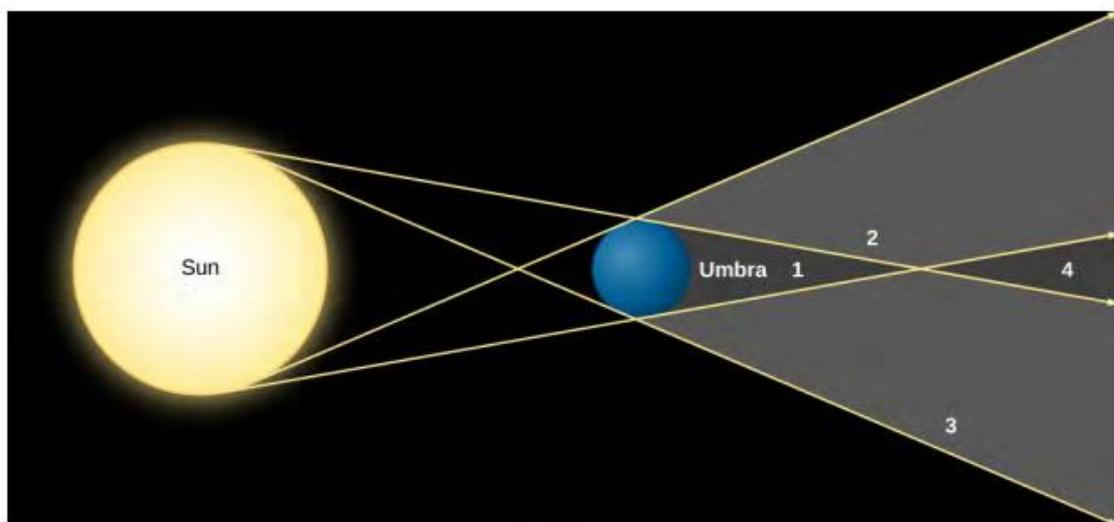


## 4.7 ECLIPSES OF THE SUN AND MOON

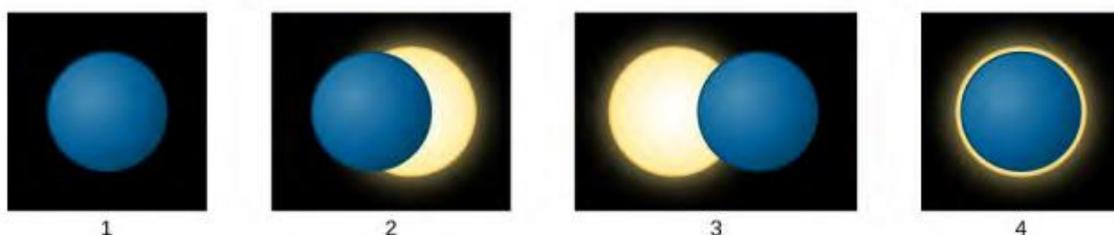
One of the coincidences of living on Earth at the present time is that the two most prominent astronomical objects, the Sun and the Moon, have nearly the same apparent size in the sky. Although the Sun is about 400 times larger in diameter than the Moon, it is also about 400 times farther away, so both the Sun and the Moon have the same angular size—about  $1/2^\circ$ . As a result, the Moon, as seen from Earth, can appear to cover the Sun, producing one of the most impressive events in nature.

Any solid object in the solar system casts a shadow by blocking the light of the Sun from a region behind it. This shadow in space becomes apparent whenever another object moves into it. In general, an eclipse occurs whenever any part of either Earth or the Moon enters the shadow of the other. When the Moon's shadow strikes Earth, people within that shadow see the Sun at least partially covered by the Moon; that is, they witness a solar eclipse. When the Moon passes into the shadow of Earth, people on the night side of Earth see the Moon darken in what is called a lunar eclipse. Let's look at how these happen in more detail.

The shadows of Earth and the Moon consist of two parts: a cone where the shadow is darkest, called the umbra, and a lighter, more diffuse region of darkness called the penumbra. As you can imagine, the most spectacular eclipses occur when an object enters the umbra. Figure 4.21 illustrates the appearance of the Moon's shadow and what the Sun and Moon would look like from different points within the shadow.



(a)



(b)

Figure 4.21 Solar Eclipse. (a) The shadow cast by a spherical body (the Moon, for example) is shown. Notice the dark umbra and the lighter penumbra. Four points in the shadow are labeled with numbers. In (b) you see what the Sun and Moon would look like in the sky at the four labeled points. At position 1, you see a total eclipse. At positions 2 and 3, the eclipse is partial. At position 4, the Moon is farther away and thus cannot cover the Sun completely; a ring of light thus shows around the Sun, creating what is called an “annular” eclipse.

If the path of the Moon in the sky were identical to the path of the Sun (the ecliptic), we might expect to see an eclipse of the Sun and the Moon each month—whenever the Moon got in front of the Sun or into the shadow of Earth. However, as we mentioned, the Moon’s orbit is tilted relative to the plane of Earth’s orbit about the Sun by about  $5^\circ$  (imagine two hula hoops with a common center, but tilted a bit). As a result, during most months, the Moon is sufficiently above or below the ecliptic plane to avoid an eclipse. But when the two paths cross (twice a year), it is then “eclipse season” and eclipses are possible.

## Eclipses of the Sun

The apparent or angular sizes of both the Sun and Moon vary slightly from time to time as their distances from Earth vary. (Figure 4.21 shows the distance of the observer varying at points A–D, but the idea is the same.) Much of the time, the Moon looks slightly smaller than the Sun and cannot cover it completely, even if the two are perfectly aligned. In this type of “annular eclipse,” there is a ring of light around the dark sphere of the Moon.

However, if an eclipse of the Sun occurs when the Moon is somewhat nearer than its average distance, the Moon can completely hide the Sun, producing a total solar eclipse. Another way to say it is that a total eclipse of the Sun occurs at those times when the umbra of the Moon’s shadow reaches the surface of Earth.

The geometry of a total solar eclipse is illustrated in Figure 4.22. If the Sun and Moon are properly aligned, then the Moon’s darkest shadow intersects the ground at a small point on Earth’s surface. Anyone on Earth within the small area covered by the tip of the Moon’s shadow will, for a few minutes, be unable to see the Sun and will witness a total eclipse. At the same time, observers on a larger area of Earth’s surface who are in the penumbra will see only a part of the Sun eclipsed by the Moon: we call this a partial solar eclipse.

Between Earth’s rotation and the motion of the Moon in its orbit, the tip of the Moon’s shadow sweeps eastward at about 1500 kilometers per hour along a thin band across the surface of Earth. The thin zone across Earth within which a total solar eclipse is visible (weather permitting) is called the eclipse path. Within a region about 3000 kilometers on either side of the eclipse path, a partial solar eclipse is visible. It does not take long for the Moon’s shadow to sweep past a given point on Earth. The duration of totality may be only a brief instant; it can never exceed about 7 minutes.

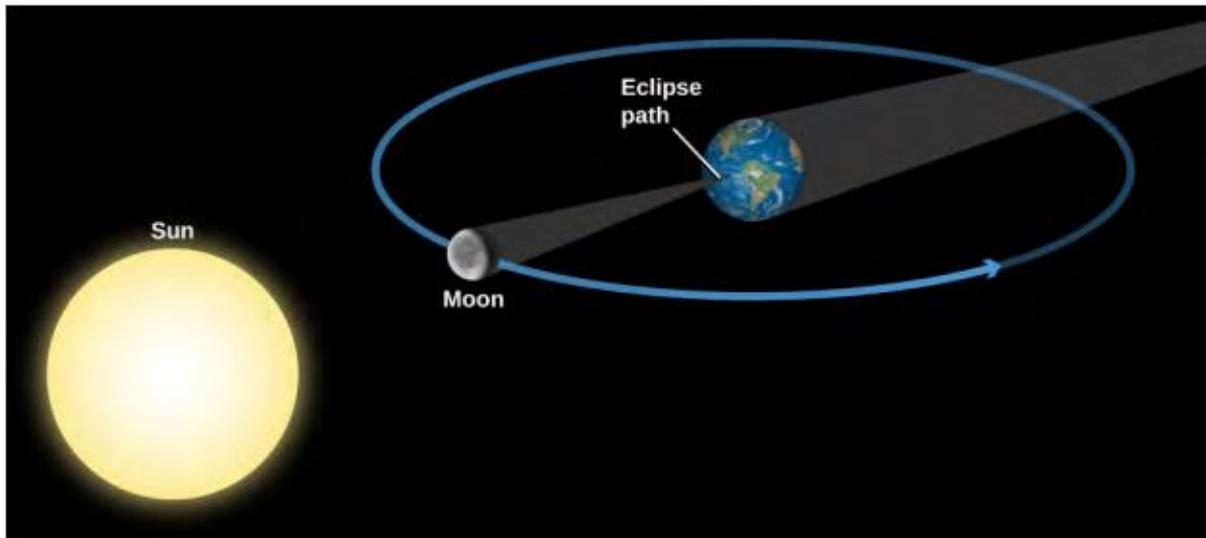


Figure 4.22 Geometry of a Total Solar Eclipse. Note that our diagram is not to scale. The Moon blocks the Sun during new moon phase as seen from some parts of Earth and casts a shadow on our planet.

## Eclipses of the Moon

A lunar eclipse occurs when the Moon enters the shadow of Earth. The geometry of a lunar eclipse is shown in Figure 4.24. Earth's dark shadow is about 1.4 million kilometers long, so at the Moon's distance (an average of 384,000 kilometers), it could cover about four full moons. Unlike a solar eclipse, which is visible only in certain local areas on Earth, a lunar eclipse is visible to everyone who can see the Moon. Because a lunar eclipse can be seen (weather permitting) from the entire night side of Earth, lunar eclipses are observed far more frequently from a given place on Earth than are solar eclipses.

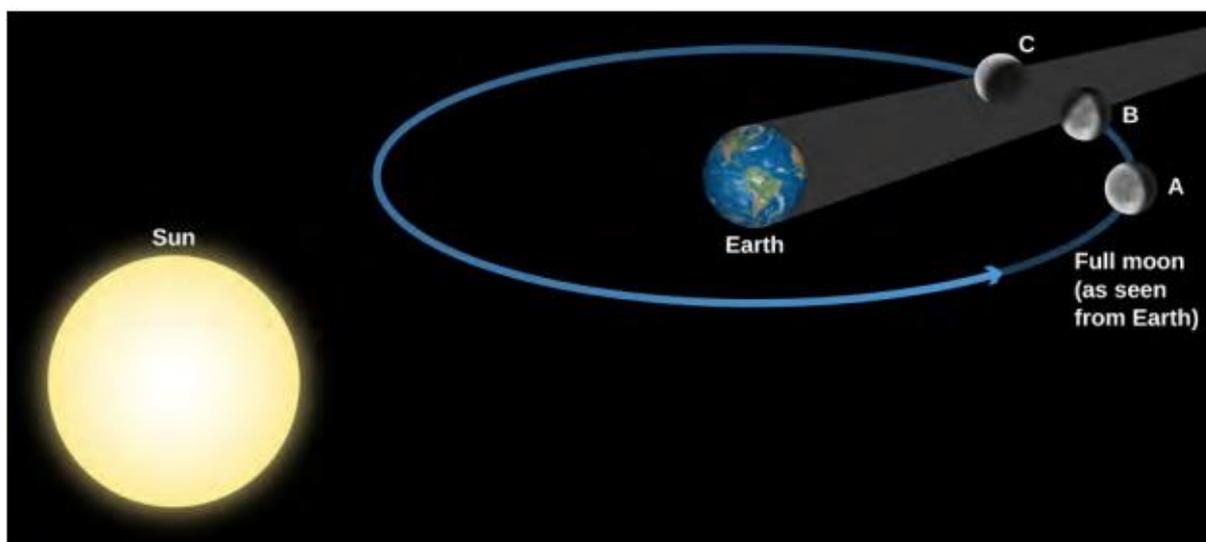


Figure 4.24 Geometry of a Lunar Eclipse. The Moon is shown moving through the different parts of Earth's shadow during a total lunar eclipse. Note that the distance the Moon moves in its orbit during the eclipse has been exaggerated here for clarity.

An eclipse of the Moon is total only if the Moon's path carries it through Earth's umbra. If the Moon does not enter the umbra completely, we have a partial eclipse of the Moon. But because Earth is larger than the Moon, its umbra is larger, so that lunar eclipses last longer than solar eclipses, as we will discuss below. A lunar eclipse can take place only when the Sun, Earth, and Moon are in a line.

The Moon is opposite the Sun, which means the Moon will be in full phase before the eclipse, making the darkening even more dramatic. About 20 minutes before the Moon reaches the dark shadow, it dims somewhat as Earth partly blocks the sunlight. As the Moon begins to dip into the shadow, the curved shape of Earth's shadow upon it soon becomes apparent. Even when totally eclipsed, the Moon is still faintly visible, usually appearing a dull coppery red.

The illumination on the eclipsed Moon is sunlight that has been bent into Earth's shadow by passing through Earth's atmosphere. After totality, the Moon moves out of the shadow and the sequence of events is reversed. The total duration of the eclipse depends on how closely the Moon's path approaches the axis of the shadow. For an eclipse where the Moon goes through the center of Earth's shadow, each partial phase consumes at least 1 hour, and totality can last as long as 1 hour and 40 minutes.

Eclipses of the Moon are much more "democratic" than solar eclipses. Since the full moon is visible on the entire night side of Earth, the lunar eclipse is visible for all those who live in that hemisphere. (Recall that a total eclipse of the Sun is visible only in a narrow path where the shadow of the umbra falls.)