The Moon

Like all celestial objects, the Moon rises in the east and sets in the west. Also, like the Sun, the Moon shifts its position across the background stars from west to east. You can verify this motion by observing the Moon at the same time each evening and checking its position with respect to nearby stars. In fact, if the Moon happens to lie close to a bright star, its motion may be seen in a few minutes, because in 1 hour the Moon moves against the sky by approximately its own apparent diameter.

Lunar Phases

One of the most striking features of the Moon is that, unlike the Sun, its shape seems to change throughout the month in what is called the cycle of lunar **phases**. During a period of approximately 29.5 days, the Moon grows or *waxes* from invisibility (*new* phase), to a *crescent* shape, then *gibbous* when it is more than half lit, until it is a fully illuminated disk (*full*). Next it shrinks or *wanes* backward through this sequence until it is new again (fig. 1.18). This is the origin of the month as a time period and also the source of the name "month," which was derived from the word moon.

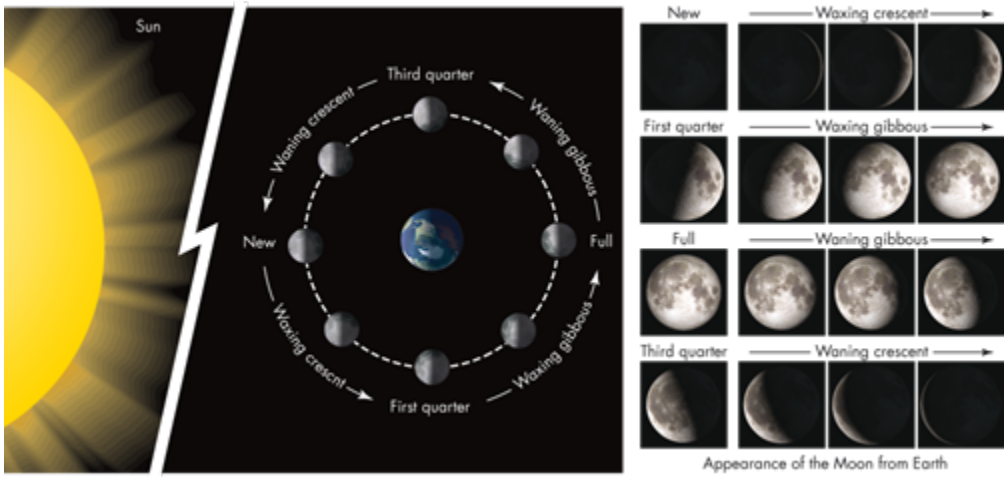

FIGURE 1.18
The cycle of the phases of the Moon, from new to full and back again. The phases are caused by our seeing different amounts of the half of the Moon's surface that is illuminated by the Sun. Images of the Moon's appearance in different phases are shown at right. Sizes and distances of objects are not to scale. In particular, the Moon is so small and far away that the Earth's shadow rarely falls upon it.

The cycle of the phases and the Moon's changing position against the stars are caused by the Moon's orbital motion around the Earth. Many people mistakenly believe that these changes in shape are caused by the Earth's shadow falling on the Moon. This clearly cannot be the explanation, because the crescent phases occur when the Moon and Sun lie approximately in the same direction in the sky and

the Earth's shadow must therefore point *away* from the Moon. In fact, half of the Moon is always lit by the Sun, but as the Moon orbits around us, we see different amounts of its illuminated half. When the Moon lies approximately between us and the Sun, its fully lit side is turned nearly completely away from us, and therefore the side facing us is dark, as illustrated in figure 1.18. At the *first quarter* and *third quarter* points, the Moon is 90° from the Sun and appears half lit. When the Moon lies approximately opposite the Sun in the sky, the side of the Moon facing the Earth is fully lit. The alignment is rarely exact, so the Earth's shadow usually misses the Moon.

The Moon's motion around the Earth causes it to shift eastward through the stars. As a result, the Earth itself must rotate eastward a little extra each day to bring the Moon back above the horizon. This extra rotation takes about 50 minutes each day, on average. So if the Moon rises at 8 P.M. one evening, the next evening it will rise at about 8:50 P.M., the following night at about 9:40 P.M., and so forth. See Astronomy by the Numbers: "Estimating When the Moon Will Rise."

Page 27
ASTRONOMY *by the numbers*
ESTIMATING WHEN THE MOON WILL RISE

If you know the Moon's phase, you can estimate the times when the Moon rises, sets, and is highest in the sky.

For example, when the Moon is at first quarter, it is one-quarter of the way around the sky, eastward of the Sun by about 90° (fig. 1.18). Therefore the Earth must turn about an additional 90° to bring the Moon to approximately the same position as the Sun. How long does it take the Earth to rotate those extra 90°? Since it takes the Earth 24 hours to rotate once (360°), to rotate 90° (= 360°/4) takes 6 hours (= 24 hours/4). Thus, the first-quarter Moon is highest in the sky at 6 hours after noon, or 6 P.M., rises about 6 hours earlier at about noon, and sets at about midnight. With similar reasoning, you can find when the Moon rises and sets in other phases.

As the Moon moves eastward from the Sun and its phase changes, it rises about 49 minutes later each night. This shift is simply the result of the Moon's orbital motion around the Earth, resulting in a complete cycle of phases over 29.5 days: 24 hours/29.5 days = 49 minutes/day.

Because the Moon orbits close to the plane of the ecliptic, it shifts north and south of the celestial equator during the month, just as the Sun does during the year. A consequence of this is that the full Moon's behavior is the opposite of the Sun's—the full Moon is relatively low in the sky in the summer and high in the sky in the winter. The Moon's position north or south of the celestial equator also affects the time between moonrise and moonset, just as the length of days depends on the Sun's position.

The changing time of moonrise means that the Moon is visible at different times and places during the night or day depending on its phase. For example, shortly after the new phase you can see the Moon low in the western sky after sunset. A few hours later that same evening it will have set and become invisible. On the other hand, when the Moon is full, it rises at about sunset and doesn't set until dawn. Thus, the full moon is visible throughout the night. In most of its phases, you can see the Moon during some part of the day if you know where to look. The different times when the Moon is visible are explored further in Extending Our Reach: "Observing the Moon."

Because the Moon's orbit is close to the orbital plane of the Earth around the Sun, the Moon, like the Sun, moves through the constellations of the zodiac. While the Moon takes about 29.5 days to go

through its cycle of phases, the combination of the Moon's and the Earth's orbits have the effect that the Moon requires only 27.3 days to complete its motion through the constellations of the zodiac. The reason for this is illustrated in figure 1.19, where you can see that after a month has passed the Earth has shifted its position in its orbit, so the Sun is in a different direction. After the Moon comes back into alignment with distant stars in 27.3 days, it must still travel farther around in its orbit two more days to come back into alignment with the Sun.

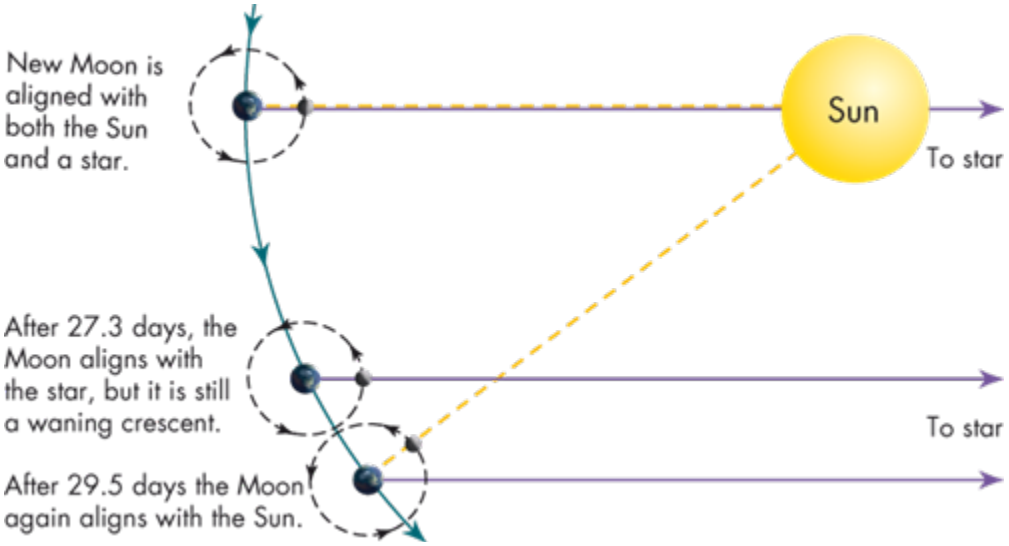

FIGURE 1.19
The sidereal month is the time the Moon takes to complete an orbit relative to the distant stars. This is about 27.3 days, less than the lunar month because as the Moon is orbiting the Earth, the Earth is orbiting the Sun. It takes about two additional days for the Moon to come back in alignment with the Sun.

EXTENDING *our reach*

OBSERVING THE MOON

When the Moon is full, it lies approximately opposite to where the Sun lies, but when the Moon is a thin crescent, it lies in nearly the same direction as the Sun (see the middle of figure 1.20). These connections between the Moon's phase and its position with respect to the Sun are the key to understanding when the Moon is visible from Earth.

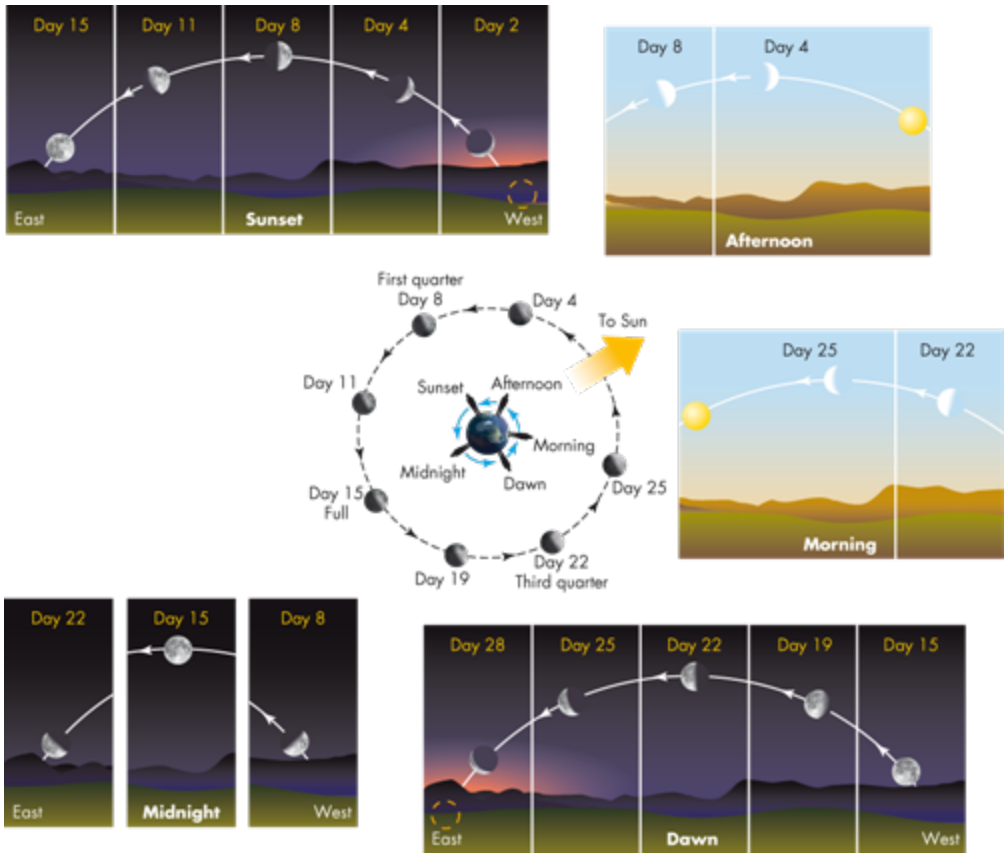

FIGURE 1.20
Where do you look for the Moon and how does it appear at different times of day as it goes through its monthly cycle of phases? The central diagram shows a person standing on the Earth at five times of day: dawn, morning, afternoon, sunset, and midnight. The Moon's position in its orbit is shown on 7 days of the lunar cycle (days 4, 8, 11, 15, 19, 22, and 25).The five surrounding panels show what a person would see at each of those times of day as the Moon moves through its orbit.

Because the full Moon is approximately opposite the Sun, it *rises* above the eastern horizon at about the same time that the Sun *sets* below the western horizon. Likewise, the full Moon *sets* at about the time the Sun *rises*. Therefore, the full Moon is visible all night and highest in the sky near midnight.

On the other hand, the crescent moon is not visible during most of the night. Because it lies in nearly the same direction as the Sun, once the Sun is well below the horizon, the crescent Moon must be below the horizon too. Moreover, the crescent Moon is hard to see during the day because it is only a sliver of light, so it is lost in the brightness of the daytime sky. Therefore, when the Moon is a few days past its new phase and is a thin crescent, you can see it low in the western sky at sunset. This crescent moon will set shortly after the Sun and not be visible again until after sunrise the next day.