF STARS AND OTHER OBJECTS ACROSS EARTH'S SKY FROM EAST TO WEST



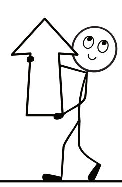
Diurnal Motion

LINES THAT MEASURE DISTANCE FROM THE PRIME MERIDIAN



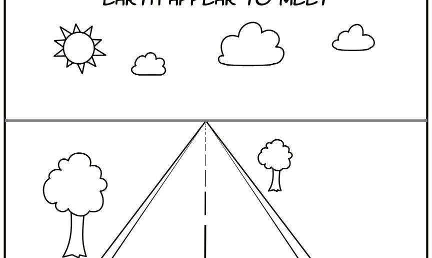
Longitude

THE POINT IN THE SKY THAT IS DIRECTLY ABOVE THE OBSERVER



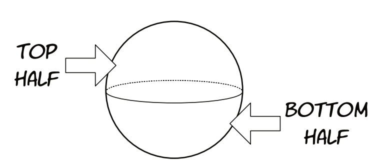
Zenith

THE LINE WHERE THE SKY AND EARTH APPEAR TO MEET



Horizon

HALF OF A SPHERE



Hemisphere

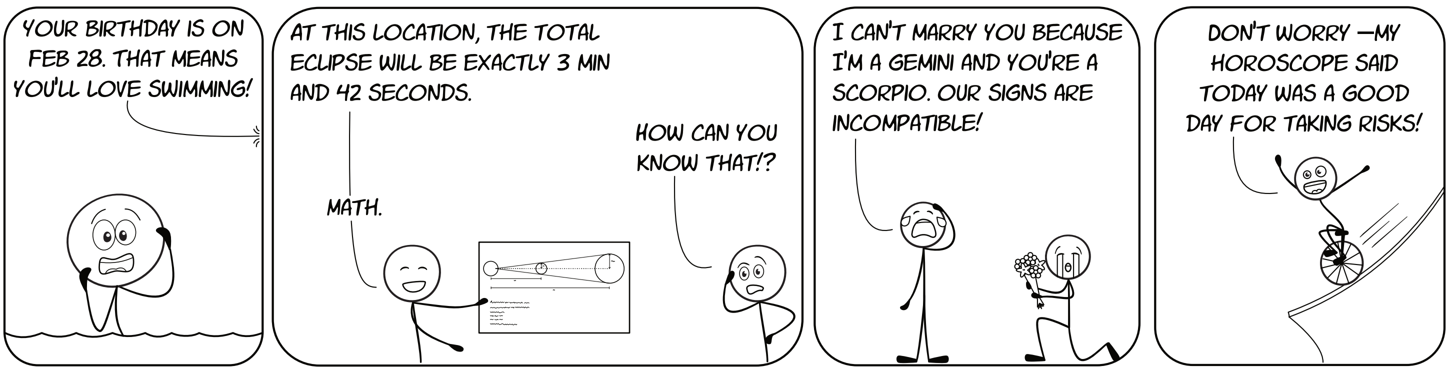
What is Astronomy?

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

Astronomy is: A BRANCH OF SCIENCE FOCUSED ON UNDERSTANDING THE OBJECTS AND MATTER BEYOND EARTH'S ATMOSPHERE. IT IS EVIDENCE-BASED.

Astrology is: A SET OF IDEAS AND SUPERSTITIONS ABOUT HOW THE POSITION OF STARS AND PLANETS INFLUENCE HUMANITY. IT IS NOT EVIDENCE-BASED (IT'S A PSEUDOSCIENCE).

IS IT ASTRONOMY OR ASTROLOGY? Label each scenario below:



ASTROLOGY	ASTRONOMY	ASTROLOGY	ASTROLOGY

IS IT SCIENCE OR PSEUDOSCIENCE?

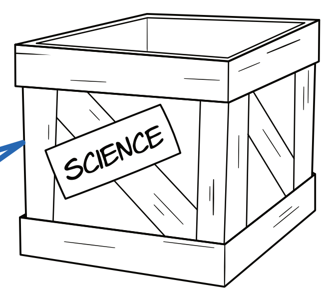
Match each characteristic with the appropriate box

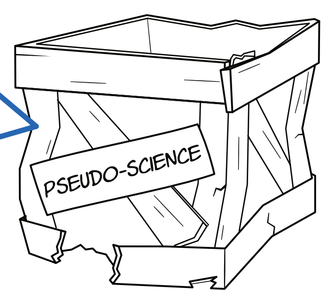
Relies on anecdotal evidence

Relies on data, controlled studies, and reproducible observations

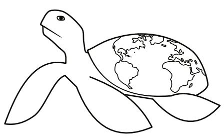
Responds to contradictions & criticism by gathering additional data or revising ideas

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





Concepts of Earth through Human History



MYTHOLOGY

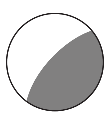
SPHERICAL EARTH

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.

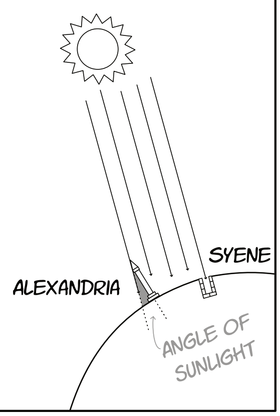
Aristotle
approximately 350 BCE

Aristotle observed that Earth cast a circular shadow on the Moon during a lunar eclipse, which meant the Earth was spherical.



Eratosthenes
approximately 250 BCE

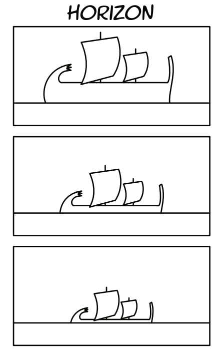
Eratosthenes famously measured shadows in both Syene and Alexandria on the summer solstice. Using geometry, he then calculated the circumference of the Earth. His answer was surprisingly accurate!



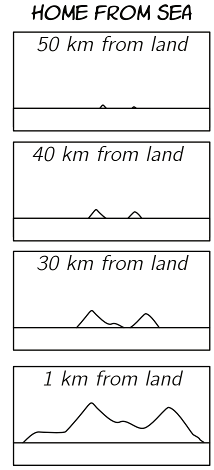
Ptolemy
approximately 150 CE

Observations from ships at sea were consistent with a curved body of water. Ships disappear hull-first when sailing over the horizon. Conversely, land appears "top first" when viewed from someone who is out at sea.

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



LAND APPEARS "TOP FIRST" WHEN COMING HOME FROM SEA



Our Current View of Earth:

Earth is an oblate ellipsoid! It's spinning motion makes it about 44 km wider at the equator than at the poles.

Diameter ~ 12,756 km (Equator) or ~ 12,712 km (pole-to-pole).

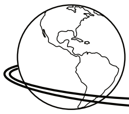
Day length = 23 hours and 56 minutes.

Year length = 365.25 days

Distance from Sun = 150 million km (also called 1 Astronomical Unit or AU)

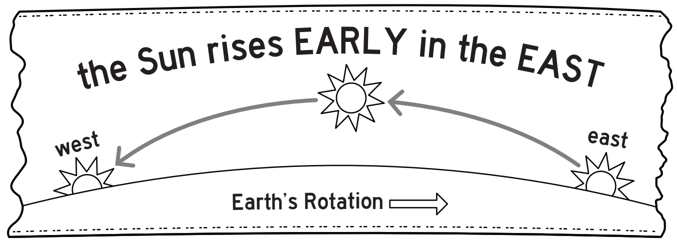
If the Sun were as tall as a typical front door, Earth would only be the size of a nickel.

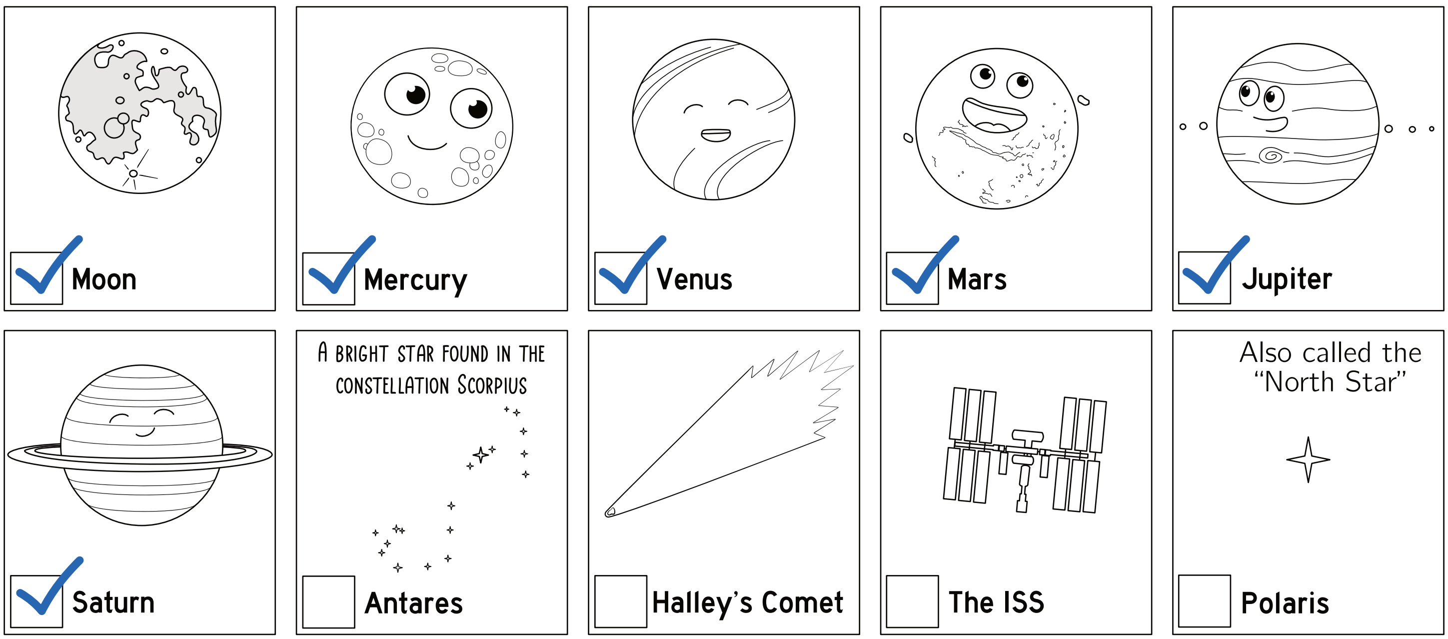
Diurnal Motion: resulting from the rotation of the Earth



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:

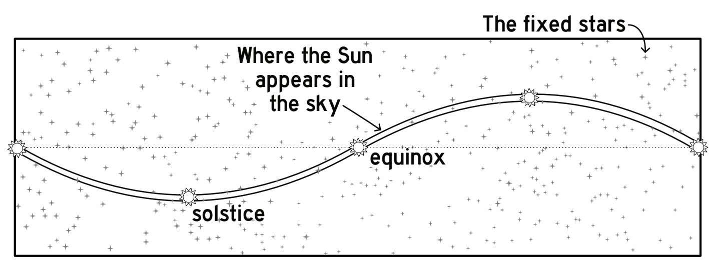


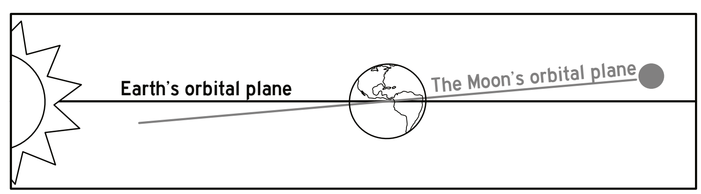


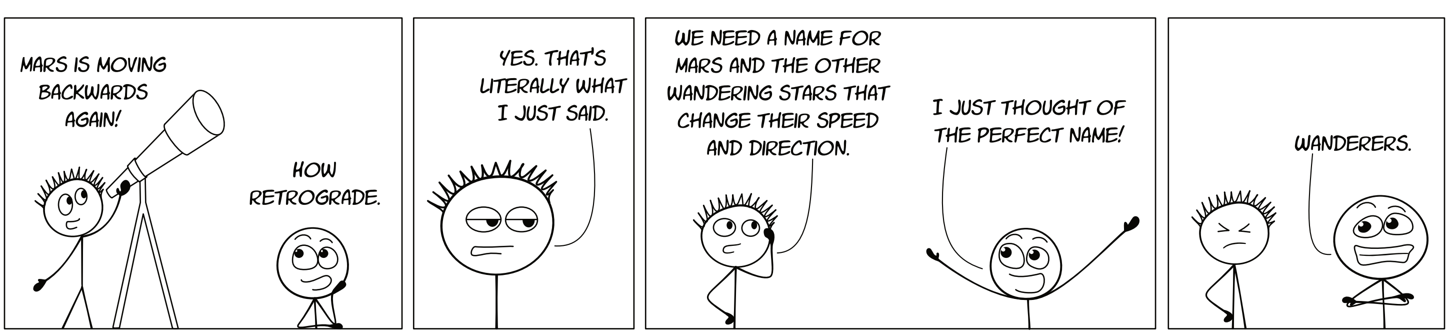
Over the course of a year, the Sun appears to travel through the fixed stars, tracing a path called the **ecliptic**.

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.



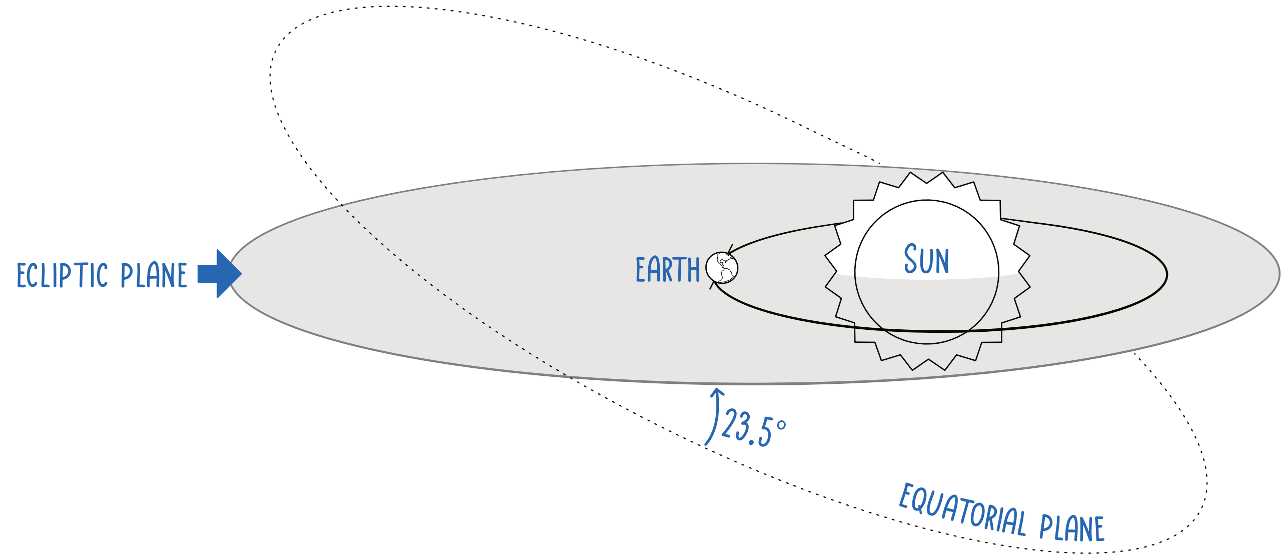




The English word "planet" comes from the Greek word planētēs which means "wanderer."

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!

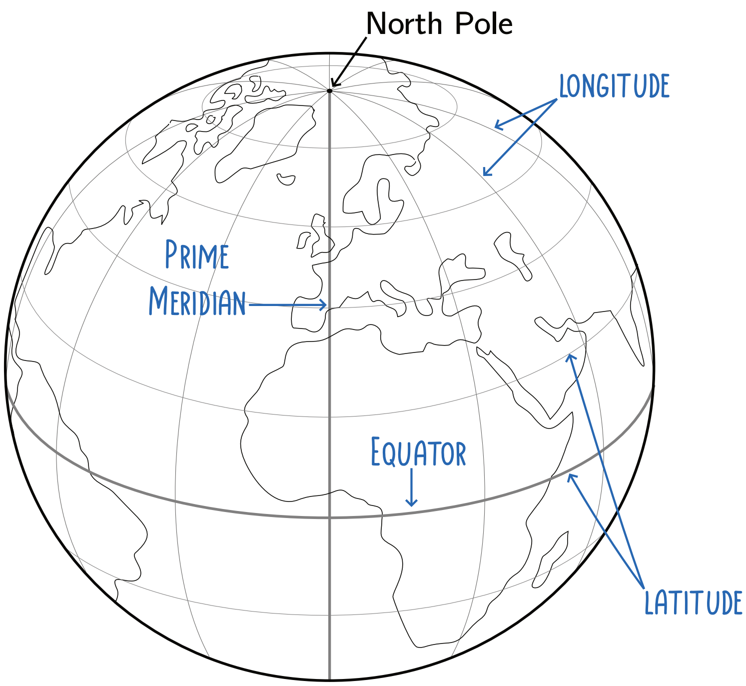
Define these terms and describe how long it takes the Earth to complete one of each:

Rotation: TO SPIN OR MOVE AROUND AN AXIS OR CENTER. EARTH COMPLETES ONE ROTATION IN APPROXIMATELY 24 HOURS.

Revolution: TO MOVE IN A CIRCULAR PATH AROUND AN OBJECT. IT TAKES EARTH 365.25 DAYS TO COMPLETE ONE REVOLUTION AROUND THE SUN. THE EXTRA QUARTER OF A DAY IS WHY WE HAVE A "LEAP YEAR" EVERY 4 YEARS.

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.

LINES OF LATITUDE

Parallel lines that measure distance from the equator.

PRIME MERIDIAN

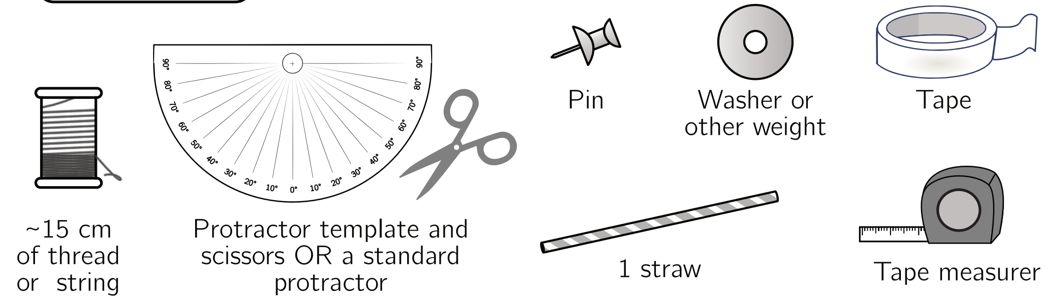
A line from the North Pole to the South Pole that passes through Greenwich, England.

LINES OF LONGITUDE

Lines that measure distance from the prime meridian.

Measure Your Latitude

MATERIALS



GOALS

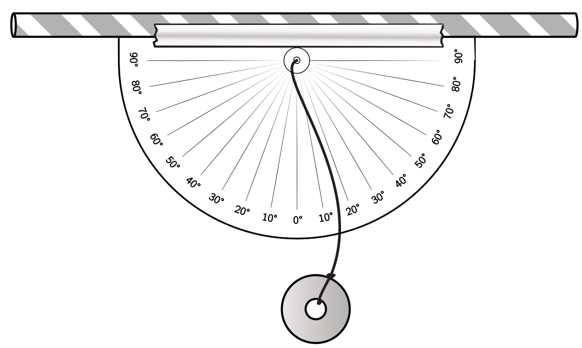
- Build a device to measure the angle of incline of a distant object.
- Find the latitude of your current location.

Purpose of an inclinometer

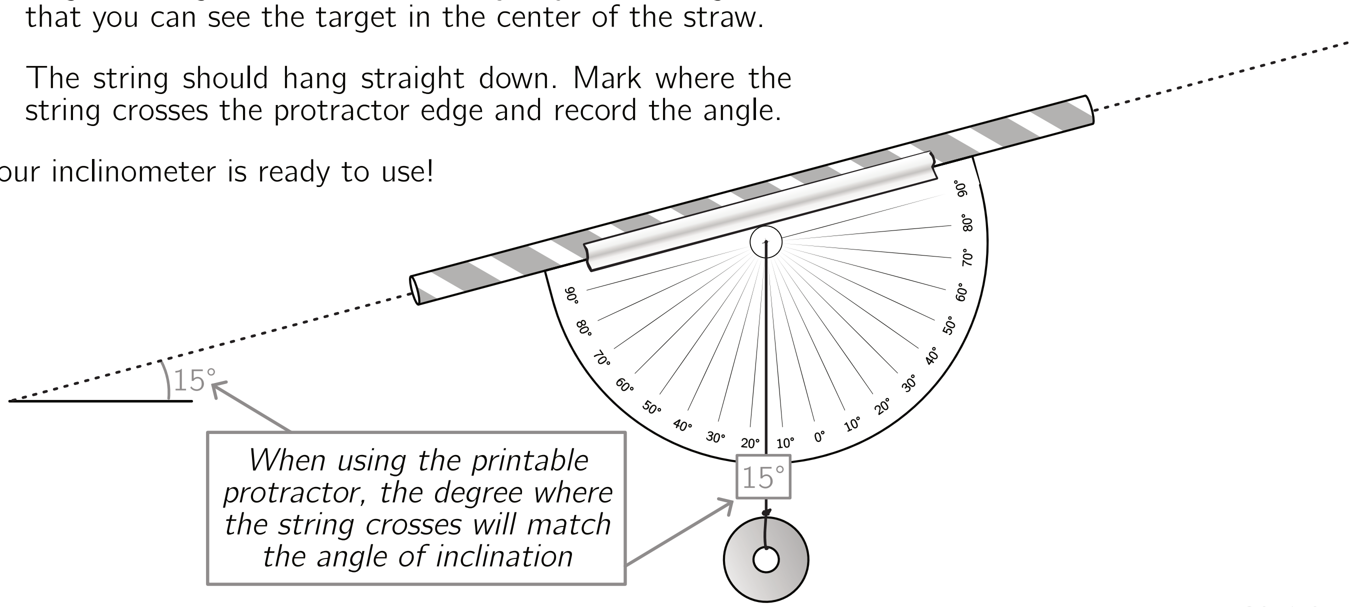
An inclinometer (sometimes called clinometer) is a tool that helps you to measure the angle or inclination of an object. With a little bit of geometry, inclinometers can be used to find the height of an object or the latitude of a person's current location.

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 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.

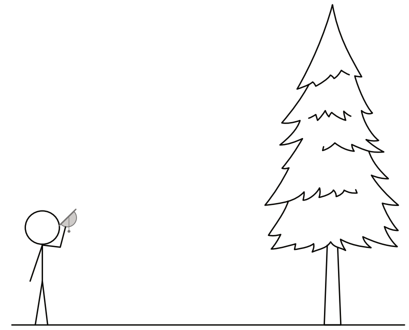


Your inclinometer is ready to use!



How tall is it?

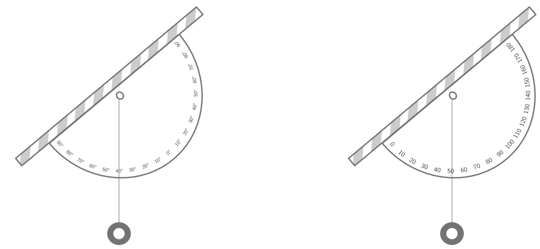
Before finding our latitude, it's important to understand how an inclinometer works by using it to find the height of an object.



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:

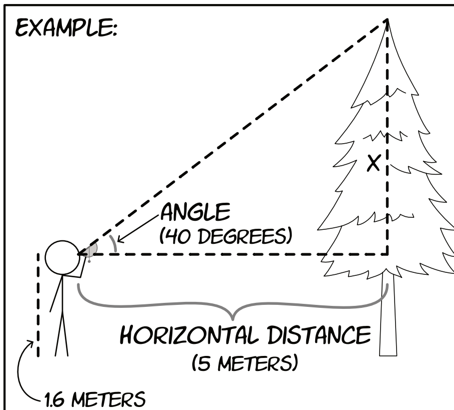
   x = tangent(angle of inclination) · horizontal distance

8. Add the height of the observer to x to find the total height of the object.



PRINTABLE PROTRACTOR
Angle of inclination: 40°

STANDARD PROTRACTOR
Angle of inclination:
90°-50° = 40°



x = tan(40°)·5
x = 4.2 meters
Tree height = 4.2 + 1.6 = **5.8 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 = tangent(angle of inclination)·horizontal distance

Estimated height before measuring: __________

Horizontal distance (observer to object): __________

Eye level height of observer: __________

x + eye level height of observer = object height

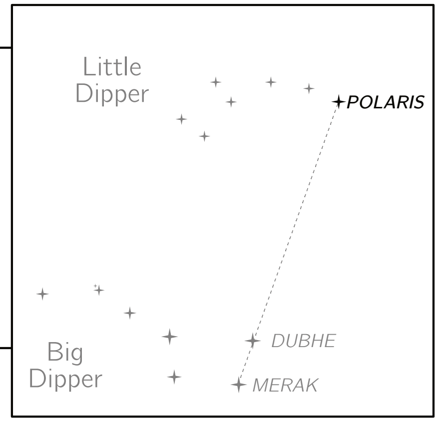
Angle of inclination: __________

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

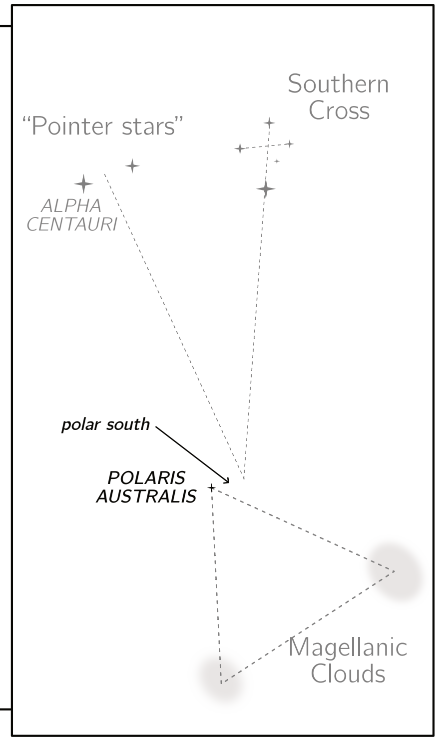
Use the inclinometer to find your latitude by locating Sigma Octantis (also called Polaris Australis or the Southern Star). It is not located exactly over polar south, but it's close! You can use an app such as Sky Guide or find it by using one of these approaches:

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.

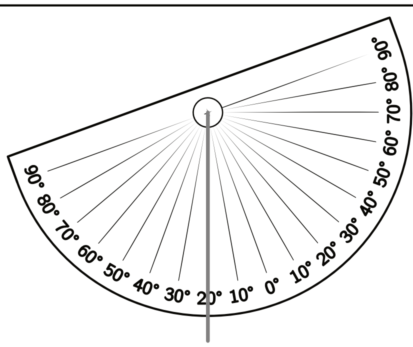
To find your latitude with the inclinometer, look at Polaris Australis, through your straw. Hold the inclinometer steady with the string hanging freely down. Note where the string crosses the edge of the protractor.



The **printable protractor** has angles labeled with 90°−x. Where the string crosses the edge will match the protractor's ***angle of inclination***.

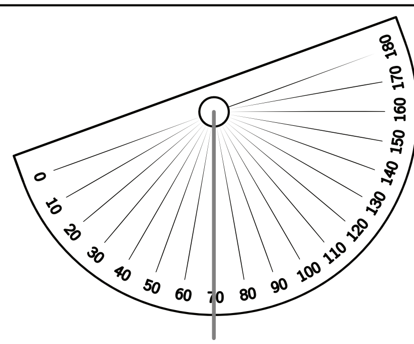
If using a **standard protractor**, take the angle where the string crosses the edge and then subtract it from 90°. Now you have found the ***angle of inclination***.

EXAMPLE WITH PRINTABLE PROTRACTOR:



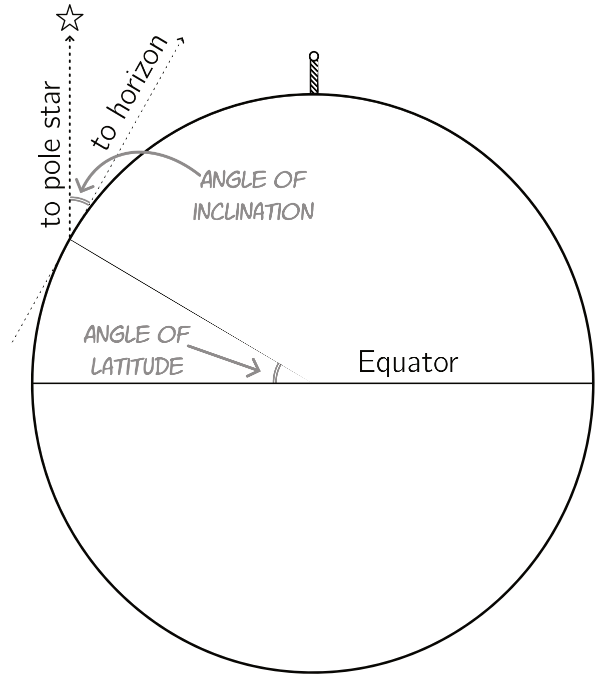
The string crosses at 20°, so the angle of inclination to the pole star and latitude are also 20°. If in the Northern Hemisphere, the latitude would be 20° North. In the Southern Hemisphere, the latitude would be 20° South.

EXAMPLE WITH STANDARD PROTRACTOR:



The string crosses at 70°, so the angle of inclination is 90°-70°= 20°. 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.



LATITUDE IS THE ANGULAR DISTANCE FROM THE EQUATOR.

IT'S MEASURED BY TAKING THE ANGLE BETWEEN THE HORIZON AND EARTH'S AXIS OF ROTATION (NORTH/SOUTH POLES).

WHEN YOU OBSERVE A POLE STAR SUCH AS POLARIS, THE ANGLE IT MAKES ABOVE THE HORIZON CORRESPONDS TO HOW FAR YOU ARE NORTH OF THE EQUATOR (YOUR LATITUDE).

AT THE NORTH POLE, POLARIS IS DIRECTLY OVERHEAD (NINETY DEGREES ABOVE THE HORIZON)

AT THE EQUATOR, POLARIS LIES AT THE HORIZON (0° ABOVE THE HORIZON).

2. At your location, what angle of inclination did you observe when sighting the pole star (Polaris or Polaris Australis)?

ANSWERS WILL VARY DEPENDING ON LOCATION.

DON'T FORGET TO ADJUST HOW YOU READ THE ANGLE ACCORDING TO WHICH TYPE OF PROTRACTOR YOU'RE USING!

3. Look up your actual latitude. Did the angle of inclination match your latitude? If not, what do you caused the difference?

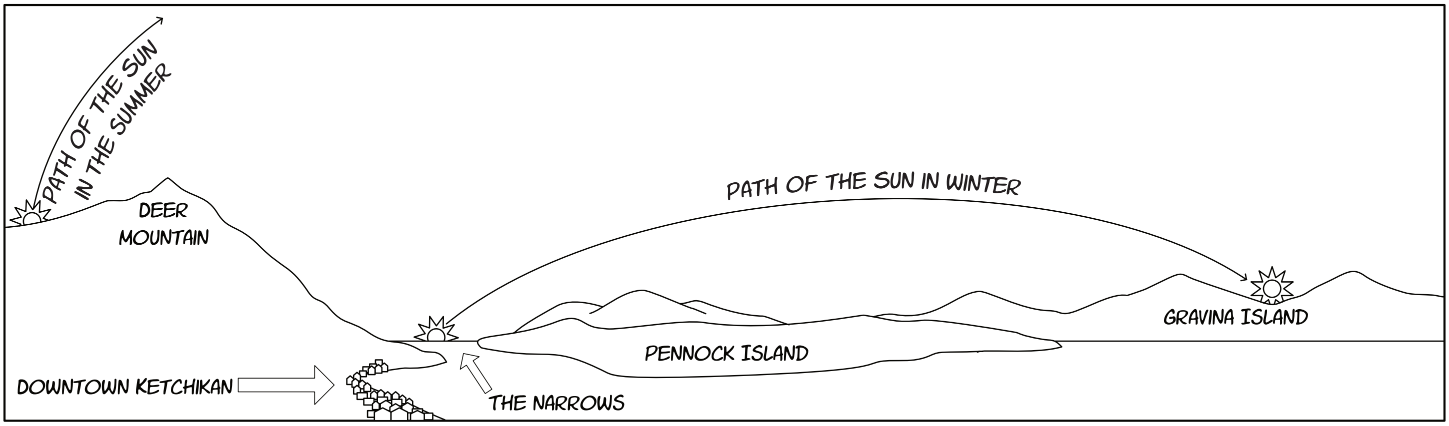
ANSWERS WILL VARY DEPENDING ON LOCATION. IF EITHER POLARIS OR POLARIS AUSTRALIS WAS SUCCESSFULLY SIGHTED, THEN THE ANGLE OF INCLINATION SHOULD BE WITHIN A FEW DEGREES OF THE ACTUAL LATITUDE. SMALL ERRORS IN READING THE ANGLE CAN CAUSE THE INCLINOMETER READING TO BE DIFFERENT FROM ACTUAL LATITUDE. ALSO, THE CLOSER ONE IS TO THE EQUATOR, THE LOWER THE STAR WILL BE IN THE SKY. ATMOSPHERIC HAZE OR REFRACTION CAN INTERFERE WITH THE SIGHTING.

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?

MOST LIKELY, SITI WILL NOT BE ABLE TO USE AN INCLINOMETER TO SEE POLARIS OR POLARIS AUSTRALIS. WHILE BOTH STARS WOULD BE ON THE HORIZON, IT WOULD BE DIFFICULT TO SEE THEM DUE TO ATMOSPHERIC HAZE AND REFRACTION.

THIS ACTIVITY COULD BE DIFFICULT OR EVEN IMPOSSIBLE FOR ANYONE LOCATED BETWEEN THE LATITUDES OF ABOUT 10° N AND 10° S. THE COMBINATION OF ATMOSPHERIC INTERFERENCE AND OBSTACLES ON THE HORIZON (LAND, BUILDINGS, OR VEGETATION ETC) MAKE IT MUCH MORE DIFFICULT TO GET AN ACCURATE SIGHTING OF A POLE STAR AT THOSE LATITUDES.

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!

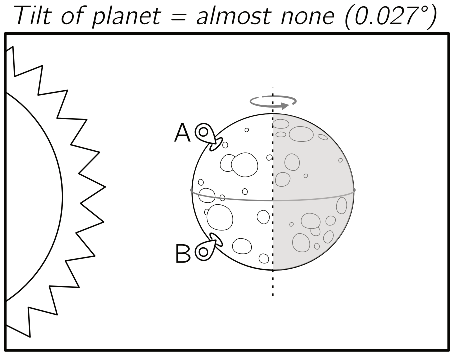
What seasonal differences in the position of the Sun have you observed where you live? When and where does the Sun rise and set? Where is the Sun in the sky at noon?

During winter: Answers will vary. Most locations should include the observation that the Sun is lower in the sky in winter and there are fewer hours of daylight.

During summer: Answers will vary. Most locations should include the observation that the Sun is higher in the sky and there are more hours of daylight.

How much sunlight in 1 day?

Tilt of planet = almost none (0.027°)

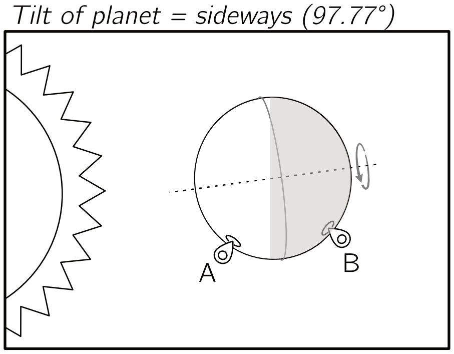


A planet with almost no tilt undergoes 1 complete rotation in 24 hours. During that time, will point A receive more, less, or the same amount of sunlight as point B? Point A and B are the same distance away from the equator.

Point A will receive the same amount of sunlight as point B (both about 12 hours).

Bonus fact: The planet Mercury has a tilt of 0.027°

Tilt of planet = sideways (97.77°)

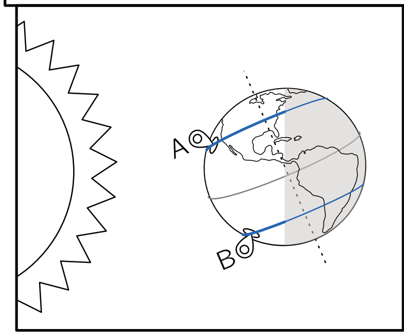


A planet with an extreme tilt of 97° undergoes 1 complete rotation in 24 hours. During that time, will point A receive more, less, or the same amount of sunlight as point B? Points A and B are the same distance away from the equator.

Point A will get much more sunlight! Point A will have 24 hours of sunlight and point B will have 24 hours of darkness.

Bonus fact: The planet Uranus has a tilt of 97.77°

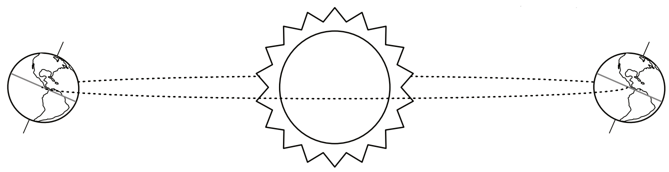
Earth is tilted at 23.5 degrees



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.

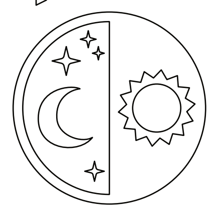
POINT A WILL GET MORE SUNLIGHT THAN POINT B. IF PATHS ARE TRACED TO SHOW THE PATH OF EACH POINT (PARALLEL TO THE EQUATOR) WE CAN SEE THAT WHEN THE TILT IS TOWARD THE SUN, A SPENDS THE MAJORITY OF IT'S PATH IN SUNLIGHT. THE OPPOSITE FOR B: THE MAJORITY OF ITS PATH IS DURING NIGHT.

Solstice



DEFINITION: THE TIMES OF YEAR WHEN THE SUN APPEARS TO REACH EITHER ITS HIGHEST OR LOWEST POINT IN THE SKY; WHEN EARTH'S AXIS IS POINTED DIRECTLY TOWARD OR AWAY FROM THE SUN

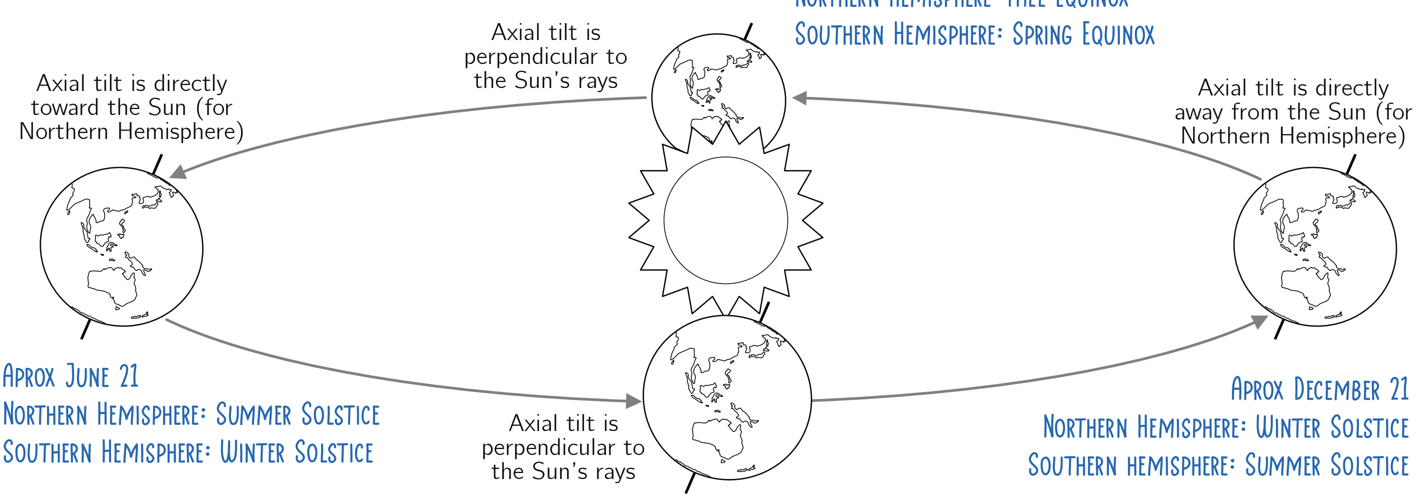
Equinox



DEFINITION: THE TIMES OF YEAR WHEN THE SUN APPEARS TO PASS DIRECTLY OVER THE EQUATOR. FROM THE LATIN "AEQUI" WHICH MEANS EQUAL AND "NOX" WHICH MEANS NIGHT.

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.

APROX SEPTEMBER 23
NORTHERN HEMISPHERE: FALL EQUINOX
SOUTHERN HEMISPHERE: SPRING EQUINOX



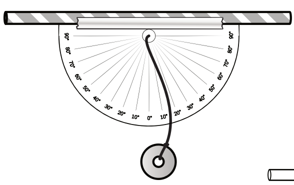
APROX JUNE 21
NORTHERN HEMISPHERE: SUMMER SOLSTICE
SOUTHERN HEMISPHERE: WINTER SOLSTICE

APROX DECEMBER 21
NORTHERN HEMISPHERE: WINTER SOLSTICE
SOUTHERN HEMISPHERE: SUMMER SOLSTICE

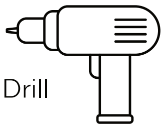
APROX MARCH 20
NORTHERN HEMISPHERE: SPRING EQUINOX
SOUTHERN HEMISPHERE: FALL EQUINOX

DIY Equatorial Sundial

MATERIALS

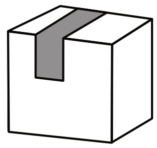


Inclinometer

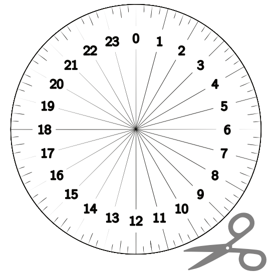


Drill

Wooden dowel



Cardboard or wood



Sundial template and scissors

GOALS

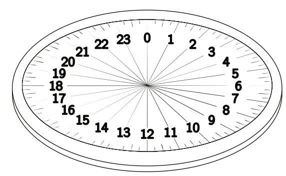
- Learn more about the Sun's path and Earth's orbit by building a working sundial.
- Adjust your sundial to give accurate time by considering various factors.

What's an Equatorial Sundial?

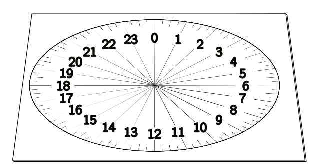
An equatorial sundial uses a shadow stick (gnomon) to cast a shadow on a circular dial. The dial is placed so that it's parallel to the Earth's equator. As long as it's properly aligned, it can be used anywhere on Earth!

How to make an equatorial sundial:

1. Print the sundial cutout from the appendix and cut it out.

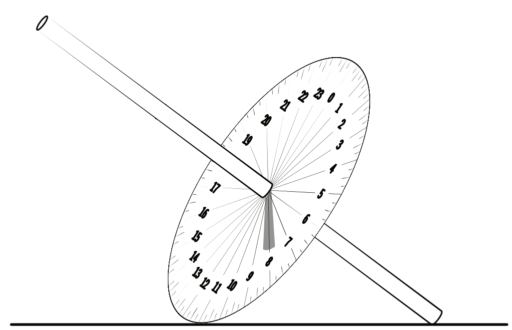


2. Glue or tape it to a solid backing such as cardboard so that it is rigid and sturdy. The backing should be sufficiently thick and rigid so that it can hold a rod perpendicular to the face of the dial without tipping.



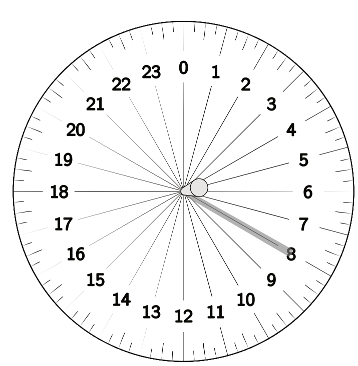
3. Drill a hold in the center of the dial so that the dowel fits snugly in the hole but can be slid in or out.

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). Slide the gnomon in or out so that the dial rests on the ground with the gnomon still pointed at the North Star. The easiest way to do this is to locate the North Star with the inclinometer and note the exact angle. Then use the inclinometer protractor as a reference to maintain the same angle for the gnomon.



5. You'll be making adjustments during the day, so you'll need to note the direction of true north or true south during the night. True north/south is different than magnetic north or south which you would get from a compass.

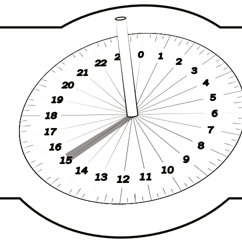
6. On the hour, rotate the dial so that the center of the shadow is at the same hour on the sundial. For example, at 8 am rotate the dial so the shadow is over 8 am. However, you must do this in such a way that the gnomon remains pointing to the North Star. Verify that your gnomon is still pointed at the the angle you found on the inclinometer in step 4 (which should match your latitude) and that it is still pointed in the direction of true north.



7. Now the exact center of the shadow should give the correct solar 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?

   There are several items that might cause sundial time to differ from the time shown on a clock.

   - Daylight savings: this will shift the time by an hour.
   - Timezones: when deciding on timezones, it's a balance between setting the clock to match the solar experience (with noon being near the sun's zenith) and human convenience. People tend to want as few time zones to deal with as possible. Dials in different parts of the same timezone will need to be rotated differently to show the same time relative to the sundial.
   - The elliptical shape of the Earth's orbit causes the Earth to move faster when it is closer to the Sun (January) and slower when it is further from the Sun (July). So the Sun appears to move more quickly /slowly across the sky at different times of year. This can impact the solar time by up to 16 minutes.
   - Any error in the angle of the gnomon will cause a correspondingly large error in the time shown.

2. Would your sundial work if located at the North Pole or South Pole? Why or why not?

   The sundial would work at any location (if there's sunlight) as long as the gnomon is aligned to point at the North Star in the northern hemisphere or at Polaris Australis/geographic south pole in the southern hemisphere. There are working sundials north of the arctic circle in Svalbard and south of the Antarctic circle at McMurdo Station in Antarctica. They both work, but only when sunlight is visible. In both locations, the sundials are not functional during polar night.

3. Why does a sundial in the Northern Hemisphere need to be aligned with geographic north rather than magnetic north?

   Geographic north is aligned with Earth's rotational axis. It's the point around which the Earth rotates. If the Sundial is aligned in any other direction, it will cause the sundial to be inaccurate. Magnetic north is close to geographic north, but it is not the same! It is different enough to cause significant errors in how the sundial reads.

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?

   Answers will vary

LINES OF LATITUDE: significant circles

DECEMBER SOLSTICE

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."

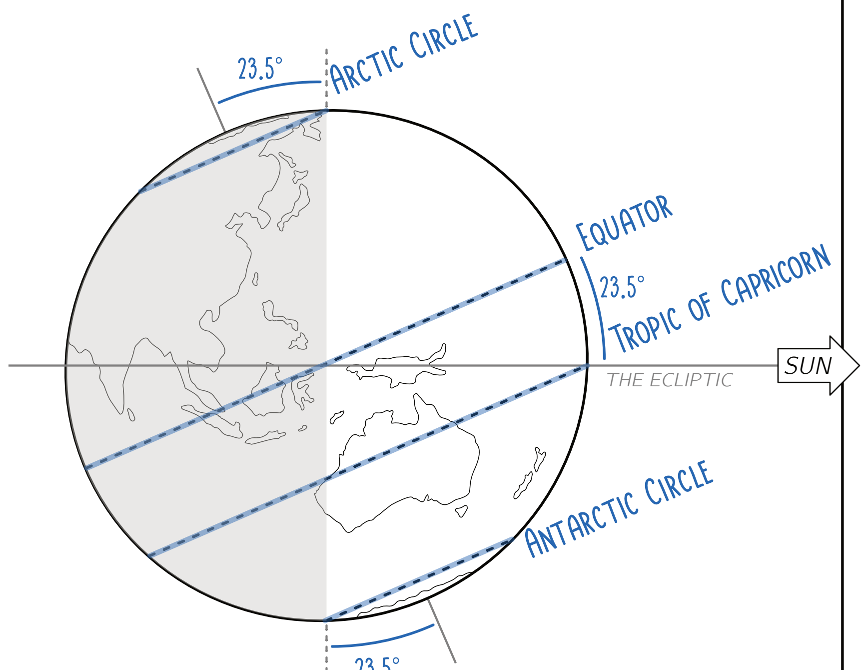
The border of this region where the Sun does not set below the horizon on December solstice is called the **Antarctic Circle**.

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.

Label the dotted lines of latitude



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

Everything north of the Arctic circle

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

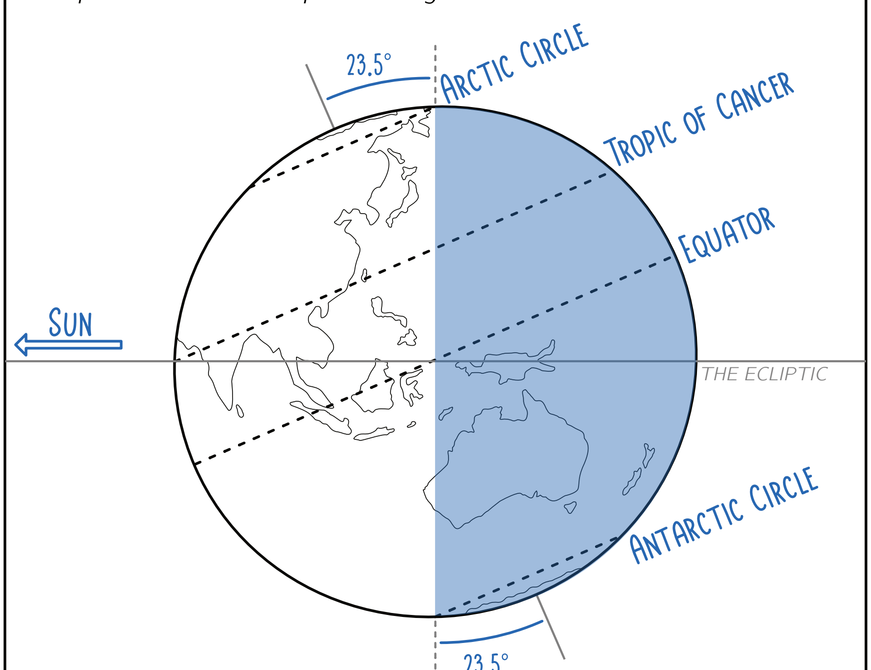
Everything south of the Antarctic circle

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

No. At the equator, the Sun appears north of the zenith on the June solstice and south of the zenith on the December solstice.

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.

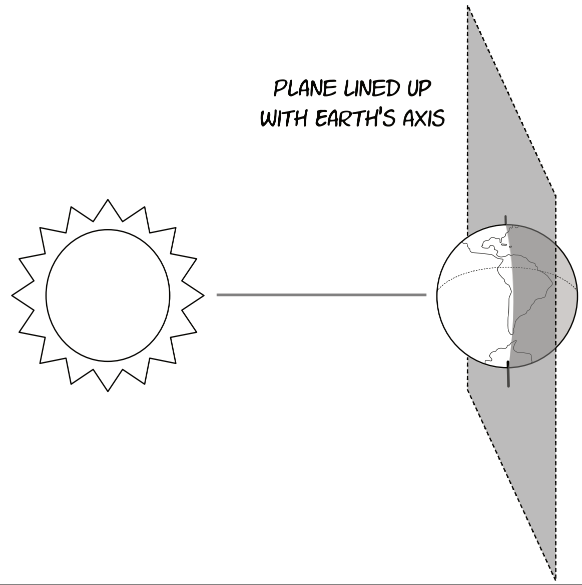


Fill in the blanks:

equal   equinox   location   overhead   perpendicular   terminator

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

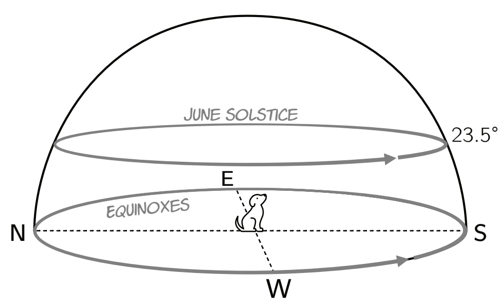
When the solar TERMINATOR or "edge" between night and day is perpendicular to the equator, it causes a cool effect: Each equinox, almost every LOCATION on Earth experiences EQUAL hours of light and darkness.



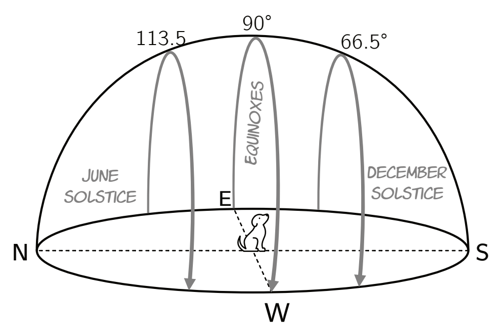
SOLSTICE vs EQUINOX Views from the ground

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.

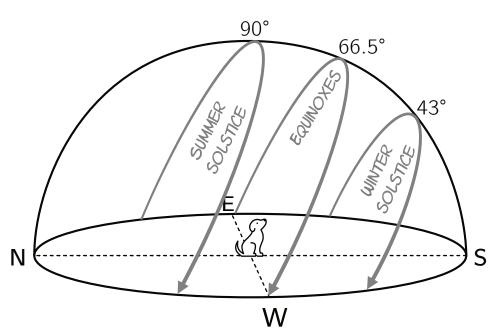
Locations could be: Arctic Circle, Antarctic Circle, equator, North Pole, South Pole, Tropic of Cancer, or Tropic of Capricorn.



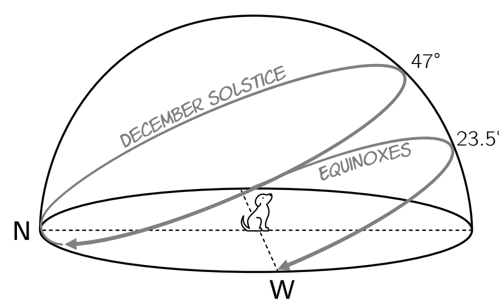
NORTH POLE



EQUATOR



COULD BE EITHER THE TROPIC OF CANCER (SUMMER SOLSTICE = JUNE 21) OR TROPIC OF CAPRICORN (SUMMER SOLSTICE = DECEMBER 21)



ANTARCTIC CIRCLE

THE MOON: Earth's closest friend

Make a Model

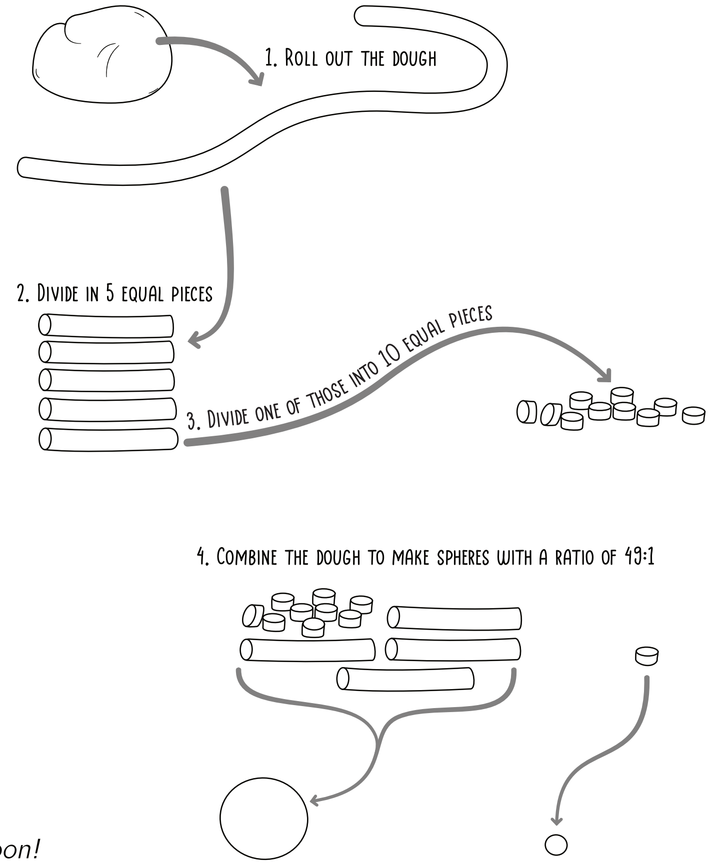
Earth and its moon are usually illustrated with their distance and size NOT to scale.

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!

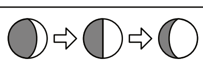


Moons are natural satellites that orbit planets. Earth's moon, known simply as the Moon, is unusually large compared to the size of the Earth.

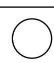
As it orbits Earth, different portions of its illuminated surface are visible from Earth; these are called the **phases of the Moon**. People have used them to measure the passage of time and other animals change or coordinate their activity based on the lunar cycle.

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

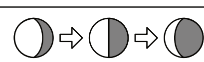
The illuminated portion of the Moon is getting bigger



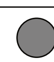
The visible Moon is fully illuminated by sunlight



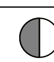
The near side of the Moon is becoming more shadowed



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

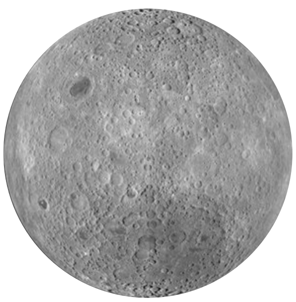
The Near & Far Sides of the Moon

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

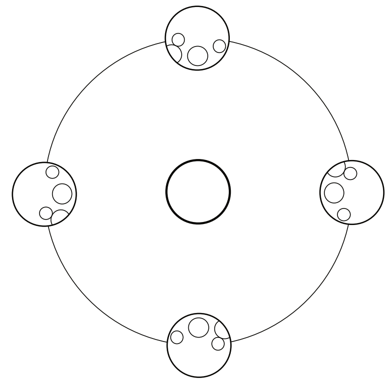
THERE ARE MORE MARIA ON THE NEAR SIDE OF THE MOON AND THEY ARE LARGER. THE FAR SIDE HAS VERY FEW MARIA BECAUSE IT HAS A THICKER CRUST.



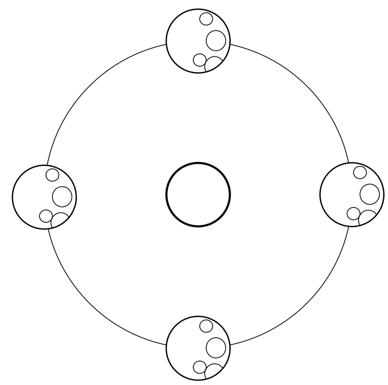
FAR SIDE

THE MOON ROTATES! IF IT DIDN'T ROTATE THEN WE WOULD SEE BOTH THE NEAR AND FAR SIDE. IT'S ROTATION PERIOD MATCHES THE LENGTH OF ITS ORBIT AROUND EARTH.

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.

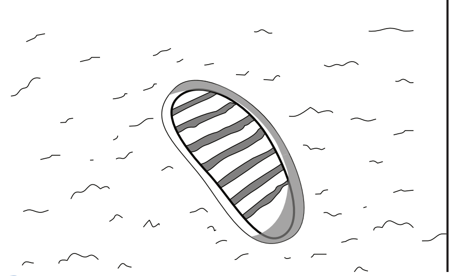
Fact or Fiction?

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

FICTION THE GIANT IMPACT HYPOTHESIS IS THE LEADING THEORY. IT SAYS A MARS-SIZED PLANET CRASHED INTO EARTH AND THE RESULTING DEBRIS COALESCED INTO THE MOON

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



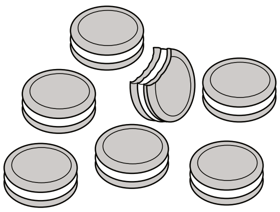
FACT AS OF 2025, 12 PEOPLE HAVE VISITED THE MOON. THEY WERE ALL FROM THE APOLLO MISSIONS (1961 TO 1972). ARTEMIS IS SCHEDULED TO TAKE PEOPLE TO THE MOON AGAIN IN 2028. EARTH-BASED TELESCOPES DON'T HAVE HIGH ENOUGH RESOLUTION TO SEE THE FOOTPRINTS, BUT MULTIPLE SATELLITES AROUND THE MOON HAVE TAKEN PHOTOS OF THE PRINTS.

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

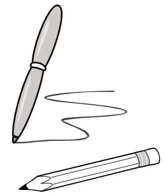
FICTION THE MOON IS MOVING AWAY BUT NOT AT 4 M PER YEAR. THE RATE IS 4 CM PER YEAR.

Cookie Models and Journal

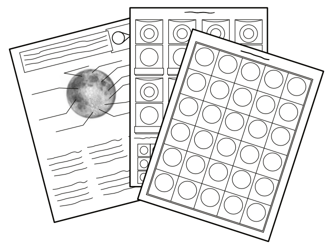
MATERIALS



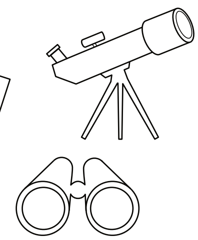
Sandwich style cookies with cream filling and a butter knife (optional)



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 it's 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.

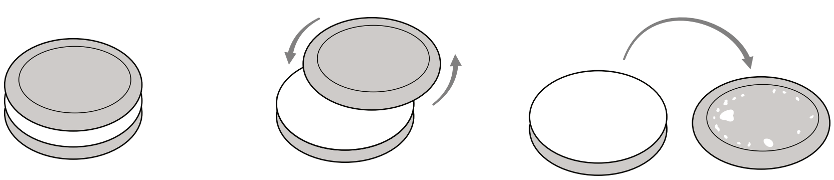
If you are unable to observe the Moon directly, you can explore virtually at https://science.nasa.gov/moon/

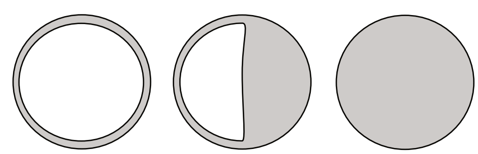
Use the descriptions of the craters and maria and online resources such as NASA to label the features on the **Observe the Moon** page. Then check the boxes next to each feature you're able to observe on the actual Moon.

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?

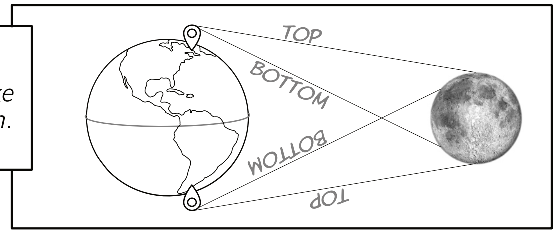
____

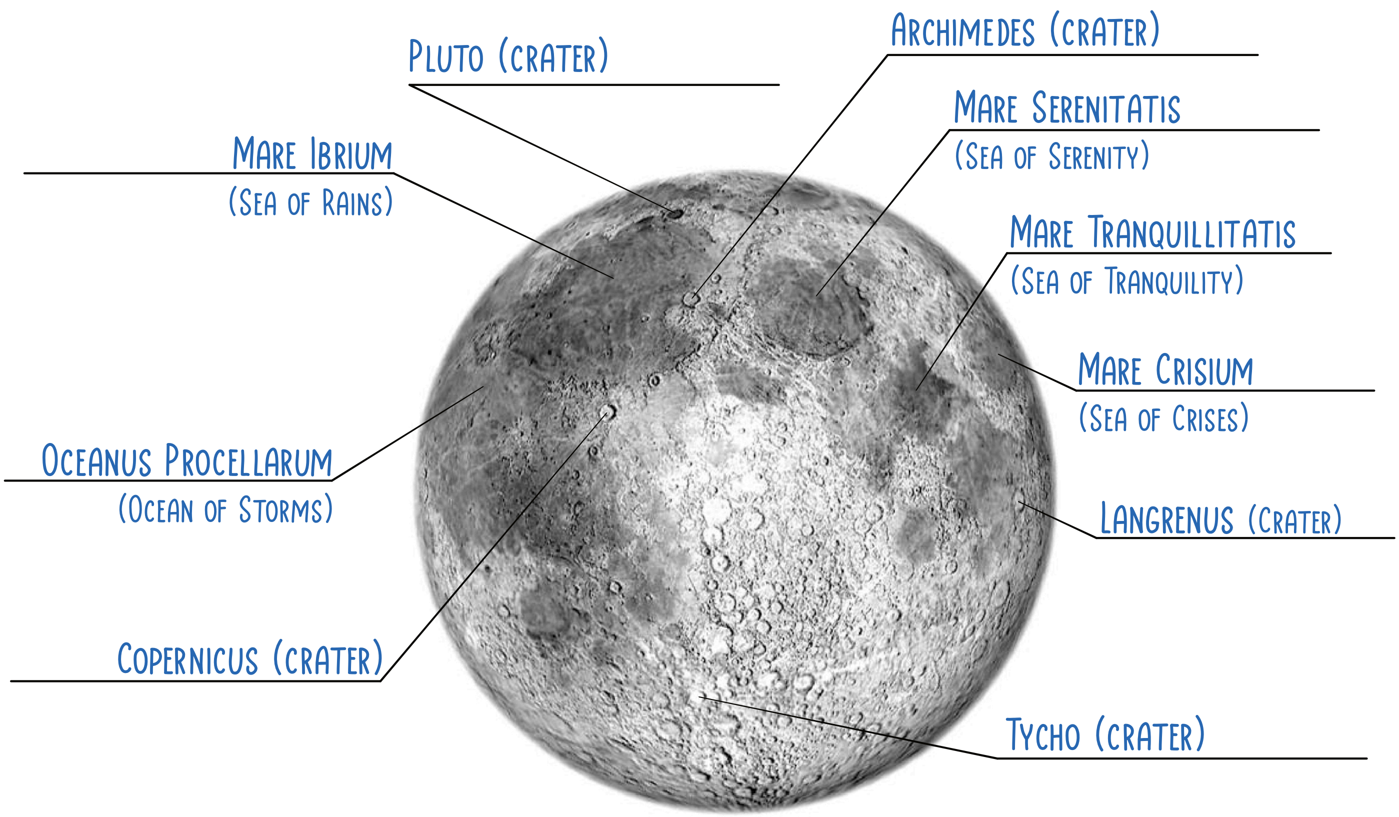
____

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). It's 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

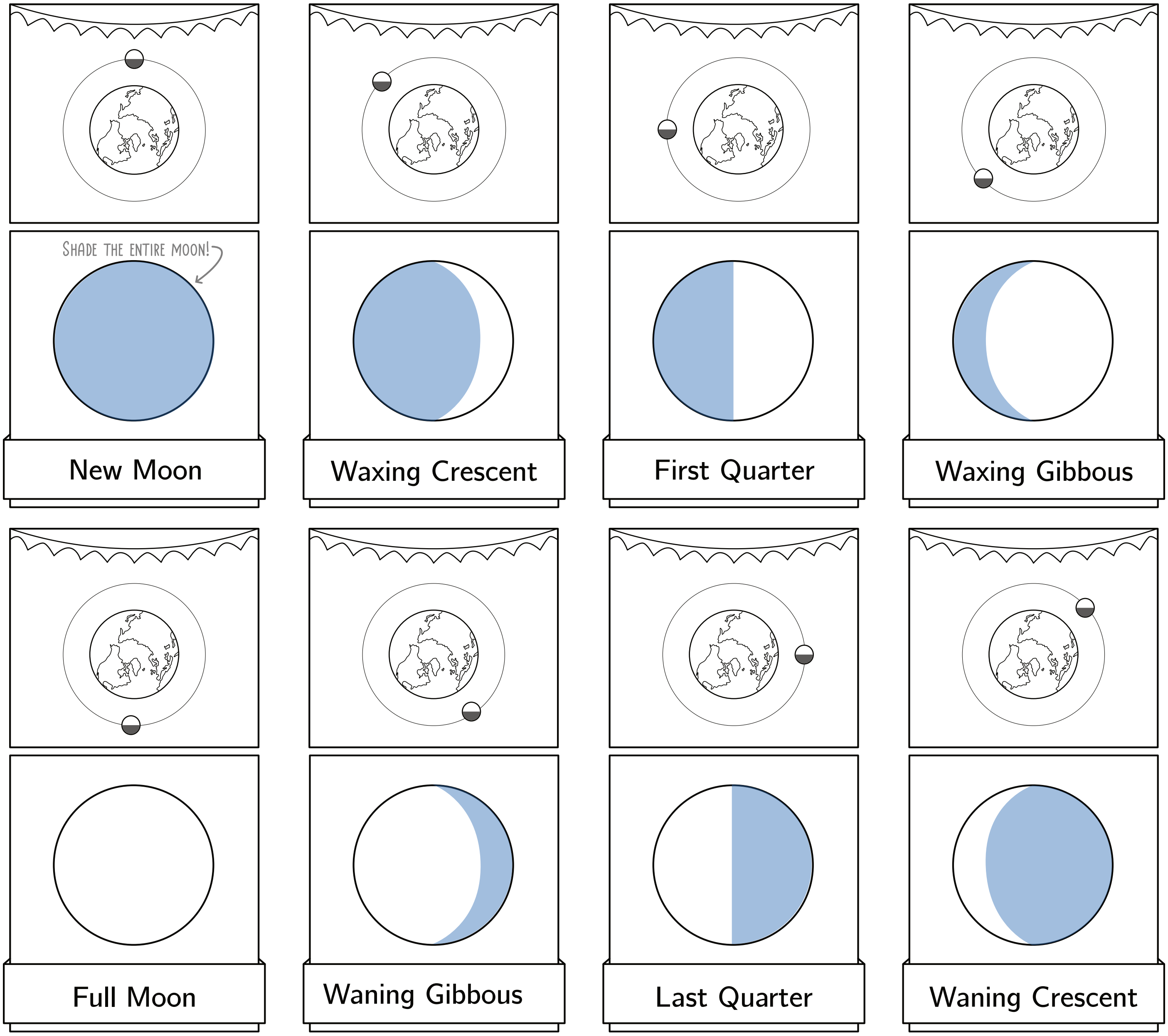
☐ Mare Serenitatis - This mare has a distinct circular shape. It has been visited by multiple lunar landers, including Luna 21 and Apollo 17.
Diameter: 674 km

☐ 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!

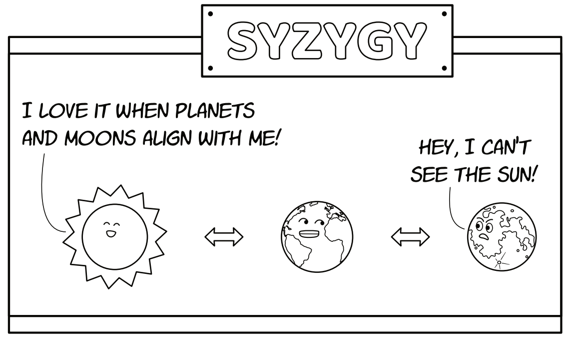
Moon Journal

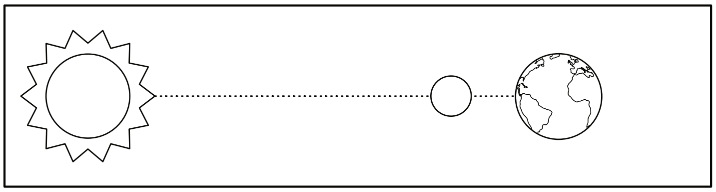
Date:	Date:	Date:	Date:	Date:
Date:	Date:	Date:	Date:	Date:
Date:	Date:	Date:	Date:	Date:
Date:	Date:	Date:	Date:	Date:
Date:	Date:	Date:	Date:	Date:
Date:	Date:	Date:	Date:	Date:

ECLIPSED

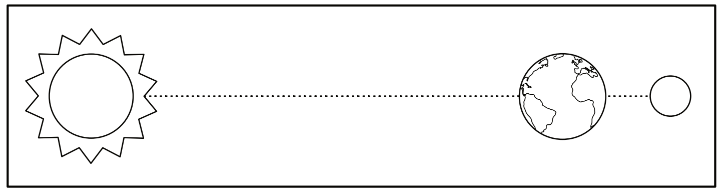
When 3 or more objects are arranged in a straight line, it's called **syzygy**. When an object that appears small (such as a distant planet) moves in front of an object that appears big (such as a large star) we call it a **transit**. If the objects are close enough that the shadow of one object covers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



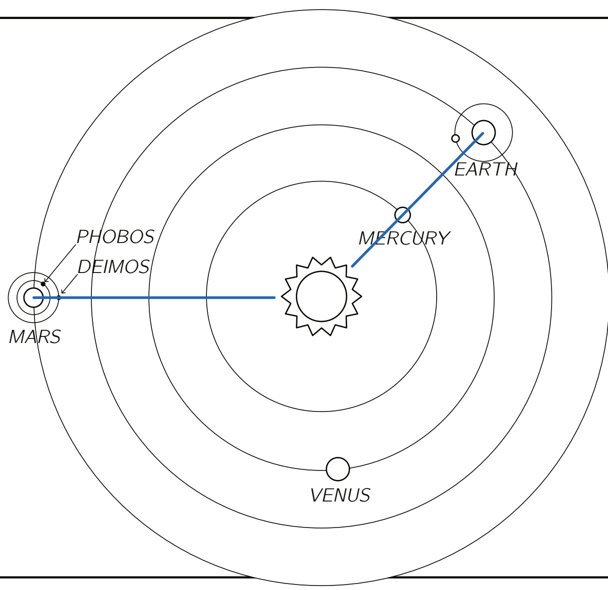


When the Moon passes between the Earth and Sun, it's a SOLAR eclipse.



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

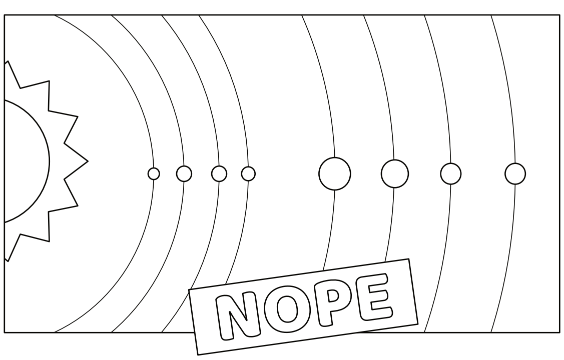
Which planets or moons are in syzygy with the Sun?



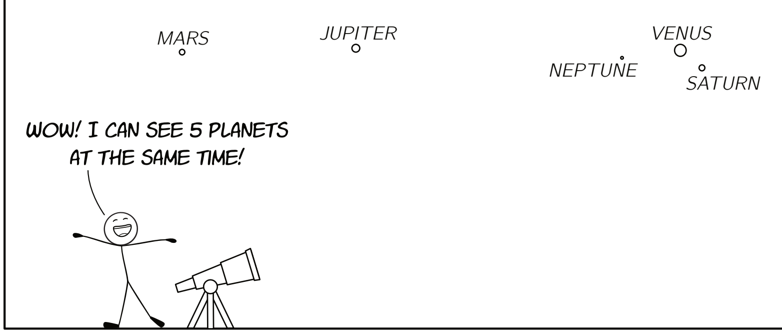
MERCURY AND EARTH ARE IN SYZYGY. TRANSITS OF MERCURY HAPPEN AROUND 10 TIMES IN A CENTURY. THE NEXT ONE WILL BE IN NOVEMBER OF 2032. VENUS TRANSITS ARE RARER, HAPPENING ABOUT ONCE A CENTURY. THE NEXT ONE WONT BE TILL 2117.

MARS AND DEIMOS ARE IN SYZYGY. FROM THE RIGHT LOCATION ON THE SURFACE OF MARS, THE MOON PHOBOS IS LARGE ENOUGH TO PRODUCE AN ANNULAR ECLIPSE (IT DOESN'T COMPLETELY COVER THE SUN, BUT BLOCKS MUCH OF THE LIGHT). DEIMOS IS TOO SMALL TO CAUSE AN ECLIPSE. WHEN IT IS IN SYZYGY SOMEONE ON MARS COULD OBSERVE IT TRANSIT THE SUN (IF THEY HAD THE RIGHT SOLAR FILTERS AND GEAR).

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.



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?

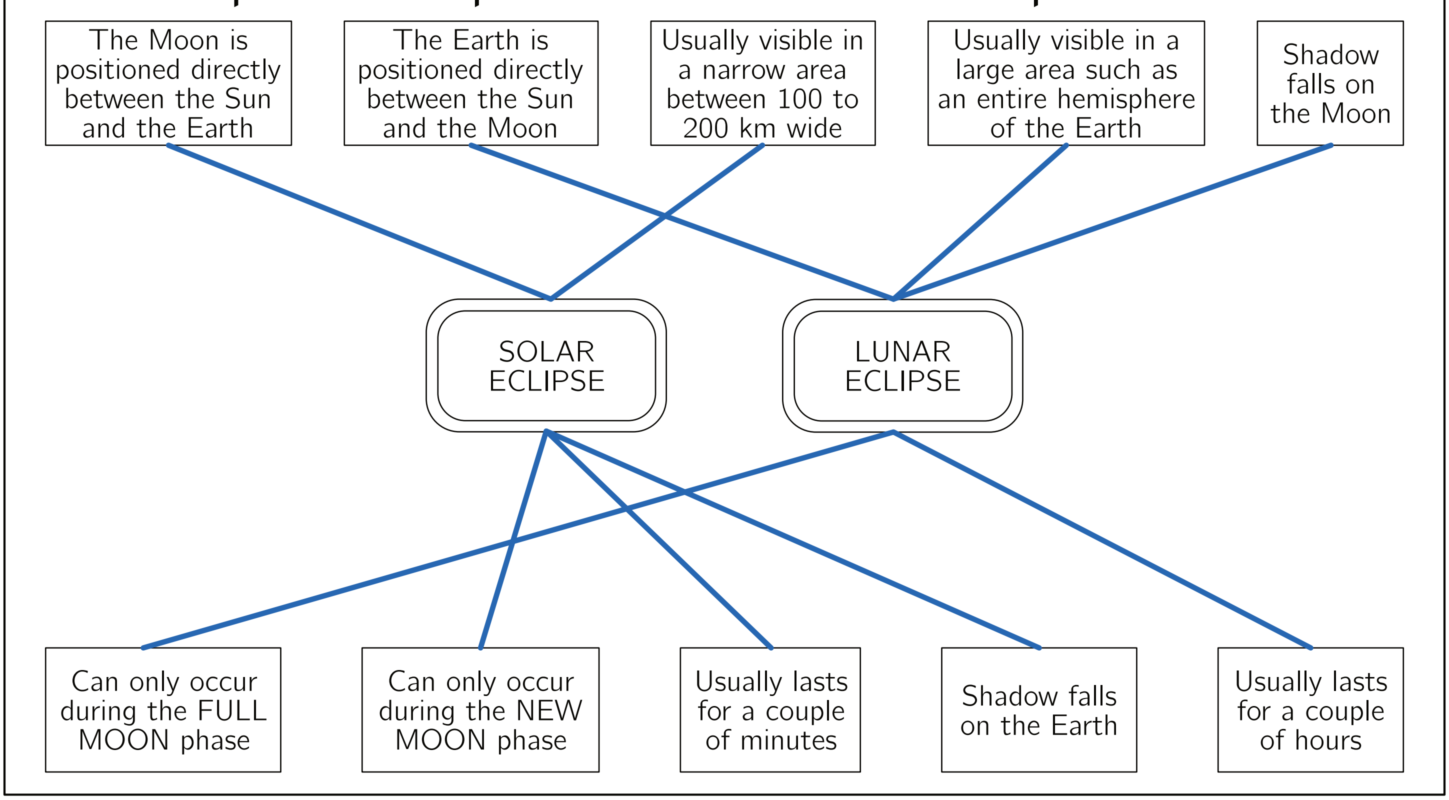
First calculation of the speed of light:

IN 1676, DANISH ASTRONOMER OLE RØMER MEASURED THAT AN ECLIPSE OCCURRED 11 MINUTES LATE WHEN JUPITER WAS FURTHEST FROM EARTH. THIS SHOWED LIGHT TAKES TO TIME TO TRAVEL. RØMER ESTIMATED A SPEED OF 211,000 KM/S (ACTUAL SPEED IS 300,000 KM/S)

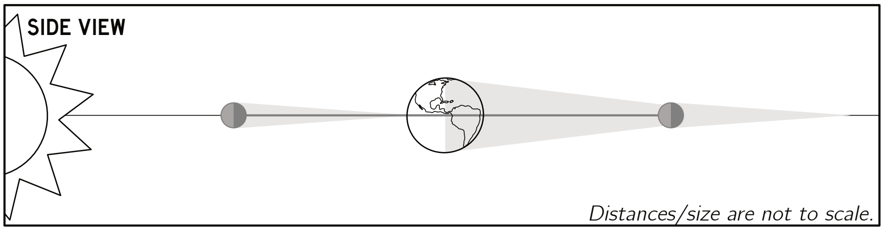
What other discoveries came from observing eclipses?

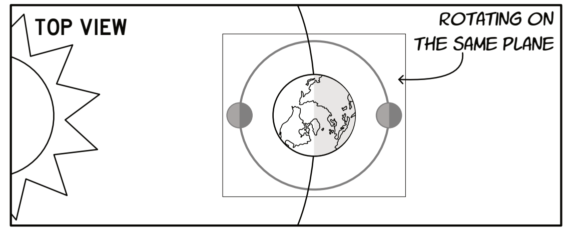
DISCOVERY OF HELIUM, GENERAL RELATIVITY CONFIRMED, EXOPLANET DETECTION, SIZE OF MOON AND SUN AND DISTANCE TO THE MOON AND SUN CALCULATED, LEARN MORE ABOUT EARTH'S ATMOSPHERIC COMPOSITION AND THE SUN'S CORONA.

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



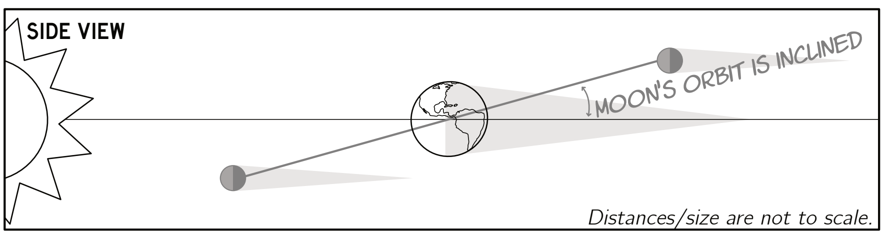
TOTALITY: a closer look at solar & lunar eclipses

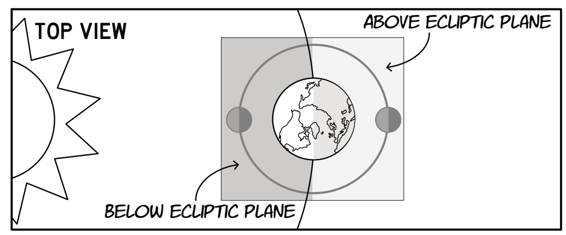




If the Moon, Earth, and Sun were all on the exact same plane, when would we see solar and lunar eclipses?

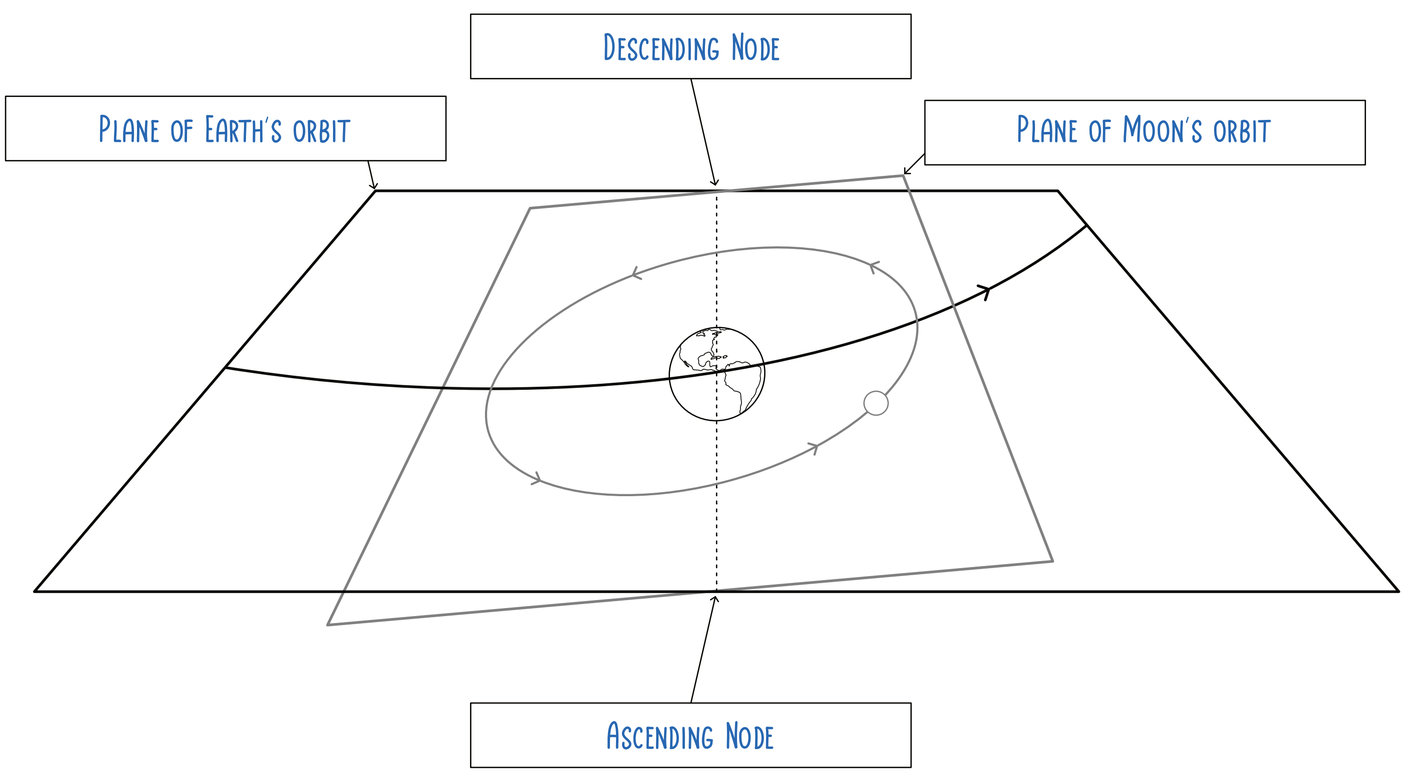
If there was no inclination to the Moon's orbit, then we would see solar eclipses with every new moon and lunar eclipses with every full moon.





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

An eclipse can only happen when the Moon crosses the ecliptic plane. This occurs twice each lunar orbit, but to produce an eclipse, the crossing has to coincide with either a new or full moon.



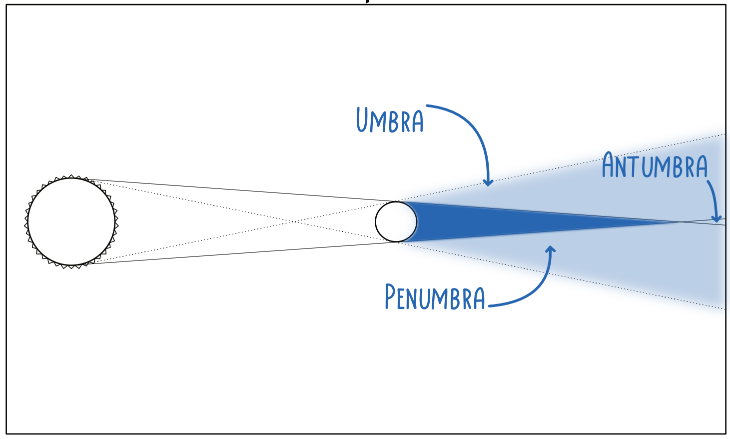
When sunlight shines on an opaque object, it casts a shadow. Most shadows have 3 parts:

Umbra: The dark inner part of a shadow. When viewed from the umbra, the Sun is completely blocked or obscured.

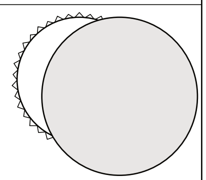
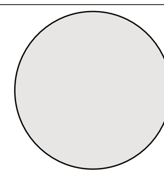
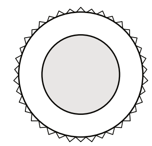
Penumbra: The lighter edge of a shadow. If the Sun is viewed from the penumbra, only part of it is blocked or obscured.

Antumbra: Not visible with short shadows. In the antumbra, the object making the shadow appears to be entirely within the Sun.

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



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

PART OF THE SUN IS BLOCKED.	NONE OF THE SUN IS VISIBLE.	PART OF THE SUN IS BLOCKED.
		
Penumbra	Umbra	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

Fact – due to sunlight scattering through Earth's atmosphere, a phenomenon known as "Rayleigh scattering."

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

Fiction – Jupiter's large moons, like Io, Europa, and Ganymede, frequently cast shadows on the planet.

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

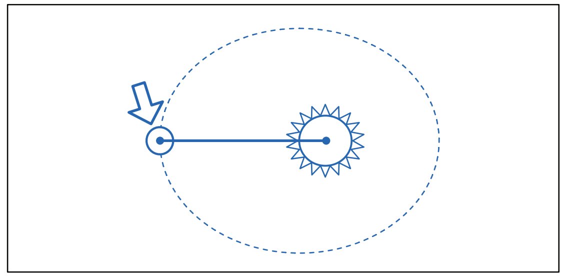
Fiction – The Earth and Moon will never cast shadows on each other simultaneously. Lunar eclipses can only happen at a full moon and solar eclipses occur during a new moon.

Earth & Moon Review

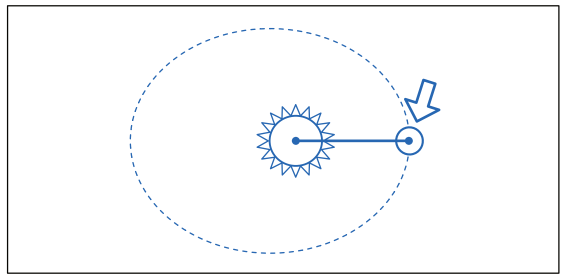
IN YOUR OWN WORDS!

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.

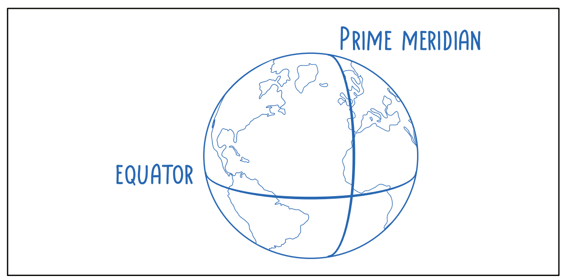
APHELION: THE POINT IN AN ORBIT WHEN AN OBJECT IS FARTHEST FROM THE SUN



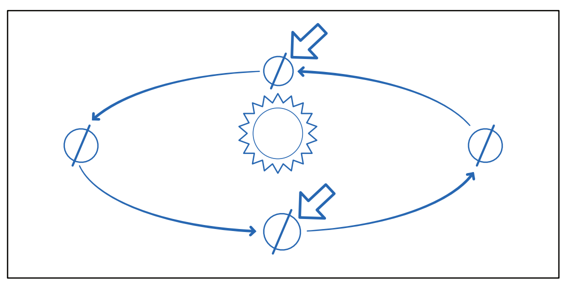
PERIHELION: THE POINT IN AN ORBIT WHEN AN OBJECT IS CLOSEST TO THE SUN



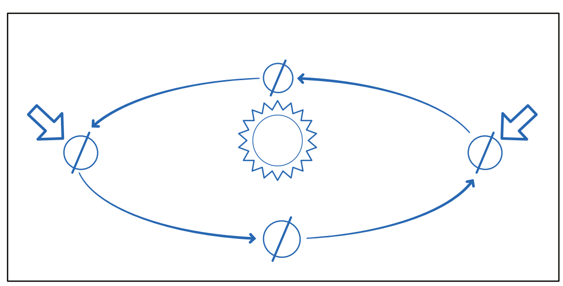
EQUATOR and PRIME MERIDIAN: EQUATOR = THE MIDPOINT BETWEEN THE N AND S POLES. 0° NORTH/SOUTH. PRIME MERIDIAN = THE LONGITUDE LINE THAT RUNS THROUGH GREENWICH ENGLAND. 0° EAST/WEST.



EQUINOX: THE TIME OF YEAR WHEN EARTH'S AXIS IS PERPENDICULAR TO THE SUN'S RAYS. ALSO THE TIME OF YEAR WHEN THE SUN IS DIRECTLY OVERHEAD FROM THE EQUATOR. LENGTH OF DAY AND NIGHT IS ALMOST EQUAL.



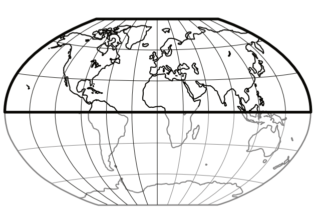
SOLSTICE: THE TIME OF YEAR WHEN EARTH POLES ARE MOST EXTREMELY TILTED OR INCLINED FROM THE SUN. ALSO WHEN THE SUN IS FURTHEST NORTH OR SOUTH RELATIVE TO EARTH'S EQUATOR.



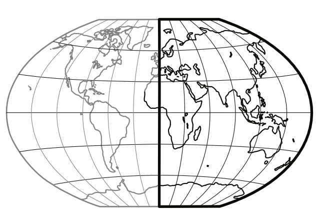
MATCH THE WORD WITH THE CORRECT DEFINITION

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

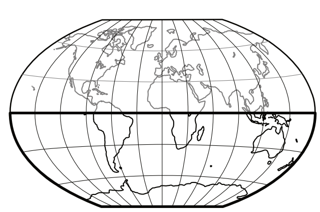
LABEL THE HEMISPHERES



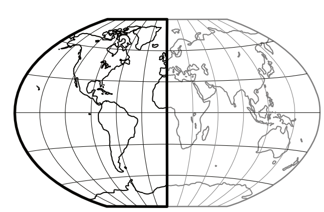
Northern Hemisphere



Eastern Hemisphere



Southern Hemisphere



Western Hemisphere

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

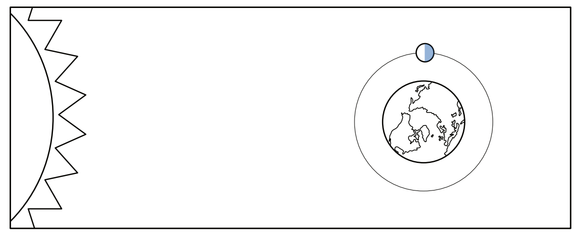
3. If a star sets during the night, in which direction will it fall below the horizon?
   A. North
   B. East
   C. South
   D. West

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



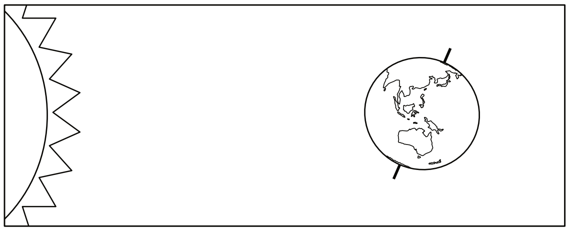
8. What phase of the Moon is visible if the Sun, Moon, and Earth are positioned as pictured above?
   A. Full moon
   B. Crescent or gibbous
   C. Quarter
   D. New moon

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

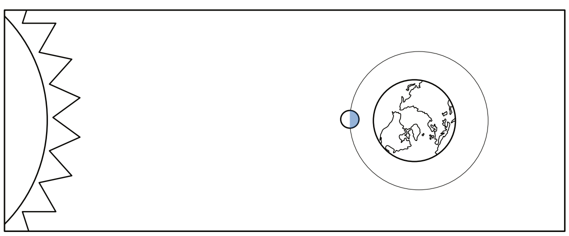
12. When is the autumn equinox in the *Southern Hemisphere*?
    A. December
    B. March
    C. September
    D. June



13 In the illustration above, is the Southern Hemisphere experiencing winter or summer?
- A. Winter
- B. Summer
- C. Neither

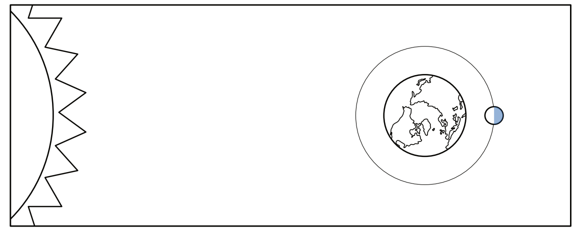
14 A **solar eclipse** can only occur at what phase of the Moon?
- A. New moon
- B. First quarter
- C. Full moon
- D. Last quarter

15 The dark areas on the Moon's surface are best described as:
- A. Craters
- B. Lava plains
- C. Mountains
- D. Oceans

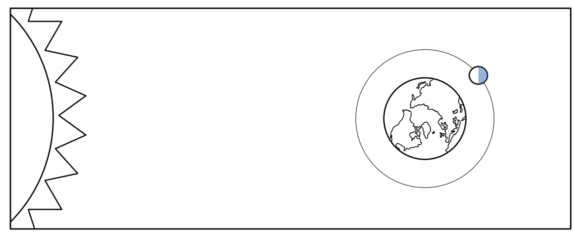


16 What phase of the Moon is visible if the Sun, Moon, and Earth are positioned as pictured above?
- A. Full moon
- B. Crescent or gibbous
- C. Quarter
- D. New moon

17 What is the name for the lighter outer part of a shadow?
- A. Umbra
- B. Penumbra
- C. Antumbra



18 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



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

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

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."

ANNULAR SOLAR ECLIPSE

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

TOTAL LUNAR ECLIPSE

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

PARTIAL SOLAR ECLIPSE

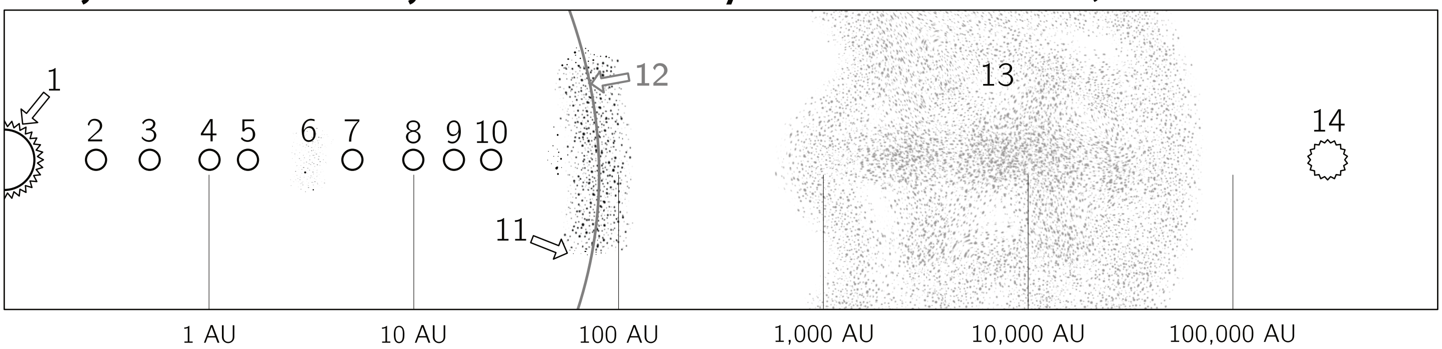
Our Solar System: scope and story

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

planets	*Sun*	*dwarf*	*asteroids*	*comets*	*moons*

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

A logarithmic scale diagram of our solar system (and it's closest neighbor)



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

Label and briefly describe the features in the diagram above:

1 OUR SUN (NAMED SOL) – CENTER OF THE SOLAR SYSTEM

2 MERCURY – A ROCKY PLANET

3 VENUS – A ROCKY PLANET

4 EARTH – A ROCKY PLANET

5 MARS – A ROCKY PLANET

6 THE ASTEROID BELT – MATERIAL THAT COULD HAVE FORMED A PLANET IF JUPITER'S GRAVITY HADN'T INTERFERED

7 JUPITER – A GAS GIANT

8 SATURN – A GAS GIANT

9 URANUS – AN ICE GIANT

10 NEPTUNE – AN ICE GIANT

11 THE KUIPER BELT – PRONOUNCED "KY-PER" CONTAINS ICY ASTEROIDS, COMETS, AND DWARF PLANETS (PLUTO, ERIS ETC)

12 EDGE OF THE HELIOSPHERE – THE REGION WHERE THE SOLAR WIND HAS A SIGNIFICANT INFLUENCE

13 THE OORT CLOUD – A BUBBLE-SHAPED REGION OF ICY MATERIALS, SOURCE OF COMETS

14 ALPHA CENTAURI – THE CLOSEST STAR TO OURS

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?

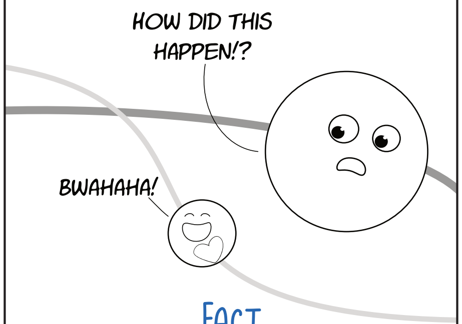
Consider each statement, then write whether it is fact or fiction.

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

FICTION

THE MOONS ENCELADUS AND EUROPA HAVE LIQUID WATER OCEANS BENEATH ICE. CERES AND PLUTO MAY ALSO HAVE LIQUID WATER.

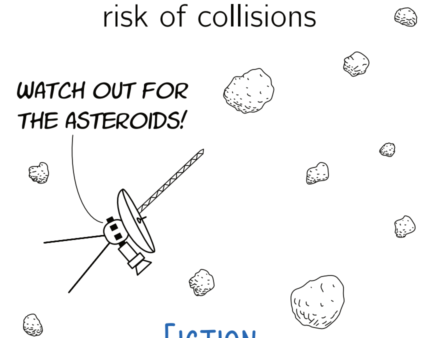
Neptune is sometimes further from the Sun than Pluto



FACT

PLUTO HAS AN IRREGULAR AND TILTED ORBIT THAT SOMETIMES TAKES IT INSIDE OF NEPTUNE'S ORBIT.

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



FICTION

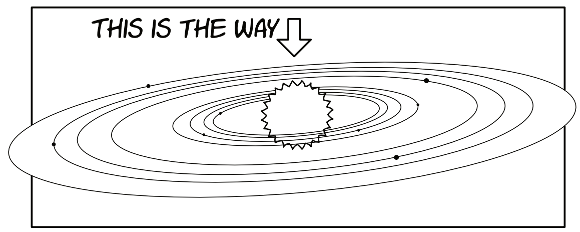
ON AVERAGE, ASTEROIDS IN THE BELT ARE 1 MILLION KILOMETERS APART! IT WOULD BE MORE CHALLENGING TO COLLIDE WITH AN ASTEROID THAN TO MISS THEM.

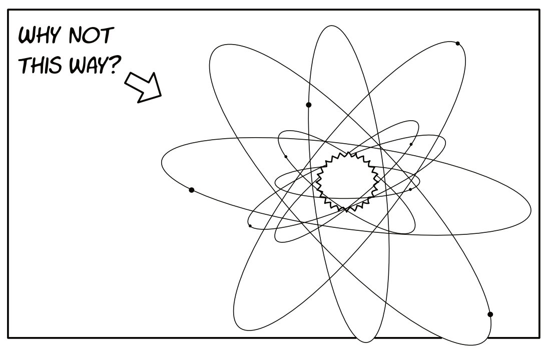
Why do the planets all rotate in the same plane?

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

ANSWERS WILL VARY. THE GOAL OF THIS QUESTION IS TO INVITE THINKING AND CONNECTIONS.

STUDENTS MIGHT NOTE THAT SPINNING THINGS TEND TO FLATTEN OUT (TOSSING PIZZA DOUGH, CHAIR SWING RIDE AT AN AMUSEMENT PARK).

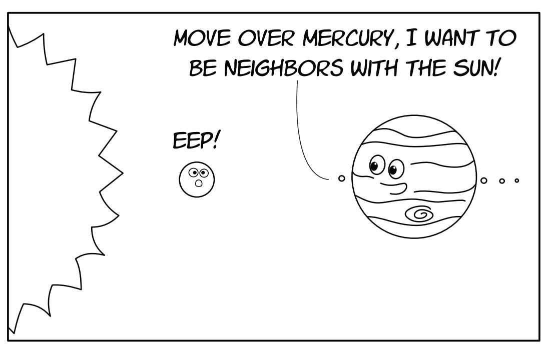




Why rocky, then gassy, then icy?

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

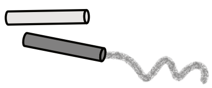
ANSWERS WILL VARY. THE GOAL OF THIS QUESTION IS TO INVITE THINKING AND CONNECTIONS.



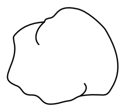
THE ORDER AND SHAPE OF THE PLANETS HAS TO DO WITH HOW THEY WERE FORMED, SOMETHING WE'LL LEARN MORE ABOUT WHEN WE TALK ABOUT STAR FORMATION! BUT THE BRIEF OVERVIEW IS THAT A NEBULA (CLOUD OF DUST AND GAS) COLLAPSES TOGETHER AND BEGINS TO SPIN. THIS FORMS A DISK WHERE BIGGER PIECES COLLIDE WITH EACH OTHER TO FORM PLANETS AND A STAR. WHEN THE STAR BEGINS FUSION, THE SOLAR WIND BLOWS THE REMAINING GAS OUT OF THE SOLAR SYSTEM.

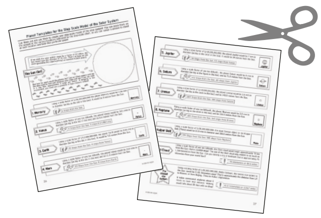
The Scale of the Solar System

MATERIALS

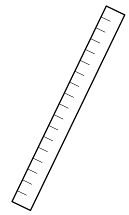


Chalk or something to mark a location





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



A yardstick or tape measure (optional)

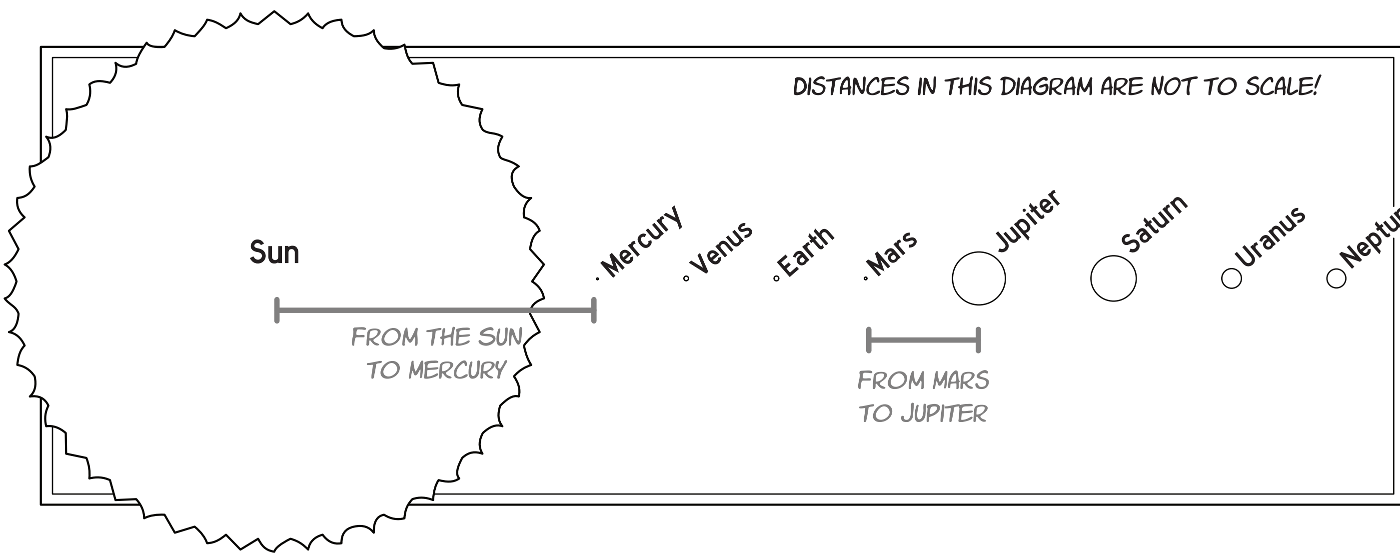
GOALS

- 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!

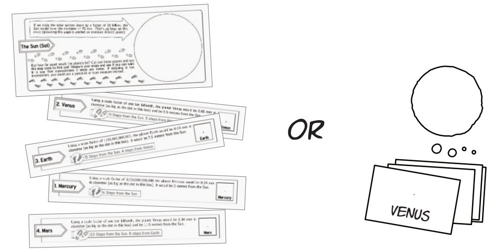
Your guess or estimate:

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

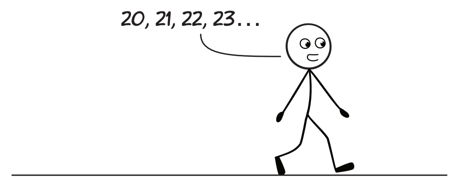


1. Make models of the objects in our solar system either by cutting out the printable scaled planets in the appendix OR by making them with clay or dough (note: if using clay, the inner planets will be almost too small to pick up! You could place them on index cards for easier handling.)

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.

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

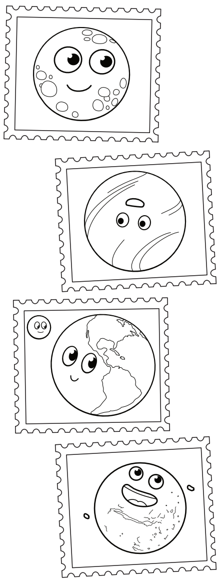
This chart assumes each step is half a meter in length.

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 are 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:

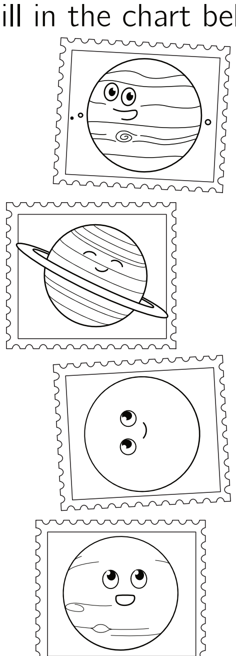


	Distance from the Sun AU	Solid surface Y or N	Number of moons	Atmosphere	Average surface temperature Celsius	Volcanism in present or past Y or N
Mercury	0.38	Y	0	No	333°C Most extreme temperature swing: -170 to 430°C	Yes
Venus	0.72	Y	0	Yes: Thick 96% CO_2 3% N_2	464°C	Yes
Earth	1	Y	1	Yes: Perfect 78% N_2 21% O_2	15°C	Yes
Mars	1.5	Y	2	Yes: Thin 95% CO_2 3% N_2	-65°C	Yes

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.

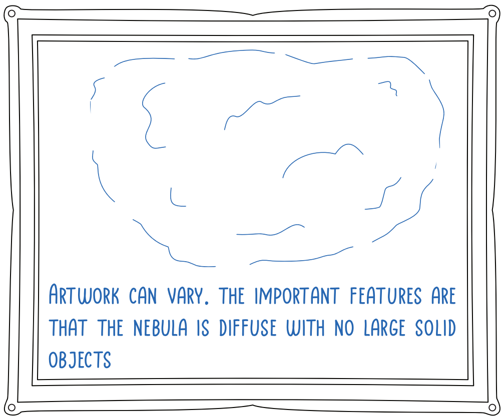
Fill in the chart below for the outer planets:



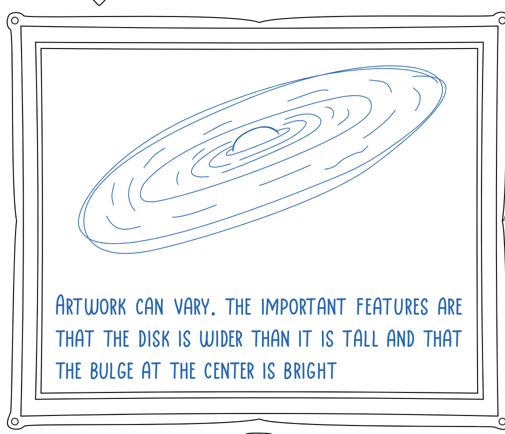
	Distance from the Sun AU	Solid surface Y or N	Number of moons	Most abundant elements outside of the small rocky core	Temperature at 1 atm of pressure in Celsius	Does the planet have rings? Y or N
Jupiter	5.2	N	95	Hydrogen Helium	-110°C	Yes
Saturn	9.6	N	146	Hydrogen Helium	-140°C	Yes
Uranus	19.2	N	28	Water Methane Ammonia	-195°C	Yes
Neptune	30.1	N	16	Water Methane Ammonia	-200°C	Yes

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

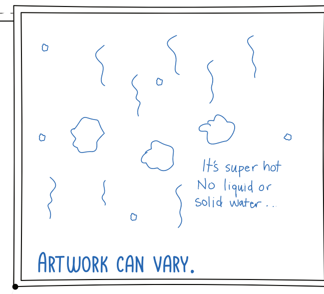
1 A large **nebula** exists in space, made of hydrogen, dust, and some heavier elements. A distant supernova sends a shockwave through the cloud and the gas begins to collapse inward.

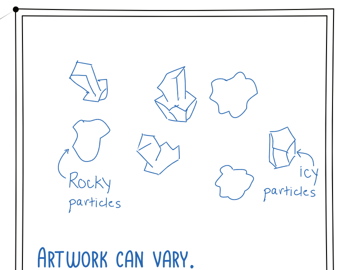


2 The material in the nebula starts contracting and swirling around until it forms a **protoplanetary disk**. The material at the center of the disk is called a **protostar**. The protostar is growing in mass and very hot and bright, but it hasn't started fusion yet.



The 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.

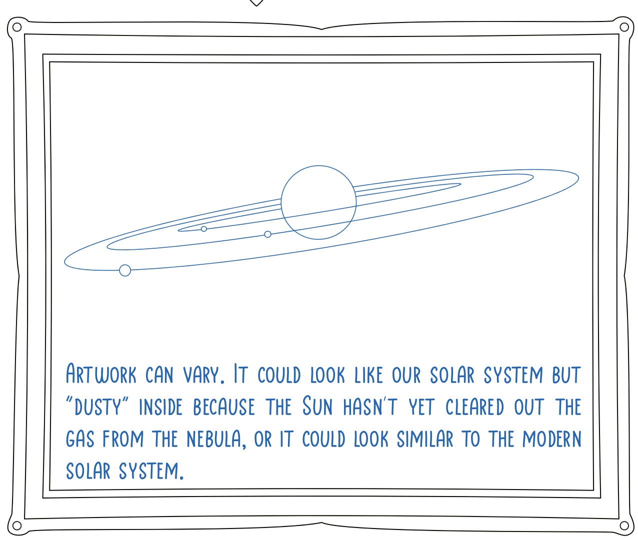




The outer region of the disk is cooler. Rocky materials are solid but so is water, methane, and ammonia. Here, accretion occurs with both rocky materials and frozen ices like water and methane.

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 ORBITS. These paths aren't perfectly circular, they are ELLIPTICAL. Planets always travel in the same DIRECTION. Viewed from Earth, the planets usually appear to move east to west along the ECLIPTIC. But sometimes they APPEAR to move backwards. Ancient astronomers called this RETROGRADE motion. The word "retrograde" comes from the LATIN 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

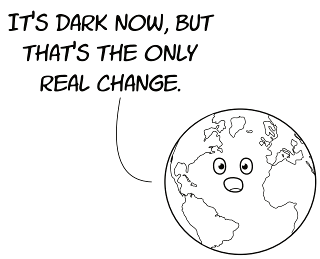
Why is this the case?

B IS CORRECT BECAUSE THE PULL OF GRAVITY BETWEEN THE SUN AND A PLANET IS STRONGER WHEN THE DISTANCE IS SHORTER. OBJECTS CLOSER TO THE SUN MUST BE MOVING FASTER IN A PERPENDICULAR DIRECTION TO MAINTAIN THEIR DISTANCE FROM THE SUN THAN OBJECTS THAT ARE FURTHER AWAY.

Fact or Fiction?

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

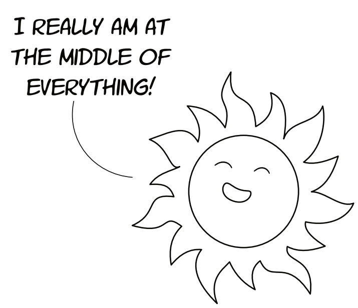
If the Sun disappeared, the planets would keep moving in their same orbits.



FICTION

THE PLANETS WOULD CONTINUE IN THE SAME SPEED AND DIRECTION AND FLY OFF INTO SPACE

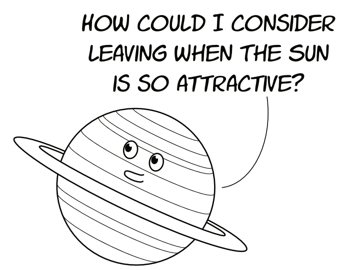
The Sun is at the exact center of each planet's orbit.



FICTION

THE SUN IS AT ONE OF THE FOCAL POINTS OF EACH PLANET'S ORBIT. IT'S NOT QUITE THE EXACT CENTER – IT'S JUST OFF CENTER

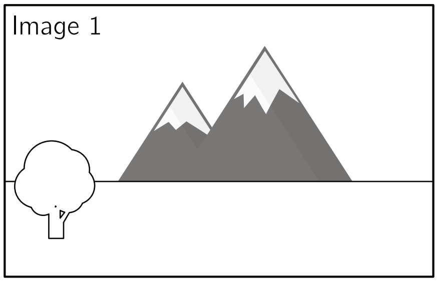
Gravity is the primary force keeping the planets in orbit around the Sun.

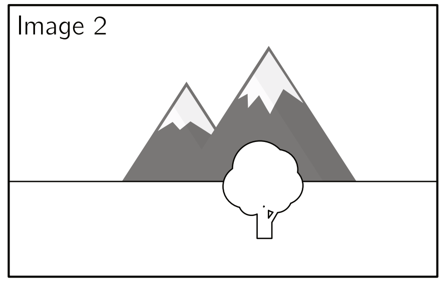


FACT

THE SUN IS THE MOST MASSIVE OBJECT IN THE SOLAR SYSTEM SO IT HAS THE STRONGEST GRAVITATIONAL PULL

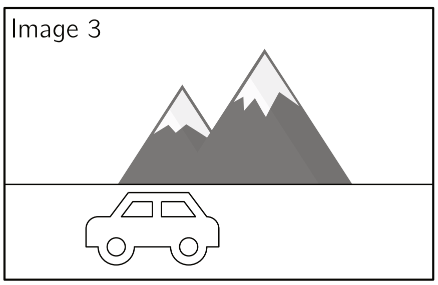
Parallax

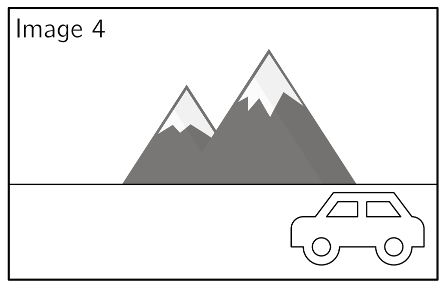




Bob looks out the car window and sees image 1. A few seconds later, he looks out the window and sees image 2. Is Bob traveling to the left or to the right? Explain.

BOB IS TRAVELING TO THE LEFT. THE TREE AND MOUNTAIN AREN'T MOVING RELATIVE TO EACH OTHER, SO BOB'S VANTAGE POINT MUST HAVE MOVED TO THE LEFT SO THAT THE TREE AND MOUNTAIN LINE UP.





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.

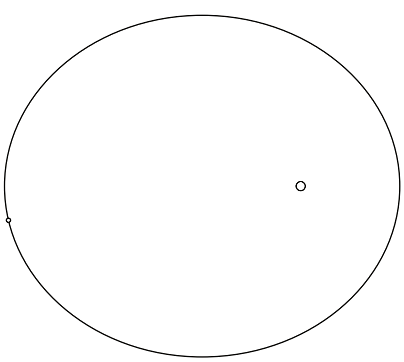
WE NEED MORE INFORMATION. BOB COULD BE STATIONARY WHILE THE CAR IS TRAVELING TO THE RIGHT. BOB COULD BE GOING TO THE LEFT AT A FASTER RATE THAN THE OTHER CAR. BOB COULD ALSO BE GOING TO THE RIGHT WHILE THE OTHER CARE IS TRAVELING TO THE RIGHT EVEN FASTER.

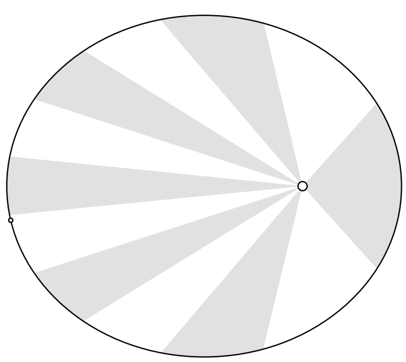
Kepler's Laws

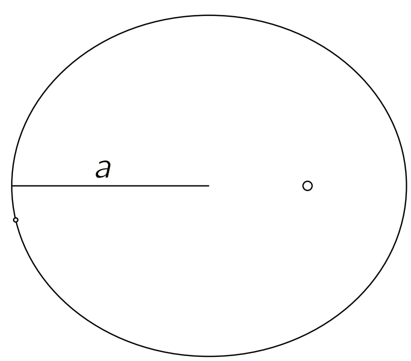
1. Planets move in elliptical orbits with the Sun as a focus.

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 a AU will complete a full orbit in $T = \sqrt{a^3}$ Earth years.

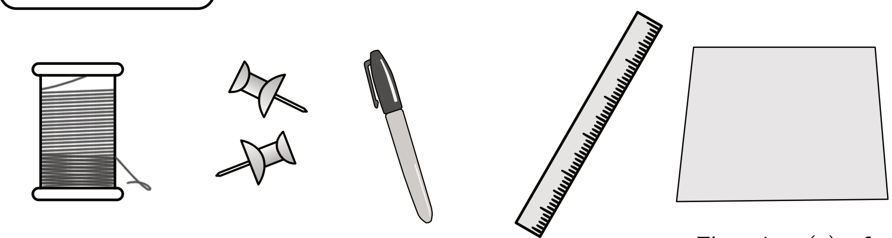






Ellipses and Orbits

MATERIALS

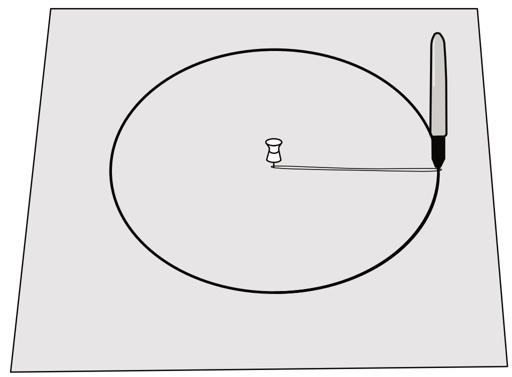


GOALS

- 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.

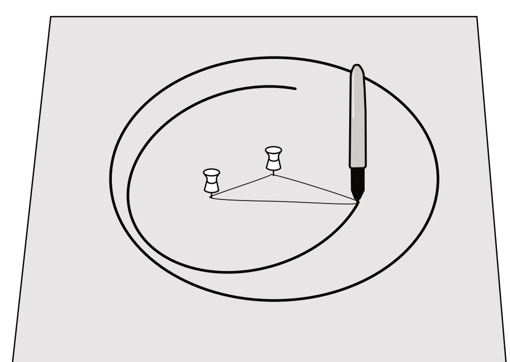
Constructing a Circle.



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.

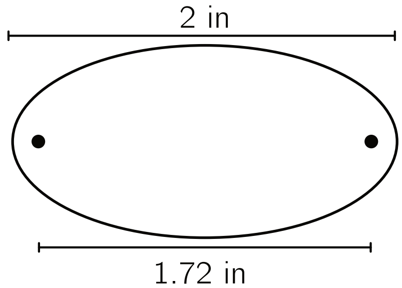
Constructing an Ellipse.

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 a 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.

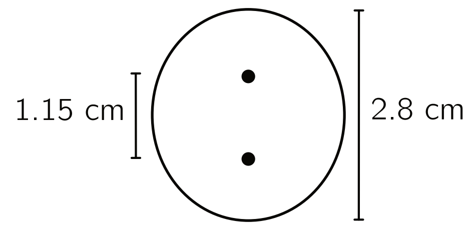


Eccentricity

A long, narrow ellipse is said 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

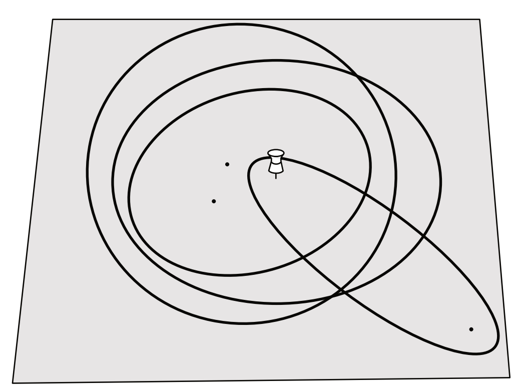
We can calculate the number of Earth years it takes for an object to complete a full orbit by measuring the semi major axis (half of the total widest distance) in AUs and then plugging that value a into the formula:

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

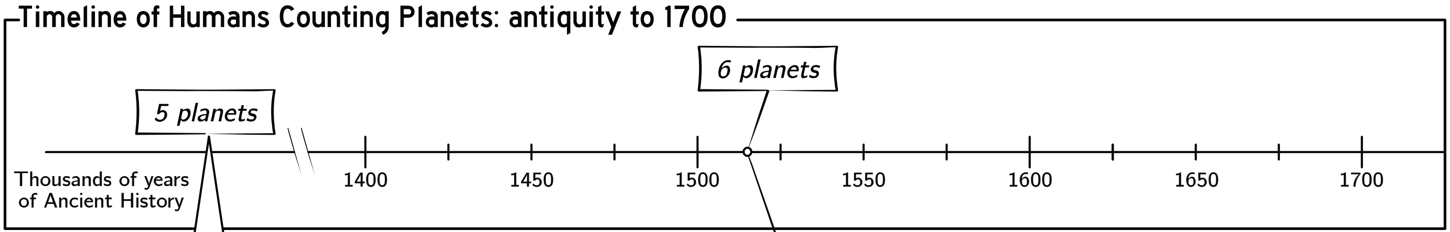
Suppose the solar system whose orbits you designed is scaled so that 1 inch equals 1 AU. Find the orbital period for each planet or satellite in your solar system.

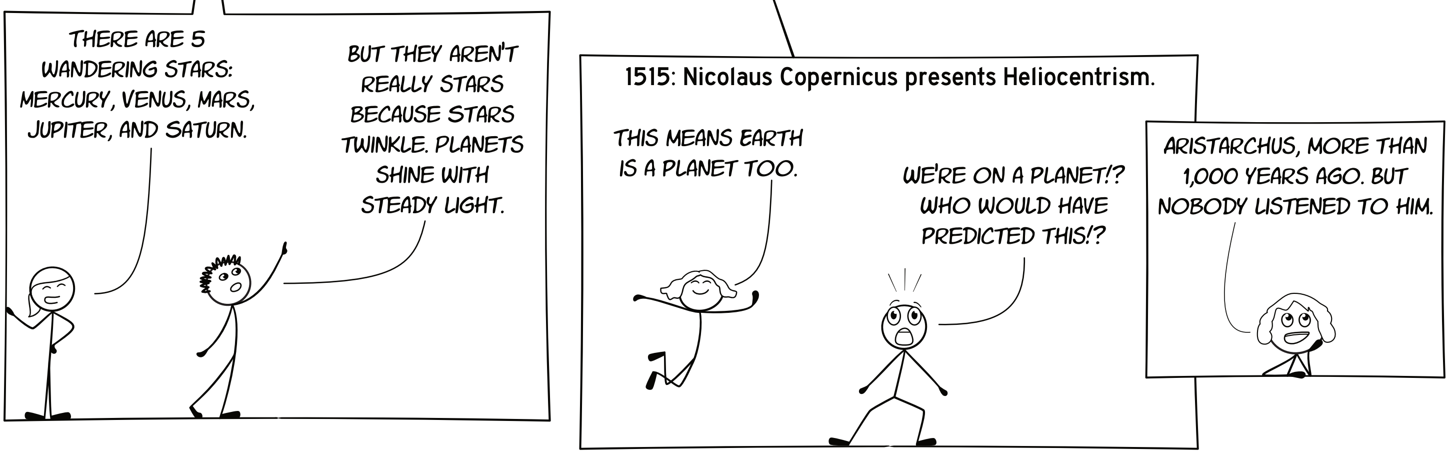
1. Measure the full width of each ellipse in inches and divide that number in half to get the length of the semi major axis.
2. Plug that value into the the formula $T = \sqrt{a^3}$ in place of a to get the number of Earth years, T. (A calculator will come in handy.)

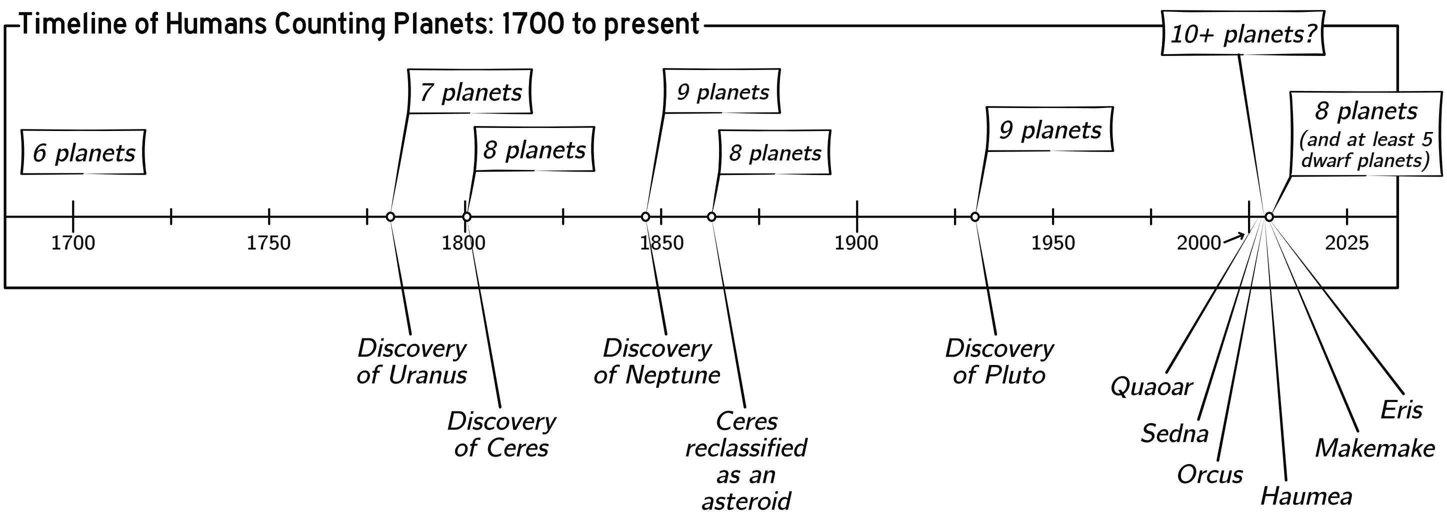
- Which of your orbits has the longest transit time?
- Were you surprised by any of the results?

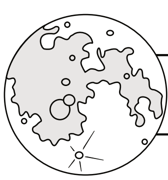


Dwarf Planets and Moons



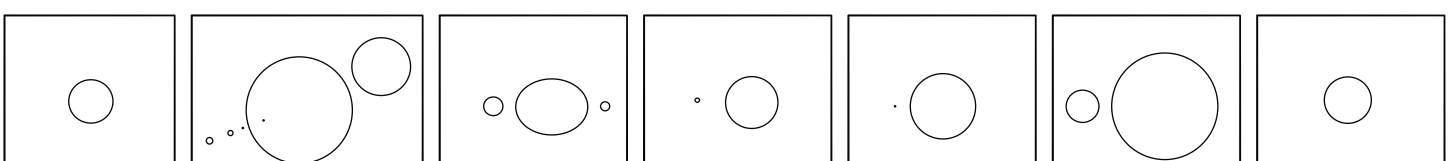






Fill in the name of each dwarf planet or Trans-Neptunian Object (TNO):

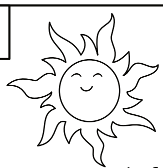
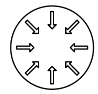
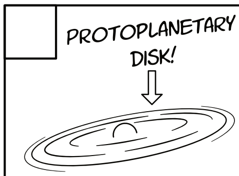
Earth's moon (diameter 4,567 km) is shown here at the same scale as the objects below

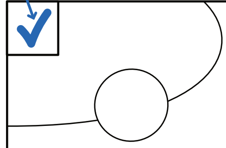
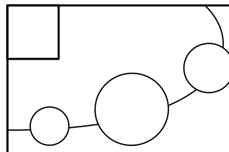
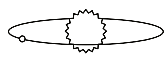
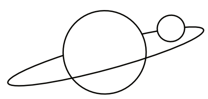
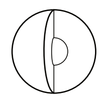
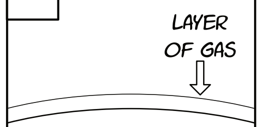


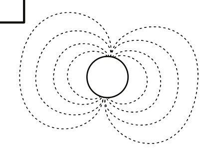
Ceres	Pluto	Haumea	Quaoar	Makemake	Eris	Sedna
952 km diameter	2,376 km diameter	1,740 km diameter	1,100 km diameter	1,430 km diameter	2,400 km diameter	900 km diameter
2.8 AU from Sun	39 AU from Sun	43 AU from Sun	43.7 AU from Sun	45.8 AU from Sun	68 AU from Sun	83.55 AU from Sun
No moons	5 moons	2 moons	1 moon	1 moon	1 moon	No moons
Discovered 1801	Discovered 1930	Discovered 2004	Discovered 2002	Discovered 2005	Discovered 2005	Discovered 2003

Characteristics of things in space:

CHARACTERISTICS FOR IAU DEFINITION OF PLANET

- [ ] 
Large enough for fusion to occur (80x the size of Jupiter)
- [x] ✓ 
Becomes round under the force of its own gravity (diameter of ~600 km)
- [ ] 

Formed at the same time as a star
- [x] ✓ 
Does NOT share orbit with similarly-sized objects
- [ ] 
Shares orbit with similarly-sized objects
- [x] ✓ 
Travels in a regular path around a star
- [ ] 
Has at least 1 moon
- [ ] 
Has a core made of more dense material such as iron
- [ ] 

Has an atmosphere
- [ ] 
Has its own magnetic field

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.

ANSWERS CAN VARY SO LONG AS YOU HAVE A SOLID JUSTIFICATION FOR YOUR DEFINITION! THE INTERNATIONAL ASTRONOMICAL UNION (IAU) DEFINES A PLANET AS BEING A CELESTIAL BODY THAT IS IN ORBIT AROUND A SUN, HAS ENOUGH MASS TO BE ROUND (HYDROSTATIC EQUILIBRIUM), AND HAS "CLEARED THE NEIGHBORHOOD" AROUND ITS ORBIT. PERSONALLY, I PREFER A BROADER DEFINITION BECAUSE PLANETS THAT GET EJECTED FROM A SOLAR SYSTEM (ROGUE PLANETS) ARE STILL PLANETS EVEN IF THEY NO LONGER ORBIT A STAR.

Moons to know in our solar system

Io	Europa	Ganymede	Callisto
INNERMOST MOON OF JUPITER. SLIGHTLY LARGER THAN EARTH'S MOON. SUPER DENSE. HAS MOUNTAINS TALLER THAN EVEREST AND MORE THAN 400 ACTIVE VOLCANOES! CRUST AND MANTLE ARE HIGH IN SULFUR, GIVING IT BEAUTIFUL COLORS OF YELLOW, RED, WHITE, AND BLACK.	SMALLEST GALILEAN MOON (SLIGHTLY SMALLER THAN EARTH'S MOON). HAS AN OCEAN OF LIQUID WATER UNDERNEATH IT'S CRUST OF FROZEN WATER. HAS THE SMOOTHEST SURFACE OF ANY OBJECT IN THE SOLAR SYSTEM.	LARGEST MOON IN SOLAR SYSTEM (3/4 THE SIZE OF MARS!) THE ONLY MOON WITH ITS OWN MAGNETIC FIELD BUT IT DOESN'T HAVE MUCH OF AN ATMOSPHERE. IT'S INTERNAL OCEAN HAS LIQUID WATER.	3RD LARGEST MOON IN SOLAR SYSTEM. MOST HEAVILY CRATERED OF ANY OBJECT IN SOLAR SYSTEM! MIGHT HAVE LIQUID WATER UNDERNEATH ITS THICK AND ICY SURFACE.

The Galilean Moons of Jupiter

2 moons of Saturn

Titan

2ND LARGEST MOON IN SOLAR SYSTEM (LARGER THAN MERCURY). ONLY MOON WITH AN ATMOSPHERE DENSER THAN EARTH'S ATMOSPHERE (IT'S MOSTLY NITROGEN AND METHANE).

IN OUR SOLAR SYSTEM, TITAN IS THE ONLY OBJECT BESIDES EARTH TO HAVE RAIN, LAKES, AND RIVERS. BUT TITAN'S RAIN IS MADE OF HYDROCARBONS! IT'S SO COLD ON TITAN THAT METHANE CONDENSES. ALL THE WATER ON TITAN IS FROZEN.

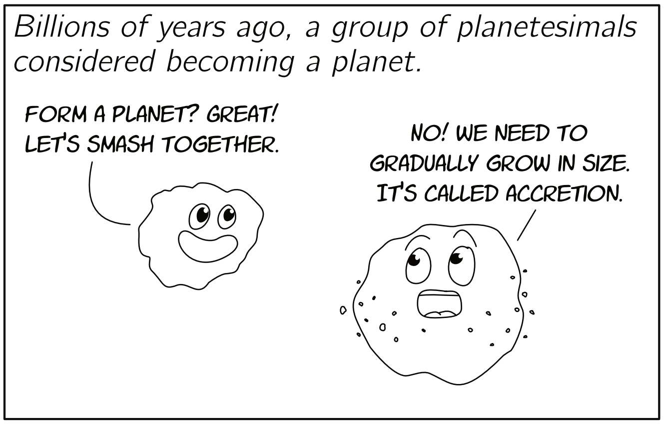
Enceladus

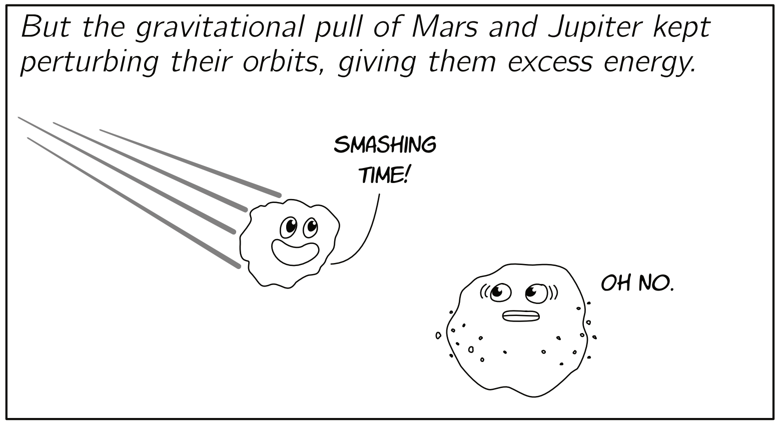
THIS SMALL MOON IS SUPER BRIGHT. IT'S ONE OF THE MOST REFLECTIVE BODIES IN THE SOLAR SYSTEM.

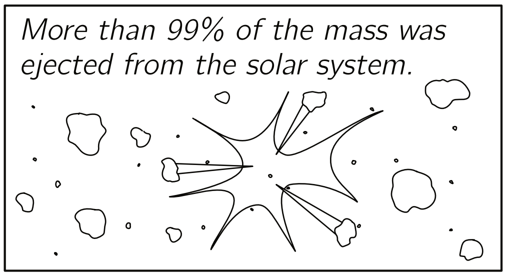
WATER ERUPTS CONTINUOUSLY FROM THE SURFACE. SOME OF IT LEAVES ENCELADUS AND CONTRIBUTES TO SATURN'S E-RING. BUT MOST FREEZES AND FALLS BACK TO THE MOON'S SURFACE AS SNOW.

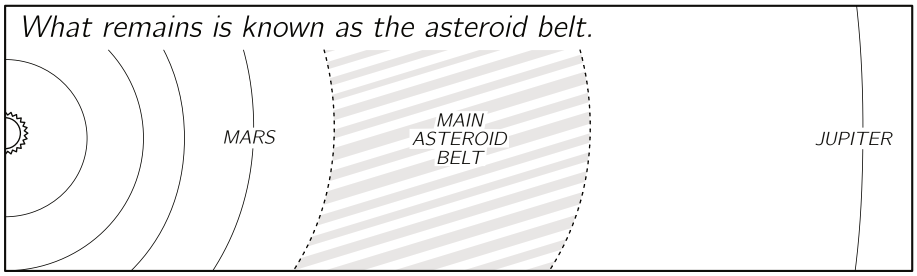
ITS OCEAN OF LIQUID WATER IS ONE OF THE MOST LIKELY PLACES TO FIND LIFE OUTSIDE OF EARTH.

Asteroids, Comets, and Meteors









Asteroid Facts:

Total mass of main asteroid belt is: Less than Earth's moon. (About 4% of the Moon's mass)

Most of that mass is contained in: The 4 largest bodies: Ceres, Vesta, Pallas, Hygiea contain 60% total mass.

Number of asteroids larger than 1 km: 1 to 1.9 million

Outside the main belt, asteroids are found: Near Earth Objects (NEO), In the orbits of planets (Trojans), between Jupiter and Neptune (Centaurs), Kuiper Belt, and Oort Cloud

Match the Terms with the correct definition:

ASTEROID

COMET

METEOR

METEORITE

METEOROID

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

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 IN OUTER SPACE, USUALLY OF SMALLISH SIZE.

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.

Comets

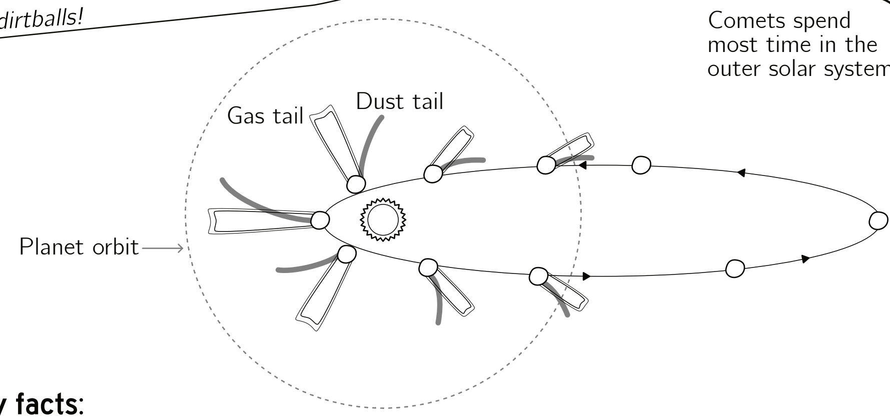
Also known as dirty snowballs or snowy dirtballs!

Composition

COMETS ARE MADE OF FROZEN "ICES" SUCH AS WATER, METHANE, AMMONIA, CARBON DIOXIDE, AND CARBON MONOXIDE. THEY ALSO HAVE DUST OR ROCKY MATERIALS.

THE NUCLEUS OF THE COMET IS USUALLY AROUND 10 KM ACROSS OR LESS.

AS THE COMET GETS CLOSE TO THE SUN IT DEVELOPS AN ENVELOPE OF GAS (COMA) AND 2 TAILS.



Key facts:

VERY ELLIPTICAL ORBITS. ONLY GROW COMA/TAILS WHEN CLOSE TO THE SUN. TAILS ALWAYS POINT AWAY FROM SUN. COMETS GET SMALLER EACH TIME THEY PASS THE SUN; AS GAS SUBLIMES FROM THEM IT CAN DISLODGE ROCKY MATERIAL, FORMING SMALL METEORS.

SHORT PERIOD COMETS (ORBITS LESS THAN 200 YEARS) ARE THOUGHT TO COME FROM THE KUIPER BELT & LONG PERIOD COMETS ARE THOUGHT TO COME FROM THE OORT CLOUD.

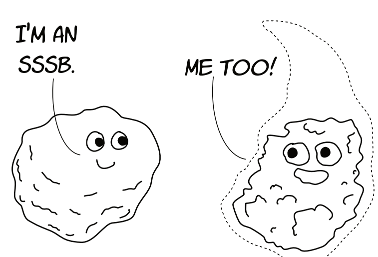
Fact or Fiction?

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

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

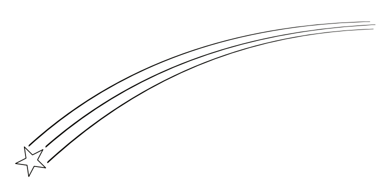
FACT: DESERTS HAVE THE MOST METEORITE FINDS, AND ANTARCTICA IS THE WORLD'S BIGGEST DESERT.

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



FACT

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

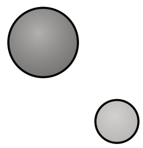


SAND-SIZE METEORS PLUS ATMOSPHERE = A BEAUTIFUL SIGHT!

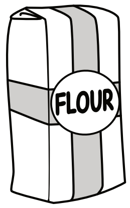
ALMOST FACT: 2 OF THEM (GEMINIDS AND QUADRANTIDS) ARE FROM COMET-LIKE ASTEROIDS

Crater Creator

MATERIALS

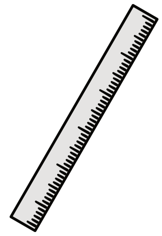


Two marbles or ball bearings of different size.

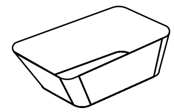


Flour

Cocoa powder



Ruler



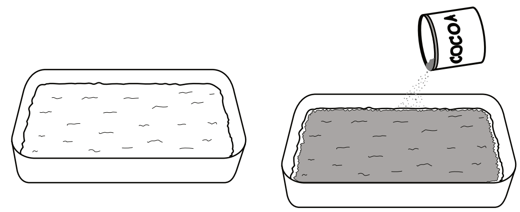
A wide non-breakable container

GOALS

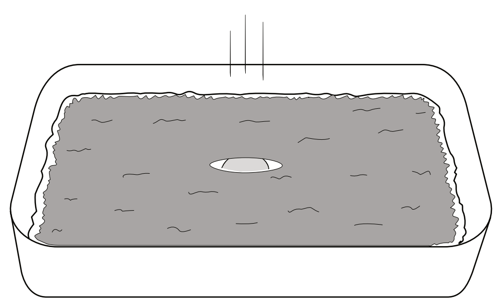
- Simulate meteors colliding with the ground.
- Formulate and test a hypothesis about meteor collisions.

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:



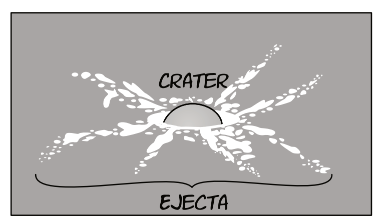
1. Pour flour into the container to a depth of three to four inches. Flatten it out by shaking or jostling the container.
2. Spread a layer of cocoa powder on the top of the flour. For best results, the layer should entirely cover the flour.
3. Drop a marble into the flour to simulate a meteor colliding with the ground.
4. Observe the impact site.
5. 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:

1. The diameter of the crater.
2. The depth of the crater, measured from flour surface to the bottom of the marble.
3. 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:

ANSWERS WILL VARY. A GOOD HYPOTHESIS IS TESTABLE AND THE EXPERIMENT RESULTS WILL EITHER PROVE OR DISPROVE THE HYPOTHESIS.

FOR EXAMPLE: OUR HYPOTHESIS IS THAT SIZE HAS A LARGER INFLUENCE ON CRATER FORMATION THAN SPEED. WE PREDICT THAT TRIPLING THE SIZE WILL CREATE LARGER CRATERS THAN TRIPLING THE SPEED.

Methods

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

ANSWERS WILL VARY. GOOD METHODS SHOULD BE DESCRIBED THOROUGHLY ENOUGH SO THAT SOMEONE ELSE COULD RECREATE THE EXPERIMENT.

FOR EXAMPLE:

WE PREPARED THE "GROUND" BY SLIDING THE PAN BACK AND FORTH UNTIL THE FLOUR WAS EVEN. THEN WE COVERED IT THOROUGHLY WITH COCOA POWDER. OUR INITIAL CRATER SIZE WAS MEASURED WITH A MARBLE WEIGHING 4 GRAMS. WE DROPPED THE MARBLE FROM A HEIGHT OF 20 CM. THIS WAS REPEATED 5 TIMES SO THAT WE COULD GET A MORE ACCURATE IDEA OF CRATER DEPTH, DIAMETER, AND EJECTA SIZE.

FOR THE NEXT ROUND OF IMPACT EVENTS, WE PREPARED THE FLOUR AND COCOA IN THE SAME WAY. THEN WE DROPPED A 12 GRAM MARBLE FROM THE SAME HEIGHT OF 20 CM. WE REPEATED THE DROP 5 TIMES AND CALCULATED THE AVERAGE DEPTH, DIAMETER, AND EJECTA SPREAD.

FOR THE LAST ROUND OF IMPACT EVENTS, WE PREPARED THE FLOUR AND COCOA IN THE SAME WAY. THEN WE DROPPED THE 4 GRAM MARBLE FROM A HEIGHT OF 180 CM. BY USING A HEIGHT THAT WAS NINE TIMES HIGHER, THE SPEED AT IMPACT WAS TRIPLED. WE REPEATED THE DROP 5 TIMES AND CALCULATED THE AVERAGE DEPTH, DIAMETER, AND EJECTA SPREAD.

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?

ANSWERS WILL VARY. GOOD CONCLUSIONS SHOULD DISCUSS HOW THE DATA EITHER SUPPORTS OR DISPROVES THE HYPOTHESIS. THEY SHOULD ALSO INCLUDE SOME REASONS OR EXPLANATIONS FOR THE RESULTS.

FOR EXAMPLE:

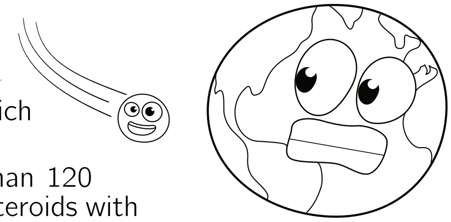
OUR DATA DISPROVED OUR HYPOTHESIS. WE EXPECTED CRATER SIZE TO BE MORE HEAVILY IMPACTED BY THE SIZE OF THE MARBLE THAN THE SPEED, BUT THIS WAS NOT THE CASE.

WHEN WE TRIPLED THE MASS OF THE MARBLE, THE CRATER INCREASED BY ____ AMOUNT.

WHEN WE TRIPLED THE SPEED OF THE MARBLE, THE CRATER INCREASED BY ____ AMOUNT.

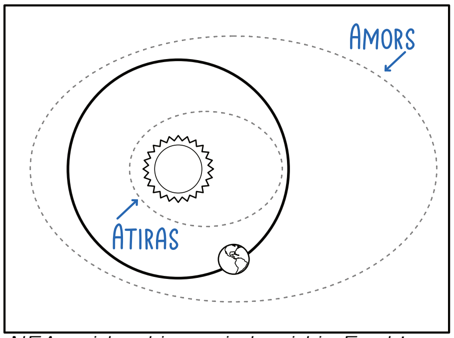
THEREFORE, SPEED OR VELOCITY HAS MORE IMPACT THAN MASS. IF WE LOOK AT THE EQUATION FOR KINETIC ENERGY ($KE = 1/2\ mv^2$) THEN WE CAN SEE WHY THIS IS THE CASE. TRIPLING THE SPEED MULTIPLIED THE KINETIC ENERGY BY A FACTOR OF NINE, WHICH CAUSES A MUCH LARGER CRATER.

Near Earth Objects

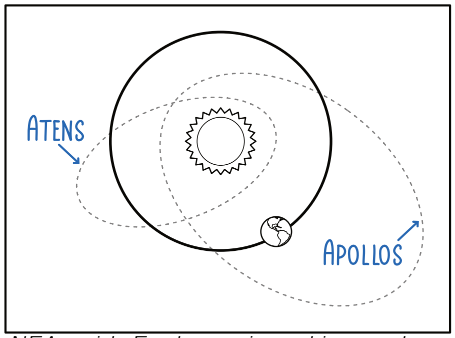


Near-Earth Objects (NEOs) are small Solar System bodies orbiting the Sun which have a perihelion approach of 1.3 AU or less.

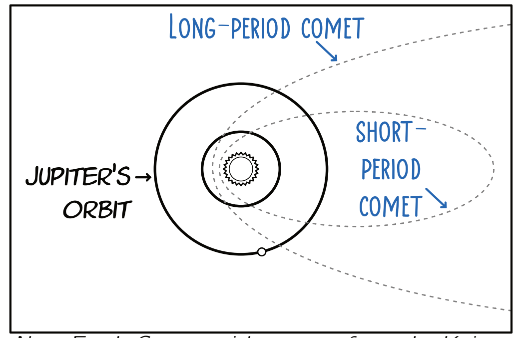
There are more than 34,000 known near-Earth asteroids (NEAs) and more than 120 near-Earth comets. Some have orbits that are outside or inside Earth's orbit. Asteroids with Earth-crossing orbits are more likely to be classified as PHAs (Potentially Hazardous Asteroids).



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:

SIZE | **FREQUENCY**: Every hour — Every day — Every year — Every century — Every millennium — Hundred million years or longer — Only a few times in all of Earth's history

Size scale: 1 µm *microscopic* — 1 mm *sand* — 1 cm *pebble* — 1 m *boulder* — 10 m *house* — 100 m *field* — 1 km — 10 km *a small city!*

Size of meteor that can cause this effect and how often it happens:

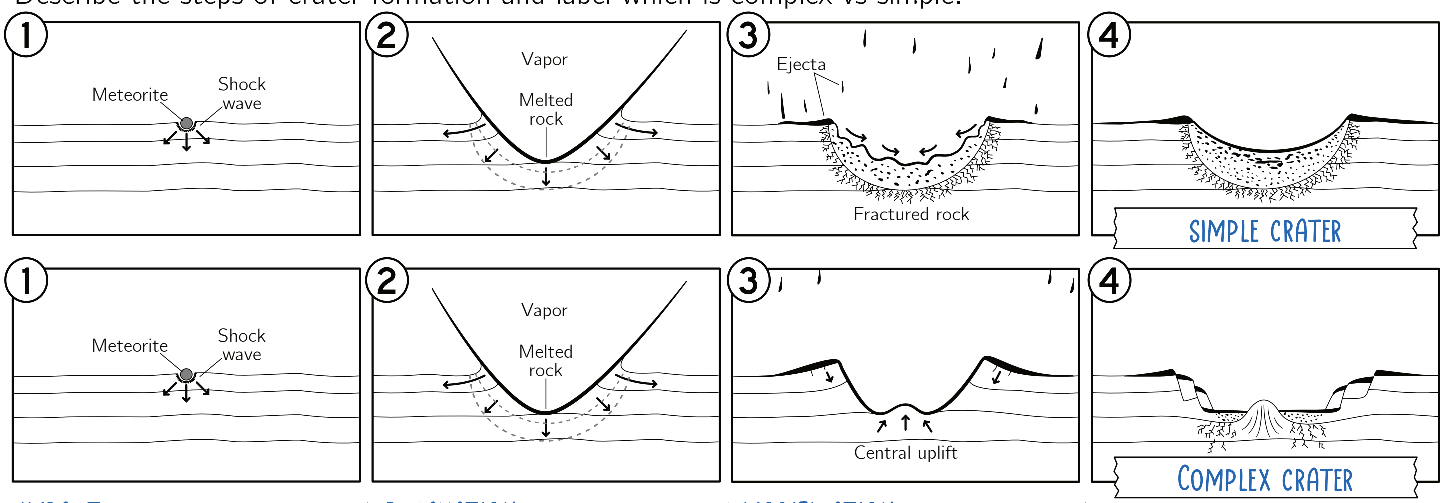
Effect	Size of meteor that can cause this effect and how often it happens
SHOOTING STAR (brightness is similar to stars)	DUST-SIZE TO SMALL PEBBLES MOST SHOOTING STARS ARE ABOUT THE SIZE OF A GRAIN OF RICE OR A PIECE OF SAND. IMPACTS HAPPEN MULTIPLE TIMES PER HOUR ALL OVER THE WORLD. IT'S ESTIMATED THAT MORE THAN 48.5 TONS (44,000 KILOGRAMS) OF METEORITIC MATERIAL FALLS ON EARTH EACH DAY, ALMOST ALL OF WHICH IS SMALL AND VAPORIZES IN THE ATMOSPHERE.
FIREBALL (brightness greater than Venus)	DEPENDS ON COMPOSITION. MOST FIREBALLS ARE BASKETBALL TO CAR SIZE. FIREBALLS OCCUR DAILY BUT MOST OF THEM ARE MASKED BY DAYLIGHT OR OVER OCEANS, SO THEY AREN'T FREQUENTLY OBSERVED BY PEOPLE. SMALLER ONES BURN UP COMPLETELY. SMALL METEORITES (LESS THAN 1 M) THAT REACH THE GROUND (EX PEEKSHILL METEOR IN 1994) OCCUR A FEW TIMES EACH YEAR.
SIGNIFICANT ATMOSPHERIC EXPLOSION OR CRATER	HOUSE TO FIELD SIZE. THESE OCCUR A FEW TIMES PER CENTURY. EXAMPLES INCLUDE THE CHELYABINSK METEOR THAT EXPLODED OVER RUSSIA IN 2013, ESTIMATED TO BE 18M DIAMETER AND THE SULAWESI SUPERBOLIDE IN 2009.
LARGE CRATER, WIDESPREAD DEVASTATION	FIELD TO 1KM SIZE. FORTUNATELY, THESE SIZE IMPACTS ARE RARE, OCCURRING EVERY 10,000 YEARS FOR 100 M ASTEROIDS AND MORE THAN 500,000 YEARS APART FOR 1 KM ASTEROIDS. THE 1908 TUNGUSKA EVENT WAS CAUSED BY A 50-60 METER ASTEROID THAT EXPLODED AT ABOUT 10 KM ABOVE THE SURFACE. IT FLATTENED TREES OVER MORE THAN 2,000 SQUARE MILES!
MASS EXTINCTION, WORLD-WIDE EFFECTS	BIGGER THAN 1KM. FORTUNATELY, THIS SIZE OF IMPACTS ARE EXTREMELY RARE, WITH HUNDREDS OF MILLIONS OF YEARS BETWEEN IMPACTS. THE CHICXULUB IMPACTOR AT THE END OF THE CRETACEOUS PERIOD IS ESTIMATED TO HAVE BEEN ABOUT 10 KM IN DIAMETER.

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 EH_1 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.



IMPACT

METEOR MAKES CONTACT AND COMPRESSES THE TARGET ROCK.

EXCAVATION

CRATER EXCAVATION, MELTED ROCK IS THROWN INTO AIR, DISINTIGRATION OF METEORITE

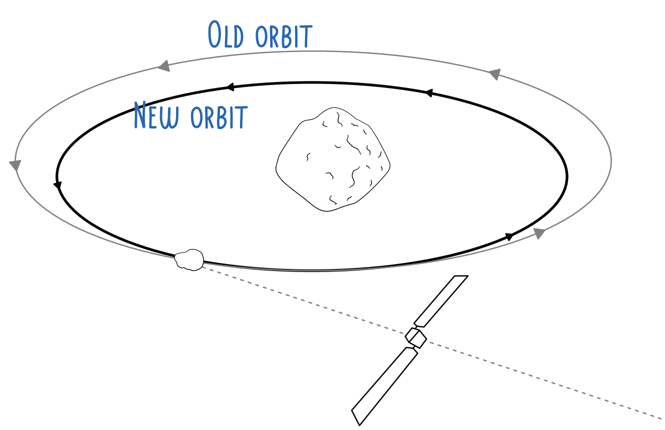
MODIFICATION

FRACTURING OF ROCK OR CENTRAL UPLIFT OCCURS

FINAL SHAPE: SIMPLE CRATERS ARE BOWL SHAPED. COMPLEX CRATERS HAVE A CENTRAL PEAK AND ARE FORMED BY A LARGER AND MORE POWERFUL IMPACT

PanSTARRS and DART

DOUBLE ASTEROID REDIRECTION TEST (DART)TARGETED ASTEROID DIDYMOS AND ITS MOONLET DIMORPHOS. THE TEST SHOWED THAT (WITH ENOUGH WARNING) WE COULD DEFLECT A POTENTIALLY HAZARDOUS ASTEROID AND PREVENT IT FROM HITTING EARTH. PANSTARRS IS THE LARGEST NEO DETECTION TELESCOPE SYSTEM.



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: Asteroids are made of rocky material. They're not large enough to be round under the force of their own gravity (if smaller than 600 km diameter).

BOLIDE: Large meteors that explode in the atmosphere.

COMET: Made of both icy and rocky material. Sometimes called dirty snowballs or snowy dirtballs. They formed further out from the Sun where there was more icy material like frozen water, methane, and ammonia.

ELIPSE: An oval shape where the sum of the distances from two focal points is always the same. A circle is a special type of elipse where the 2 focal points are the same.

FIREBALL: A very bright meteor that shines more brightly than the stars as it travels through the atmosphere.

METEOR: A rocky object from outer space that has entered Earth's atmosphere. Friction with the air makes it glow brightly. Small meteors are called "shooting stars." Larger meteors are called "fireballs."

METEORITE: A rocky object from outer space that survived its descent through Earth's atmosphere and made impact with the ground.

NEBULA: A collection or cloud of gas and dust particles in outer space.

PARALLAX: The effect that makes the position or direction of an object appear differently when viewed from a different position. IE when passing a car on the freeway the car appears to travel backwards relative to the viewer while it's being passed.

PROTOPLANETARY DISK: A rotating disk of gas and dust surrounding a newly-forming star. The birthplace of stars, planets, asteroids, and comets!

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

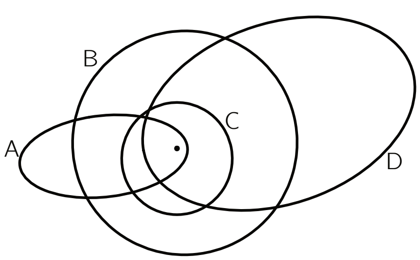
15. What is the approximate time it takes for sunlight to reach Mars?
   A. 1.5 minutes
   B. 6 minutes
   C. 12.5 minutes
   D. 20 minutes

16. The Cassini Division is:
   A. A gap in Saturn's rings
   B. A region of the asteroid belt
   C. A crater on Mercury
   D. A zone in Jupiter's atmosphere

17. Which planet was discovered through mathematical calculations before it was observed?
   A. Uranus
   B. Neptune
   C. Saturn
   D. Mars

18. The surface of Venus is obscured by clouds primarily composed of:
   A. Water vapor
   B. Methane
   C. Sulfuric acid
   D. Ammonia

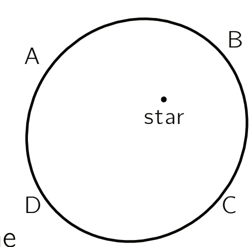
19. The orbits are shown for objects A, B, C, and D. Place them in order from shortest year (full orbit) to longest year.



THE SMALLER THE MEASURE OF THE MAJOR AXIS, THE FASTER THE PLANET WILL COMPLETE THE ORBIT.

YEAR FOR C < YEAR FOR A < YEAR FOR B < YEAR FOR D

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. A
   B. B
   C. C
   D. D
   E. The planet is always moving the same speed along the orbit.

THE FASTEST SPEED OCCURS CLOSE TO THE STAR.

21. Mercury's "day" (one full rotation on its axis) is approximately how long compared to its "year" (one orbit around the Sun)?
   A. 1/4 of a Mercurial year
   B. 2/3 of a Mercurial year
   C. 2 Mercurial years
   D. 3 Mercurial years

22. What causes the blue color of Neptune?
   A. Water reflection
   B. Methane in its atmosphere
   C. Surface ice
   D. Nitrogen compounds

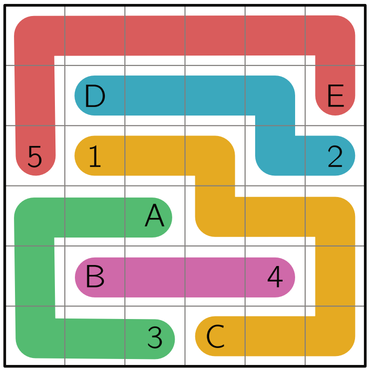
23. Which moon is the only one known to have a thick atmosphere?
   A. Europa
   B. Callisto
   C. Ganymede
   D. Titan

24. The Galilean moons are associated with which planet?
   A. Saturn
   B. Jupiter
   C. Uranus
   D. Neptune

25. Which planet has the shortest day (rotation period)?
   A. Mercury
   B. Venus
   C. Mars
   D. Jupiter

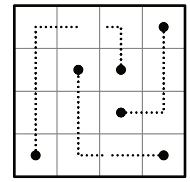
26. Mark each statement as true or false.
   T F Half of the Moon never receives sunlight.
   T F The same side of the Moon is always facing the Earth.
   T F Mercury is the hottest planet in the solar system.
   T F The asteroid belt contains more total mass than Earth's moon.
   T F Venus rotates in 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

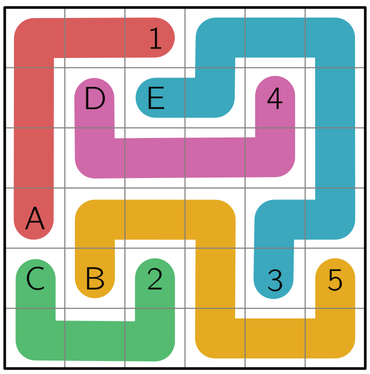


Rank the planets below by number of moons and join the corresponding letter and number with a continuous stroke. Each square in the grid should be visited by exactly one pipe as in the example grid shown below.

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



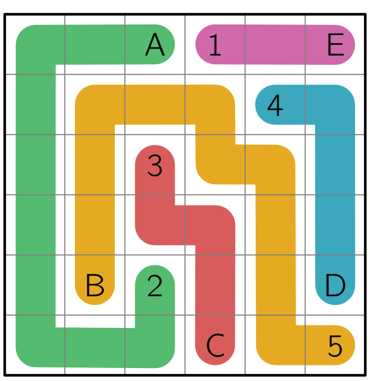
Pipe Flow Matching - Planet Facts 1



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



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