Lunar Observation Lab:

Understanding the motion and phases of the Moon

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Learning Goals

In this activity, you will learn the names for the phases of the Moon and that the phases are caused by the position of the Moon in its orbit with respect to the Sun and Earth. Students will also gain practical experience in naked-eye observations with detailed, recorded notes, including sketches. Specifically, students will:

1) Address the misconception that the phases of the Moon are caused by Earth's shadow falling on the Moon. THIS IS NOT TRUE. The phases of the Moon are caused by the geometry between the Sun, Earth, and Moon.

2) Understand the connections of the phases of the Moon and what time the Moon is up in the sky.

3) Understand the difference between the synodic and sidereal periods of the Moon.

3) Learn how to accurately document observations.

Lab Abstract

The Lunar Observation Lab provides the student with practical experience in naked-eye observations of the Moon. The student will make detailed naked-eye observations of the Moon over a minimum of a five-week period. Specifically, the observations are to identify the phase of the Moon and its location in the sky (direction and altitude) over a time period slightly longer than full lunar cycle In doing so, the student will experience a full set of phases of the Moon and participate in a series of exercises design to increase understanding that the phases of the Moon are the result of the location of the Moon in its orbit relative to the Sun and the Earth. The phases of the Moon are not caused by Earth's shadow, but rather by what portion of the Moon that is illuminated by the Sun (in sunlight) a person on Earth can see. In this lab, the student will make a minimum of 10 lunar observations and document the time, date, direction, altitude, and phase of the Moon. Additionally, the student will provide three sketches of the Moon: 1) A sketch of what the Moon looks like at the time of observation; 2) a sketch of where the Moon is in the sky at the time of observation; and 3) an indication of where the Moon is in its orbit at the time of observation.

Fig. 1. *The Lunar Cycle of phases excluding the New Moon, which cannot be seen. The full cycle is shown starting at the upper left (Waxing Crescent) and proceeding from left-to-right row-by-row, to the lower left (Waning Crescent). For reference, the first three depicted phases would all be referred to as Waxing Crescents, and the first two Moons of the second row would both be Waxing Gibbous Moons.*

1. Background

It is a common misconception that the phases of the Moon are caused by Earth's shadow falling on the surface of the Moon blocking out some of the light. THIS IS NOT TRUE. On relatively rare occasions, Earth's shadow does fall on the Moon, but that is what causes Lunar eclipses, not the phases of the Moon. Additionally, for this to be the case, the Moon would have to be positioned in its orbit so that the Earth's shadow can fall on it. If you think about the Moon orbiting around and around the Earth, the opportunity for Earth's shadow to fall on the Moon will only occur once per trip around the Earth when the Sun, Earth, and Moon are all in a line with the Moon on the opposite side of the Earth. This simple thought experiment is enough to show us that the Earth's shadow falling on the Moon is an incorrect explanation for what causes the phases of the Moon. What then, is the reason for the lunar cycle of Moon phases?

1.1 The Lunar Cycle of Phases

Why is it that night after night, the appearance of the Moon slowly changes? Over the course of 29.5 days, the Moon will slowly change its appearance in the sky, such that after approximately one month, the Moon will return to the same appearance and start the cycle over again. We refer to the specific appearances the Moon takes over the 29.5 day cycle ***phases.*** Starting with the bright part of the Moon appearing as a thin crescent, day by day, the phase will change from a crescent, to half illuminated, to fully illuminated, and then the pattern seemingly reverses and the less and less of the visible Moon surface can be observed until it can't be seen at all. It will then start all over again going through the exact same series of appearances over the same time period of 29.5 days. Starting with the phase where we cannot see any of the illuminated part of the Moon, the ***New Moon*** phase, on each successive night we will see a bit more of the right hand side of the Moon illuminated as it goes through what is known as a ***Waxing Crescent***; eventually it will become a half-illuminated disk, the ***First Quarter***, and then with each passing night, we will more than 50% of the right-hand side illuminated in what is called the ***Waxing Gibbous,*** and ultimately, after about two weeks have passed, the full disk of the Moon will be illuminated in the ***Full Moon***. During this stage, when more of the more is visible night-to-night as it goes from a ***New Moon*** to a ***Full Moon***, we say the Moon is ***waxing***. After the ***Full Moon***, we begin to see less and less of the Moon illuminated night after night, with the left-hand side now bright. While more than half of the left-hand side of the Moon is illuminated, the Moon is in a ***Waning Gibbous***; at half-illuminated disk it is known as the ***Third Quarter***; and at less than half, the Moon is a ***Waning Crescent***. Finally, it returns to our ***New Moon*** starting point where we are cannot see any of the sunlit part of the Moon. During this stage of the left-hand side being bright and a little less of it visible night after night, we say the Moon is ***waning***. This 29.5 day ***Lunar Cycle of phases*** (hereafter, Lunar cycle) defines the ***synodic period*** of the Moon, or rather the time it takes to complete one full cycle of phases. Images of the ***phases*** of the ***Lunar Cycle*** are shown in Fig. 1.

Note that in the preceding description of the ***waxing phases*** being bright on the right-hand side and the ***waning phases*** bright on the left-hand side is the Lunar cycle for the Northern hemisphere. If we were to describe the ***Lunar Cycle*** in the Southern hemisphere, the ***waxing phases*** would be bright on the left-hand side, and the ***waning phases*** would be bright on the right-hand side.

1.2 The cause of phases

The Moon is a large (R = 1,738 km), mostly rocky sphere that orbits the Earth. Since it is a rocky body, like the Earth, it gives off no light of its own, but rather it "shines" due to sunlight reflecting off its surface and eventually reaching us here on Earth. That means that half of the Moon's spherical surface is in daylight at any given time; again, just like the Earth. What changes, is what part of that sunlit portion of the Moon we can see here on Earth.

It is difficult to picture the spherical Moon orbiting around the Earth once every 27.3 days (the ***sidereal period)*** at an average distance of 384,400 km (238,900 mi), while the Earth itself is orbiting the sun at distance of 149,600,000 km (93,000,000 mi) once every 365.25 days. However, this orbital motion determines how much, if any, of the sunlit part of the Moon we can see from Earth. The portion of the sunlit side we can see from Earth is what gives each ***phase*** its appearance. To help imagine this motion and the view of the Moon from Earth, Fig. 2, provides a not-to-scale view of the Earth-Moon system with sunlight coming in from a relatively very far off distance. In Fig. 2, eight orbital positions of the Moon are depicted showing the nominal points in the orbit for each of the Moon ***phases***. For this figure, we assume we are looking down onto the North Pole of the Earth. In this standard view, the Earth and Moon's rotation and orbital direction are counter-clockwise.

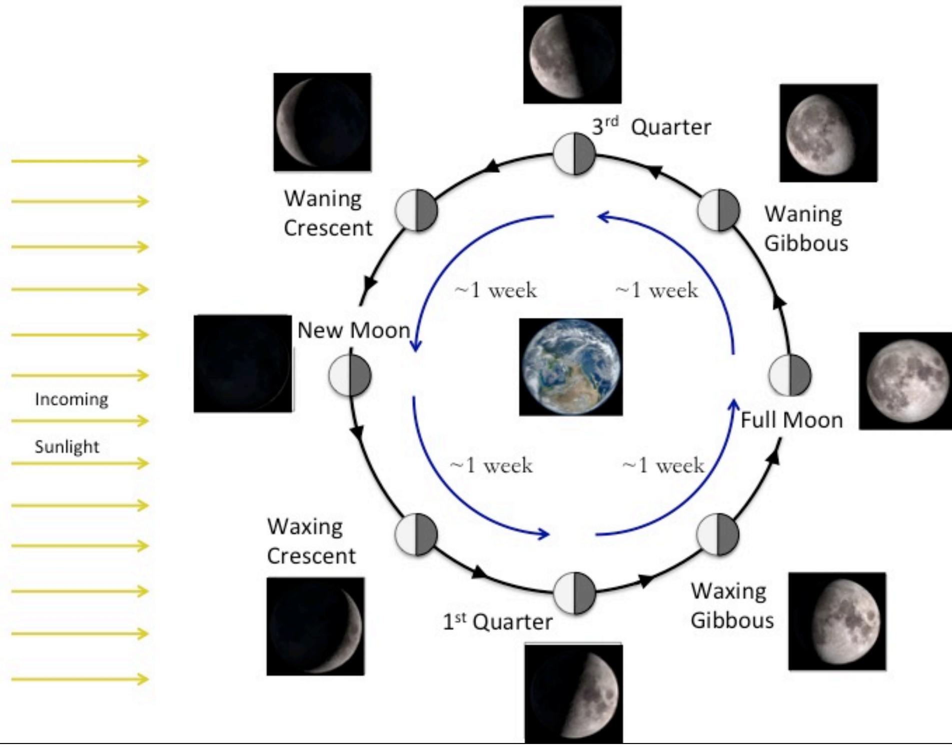

Fig. 2. *The Lunar Cycle depicted on the orbital path of the Moon. The eight shown Moons are the locations in the Moon's orbit for the eight Moon phase names. In this image, we are looking down onto the North Pole of the Earth, which rotates counter-clockwise (ccw). The Moon also orbit ccw, and completes a quarter of it's 29.5 day synodic orbit in approximately one week.*

In order to fully picture what each phase looks like as viewed from Earth, you must imagine yourself standing on Earth looking up toward the Moon. With this in mind, you can see that while the Moon is ***waxing*** that right-hand side of the Moon will be bright; and that while the Moon is ***waning*** the left-hand side of the Moon will be bright. As the ***Lunar Cycle*** of phases lasts 29.5 days, in approximately one week, the Moon will move about a quarter of the way around its orbit (4 x 7 = 28 days; close to the 29.5 days). This means that it takes about 1 week for the Moon to go from ***New Moon*** to ***First Quarter***; another week to go from ***First Quarter*** to ***Full Moon***; another week to go from ***Full Moon*** to ***Third Quarter***; and finally another week to go from ***Third Quarter*** back to ***New Moon***. Notice that this cycle takes about one ~~moonth~~ month to complete.

1.3 The difference between Sidereal and Synodic Periods

So far, two cyclic time periods have been mentioned for the Moon. The first being the 29.5 days it takes from the Moon to complete a full cycle of phases, or rather go from New Moon to New Moon, or equivalently, Full Moon to Full Moon. This 29.5 day time period for the ***Lunar Cycle*** is the ***synodic period*** of the Moon. The second cyclic time period is the 27.3 days, or ***sidereal period***, it takes the Moon to complete a full 360° orbit around the Earth. Why is it that the time period to complete a cycle of phases is about two days longer than it takes the Moon to orbit the Earth?

To understand this two-day difference, we have to account for both the Moon's orbital motion around the Earth, and the Moon's orbital motion around the Sun. While the Moon is completing its orbit around the Earth in 27.3 days, the Earth is also moving along its orbit. Specifically, in 27.3 days, the Earth will move about 7.5% (100 x 27.3 days/365.25 days) along its orbit. This means that after 27.3 days, the angle that between imaginary lines that connect the Sun and Earth, and the Earth and Moon is about 27° (0.075 x 360° = 27°). From Fig. 2, we see that the Sun-Moon-Earth must be in a straight line, or rather the angle between the Sun-Earth and the Earth-Moon lines must be 0° for it to be a New Moon. In order for the Moon to get back to a New Moon and complete the New Moon to New Moon ***synodic period***, the Moon must orbit the additional 27° degrees. This will get the alignment back to the Sun, Moon, and Earth being in a perfectly straight line. Using the fact that the Moon travels 360° in 27.3 days, we can determine that the Moon moves about 13.2 degrees per day (360 degrees/27.3 days = 13.2 degrees per day). So, it takes about two addition days to travel the additional 27.3 degrees, thus explaining the two-day difference between the ***sidereal*** and ***synodic periods***. An astute reader, will have noticed that during that additional two day period, the Earth will still be moving in its orbit around the Sun, and this will create an additional angular difference the Moon must "catch up" to in order to get back to a New Moon. This additional angular difference explains why the more precise time difference between the ***sidereal*** and ***synodic periods*** is 2.2 days instead of just barely over 2.0 days.

Observation Instructions

For this lab, you are going to make a series of at least ten observations of the Moon over the next five weeks. The goal of these observations are to help you understand that it is the location of where the Moon is in its orbit that determines the phase of the Moon, what each phase looks like, the order of the lunar phases, and what times of day the Moon is up for each phase. Each observation will consist of going outside at a time the Moon is up (if it is up within your normal waking hours, whatever those my be); locating where the Moon is in the sky with respect to direction and altitude; identifying the phase of the Moon; and making a series of three drawings related to the observation. Specifically, your task will be to carefully record the details about your lunar observation, sketch what that particular phase of the Moon looks like; draw where the Moon appears with respect to the horizon and meridian; and finally indicate where the Moon is in its orbit with respect to the Sun and the Earth at the time of observation.

The instructions on how to record these observations on the Observation Sheets are provided below. Additionally, you can find an example of a filled out Observation Sheet on the lab website. It is suggested that you make your observations at nearly the same time every day. You will notice, however, that eventually the Moon will no longer be up at that time, so adjust your observation time accordingly (Hint: The Moon rises about 50 minutes later each night, until it cycles around the clock.)

<u>INSTRUCTIONS</u>: For this lab, you must complete TEN Observation Sheets of the Moon. You should make two observations per week for the next five weeks. Your lab instructor will check your observations sheets roughly half way through your observations to ensure that you are doing them correctly. This check in is a grade portion of the lab. In addition to the TEN observation sheets, you will need to answer the ten questions at the end of this lab.

<u>Step 1, Lunar Observation Documentation:</u>

An important part of making any observation is to have accurate records of that observation. In general, observation logs should include detailed notes including when the observation was made, all the details of that particular observation (who made them and what was observed), the conditions under which it was made, any events outside of the norm that occurred, and any other notes the researcher might find useful at a later date. In the case of your Lunar Observations, you will record this information in the upper left panel of your Observation Sheets. Prompts with blank spaces to write in the relevant information have been provided. Please write your name in the space for your name. Also, record what observation number this is in the sequence of your ten observations, and put the date that the observation was made.

For "Direction" you need to record what direction in the sky the Moon appeared in to the best of your ability. For this, it is recommended that you download a compass application for you smart phone and record the direction based on a compass reading. For example, due North (N), East (E), South (S), and West (W) would be 0°, 90°, 180°, and 270°, respectively. If you use a compass, record your best estimate of the angle the Moon appears at. If you do not have access to a compass, record your direction as to the best of your ability using the information provided in Table 1. For example, you can record the direction as SW or write 225°.

Table 1. Degrees for nominal directions

Direction	Abbreviation	Angle (degrees)
North	N	0
North East	NE	45
East	E	90
South East	SE	135
South	S	180
South West	SW	225
West	W	270
North West	NW	315

For "Altitude" you need to record your best estimate of what altitude the Moon appears at during your observation. Astronomers measure altitude in number of degrees above the horizon (regardless of what direction you are facing), such that an object on the horizon is 0°, and an object directly above your head, or what is known as your ***zenith***, is 90°. The imaginary line that goes from due South to due North and passes through the ***zenith*** is called the ***meridian***. When an object crosses your local meridian (known as ***upper culmination***), it will be at its highest altitude for that day. An example of how astronomers use direction, altitude, zenith and meridian is provided in Fig. 3. Notice that the combination of altitude and direction uniquely define the position of the Moon in your observation.

For "Phase" you need to record the phase of the Moon as you observe it in. For the phase names, please refer to Fig. 2. Note that while only eight phase names are given, the Moon will have one of these phase names applied to it for every night during a lunar cycle. Record any thin to thick crescent/gibbous as either a Waxing or Waning Crescent/Gibbous. If the disk of the Moon is close to half illuminated, but it is difficult to tell if it is more or less than 50% illuminated, then recording the phase as ***First*** or ***Third Quarter*** is appropriate.

The space "Additional Notes" is provided to you for to write any additional notes you think are relevant for your observation. An example might be, "Partially obscured by clouds", or any other information you might want to remember later or provide to your instructor.

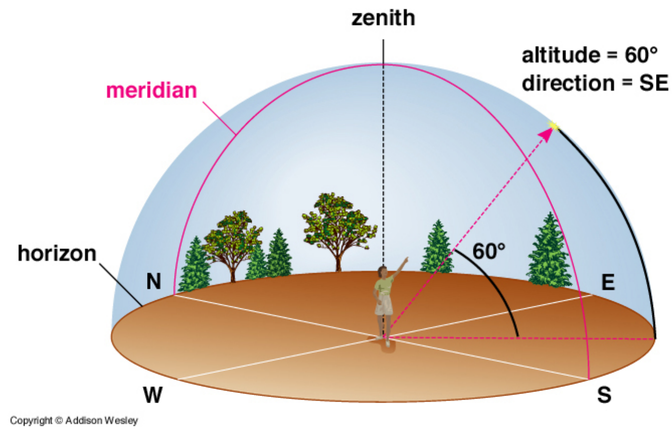

Fig. 3. *Example of a local horizon showing direction, altitude, zenith, and the meridian. Your task in the horizon Sketch is to create a two-dimensional version of this diagram.*

Step 2, Lunar Observation Sketches

An important part of understanding the phases of the Moon and the lunar cycle is to observe the Moon night after night and document what it look likes (i.e., what each phase looks like) and where the Moon is in the sky at what time of day/night. To this end, in addition to the information recorded in the upper left panel of your Observation Sheets, you will also make three sketches for each observation. An example of a filled out Observation Sheet with sketches is provided for you on the astronomy lab website. On the bottom panel of the Observation Sheet, you have been provided with spaces to make a sketch of how the Moon appears during your observation, and a simplified, two-dimensional view of where (what direction) and how high (altitude) the Moon appears with respect to the horizon.

In the circle marked as **Observation Sketch**, you need to sketch what the phase of the Moon looks like. Provide as much detail as you can, including any differences in coloration (lighter gray versus darker grey areas) and the location of the ***terminator***, or rather the line between the day-side and the night-side of the Moon.

A two dimensional view of the southern horizon is provided to the right of the **Observation Sketch**. Here, in the **Horizon Sketch,** you need to indicate where in the sky the Moon is during your observation. This information should reflect the direction and altitude that you have recorded for the observation. Each night, the Moon will rise in the East, travel through the Southern sky across the ***meridian***, and set in the West. However, what time the Moon rises, appears highest in the sky (when it crosses the ***meridian***), and sets on depends on what phase, or rather where in its orbit around the Earth, the Moon is in. On the **Horizon Sketch**, draw a miniature version of the Moon in your Observation Sketch where and how high you see it in the sky. It is not required, but it is encouraged to provide as much detail, such as landmarks on the sketch. An example of a ***Horizon Sketch*** can be seen in Fig. 4.

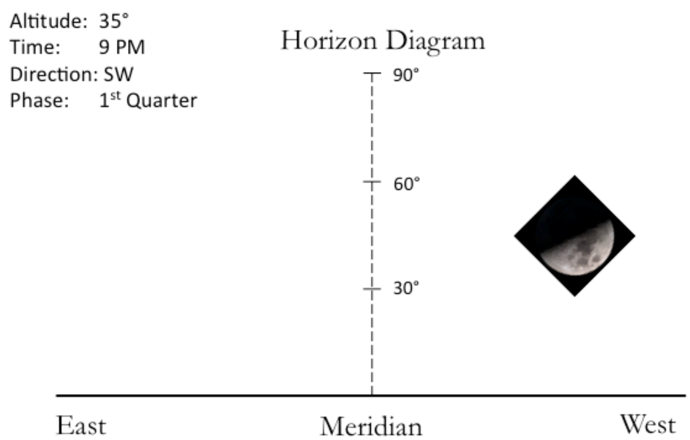

Fig. 4. *An example of a filled in Horizon Sketch for a First Quarter Moon.*

The final sketch you need to make, in the **Orbit Sketch** area, is an indication of where the Moon is in its orbit. This is not a direct observation, but rather, it is there to provide context to all of your lunar observations. Recall that the phases of the Moon are caused by the location of the Moon in its orbit; this determines what part of the illuminated Moon is seen from the Earth. Using your knowledge of the phases of the Moon, and the orbital position for the nominal phases shown in Fig. 2, draw a circle representing the Moon at the approximate correct position for the observed phase. Note that the Moon is constantly orbiting the Earth and so is constantly moving around the circle representing the Moon's orbit. Hence, while Fig. 2 only shows the Moon in eight positions in its orbit, the Moon can appear anywhere on the circle representing its orbital path.

Name: ______________________________

Lab Section: ________________________

Lab Instructor: _____________________

Lunar Observation Lab Questions

1. How long is the ***sidereal period*** (in days) of the Moon?

2. How long is the ***synodic period*** (in days) of the Moon?

3. Which period corresponds to a single 360° revolution (orbit) of the Moon, and which one corresponds to a full cycle of the phases?

4. Why is the ***synodic period*** longer than the ***sidereal period***?

5. What determines the phase of the Moon on any given night?

6. How much of the Moon's total surface (from 0 – 100%) is illuminated during a ______________. [Hint: Not as viewed from Earth, but how much is in daylight].
   Full Moon:
   Waxing Crescent:
   New Moon:
   Third Quarter:
7. Approximately (from 0 – 100%) how much of the illuminated surface of the Moon is visible from Earth?
   Full Moon:
   New Moon:
   First Quarter:
   Third Quarter:

8. Assuming that the Moon is in the First Quarter phase, what phase will it be in roughly one week?

9. Assuming that the Moon is in a Waning Crescent phase, what phase will it be in roughly three weeks?

10. Based on your observations, document any patterns you observed. For example, did at what time of day do you observe certain phases? About how much more or less of the illuminated portion of the Moon was observable night to night? Did the rise/set/highest point times change with a recognizable pattern?