Questions

What is meant by Moon's *changing illumination condition*? What is the underlying mechanism causing this phenomenon?

Materials Needed

For this activity, you will need the following materials:

- your lunar observations that were done earlier in the course
- a darkened room, the darker the better but total darkness is not necessary
- a light source to represent Sun
- a dylite (or styrofoam) ball to represent Moon
- your head to represent Earth, with your eyes representing those of an Earthly observer
- a lollipop stick to hold the dylite ball and a toothpick (or pin)
- a ruler
- a pencil (do not use ink)
- the ability to read and follow directions

Points To Remember

The same advice about terminology in previous shadow activities applies in this activity as well.

For this specific activity, do not use the terms "phase," "waxing," "waning," "new," "crescent," "gibbous," "quarter," or "full" alone or in combinations until explicitly asked to do so. Do not use the term "shadow" unless a question specifically asks you to. When specifying times, do not use "12:00" as a substitute for "noon." Do not use the terms "rotation," "revolution," or "orbit" at all.

1 Just The Facts

1.1 Establishing The Basics

The answers to some of these initial questions may seem easy, maybe even obvious, to you. If that is the case, then you are in an excellent position to help your fellow students to thoroughly understand the underlying concepts. Remember that no matter how simple an idea seems to you, it is likely to be very difficult to someone else, especially someone else who has never been exposed to that idea before. If you have never been exposed to the concepts in this activity before, then take the time to explore and absorb them. That is one purpose of this course.

Be patient and make certain you understand what is being asked in each question. Take care to make certain your responses clearly address the questions being asked.

When we look at a spherical object, we do not see it as spherical. We see it as a *flat disk*, and we can refer to it as a disk even though we may already know it is spherical.

1.1.1 Place 1

Randomly pick a location in the room and stand in that location with your Moon held in your hand with your arm fully extended in a random direction. Do not change the direction in which your arm is pointing until asked to do so. Take care not to let your body or anyone else's body interfere with your Moon's appearance. None of the questions you will be asked has anything to do with your body or any part thereof.

Look at your Moon. Stick the toothpick into Moon so that it is at the center of Moon's disk **as you observe it**. Use the lollipop stick to hold Moon so your fingers are not on Moon. Determine how much of Moon's **entire** surface faces you right now and express this as a percentage (0%-100%).

Look at your Moon. Determine how much of Moon's **entire** surface is illuminated and express this as a percentage (0%-100%). You will have the opportunity to come back and modify your response to this question, so do not worry about getting the correct answer now. **This question has nothing to do with how much of any illumination you observe while holding your Moon. It only addresses the issue of how much of Moon's entire surface is illuminated by Sun.**

Make certain you are supporting Moon with the lollipop stick, your arm is fully extended, and the toothpick is at the center of Moon's disk. Estimate how much of Moon's **illuminated surface** faces you. Do not obsess over exactness here, just provide an estimate expressed as a percentage. **This question is not the same as the previous question. It addresses the issue of how much of the illuminated surface of Moon faces you.**

Once again make certain you are supporting Moon with the lollipop stick, your arm is fully extended, and the toothpick is at the center of Moon's disk. Estimate how much of Moon's **unilluminated surface** faces you. Do not obsess over exactness here, just provide an estimate expressed as a percentage. **This question is not the same as the previous question. It addresses the issue of how much of the unilluminated surface of Moon faces you.**

What is the value of the sum of the two percentages you just estimated? Is this what you would have predicted? Why?

Now pretend that you are far above the room looking down on this activity. You can see everyone and everything involved. The answer box below (it may be on the next page) is approximately the same shape as your classroom. Orient the box any way you desire so as to represent your classroom and draw a dot to represent Sun, a circle of about 2 cm diameter to represent Moon, and a small stick figure to represent you. They must be drawn with the same *relative* positions as in the actual situation. If you do not know what *relative* means in this context, ask your instructor. The circle and stick figure must not be too close together.

Use your ruler (do not freehand it) to draw a line connecting Sun and Moon's center, and extend it beyond Moon's center. This line represents the *line of sight* from Sun to Moon.

Use your ruler (do not freehand it) to draw a line dividing Moon into two halves. One half should directly face Sun and the other half should face opposite that direction. **As a hint, note that this line should be perpendicular to the line of sight from Sun to Moon.**

With your pencil, shade in the unilluminated portion of Moon. Leave the illuminated portion white. At this point, you may wish to go back and revise the answer to a previous question.

Use your ruler (do not freehand it) and draw in the line from the observer's (your) eyes to the center of Moon. This line represents the line of sight from Earth to Moon. It lets you picture what the observer is looking at. **As a hint, the toothpick should lie along this line.**

Use your ruler (do not freehand it) to draw another line dividing Moon into two halves. One half should directly face the observer and the other half should face opposite that direction. **As a hint, note that this line should be perpendicular to the line of sight from Earth to Moon.**

Based on your drawing, predict how the observer (you) would describe Moon's visual appearance in one or two sentences. Your description should only contain references to the illuminated and unilluminated portions of Moon. See how consistent this prediction is with your observations in previous questions.

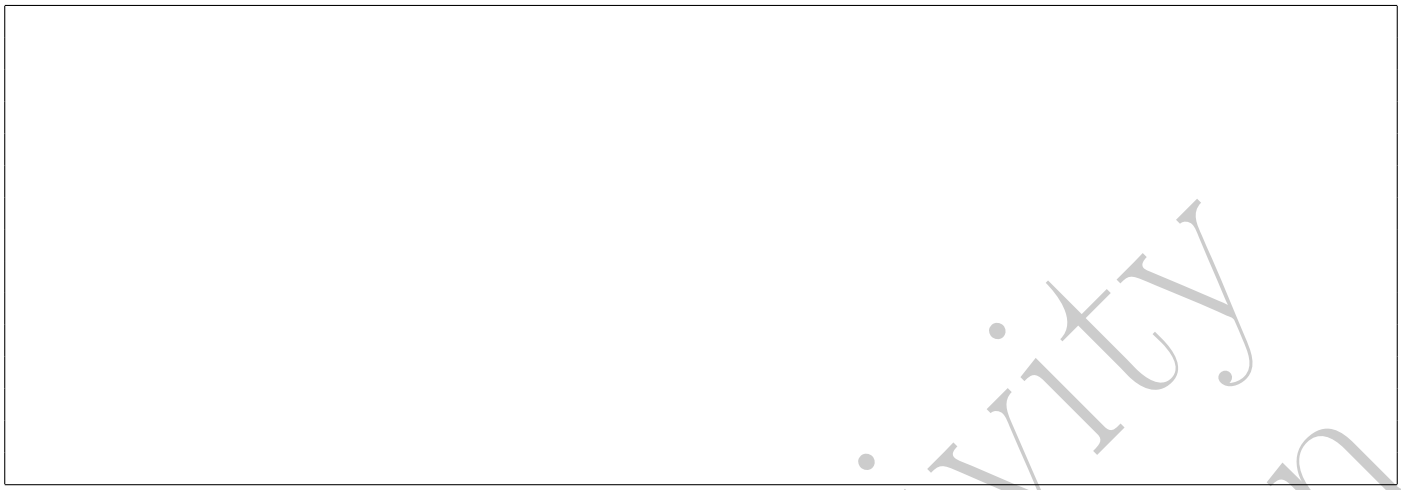
Make absolutely certain you understand **everything** you just did. Successful completion of this activity relies on your understanding of this first part. Ask your fellow students for help if you need to.

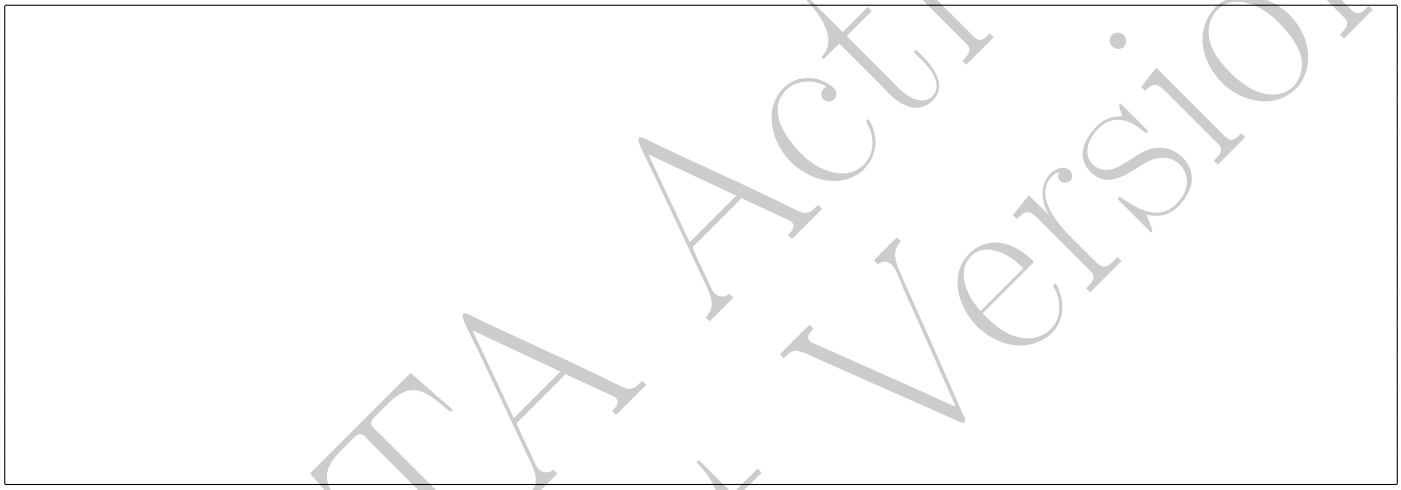
——— CHECKPOINT ———

1.1.2 Three Other Places

Repeat the activity three times by randomly choosing three additional locations in the room at which to stand and a new random direction for your outstretched arm at each location. Fill in the table, and do three other drawings.

	% facing you	% illuminated	% ill. surface facing you	% unill. surface facing you	sum of prev. two percentages
Location 1					
Location 2					
Location 3					
Location 4					





1.2 Sanity Check

Look at **your** observations from all four previous locations and think about the illumination condition at each location. Did anything stay the same from location to location? If so, what? Did anything change from location to location? If so, what?

As a class, look at **everyone's** observations from all locations and think about the illumination condition at each location. Did anything stay the same from location to location? If so, what? Did anything change from location to location? If so, what?

CHECKPOINT

2 Moving Around Earth

Choose one student to hold Moon and another student to hold Sun. The remaining students huddle in the center of a large circle. The huddling students collectively represent Earth. Moon and Sun can simultaneously stand anywhere around the circle, but they must stand so that Earth sees none of Moon's illuminated side. Everyone at the circle's center must agree on where Moon should be relative to Sun.

Now, as a first attempt at simulating your real lunar illumination observations, Moon stays stationary while Sun moves around the circle.

Describe the motions necessary to replicate the illumination patterns you have observed **as accurately as possible.** Be precise in your description, especially regarding directions and relative positions. It may be helpful to use objects in the room or features on the wall as distant "celestial reference points" (e.g. stars) in describing what you observe.

Repeat this part of the activity so that every student can experience every perspective. **Observers must unanimously agree on what is observed and how to describe it.**

——— CHECKPOINT ———

3 Moving Around Sun

Choose one student to hold Moon, another student to hold Sun, and another student to be Earth. Put Sun at the circle's center. Earth and Moon now must figure out how to move so as to exactly replicate the sequence of illumination patterns observed previously.

Describe the motions necessary to replicate the illumination patterns you have observed **as accurately as possible.** Be precise in your description, especially regarding directions and relative positions. It may be helpful to use objects in the room or features on the wall as distant "celestial reference points" (e.g. stars) in describing what you observe.

Repeat this part of the activity so that every student can experience every perspective. **Observers must unanimously agree on what is observed and how to describe it.**

——— CHECKPOINT ———

4 Science

Make a list of **no more than ten** explanations you can think of to explain Moon's changing illumination conditions. Don't worry about an explanation being correct or incorrect. You're basically just brainstorming here. Consider **everything** you can think of no matter how far fetched it may sound.

For each explanation you came up with in the previous question, rule out **as many as you can**. For each explanation that is ruled out, give the justification for ruling it out. Be as specific as you can and feel free to cite **evidence** from the activities you have done. You may need to carry out additional simulations and activities to rule out some of your explanations that can't otherwise be ruled out. You may not be able to construct a simulation or activity for some of your explanations. If this is the case, think about what this means.

If there are any explanations for which you cannot construct a simulation or activity, list them here.

At this point, you should only have one remaining explanation, and it is most likely the correct one. **The process you have just gone through to get the most probable explanation is called *science*.** Learning to rule out explanations based on evidence is an important part of *critical thinking*, and critical thinking is an important part of science.

What is the underlying mechanism causing Moon's changing illumination conditions?

——— CHECKPOINT ———

5 Inquiry

You have no doubt read or heard about lunar *phases*. Based on this activity, formulate an operational definition of what is meant by the term *phases*.

You have also no doubt heard of specific names given to specific illumination conditions of Moon's disk. Formulate an operational definition of what is meant by *full* when referring to the appearance of Moon's disk.

Formulate an operational definition of what is meant by *new* when referring to the appearance of Moon's disk.

Another term you may have heard is *quarter*, but this term is slightly misleading in that it does not directly refer to Moon's visual appearance. Instead, the term *quarter* refers to being one fourth or three fourths of the way through an illumination cycle. Knowing this, formulate an operational definition of what is meant by *quarter* when referring to the appearance of Moon's disk.

Formulate an operational definition of what is meant by *crescent* when referring to the appearance of Moon's disk.

There is one more technical term, *gibbous*, used in astronomical terminology. Its operational definition should be simple to figure out because it is the only remaining possible combination of illuminated and unilluminated halves. Formulate an operation definition of what is meant by *gibbous* when referring to the appearance of Moon's disk.

Having now operationally defined specific terms for specific illumination conditions, we can now operationally define two more specific terms. While Moon transitions from *new* to *full*, the portion of the illuminated side facing the observer (or indeed, Earth) increases. This is the operational definition of *waxing*. While Moon transitions from *full* to *new*, the portion of the illuminated side facing the observer (or indeed, facing Earth) decreases. This is the operational definition of *waning*. Now we have a way of distinguishing between the two *crescent* illumination conditions, the two *quarter* illumination conditions, and the two *gibbous* illumination conditions.

A disturbingly large fraction of both students and laypersons, when asked to explain the underlying cause of lunar phases, cites Earth's shadow as the cause. Cite evidence from this activity that eliminates this hypothesis. Be as specific as you can. You may use the term "shadow" in your response.

During any part of this activity, did Sun's position with respect to the walls and corners change? If so, describe what was happening during the change.

During any part of this activity, did Earth's position with respect to the walls and corners change? If so, describe what was happening during the change.

Choose **any** desired lunar illumination condition. To make life easy, choose one of the four main ones from the questions above. For your chosen lunar illumination condition, simulate the geometry necessary to produce that illumination condition **twice, once with Earth at the center of the circle and once with Sun at the center of the circle.** Sketch **both** simulations in the space below and clearly label the objects involved. Also indicate which object is at the center of the circle. It should be explicitly clear which diagram is which. The diagrams should be as neat as possible.

If you see any discrepancies between the two simulations, discuss them here.

If you see any similarities between the two simulations, discuss them here.

Discuss which of the two diagrams best explains the observed lunar illumination condition.

Formulate an explanation, as concisely and as accurately as possible, for the changes we observe in Moon's illumination. The explanation must be consistent with both of the above simulations.

It is an observational truth that if a full moon is observed in a particular constellation, the very next full moon will be observed in the next constellation toward the east along the ecliptic. Formulate an explanation for this and reduce it to one well constructed sentence. (Hint: Use *science*!)

When Moon is crescent, you can usually observe the part of the unilluminated side facing Earth. This is called *earthshine* and is the result of sunlight reflected from Earth to Moon and back again. As Moon waxes, earthshine becomes more and more difficult to see. Explain why this happens in one or two sentences.