

# The Moon

## 1 Introduction

In this lab you will learn about the Moon. The Moon is the brightest object in the night sky and has played an important role in many cultures throughout the history of mankind. It is Earth's only natural satellite and the only extraterrestrial body ever visited by the human beings (but not for much longer, fingers crossed). In this lab we will investigate the moon in some detail. We'll learn about the Moon's orbit and phases, look into why we only see the near side of the Moon, and discover what causes the tides in the oceans. We'll also go up onto the roof, and take some measurements and pictures!

## 2 The Moon's Orbit

### 2.1 The Far Side of the Moon

Over time, tidal forces from the Earth have slowed the Moon's rotation, such that the same side of the Moon always faces the Earth. This causes there to be one side of the Moon that we can see from the Earth and another that we cannot. The far side of the Moon, sometimes called the "dark side of the Moon", is the lunar hemisphere that permanently faces away from the Earth. It is therefore not visible from the Earth's surface. The far hemisphere was first photographed by the Soviet Luna 3 probe in 1959, and was first directly observed by human eyes when the Apollo 8 mission orbited the Moon in 1968. Some conspiracy theorists have alleged that some Apollo astronauts had seen UFOs on the far side of the Moon but were told to keep quiet about them. Let's figure out why we can't see this mysterious side of the Moon.

1. In groups of 3 or 4, assign one person to be the Moon, one person to be the Earth, and one (or two) people to be observers. Have the Moon revolve around the Earth, while always facing it. Have the observers stand outside of the orbit and observe the Moon from a fixed direction.
2. The Earth in this scenario will always see the same side of the Moon, by construction. Observers: is that true for you as well? If not, what portion of the orbit must the Moon complete before you see the same side again?
3. Why do we always see the same side of the Moon? Think about how long it takes for the moon to complete one orbit around the Earth and how long it takes for the moon to rotate once about its axis.
4. Why does the far side of the Moon have more craters?

5. Why might calling the far side of the Moon the “dark side” be confusing?

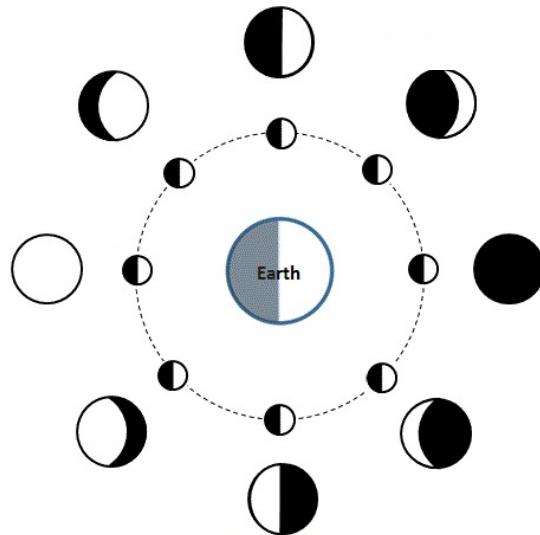
## 2.2 The Moon’s Phases

So we now know that the same side of the moon always faces Earth. This fact, plus the fact that the Moon itself doesn’t emit light, but instead is only reflecting light from the Sun, gives us enough information to understand why the Moon appears as it does in the night sky. Over the course of 28 days, the Moon goes through one lunar cycle. A lunar phase is the shape of the sunlit part of the Moon, as seen from Earth. The stages of the Lunar cycle are often divided into eight steps:

- New Moon: the Moon isn’t visible.
- Waxing Crescent: A quarter of the “light side” of the Moon is visible.
- First Quarter: Half of the “light side” of the Moon is visible.
- Waxing Gibbous: three quarters of the “light side” of the Moon is visible.
- Full Moon: the full “light side” of the Moon is visible.
- Waning Gibbous: three quarters of the “light side” of the Moon is visible.
- Third Quarter: Half of the “light side” of the Moon is visible.
- Waning Crescent: A quarter of the “light side” of the Moon is visible.

In the figure below, we can see the Earth, and the Moon in these eight phases of its orbit. On the diagram, the 16 smaller circles are the Moon at various phases. The white space in these circles shows the light part of the Moon and the dark space shows the dark parts of the Moon. The smaller Moons (closer to the Earth in the diagram) show the total light reflected by the Moon over time, while the outer circle shows the phase of the Moon, as seen by Earth, over time.

1. In the figure, where would you place the Sun? Said differently, where is the sunlight coming from? (Hint: left, right, top or bottom) Why?
2. Can you recognize the phases of the Moon? Which configuration gives a Full Moon? Which gives a New Moon (when you cannot see the moon)?
3. The orbital period of the Moon is 28 days. If day 1 is the New Moon, then what day is the First Quarter, Full Moon, and Third Quarter?



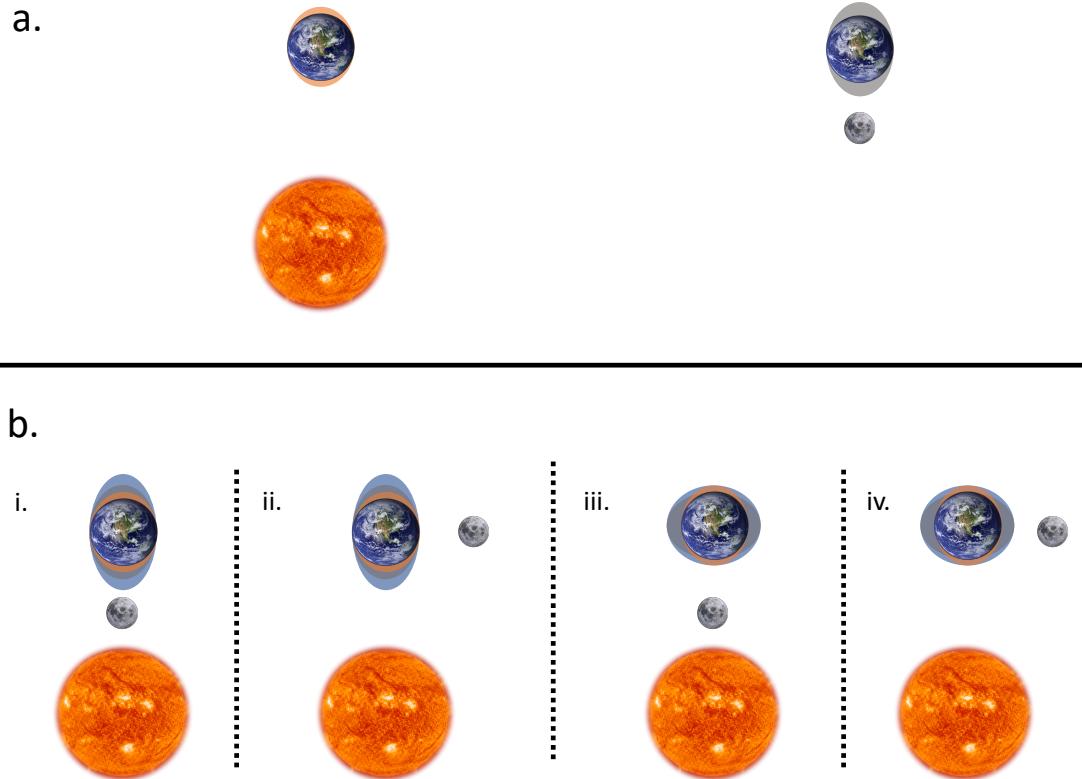
### 2.3 Eclipses

Now that you are familiar with the motion of the Moon, think about eclipses.

1. What is the phase of the Moon during a solar eclipse? During a lunar eclipse?
2. Based on this simplified picture, how often should solar and/or lunar eclipses happen? Is this actually the case? Why or why not?

[Hint: the moon's orbit is inclined by about  $5^\circ$  to the Earth-Sun plane].

## 2.4 Tides



Both the Sun and the Moon exert gravitational force to the Earth. The Sun is more massive, but the Moon is much closer. Tides in the oceans on Earth are caused by the difference in the gravitational force based on the location of the Sun and the Moon relative to Earth. The moon has a larger effect on the tides of the ocean because it is so much closer to the Earth and so there is a more significant change in gravity on the Oceans based on where the Moon is in its orbit. While the Sun's gravitational pull is larger than the Moon's in total, because it is further, the difference between the Sun's pull on the part of Earth facing it and the part of Earth not facing it is less significant than that of the Moon. The figure above shows the effects of the Sun and the Moon on the ocean tides on Earth. On the top half of the figure (part a.), we can see the effect of the Sun and the Moon independently, the Sun's pull on the tides is shown in orange shading around the Earth on the left and the Moon's shading shown in grey shading around the Earth on the right. On the bottom half of the figure (part b.) we can see 4 configurations of the Earth, Moon, and Sun system: i, ii, iii, and iv. (Hint: 2 of these configurations are physically possible and 2 are not physically possible.)

1. High tide, as the name suggests is when the ocean's height or depth increases. Low tide, similarly, is when the ocean's height or depth decreases. Based on these figures, describe the 2 locations of the Moon (relative to a location on Earth) when we expect high tide and the 2 locations of the Moon (relative to a location on Earth) when we expect low tide. Feel free to draw a diagram if helpful.
2. In reality, the Sun and the Moon both effect the Ocean tides. Let's combine the Sun's and the Moon's effects on Earth's tides. Based on part a of the figure and your understanding of tides, which two of these four configurations in part b. make physical sense? Why?
3. Which of these four configurations would we expect to cause the highest high tide and the lowest low tide (depending on your location on Earth)?
4. Which of these four configurations would we expect to cause the lowest high tide and the highest low tide (depending on your location on Earth)?

### 3 Observing the Moon

Unfortunately, clouds prevent us from observing tonight and the Lunar cycle makes it such that the Moon will set at 5:42pm and it won't be observable in the night sky. However, we will use a smaller Celestron telescope to do some hallway observing!

#### Hallway Observing...

The observing TA's will help you setup the telescope to "observe" objects at the end of the hallway.

1. What did you observe?
2. Was the magnification of the telescope more or less than you expected?

#### The Big Dome...

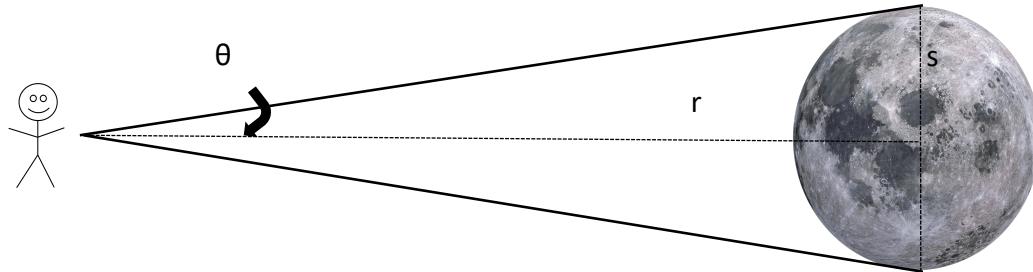
Although we cannot observe, we can still go look at the large telescope in the big dome. The telescope in the Big Dome is a Meade LX200 reflecting telescope which has a primary mirror with a  $\sim 16''$  diameter.

## Studying the Moon...

We will now look at images of the Moon that were previously taken using the telescope on the roof of Pupin in the Big Dome. They can all be found at the end of the lab. The first image is a single observation that was taken by the telescope. Next, you will see a mosaic composed of 5 different images of the Moon taken on the same night. Finally you will see a version of this mosaic that is rotated to match a labeled Lunar map. And last is the labeled Lunar map, which we can use for comparison. We will use this mosaic and the map to identify features on the Moon.

### **arc length formula:**

$$s = r \theta$$



1. Identify and label several features on your photo using the provided map.
2. Measure the diameter of some central feature in your photo (avoid features very close to the edge) using a ruler. Use [wolframalpha.com](http://wolframalpha.com) to look up the diameter of that feature and calculate the scale (i.e. the ratio of a distance on the map to the corresponding distance on the Moon surface) of your photo. Your scale should be unitless, so make sure you convert units correctly.
3. Measure the diameter of the Moon in your photo using a ruler. Based on your scale from the previous question, what is the diameter of the Moon? What is its actual diameter? Was your estimate close? If not, why?
4. We can now use a nifty trick to get an estimate for how far the Moon is from the Earth. We will use the arc length formula, our value for the angular diameter (in radians), and the physical diameter of the Moon to determine the distance to the Moon. In the figure above,  $s$  is the diameter of the Moon,  $r$  is the distance to the moon, and  $\theta$  is the angular diameter of the Moon. Remember you will have to convert your angular diameter from degrees to radians. Using this estimate, how far away is the Moon from the Earth?

## 4 Conclusions

1. The actual mean distance to the Moon is 385,000 km. What is your percent error? What sources of error are there in your measurement?
2. As you may have noticed at some point in the past, the Sun and the Moon are about the same angular size on the sky. Use this information, as well as the distance between the Sun and the Earth ( $1 \text{ AU} = 1.5 \times 10^{11} \text{ m}$ ), to calculate the radius of the Sun. Compare your answer to the actual solar radius  $R_{\odot} = 7 \times 10^8 \text{ m}$ .
3. If the lab was perfectly clear to you, what did you like or dislike? If not, what confused you? Any other feedback?







