Activity 8: Moon Phases and Eclipses

Materials:

- Light bulb at eye level
- Polystyrene ball on a wooden dowel
- White ping pong ball painted half black
- Highlighters of multiple colors

Part 1: Observing the Moon

STEP 1: Compare your Moon observations with those of the other people in your group. Paying careful attention to the dates of your observations, merge your observations into a more complete set of observations.

Suggested Procedure: In the interest of time, start with the most complete set of observations amongst the people in your group. Then, date by date, see if you can find any observations that you have but they don't have. If so, you can add your observation to their data table.

STEP 2: Looking at your compilation of observations, answer the following questions.

Did the Moon's distance (in the sky) from the Sun change over the course of your observations? In other words, did the angle between the Sun and Moon change?

What is the period of time you would expect to wait between Full Moons? If your observations aren't complete enough to answer this question, you can look at a moon phase calendar. For example, you can use this moon phase calendar:

https://www.timeanddate.com/moon/phases/

Or, specifically for Austin, you can use this one:

https://www.timeanddate.com/moon/phases/usa/austin

Write down the period of time you would expect to wait between Full Moons:

The time between Full Moons is, on average, about **29.5 days**. This is the origin of the concept of a **month**. If you look at the word *month*, it is easy to see that it has *moon* for its root.

Some calendars, called **lunar calendars**, use the month as the basic division of time (instead of the year, as in a solar calendar). An example of a lunar calendar is the Islamic calendar. The Chinese calendar and Hebrew calendar are lunar-solar hybrid calendars. This is why some holidays like Ramadan, Chinese New Year, and Rosh Hashanah occur on slightly different *solar calendar* dates each year.

What will the Moon look like (you may just draw it) 3 days from today and 7 days from today?

Important Note regarding drawing Moon phases: You must decide whether you are going to shade in the lit portion of the Moon in your drawings, or shade in the dark portion of the Moon in your drawings. It doesn't matter which you choose, but choose one that makes the most sense to you and *be consistent*. Circle your choice below.

When drawing Moon phases, from now on I will always shade in the… (circle one)

LIT portion DARK portion

Part 2: Moon Phases [1]

In this part we will use a polystyrene ball to model the Moon, a light bulb to model the Sun, and your head will model the Earth. To make it easier to hold the polystyrene ball, you can stick a pen or pencil into one side of the ball. This part works best if the only light in the room is coming from the light bulb that represents the Sun.

STEP 1: Sit or stand about 2-3 feet away from a light bulb that's at eye level. Face the light bulb and hold up the polystyrene ball in front of you, also at eye level.

What fraction of the Moon is lit? In other words, if there were people living all over the surface of the Moon, what fraction of them would be lit vs shadowed?

[1] This Part adapted from "Moon Phases" by Jet Propulsion Laboratory, California Institute of Technology

Now move to a different side of the light bulb, or pass the polystyrene ball to another group member.

Now what fraction of the Moon is lit? In other words, if there were people living all over the surface of the Moon, what fraction of them would be lit vs shadowed?

Did your answer to the previous questions change when you moved the Moon to a new location?

At any location, how much of the Moon is lit by the Sun?

What determines which side of the Moon is lit?

STEP 2: Now stand about 5-10 feet away from a light bulb that's at eye level.

Turn your back to the light bulb and hold the polystyrene ball at arm's length straight in front of you, slightly above your head so that the ball is not in your shadow.

How much of the ball *appears lit to you*? And equivalently, since your head represents the Earth, how much of the Moon appears to be lit for any observers on Earth that can see the Moon?

STEP 3: Turn to face the light bulb. Hold the ball in your left hand and straight out to your left side (90 degrees to the left). Turn your head to observe the ball.

Now how much of the ball *appears lit to you*? And therefore, since your head represents the Earth, how much of the Moon appears to be lit for any observers on Earth that can see the Moon?

STEP 4: Keeping your feet planted, swing your left arm forward about a foot or two, so that the ball is about a third of the way closer to the light bulb.

Now how much of the ball *appears lit to you*? Below, draw a picture of what the ball looks like, indicating its dark and lit portions (be sure to stick with the shading convention you chose on page 2).

STEP 5: Swing your left arm farther forward so that the ball is another third of the way closer to the light bulb. Now how much of the ball *appears lit to you*? Below, draw a picture of what the ball looks like.

SQ1:

a) During this experiment, how much of the ball is truly being lit by the light bulb?

b) We've kept the Earth (your head) and the Sun (the light bulb) stationary. So what causes the ball to look different to an observer on Earth over the course of the experiment?

SQ2:

a) Were the differences in the sizes of the lit portion of the ball caused by the shadow of the Earth falling on the ball? How can you tell from our model? *Hint:* What represented the Earth in our model, and did it cast a shadow on the Moon?

b) Were the differences in the sizes of the lit portion of the ball caused by the Moon receiving a different amount of light? How can you tell from our model? *Hint:* What represented the Sun in our model, and did its light output ever change?

The same side of the Moon is always facing towards the Earth. Therefore, is it always *the same part* of the Moon that is in the darkness? Use the bulb and ball model to help you answer this one.

Many of us have heard of the **dark side of the Moon** (anyone a Pink Floyd fan?), but it is often misconstrued to mean that the same half of the Moon is always dark. While it's true that one half of the Moon is always dark, it is not always the same portion of the Moon that is in the dark! If you did not see that when answering the previous question, use the bulb and ball model again to try to understand it.

Unlike the dark side, the **far side of the Moon** *is* always the same side of the Moon.

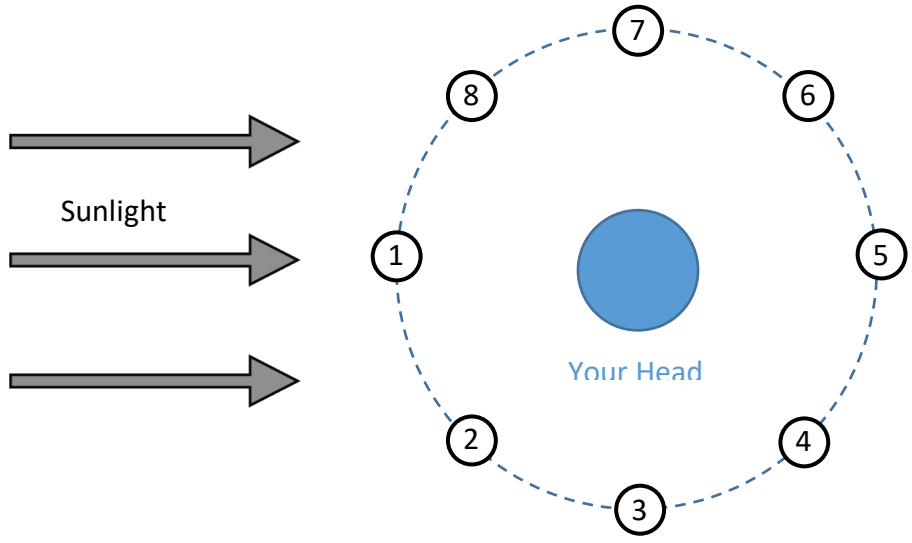
Explain the difference between the **dark side** of the Moon and the **far side** of the Moon.

STEP 6: Now we will switch our model from a polystyrene ball to using a ping pong ball that is colored half black and half white. This ping pong ball will be the Moon in our model.

Why do you think the ping pong ball is colored half black and half white? Hint: How much of the Moon is lit by the Sun at any given time? What do the white half and black half represent?

Consider the diagram at the right. The Earth is in the center, which will be represented by your head. The Moon's orbit is the dashed line around the Earth. The Sun (light bulb) is shining on the Earth from the left side of the page.

The Moon (our ping pong ball) will be placed at



different locations along its orbit, in the order indicated by the numbers 1 through 8 in the diagram.

Note the arrangement of the numbered locations. In what direction does the Moon orbit the Earth? Does this answer sound familiar?

One person in your group will be the Earth, and this person's perspective will represent the perspective of everyone on Earth.

Another person in your group will hold the ping pong ball in the approximate location as indicated in the diagram, holding it at about eye level for the person being the Earth, or maybe a little higher so that the ping pong ball is not in anyone's shadow.

If you are doing this Activity alone, you can hold the ping pong ball for yourself. You will have to turn your body to see it when, for example, it's behind your head.

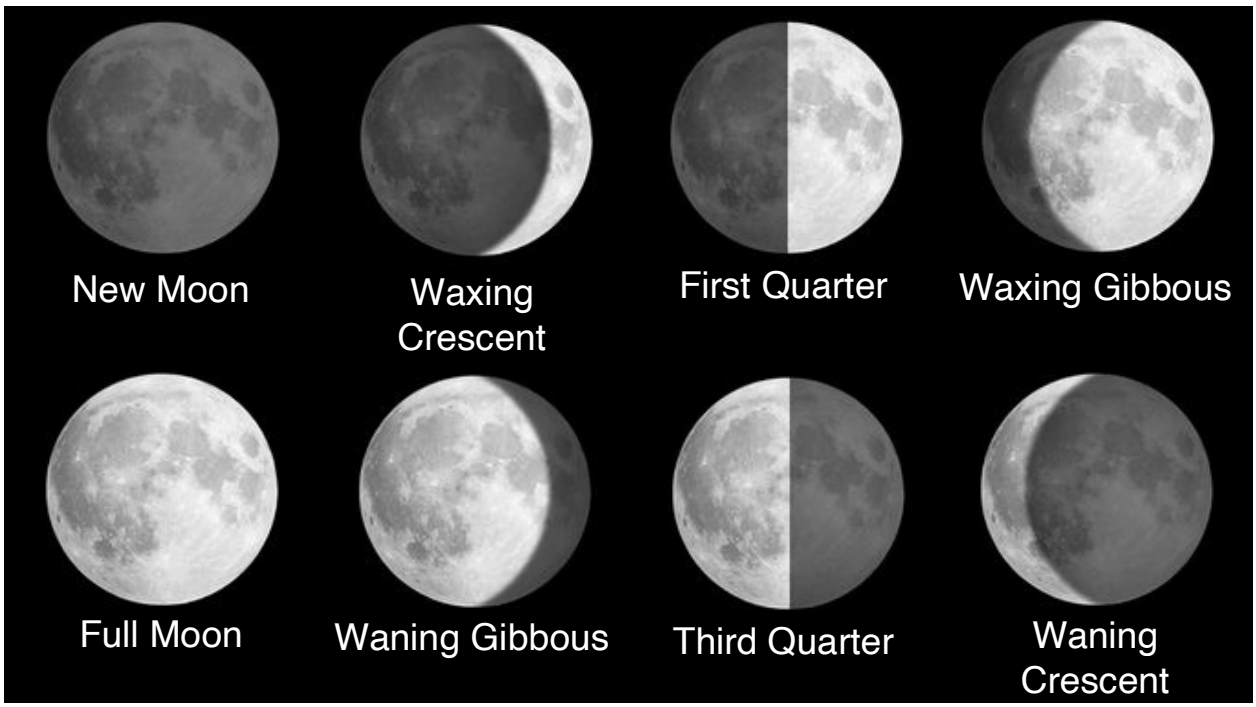
The person holding the ping pong ball should hold it so that which side of the ball (white or black) is facing the light bulb? Why?

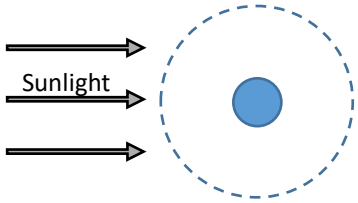
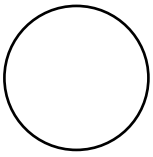
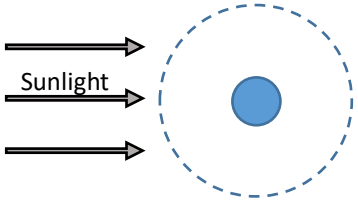
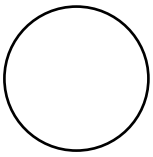
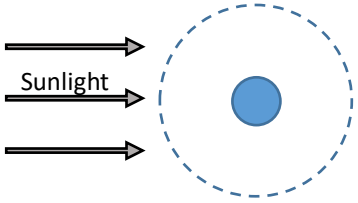
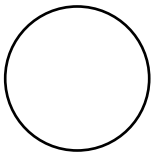
Will your answer to the previous question change depending on the numbered location where the Moon is located? Why or why not?

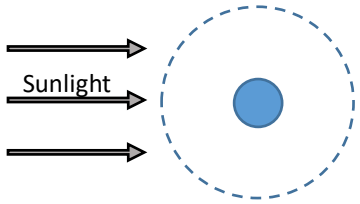
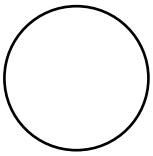
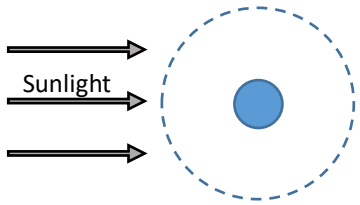
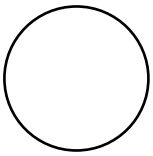
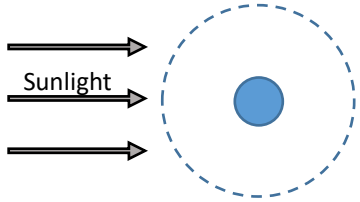
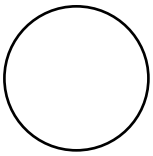
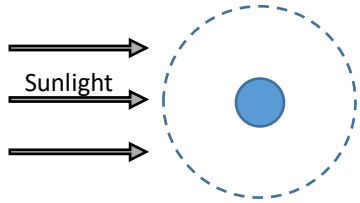
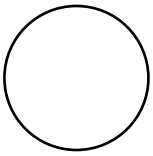
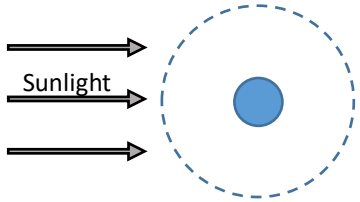
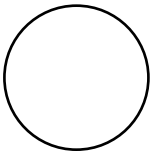
STEP 7: At each of the numbered locations, the person representing the Earth should describe the lit and shaded portion of the Moon that they see. Draw this in the table below in the appropriate row (the table starts on the next page). Remember to stick with the shading convention you chose on page 2.

Also, in each row, draw the location of the Moon in its orbit.

STEP 8: For each row in the table, write the name of the Moon phase in the rightmost column. Use the chart below to help you name the Moon phases.



#	Moon's Location	Moon's Appearance from Earth	Moon Phase
1			
2			
3			

4			
5			
6			
7			
8			

STEP 9: It is **strongly encouraged** that each member of your group take a quick turn being the Earth. For each person, have another member of the group briefly hold the ball in each numbered position. This will give each student a chance to really see first-hand that *a half-lit sphere, when orbiting around you, will produce the Moon phases*.

STEP 10: Look back at the table you've just completed to answer the following questions.

How did the apparent lit portion of the Moon change as it moved from position #1 to #5?

A **waxing** Moon is one whose lit portion appears to be growing. A **waning** Moon is one whose lit portion appears to be shrinking.

Is the Moon waxing or waning as it moves from #1 to #5? Does this agree with the names of the phases that you wrote down for these positions?

Would your previous answer change if we added an intermediate position between #1 and #2 and asked whether the Moon is waxing or waning at that intermediate position? What about for an intermediate position between #4 and #5?

Is the Moon moving closer to or farther away from the Sun as it moves from #1 to #5?

How did the apparent lit portion of the Moon change as it moved from position #5 to #6 to #7 to #8, and back to position #1?

During this portion of its orbit, is the Moon waxing or waning?

Would your previous answer change if we added an intermediate position between #5 and #6 and asked whether the Moon is waxing or waning at that intermediate position? What about for an intermediate position between #8 and #1?

During this portion of its orbit, is the Moon moving closer to or farther away from the Sun?

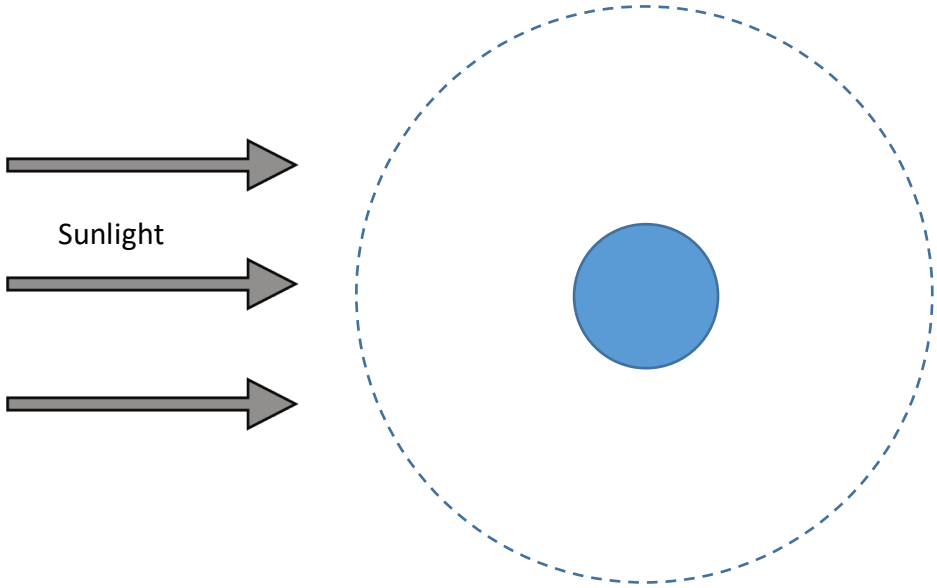
SQ3: Summarize your conclusions above by circling the appropriate words below to create two different but correct sentences:

(a) When the Moon is (waxing / waning), it is moving (closer to / farther from) the Sun.

(b) When the Moon is (waxing / waning), it is moving (closer to / farther from) the Sun.

STEP 11: On the diagram below, draw a curved arrow outside the orbit to show the direction that the Moon is orbiting around the Earth. Then use a colored highlighter to highlight the portion of the Moon's orbit in which the Moon is **waxing**. Label this "waxing". When highlighting, try to include *all* positions where you think the Moon would be waxing.

STEP 12: On the same diagram, do the same thing for **waning** by using a different colored highlighter: highlight the portion (include *all* positions) in which the Moon is waning and label this "waning".



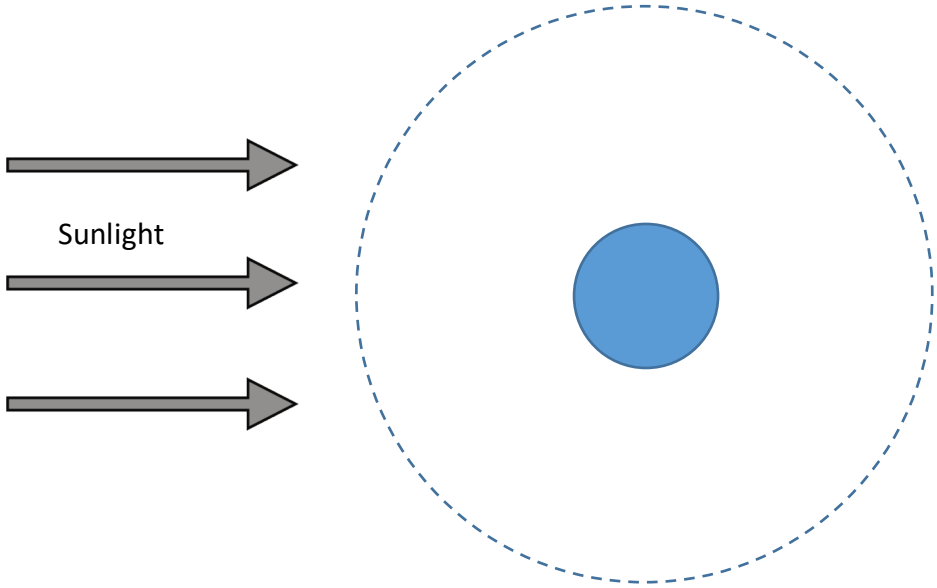
STEP 13: Also on the diagram above, place an X at the two locations where the Moon appears either completely lit or completely dark, and label these "Full Moon" and "New Moon" appropriately.

Does your highlighted diagram above agree with your answer to SQ3? Why or why not?

STEP 14: Now consider the diagram below. As before, draw a curved arrow outside the orbit to show the direction that the Moon is orbiting around the Earth.

When the Moon *appears less than half lit*, it is called a **crescent moon**.

Looking back at your table, during which portion of the Moon's orbit does it *appear less than half lit*? Use a highlighter to highlight this portion on the diagram below and label it "crescent". When highlighting, try to include *all* positions where you think the Moon would appear less than half lit. *Hint*: At what points does it appear *exactly* half lit?



STEP 15: When the Moon *appears more than half lit*, it is called a **gibbous moon**.

During which portion of the Moon's orbit does it *appear more than half lit*? Use a highlighter to highlight this portion on the diagram above and label it "gibbous". When highlighting, try to include *all* positions where you think the Moon would appear more than half lit.

STEP 16: Also on the diagram above, place an X at the two locations where the Moon *appears half lit*, and label these phases appropriately.

What are the names of the two phases where the Moon appears to be half lit?

SQ4:

a) If the Moon *appears half lit*, then why do you think these phases are called "Quarter Moons"?

b) Does a First Quarter Moon occur during the waxing or waning part of the Moon's orbit?

c) Does a Third Quarter Moon occur during the waxing or waning part of the Moon's orbit?

Using a moon phase calendar (URL on page 1), write down the date and time of the next Full Moon:

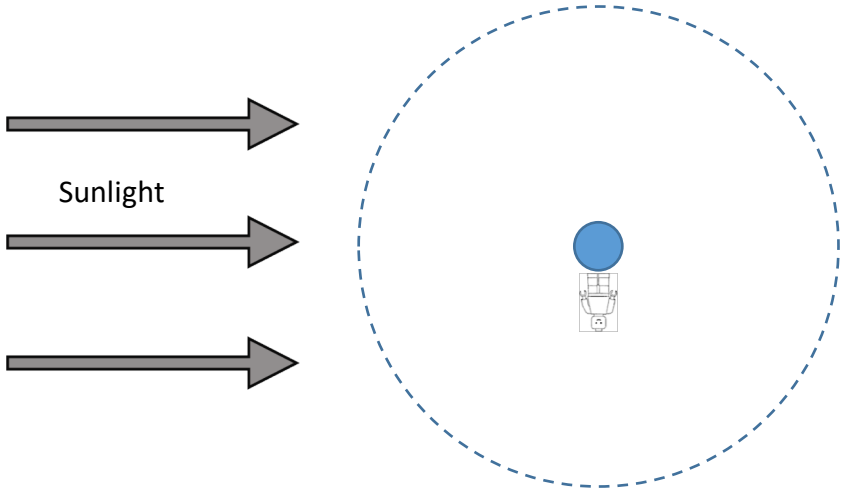
SQ5:

(a) Why do you think it's possible to specify an *exact time* for the next Full Moon, right down to the minute? *Hint*: What causes a Full Moon, and how long does it stay that way?

(b) Why in our daily lives do we experience the Full Moon as lasting a couple of days if it really occurs only for a moment? *Hint:* Do you think our eyes would be able to tell the difference between a Moon that is 99% full and one that is 98% full?

Part 3: Telling Time with the Moon [2]

STEP 1: On the diagram below, add the Moon in its orbit while it is in the Full Moon phase.

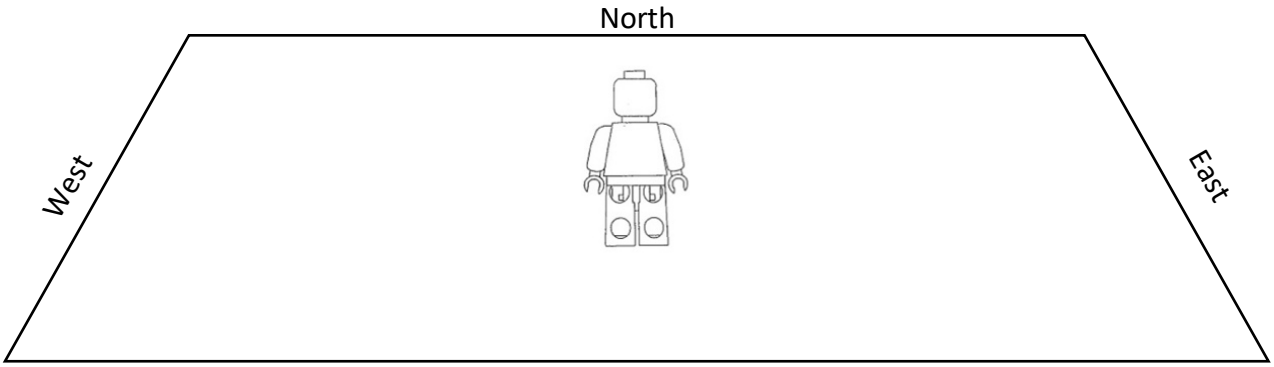


STEP 2: Notice the minifig standing on the Earth. This represents an observer standing on the equator facing North, as it did in prior activities. Where is the North Pole? Mark it on the diagram. Which way is the Earth rotating? Indicate it on the diagram with a small curved arrow.

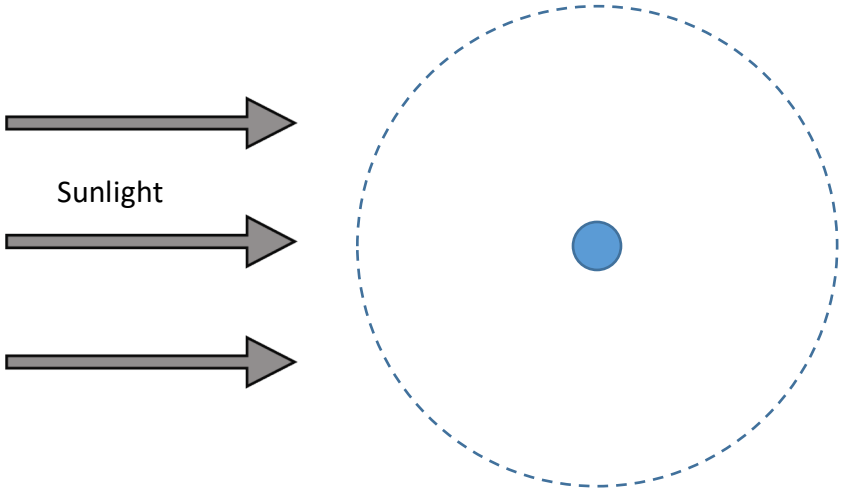
STEP 3: Draw a line on the above space diagram to represent the observer's horizon. Carefully label the ends of the horizon E and W.

[2] This part adapted from the Hands-on-Science lab manual from UTeach, College of Natural Sciences, The University of Texas at Austin.

STEP 4: Where in the observer's sky are the Sun and Moon; that is, in what direction and how high above the horizon? Draw them on the sky diagram below.



STEP 5: Now suppose the Earth has rotated through a quarter of a day. Draw the observer on the diagram below (next page) in the appropriate position and add and label the observer's horizon.



STEP 6: Add the Moon to the diagram above. Will the Moon have moved very much in a quarter day (6 hours)? Why or why not? *Hint*: How long does it take the Moon to complete one full orbit of the Earth (look back at the box on page 2 if you're unsure)?

STEP 7: For this new observer at this time, where is the Sun?

Where is the Moon? How does this compare to the position of the Sun?

STEP 8: Imagine an observer on a different part of the Earth that can still see the Moon (say, a quarter of the way around the Earth from our current observer). What Moon phase will that observer see?

Where will the Moon be for that observer (in what direction and how high above the horizon)?

SQ6:

a) Does the phase of the Moon that you see depend on where you are on Earth's surface? Why or why not?

b) What is the angle between the Sun and the Moon when the Moon is Full?

c) You see a Full Moon on the Western horizon. Where is the Sun in your sky and what time must it be?

Now we are going to change the Moon phase and do a similar analysis. This time, we will use the polystyrene ball model again.

STEP 9: Have one person in your group stand about 5-10 feet away from the light bulb. This person's head will be the Earth. An imaginary observer is standing on his/her nose.

Have another person hold the polystyrene ball at the appropriate location so that it is the First Quarter Moon.

STEP 10: The person who is the Earth should turn so that it is noon for the observer on their nose. First verify that the observer would in fact see a First Quarter Moon at noon.

What is the angle between the Sun and the Moon? You can hold out your arms, one pointing at the Moon and one at the Sun, to help you judge the angle.

STEP 11: Have the Earth rotate slowly through one full day while the Moon holder stands still. Observe what time the Moon rises and sets (from the perspective of the person standing on your nose) and record them here. If it's helpful, you can hold your hands next to your face, like we've done before, to model the horizon for someone on your nose.

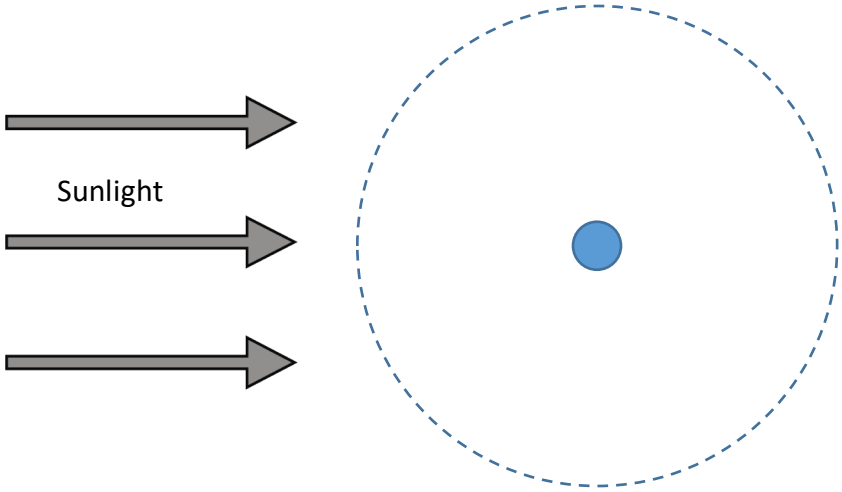
First Quarter Moonrise:

First Quarter Moonset:

Will the Moon have changed its phase much during this time between Moonrise and Moonset? Why or why not?

Does your previous answer match your everyday experience? In other words, when you see the Moon, and then see it again a few hours later, has the Moon phase changed or stayed the same?

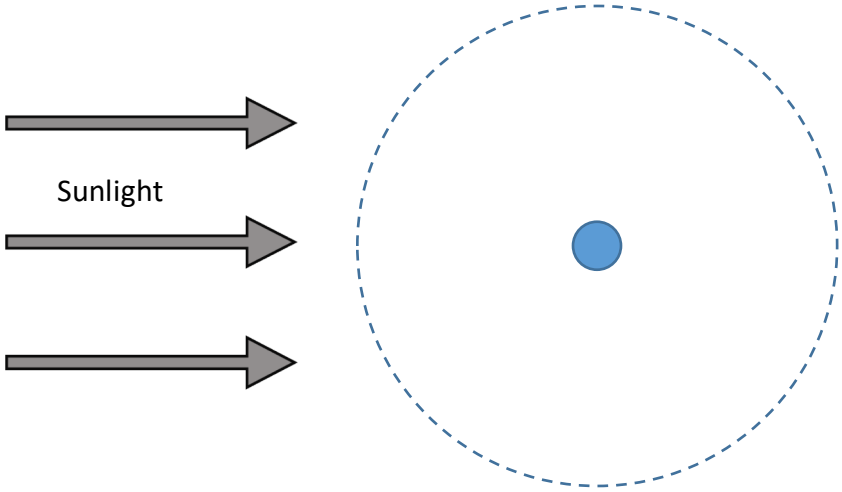
STEP 12: In the diagram below (next page), draw the Moon in the correct position in its orbit when it is a First Quarter Moon.



The North Pole of the Earth is in the center of the circle representing the Earth. Draw an observer, standing on the equator, such that the First Quarter Moon is *directly overhead* of that observer. Draw the observer's horizon and carefully label the ends "E" and "W".

You will use this diagram to answer SQ7a.

STEP 13: Repeat the previous Step for the Third Quarter Moon using the diagram below. You will use this diagram to answer SQ7b.



SQ7:

a) When the First Quarter Moon is directly overhead, where is the Sun in your sky and roughly what time is it?

b) When the Third Quarter Moon is directly overhead, roughly what time is it?

(Optional) STEP 14: Open the following URL:

https://www.google.com/doodles/earth-day-2013

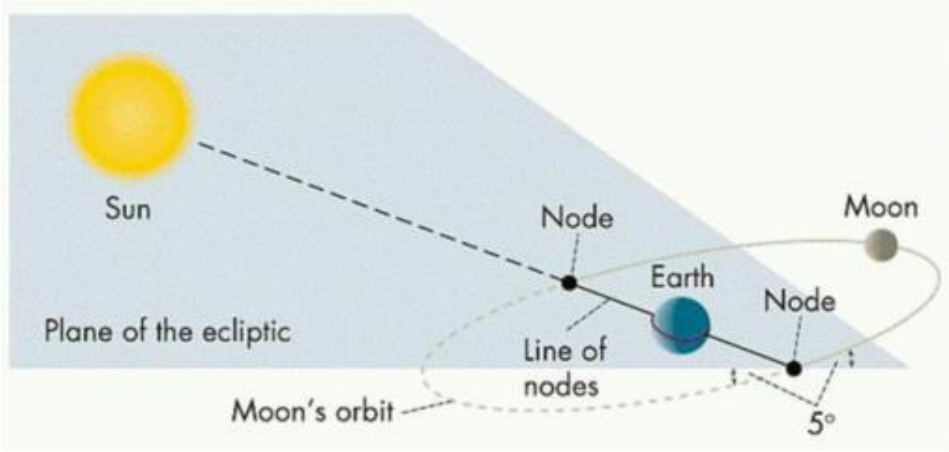
This was the Google Doodle (Google's front page logo) on Earth Day 2013. Watch the animation for one or two cycles of day and night. What is incorrect about the Moon phases as depicted in the Doodle? *Hint:* Pay attention to what time of day the Moon rises and ask yourself what the Moon phase should be if it's rising at that time.

What common misconception about the Moon do you think our friends at Google probably share with most of the population?

Part 4: Eclipses

The Moon's orbit is tilted with respect to the ecliptic. Recall that the **ecliptic** is the plane of the Earth's orbit around the Sun. The Moon's orbit is tilted by about 5 degrees with respect to the ecliptic (see diagram next page, credit: *Encyclopedia Britannica*).

An eclipse happens only when the Earth, Sun, and Moon all lie along the same line. Therefore, an eclipse can only happen when the Moon is *in the plane of the ecliptic*. In fact, that's why the plane is called the *ecliptic* in the first place.



STEP 1: The diagram above shows that the Moon spends half of its orbit "*above"* the ecliptic (the solid line portion of its orbit) and half of its orbit "*below"* the ecliptic (the dotted line portion of its orbit). The points where the Moon's orbit crosses through the ecliptic plane are called **lunar nodes**. Looking at the diagram, how many times does the Moon pass through the ecliptic in a single orbit around the Earth?

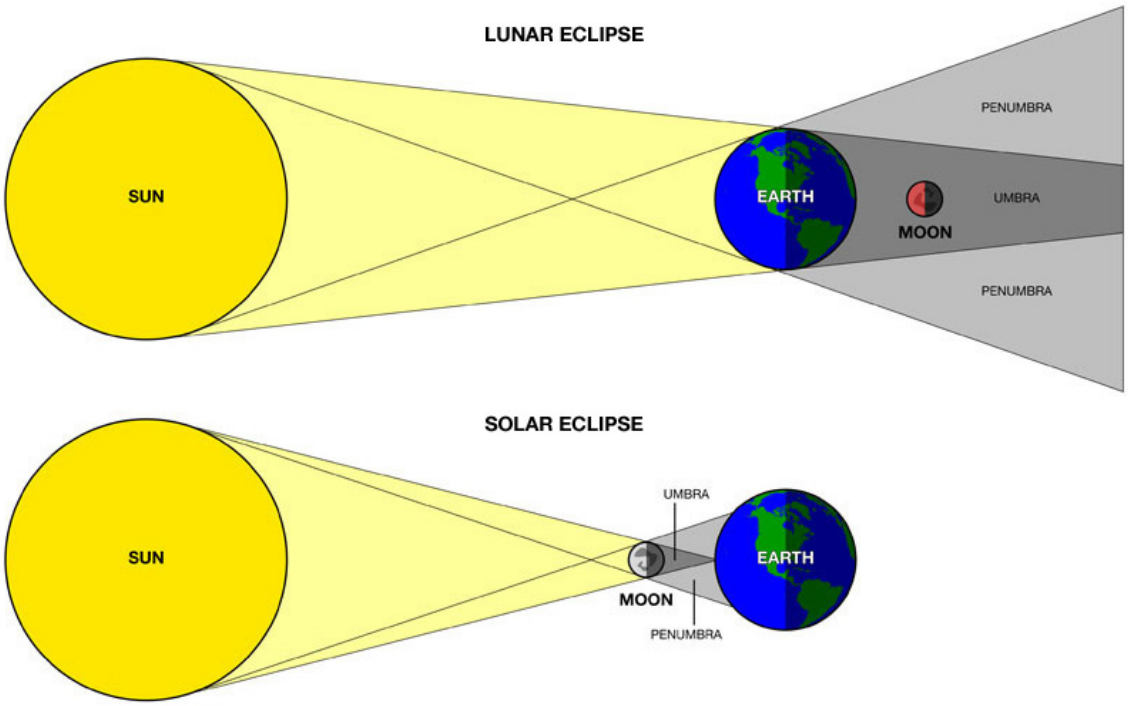
How many times a month is the Moon in the same plane as the Earth and Sun? Hint: What defines a month? Now compare this question to the previous question!

Aside from the lunar nodes, for the rest of the month the Moon is either "above" or "below" the plane of the Earth and Sun.

Do we have eclipses twice every month? No, and this is because not only does the Moon need to be in the same plane as the Earth and Sun (i.e., in the ecliptic), but the three bodies (Earth, Moon, and Sun) have to line up in a straight line, too. This only happens during certain Moon phases. Let's investigate that.

STEP 2: Consider the **lunar eclipse** in the drawing below (next page). This is an eclipse in which the Earth lies between the Moon and the Sun, so the Earth casts a shadow on the Moon making it appear dark.

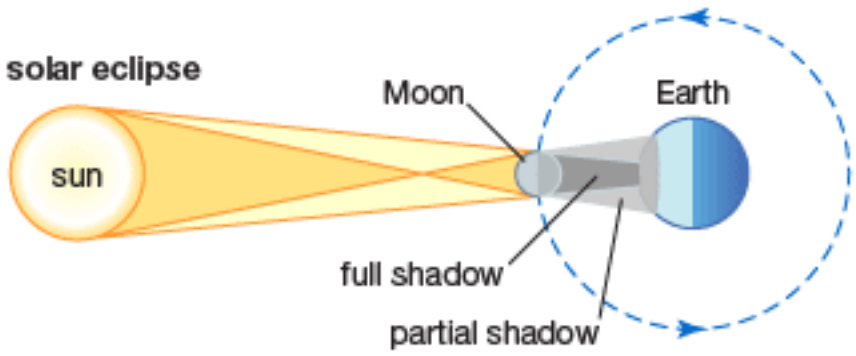
What Moon phase is it when a lunar eclipse occurs? How can you tell?



STEP 3: Consider the **solar eclipse** in the drawing above. This is an eclipse in which the Moon lies between the Earth and Sun. This has the effect of blocking out our view of the Sun from the Earth, causing darkness even in the middle of the day.

What Moon phase is it when a lunar eclipse occurs? How can you tell?

Returning to the solar eclipse, consider the diagram below and notice the umbra (full shadow) and penumbra (partial shadow). Everyone inside the **umbra** will see a **total** eclipse of the Sun. Everyone inside the **penumbra** will see a **partial** eclipse of the Sun.



Only those in the shadow (either umbra or penumbra) will be in line to see an eclipse (total or partial).

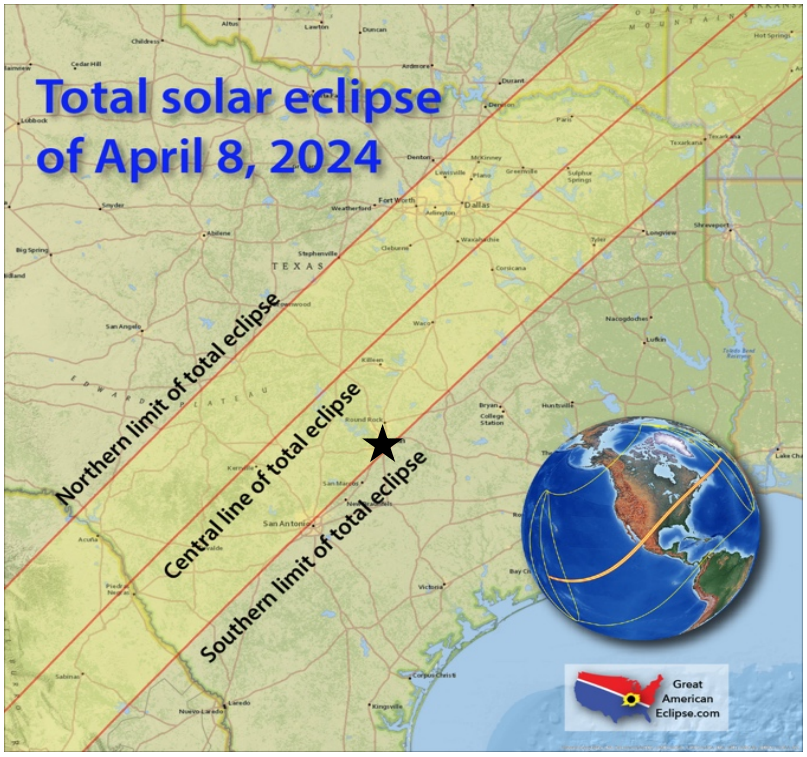
Looking at the sizes of the umbra (full shadow) and penumbra (partial shadow) on the Earth's surface, are more people on Earth going to see a partial eclipse or a total eclipse?

Are more people on Earth going to see an eclipse (of any kind) or no eclipse at all? How can you tell?

We are lucky here in Austin. The solar eclipse that occurred in 2017 was visible in North America because the umbra fell on North America. (Did you happen to see it? From Austin it would've been a partial eclipse.)

And during the next solar eclipse, in 2024, not only will the umbra fall on North America, but it will pass directly through Austin! (See map at right.) Therefore, we will see a total eclipse here in Austin.

This will happen on April 8, 2024.



SQ8:

To summarize, a solar eclipse happens when the Moon's orbit crosses

_____ at the same time as the moon phase is

_____.

And, a lunar eclipse happens when the Moon's orbit crosses _____

at the same time as the moon phase is _____.

Optional Challenge Question: If the plane of the Moon's orbit weren't tilted at all with respect to the ecliptic plane (i.e., instead of 5°, the Moon's orbit is tilted 0° with respect to the ecliptic plane), how often would we have solar and lunar eclipses? *Hint*: Think about how much time the Moon would spend in the ecliptic plane, and then apply your answer to SQ8.