

divisible by 400, were leap years. The average length of this Gregorian year, 365.2425 mean solar days, is correct to about 1 day in 3300 years.

The Catholic countries immediately put the Gregorian reform into effect, but countries of the Eastern Church and most Protestant countries did not adopt it until much later. It was 1752 when England and the American colonies finally made the change. By parliamentary decree, September 2, 1752, was followed by September 14. Although special laws were passed to prevent such abuses as landlords collecting a full month's rent for September, there were still riots, and people demanded their 12 days back. Russia did not abandon the Julian calendar until the time of the Bolshevik revolution. The Russians then had to omit 13 days to come into step with the rest of the world. The anniversary of the October Revolution (old calendar) of 1917, bringing the communists to power, thus ended up being celebrated in November (new calendar), a difference that is perhaps not so important since the fall of communism.

4.5 PHASES AND MOTIONS OF THE MOON

Learning Objectives

By the end of this section, you will be able to:

- › Explain the cause of the lunar phases
- › Understand how the Moon rotates and revolves around Earth

After the Sun, the Moon is the brightest and most obvious object in the sky. Unlike the Sun, it does not shine under its own power, but merely glows with reflected sunlight. If you were to follow its progress in the sky for a month, you would observe a cycle of **phases** (different appearances), with the Moon starting dark and getting more and more illuminated by sunlight over the course of about two weeks. After the Moon's disk becomes fully bright, it begins to fade, returning to dark about two weeks later.

These changes fascinated and mystified many early cultures, which came up with marvelous stories and legends to explain the cycle of the Moon. Even in the modern world, many people don't understand what causes the phases, thinking that they are somehow related to the shadow of Earth. Let us see how the phases can be explained by the motion of the Moon relative to the bright light source in the solar system, the Sun.

Lunar Phases

Although we know that the Sun moves 1/12 of its path around the sky each month, for purposes of explaining the phases, we can assume that the Sun's light comes from roughly the same direction during the course of a four-week lunar cycle. The Moon, on the other hand, moves completely around Earth in that time. As we watch the Moon from our vantage point on Earth, how much of its face we see illuminated by sunlight depends on the angle the Sun makes with the Moon.

Here is a simple experiment to show you what we mean: stand about 6 feet in front of a bright electric light in a completely dark room (or outdoors at night) and hold in your hand a small round object such as a tennis ball or an orange. Your head can then represent Earth, the light represents the Sun, and the ball the Moon. Move the ball around your head (making sure you don't cause an eclipse by blocking the light with your head). You will see phases just like those of the Moon on the ball. (Another good way to get acquainted with the phases and motions of the Moon is to follow our satellite in the sky for a month or two, recording its shape, its direction from the Sun, and when it rises and sets.)

Let's examine the Moon's cycle of phases using **Figure 4.14**, which depicts the Moon's behavior for the entire month. The trick to this figure is that you must imagine yourself standing on Earth, facing the Moon in each of

its phases. So, for the position labeled “New,” you are on the right side of Earth and it’s the middle of the day; for the position “Full,” you are on the left side of Earth in the middle of the night. Note that in every position on **Figure 4.14**, the Moon is half illuminated and half dark (as a ball in sunlight should be). The difference at each position has to do with what part of the Moon faces Earth.

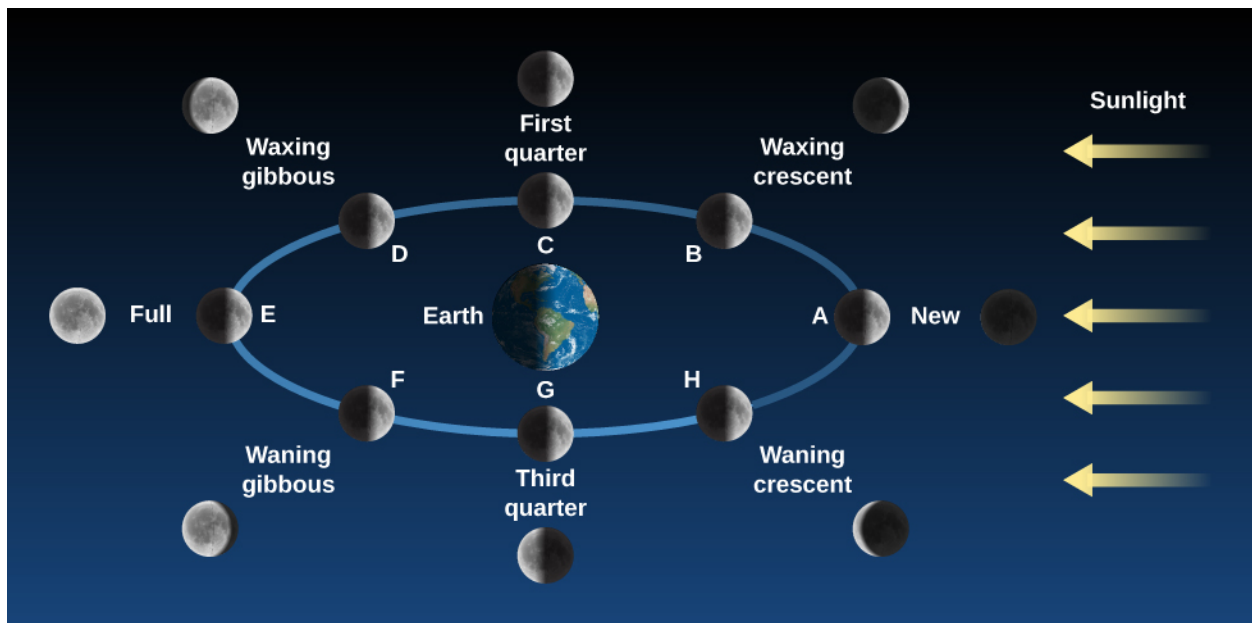


Figure 4.14 Phases of the Moon. The appearance of the Moon changes over the course of a complete monthly cycle. The pictures of the Moon on the white circle show the perspective from space, with the Sun off to the right in a fixed position. The outer images show how the Moon appears to you in the sky from each point in the orbit. Imagine yourself standing on Earth, facing the Moon at each stage. In the position “New,” for example, you are facing the Moon from the right side of Earth in the middle of the day. (Note that the distance of the Moon from Earth is not to scale in this diagram: the Moon is roughly 30 Earth-diameters away from us.) (credit: modification of work by NASA)

The Moon is said to be *new* when it is in the same general direction in the sky as the Sun (position A). Here, its illuminated (bright) side is turned away from us and its dark side is turned toward us. You might say that the Sun is shining on the “wrong” side of the Moon from our perspective. In this phase the Moon is invisible to us; its dark, rocky surface does not give off any light of its own. Because the new moon is in the same part of the sky as the Sun, it rises at sunrise and sets at sunset.

But the Moon does not remain in this phase long because it moves eastward each day in its monthly path around us. Since it takes about 30 days to orbit Earth and there are 360° in a circle, the Moon will move about 12° in the sky each day (or about 24 times its own diameter). A day or two after the new phase, the thin *crescent* first appears, as we begin to see a small part of the Moon’s illuminated hemisphere. It has moved into a position where it now reflects a little sunlight toward us along one side. The bright crescent increases in size on successive days as the Moon moves farther and farther around the sky away from the direction of the Sun (position B). Because the Moon is moving eastward away from the Sun, it rises later and later each day (like a student during summer vacation).

After about one week, the Moon is one-quarter of the way around its orbit (position C) and so we say it is at the *first quarter* phase. Half of the Moon’s illuminated side is visible to Earth observers. Because of its eastward motion, the Moon now lags about one-quarter of the day behind the Sun, rising around noon and setting around midnight.

During the week after the first quarter phase, we see more and more of the Moon’s illuminated hemisphere (position D), a phase that is called *waxing* (or growing) gibbous (from the Latin *gibbus*, meaning hump). Eventually, the Moon arrives at position E in our figure, where it and the Sun are opposite each other in the sky.

The side of the Moon turned toward the Sun is also turned toward Earth, and we have the *full* phase.

When the Moon is full, it is opposite the Sun in the sky. The Moon does the opposite of what the Sun does, rising at sunset and setting at sunrise. Note what that means in practice: the completely illuminated (and thus very noticeable) Moon rises just as it gets dark, remains in the sky all night long, and sets as the Sun's first rays are seen at dawn. Its illumination throughout the night helps lovers on a romantic stroll and students finding their way back to their dorms after a long night in the library or an off-campus party.

And when is the full moon highest in the sky and most noticeable? At midnight, a time made famous in generations of horror novels and films. (Note how the behavior of a vampire like Dracula parallels the behavior of the full Moon: Dracula rises at sunset, does his worst mischief at midnight, and must be back down in his coffin by sunrise. The old legends were a way of personifying the behavior of the Moon, which was a much more dramatic part of people's lives in the days before electric lights and television.)

Folklore has it that more crazy behavior is seen during the time of the full moon (the Moon even gives a name to crazy behavior—"lunacy"). But, in fact, statistical tests of this "hypothesis" involving thousands of records from hospital emergency rooms and police files do not reveal any correlation of human behavior with the phases of the Moon. For example, homicides occur at the same rate during the new moon or the crescent moon as during the full moon. Most investigators believe that the real story is not that more crazy behavior happens on nights with a full moon, but rather that we are more likely to notice or remember such behavior with the aid of a bright celestial light that is up all night long.

During the two weeks following the full moon, the Moon goes through the same phases again in reverse order (points F, G, and H in [Figure 4.14](#)), returning to new phase after about 29.5 days. About a week after the full moon, for example, the Moon is at *third quarter*, meaning that it is three-quarters of the way around (not that it is three-quarters illuminated—in fact, half of the visible side of the Moon is again dark). At this phase, the Moon is now rising around midnight and setting around noon.

Note that there is one thing quite misleading about [Figure 4.14](#). If you look at the Moon in position E, although it is full in theory, it appears as if its illumination would in fact be blocked by a big fat Earth, and hence we would not see anything on the Moon except Earth's shadow. In reality, the Moon is nowhere near as close to Earth (nor is its path so identical with the Sun's in the sky) as this diagram (and the diagrams in most textbooks) might lead you to believe.

The Moon is actually 30 *Earth-diameters* away from us; [Science and the Universe: A Brief Tour](#) contains a diagram that shows the two objects to scale. And, since the Moon's orbit is tilted relative to the path of the Sun in the sky, Earth's shadow misses the Moon most months. That's why we regularly get treated to a full moon. The times when Earth's shadow does fall on the Moon are called lunar eclipses and are discussed in [Eclipses of the Sun and Moon](#).

MAKING CONNECTIONS



Astronomy and the Days of the Week

The week seems independent of celestial motions, although its length may have been based on the time between quarter phases of the Moon. In Western culture, the seven days of the week are named after the seven "wanderers" that the ancients saw in the sky: the Sun, the Moon, and the five planets visible to the unaided eye (Mercury, Venus, Mars, Jupiter, and Saturn).

In English, we can easily recognize the names Sun-day (Sunday), Moon-day (Monday), and Saturn-day (Saturday), but the other days are named after the Norse equivalents of the Roman gods that gave their names to the planets. In languages more directly related to Latin, the correspondences are clearer. Wednesday, Mercury's day, for example, is *mercoledì* in Italian, *mercredi* in French, and *miércoles* in Spanish. Mars gives its name to Tuesday (*martes* in Spanish), Jupiter or Jove to Thursday (*giovedì* in Italian), and Venus to Friday (*venerdì* in French).

There is no reason that the week has to have seven days rather than five or eight. It is interesting to speculate that if we had lived in a planetary system where more planets were visible without a telescope, the Beatles could have been right and we might well have had "Eight Days a Week."

LINK TO LEARNING

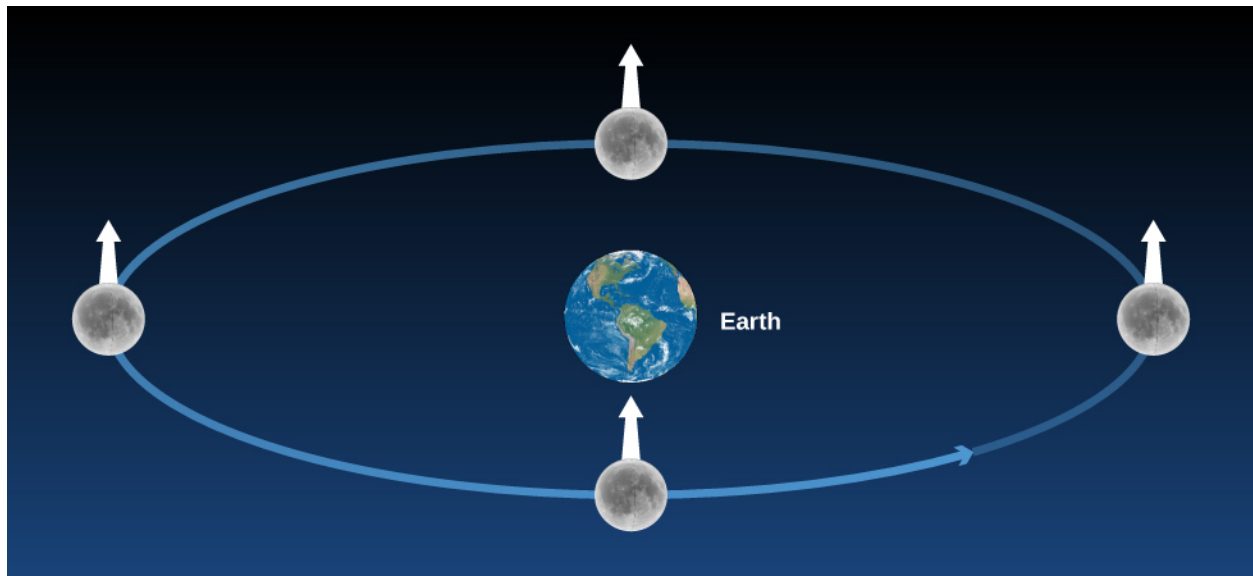


View [this animation \(https://openstaxcollege.org/l/30phamoonearth\)](https://openstaxcollege.org/l/30phamoonearth) to see the phases of the Moon as it orbits Earth and as Earth orbits the Sun.

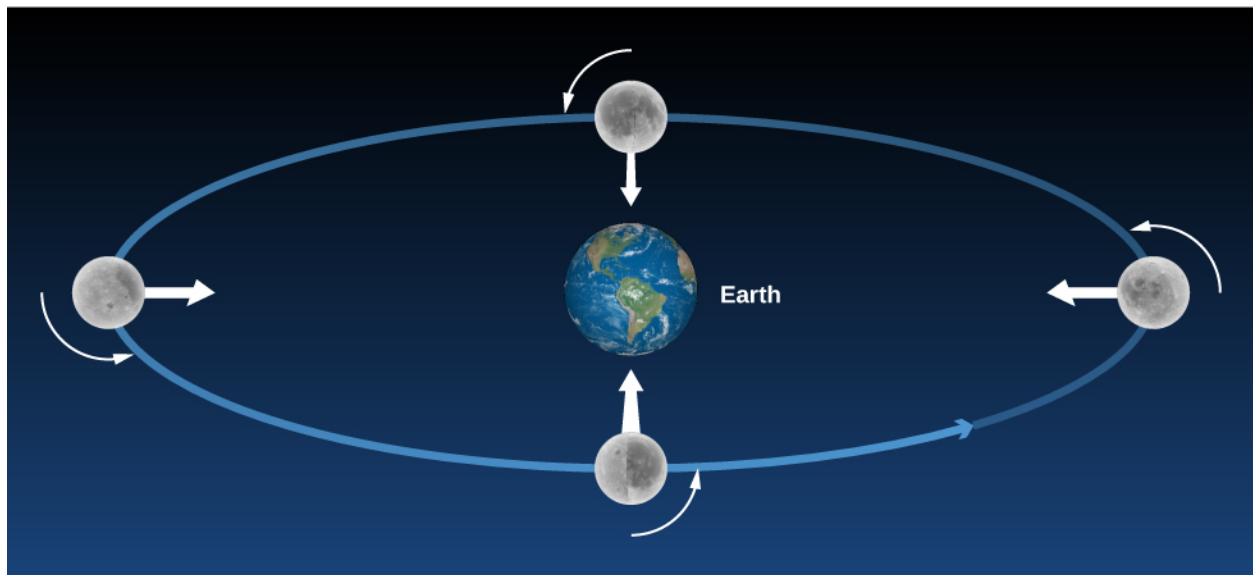
The Moon's Revolution and Rotation

The Moon's sidereal period—that is, the period of its revolution about Earth measured with respect to the stars—is a little over 27 days: the **sidereal month** is 27.3217 days to be exact. The time interval in which the phases repeat—say, from full to full—is the **solar month**, 29.5306 days. The difference results from Earth's motion around the Sun. The Moon must make more than a complete turn around the moving Earth to get back to the same phase with respect to the Sun. As we saw, the Moon changes its position on the celestial sphere rather rapidly: even during a single evening, the Moon creeps visibly eastward among the stars, traveling its own width in a little less than 1 hour. The delay in moonrise from one day to the next caused by this eastward motion averages about 50 minutes.

The Moon *rotates* on its axis in exactly the same time that it takes to *revolve* about Earth. As a consequence, the Moon always keeps the same face turned toward Earth (**Figure 4.15**). You can simulate this yourself by "orbiting" your roommate or another volunteer. Start by facing your roommate. If you make one rotation (spin) with your shoulders in the exact same time that you revolve around him or her, you will continue to face your roommate during the whole "orbit." As we will see in coming chapters, our Moon is not the only world that exhibits this behavior, which scientists call **synchronous rotation**.



(a)



(b)

Figure 4.15 The Moon without and with Rotation. In this figure, we stuck a white arrow into a fixed point on the Moon to keep track of its sides. (a) If the Moon did not rotate as it orbited Earth, it would present all of its sides to our view; hence the white arrow would point directly toward Earth only in the bottom position on the diagram. (b) Actually, the Moon rotates in the same period that it revolves, so we always see the same side (the white arrow keeps pointing to Earth).

The differences in the Moon's appearance from one night to the next are due to changing illumination by the Sun, not to its own rotation. You sometimes hear the back side of the Moon (the side we never see) called the "dark side." This is a misunderstanding of the real situation: which side is light and which is dark changes as the Moon moves around Earth. The back side is dark no more frequently than the front side. Since the Moon rotates, the Sun rises and sets on all sides of the Moon. With apologies to Pink Floyd, there is simply no regular "Dark Side of the Moon."