Phases of the Moon

Sometimes when we look at the Moon in the sky we see a small crescent. At other times it appears as a full circle. Sometimes it appears in the daylight against a bright blue background. At other times it appears silhouetted against the black night sky. The exercises that follow are designed to help us see why this happens.

The five pictures above show a crescent moon, a semi-circle moon, a bulging semi-circle moon (this is called a gibbous moon), and a full moon, and then a gibbous moon again "waning" down on its way to becoming another semi-circle moon. If you look carefully at the pictures (and if your reproduction is good enough) you will see that even on the crescent moon, although we mostly see the "illuminated" side, it is still possible to faintly see the "dark side" of the moon. What determines how much we see clearly is the amount of the illuminated side that is facing us here on Earth.

Preliminaries:

As you work through these exercises, you will want some objects that you can use as substitutes for the sun, the moon, and the Earth. A lamp (preferably with a bare light bulb) makes a good substitute for the sun. A ball makes a good substitute for the moon. Since we are imagining that you are observing the moon from the Earth, your own head makes a good substitute for the Earth.

It is best to work through some of the exercises on this worksheet with at least one other person. Much of what you do will be with a java-compliant web browser (Internet Explorer 5 works well, as does Mozilla for the Mac). The Internet parts can be done on your own, but acting out different parts with a light bulb and a ball is easiest to do with a friend.

Before starting the animations:

The motions of planets can appear very complicated so we will start with the simplest pictures first. This means we will ignore some details that aren't important for what we are considering at the start, and we will come back to correct those details later.

The first thing that we are going to look at is the way sunlight shines on the Moon. For this we will ignore the fact that we all see the Moon from the surface of a curved Earth, which is a planet that rotates around an axis that is usually tipped toward or away from the sun (it is always tipped, but sometimes it is tipped in a direction that is perpendicular to the sun – don't worry about this – we'll come back to it later).

In each of the pictures of the moon on the first page, the moon is bright on the side that is directly "on the right" or directly "on the left". We don't always see the moon that way. Even when the bright portion is on the right, from our viewpoint it may be on the right and "up" a little bit or on the right and "down" below the middle. The words "up" and "down" are determined by our perspective from the Earth.

At least for a start, we will ignore the "tipping" of the Moon in the sky. We will come back to it later. For now, this means we will imagine that the axis of the Earth is not tipped and that we are looking at the Moon as we stand on the Earth atop the North Pole. Imagining that we are at the "un-tipped" North Pole saves us from worrying about the fact that the surface of the Earth is curved (which means that we are usually standing on a part that is tipped relative to the moon).

You may now begin the animations.

Go to the website http://www.instruction.greenriver.edu/physics/moon

There should be a link for a copy of the instructions, but you don't need to get those since you already have them. You are reading those instructions right now.

Click on the first animation, "Phase of the Moon." Go ahead and click the "play" button. Playing is a good thing to do. Don't go on to the next animation yet, but you can try clicking on anything else. Try using the "pause", "reset", and "24 hours >>" buttons. Advance the time by a few hours or a week. Watch what happens.

The time in the upper left-hand corner ticks off in fractions of a 24-hour day. The time advances when you push the "play" button (or the "1 week >>" button, etc.). On most computers, the animation will run faster when you push the "1 week" button but you have to push the "play" button if you just want to sit back and watch.

If you have not already done so, click the "pause" and "reset" buttons to set the time back to "0". Imagine you are standing on the North Pole (black dot) and looking at the moon.

- **How would the Moon appear (a crescent? a semi-circle? a full circle?) to an observer in the city at the start of the animation (when Time = 0)? Is the light part of the moon toward your right or your left? Sketch two diagrams below: one diagram should show the arrangement of the Sun, the Moon, and the Earth and the other should show the appearance of the Moon.**

- **Use a ball to represent the Moon and choose another object to represent the Sun (a lamp works best). Try arranging the "Sun" (lamp), the "Moon" (ball), and the "Earth" (your head) as they are when the time = 0. How does the "Moon" appear? Sketch and/or explain your observations below.**

Now adjust the time forward by 7.5 days (you can do this with one click of the "1 week" button followed by four clicks of the "3 hour" button).

- **How would the Moon appear near dawn seven days and one night later (at a time of about 7.5)? Again, sketch two diagrams below (one showing the arrangement of the Sun, the Moon, and the Earth and the other showing the appearance of the moon). [Hint: this is probably *not* an eclipse and if you are convinced it would be, either read ahead or ask your teacher.]**

- **Again, use a ball to represent the Moon and another object to represent the Sun. Try arranging the "Sun" (lamp), the "Moon" (ball), and the "Earth" (your head) as they are when the time = 7.5. How does the "Moon" appear? Sketch and/or explain your observations below.**

A note about eclipses:

You may have thought that there would be a lunar eclipse at a time of 7.5. That is actually possible but unlikely. The reason is that although these pictures make the sun, the Earth, and the Moon appear very large and close together, they are actually very small compared to the distances between them.

Since the distance between the Earth and Moon is so large compared to their sizes, getting an eclipse of the Moon (or the Sun) is sort of like holding a ping-pong ball on a sunny day and dropping another one on the ground. The chance of the second ball landing in the shadow of the first is pretty small.

The Earth, Sun, and Moon must be aligned just right to produce an eclipse, and since there are small variations in their orbits, this only happens a once or twice each year (the more approximate arrangement that you see at 7.5 days occurs twelve or thirteen times per year). Throughout our study of the phases of the moon, we will ignore the possibility of an eclipse.

Now go ahead and let the animation run. When we can't see the moon from anyplace on Earth (and the reason is not cloudy weather) we call this "no moon" or what is labeled on the calendar as the "new moon." The phrase "new moon" refers to the disappearance of the "previous moon" which will be followed by the appearance of a "new" one. You should be able to find a time between the time "0" days and the time "30" days when there is "no moon."

- **Can you find a time when there would be "no Moon" (this is when the bright side of the Moon cannot be seen from Earth)? When is it? Sketch the arrangement of the Sun, the Moon, and the Earth during a new moon.**

- **Use the ball, lamp, etc. to represent the Moon and the Sun at this time. How do you have to arrange them? How does the "Moon" appear? Sketch and/or explain your observations below.**

Now think about times when the Moon would appear in the sky as a semi-circle. Let the animation run from a time of 10.0 to a time of 70.0.

- **Between the times 10.0 and 70.0, at how many times would the moon appear to be a semi-circle? When are those times?**

- **Sometimes when we see the moon as a semi-circle, we notice it appears larger than a semi-circle (gibbous) the next day. At other times it appears smaller (on the way to being a crescent) the next day. Between the times 10.0 and 70.0, at how many times would the moon appear to be a semi-circle that is getting smaller as days go by? When are those times?**

- **Using the ball and lamp, try to make the ball follow the path of the Moon as it orbits the Earth (your head). What is the motion of the Moon (relative to the Earth and Sun) when it appears as a semi-circle that is getting smaller?**

- **Sketch the arrangement of the Earth, the Moon, and the Sun at a time when the Moon appears as a semi-circle that will get smaller as days go by. Include an arrow to show the direction of motion of the Moon.**

You may be wondering whether you get to check your work and how you are going to do that. One way to check your work is to use the ball and the lamp until you are sure you have got it right. Another way to check the work you have done so far is to go on to the next animation.

Scroll to the bottom of the screen and go on to the next animation.

Again, feel free to play around, but you don't want to go on to the next animation yet. There is plenty to learn here. The new animation shows you the position of the Sun, Earth, and Moon at the same time that it shows the appearance of the Moon to an observer on our flat North Pole. You can use this to check your understanding.

As a start, go back over the answers you have given so far. Using the new animation, set the times to the appropriate values that you identified on the previous pages and see how you were doing. If you need to correct any of your previous work or explain new insights (to your teacher or yourself), use the space below.

To gain more practice (in a slightly more difficult situation) again allow the animation to run between times 10.0 and 70.0. Look for times when the moon would appear as a crescent, say, halfway between appearing as a semi-circle and appearing as “no moon.” Just to give it a name, we’ll call this a “half-semi-circle crescent.” There will be some judgment involved in deciding when you have a good “half-semi-circle crescent” on the screen, but you and your classmates will probably come up with similar answers. (The exact values of the times are not important!)

- **Between the times 10.0 and 70.0, at how many times would the moon appear to be a half-semi-circle crescent? When are those times?**

- **Sometimes when we see the moon as a half-semi-circle crescent, we notice it appears larger than a half-semi-circle crescent the next day (on the way to being a semi-circle). At other times it appears smaller (on the way to being “no moon”) the next day. Between the times 10.0 and 70.0, at how many times would the moon appear to be a half-semi-circle crescent that is getting larger as days go by? When are those times?**

- **Using the ball and lamp, try to make the ball follow the path of the Moon as it orbits the Earth (your head). What is the motion of the Moon (relative to the Earth and Sun) when it appears as a half-semi-circle crescent that is getting larger?**

- **Sketch the arrangement of the Earth, the Moon, and the Sun at a time when the Moon appears as a half-semi-circle crescent that will get larger as days go by. Include an arrow to show the direction of motion of the Moon.**

Hopefully by now you are getting confident enough with this stuff that you are ready to try answering some practice "quiz questions" (don't panic - they aren't being graded).

Scroll to the bottom of the screen and go on to the next animation.

This animation is very short but you can redo it as many times as you like. The situation will change a little bit each time.

The animation shows you an arrangement of the Sun, Moon, and Earth.

- **How would the moon appear in this situation? Sketch your answer below BEFORE you check your result.**

- **Check your result by clicking on the button to display the phase of the Moon. How did you do?**

Repeat this process as many times as you like.

Whenever you think you are ready, go on to the next animation.

- **How would the moon appear in this situation? Sketch your answer below and compare your results with those of your classmates.**

Whenever you think you are ready, go on to the ***next*** animation.

- **How would the moon appear in this situation? Sketch your answer below and compare your results with those of your classmates.**

Congratulations! You are done with the animations on the phases of the moon. It is now time to consider real observations of the real moon!

By now you should have a collection of observations of the moon and what it looked like on different days and at different times. ***As a start we will think only about how much of the moon is illuminated and we will ignore how it is tipped.***

- **Find a place in your journal when you have two observations of the Moon that were made within a couple of days of each other. If one of them is a crescent, that's great. Otherwise anything will do. In the space below, sketch the Moon as you observed it at the first of these two times from your observation journal *but sketch it as though it is not tipped (as though the Sun is directly to the left or right but not above or below)*. If you are having trouble understanding how you are to sketch the Moon, ask an instructor.**

- **Based on what you learned from the animations, sketch the arrangement of the Sun, the Moon, and the Earth as they must have been to produce the image of the moon that you drew above.**

- **Now sketch the moon as it appeared on the second of your observation days.**

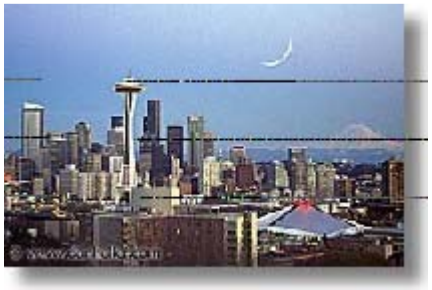
- **Based on what you learned from the animations, sketch the arrangement of the Sun, the Moon, and the Earth as they must have been to produce this image of the moon.**

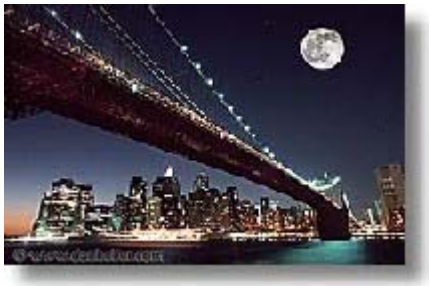
- **Think about the difference between the two observations of the Moon. Was it "getting bigger" (which is called "waxing")? Was it "getting smaller" (which is called "waning")? Can you explain this in terms of what you saw in the animations?**

It is now time to think about the information that we get by taking into account the fact that the moon as we see it usually is tipped!

<u>Why does the Moon appear tipped?</u>

The pictures of the moon below include parts of cities, which show some of our reference frame on Earth. In these pictures you see that the moon appears "tipped" relative to the person who took these pictures (and relative to the pictures on the first page). [1]





In these pictures and in our daily lives, the moon appears tipped because we are living on the surface of a curved planet. When we see the moon we are usually "tipped" relative to the position of the sun and the dark side of the moon. It was enough for us at the start of our animations to figure out the phase of the moon (how much of the moon that we see is illuminated) without worrying about how it is tipped relative to the way we are standing (or how we are tipped relative to it). When you want to interpret your own observations of the real moon in the sky, you will need to consider how it is tipped as well.

[1] You may wonder how you can tell whether a full moon is "tipped" since it is shaped like a circle. If you study the features on the moon (the craters that we can see from Earth) you will see that they are tipped compared to their orientation in the pictures on page 1). By the way, these beautiful pictures are reprinted with the permission of photographer Dan Heller. You can find more of his pictures (of the moon and other subjects) at http://www.danheller.com

- **Now go back to the first of the drawings that you reproduced from your journal (about five questions ago). Sketch the Moon in the space below *as it really appeared in the sky (probably tipped).***

- **As you looked at the Moon on that day (or night), the illuminated side revealed information about the position of the Sun. Where was the Sun?**

Consider, as a good approximation, that the Sun would have been at the highest point that it reached in the sky on that day at noon. It would have been at its lowest point below your feet at midnight. This approximation would be off by one hour during Daylight Savings Time, but it is a pretty good approximation during the winter. In this way, you can think of the position of the Sun as the "hour hand" on a huge 24-hour clock.

- **On this 24-hour clock, what time is it if the sun is halfway between straight up and straight down, just at the level of the western horizon?**

- **On this 24-hour clock, what time is it if the sun is halfway between straight up and straight down, just at the level of the eastern horizon?**

- **On this 24-hour clock, what time is it if the sun is halfway between the western horizon and straight down?**

- **Look back at your picture of the Moon and locate where the Sun would be on this 24-hour clock. What time *does your picture* suggest the time would have been?**

- **Look back at your journal and find out what time it really was. How close were you? Discuss your results with your classmates and an instructor.**

Now look back over the rest of your observations of the Moon in your journal. See whether you can predict the times just by looking at the pictures. After you have done this with a couple of your own observations, try the exercise below.

- **Ask a classmate to sketch a Moon observation (along with information about where the moon was in the sky) from his or her journal in the space below. See if you can correctly identify the time of day when the observation was made.**

- **Look through your observations as well as the observations of classmates. Repeat the exercise above for an observation of a crescent moon at nighttime. What time was it?**

- **Was the observation of a crescent moon at nighttime tipped? How did we know?**

Congratulations! You now have an honorary degree in Moon observation. Think about what you have learned on the next night when you see the Moon!