Eclipses

An eclipse occurs when the Earth lies directly between the Sun and the Moon, or when the Moon passes exactly between the Earth and the Sun so that all three bodies are on a straight line. Thus, there are two types of eclipse: lunar and solar.

Eclipses

A **lunar eclipse** occurs when the Earth passes between the Sun and the Moon and casts its shadow on the Moon, as shown in figure 1.21. A **solar eclipse** occurs whenever the Moon passes directly between the Sun and the Earth and blocks our view of the Sun, as depicted in figure 1.22.

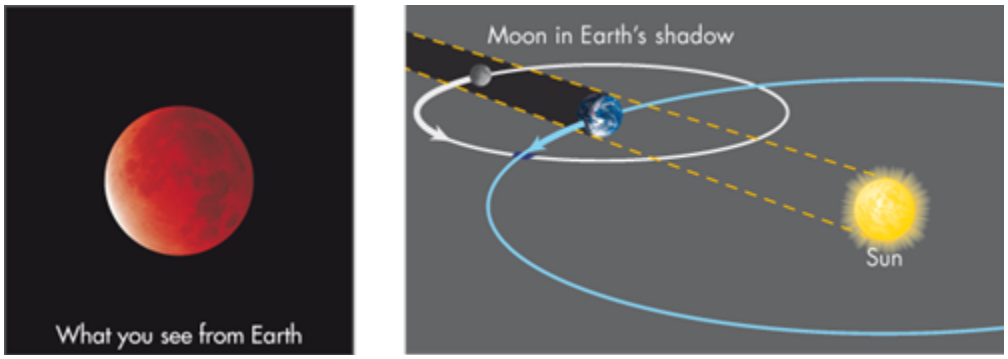

FIGURE 1.21
A lunar eclipse occurs when the Earth passes between the Sun and Moon, causing the Earth's shadow to fall on the Moon. Some sunlight leaks through the Earth's atmosphere, casting a deep reddish light on the Moon. The photo shows what the eclipse looks like from Earth.

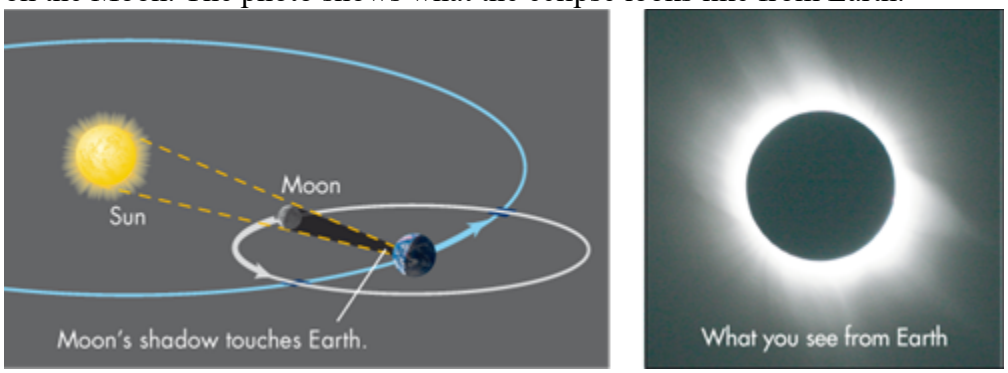

FIGURE 1.22
A solar eclipse occurs when the Moon passes between the Sun and the Earth so that the Moon's shadow touches the Earth. The photo shows what the eclipse looks like from Earth.

Appearance of Eclipses

Eclipses generally take a few hours from start to finish. Sometimes an eclipse is *partial*, with only a portion of the Moon or the Sun ever being covered over. These partial eclipses often pass unnoticed unless you know to look for them. However, *total* eclipses are beautiful and marvelous events.

As the Moon reaches the point along its orbit when it is full, it usually misses the Earth's shadow. If it happens to be crossing the ecliptic when it is full, however, the Moon will pass through the Earth's shadow, and a total lunar eclipse will occur. Total lunar eclipses are visible if you are anywhere on the night side of the Earth when the eclipse is occurring. As a total lunar eclipse begins, the Earth's shadow gradually spreads across the full Moon's face, cutting an ever deeper dark semicircle out of it. The shadow takes about an hour to completely cover the Moon and produce totality. At totality, the Moon generally appears a deep ruddy color, almost as if dipped in blood. Sometimes it becomes so dark that it may be hard to see at all. After totality, the Moon again becomes lit, bit by bit, reverting over the next hour to its unsullied, silvery light.

Q: Sometimes you see clouds after sunset that are lit red. How is this like the red color you see on the totally eclipsed Moon?

Answer

A little light falls on the Moon even at totality because the Earth's atmosphere bends some sunlight into the shadow. The light reaching the Moon is red because interactions with particles in the air remove the blue light as it passes through our atmosphere, exactly as happens when we see the setting Sun, and the path of the light is bent by the atmosphere much as a prism bends the direction of light, as shown in figure 1.23. (The bending of light by the atmosphere is discussed further in chapter 5.)

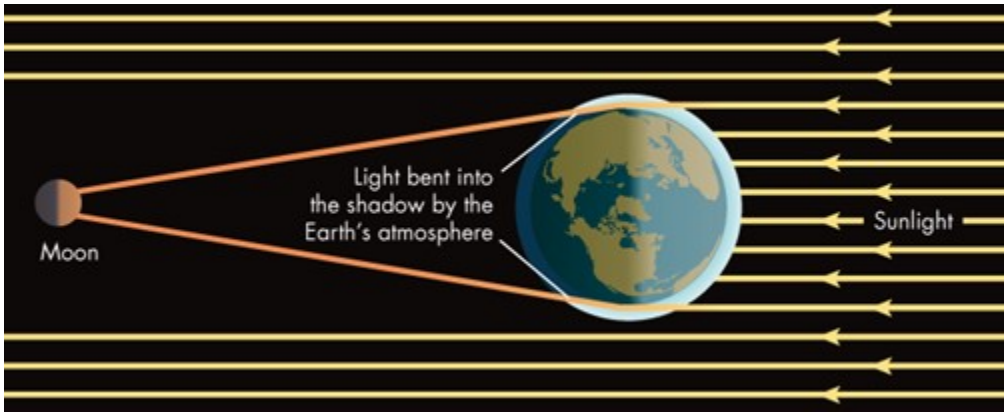

FIGURE 1.23
As sunlight falls on the Earth, some passes through the Earth's atmosphere and is slightly bent so that it ends up in the Earth's shadow. In its passage through our atmosphere, most of the blue light is removed, leaving only the red. That red light then falls on the Moon, giving it its ruddy color at totality.

Be extremely careful when watching a partial solar eclipse. Looking at the Sun through improper filters will blind you. A safer way is to *not* look directly at the Sun but to use eyepiece projection to view the Sun. Hold a piece of paper about a foot from the eyepiece of a small telescope (or even

binoculars), and a large image of the Sun will be visible on it. This method also allows many people to watch the eclipse simultaneously.

It is far rarer to see a total solar eclipse because the Moon's shadow on the Earth is quite small. In fact, you are unlikely to ever see a total solar eclipse in your lifetime unless you travel to see it, because on average they occur in any location only once every several centuries. A total solar eclipse begins with a small black "bite" taken out of the Sun's edge as the Moon cuts across its disk (fig. 1.24A). Over the next hour or so, the Moon gradually covers over more and more of the Sun. While the Sun is only partially covered, you must be careful when viewing it, so you don't hurt your eyes. If you are fortunate enough to be at a location where the eclipse is total, you will see one of the most amazing sights in nature.

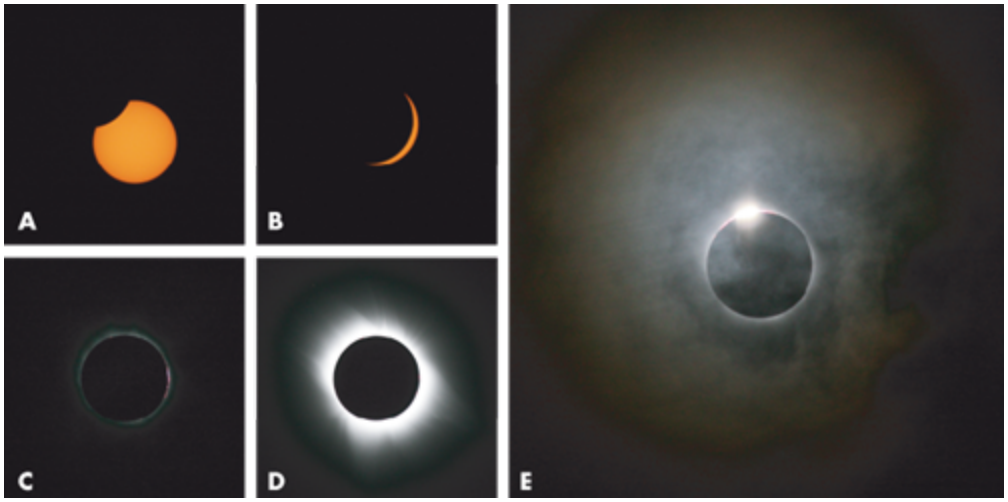

FIGURE 1.24
Pictures of a total solar eclipse in 2010. (A) One hour before totality, the Moon only partially eclipses the Sun. (B) About 5 minutes before totality. (C) With the bright part of the Sun covered, the Sun's glowing pink atmosphere becomes visible. (D) Faint hot gases form a corona around the Sun. (E) As the Moon slides off the Sun, the first glimpse of the bright portion of the Sun makes a "diamond ring," while thin clouds in Earth's atmosphere are colored by optical phenomena.

As the time when the Moon's disk completely covers the Sun (totality) approaches, the landscape takes on an eerie light. Shadows become incredibly sharp and black: even individual hairs on your head cast crisp shadows. Sunlight filtering through leaves creates tiny bright crescents on the ground. Seconds before totality, pale ripples of light sweep across the ground, and to the west the deep purple shadow of the Moon hurtles toward you at more than 1000 miles an hour. In one heartbeat you are plunged into darkness. Overhead, the sky is black, and stars become visible. Perhaps a solar prominence—a tiny, glowing, red flamelike cloud in the Sun's atmosphere—may protrude beyond the Moon's black disk (fig. 1.24C). The corona of the Sun—its outer atmosphere—gleams with a steely light around the Moon's black disk (fig. 1.24D). Birds call as if it were evening. A deep chill descends, because for a few minutes the Sun's warmth is blocked by the Moon. The horizon takes on sunset colors: the deep blue of twilight with perhaps a distant cloud in our atmosphere glowing orange. As the Moon continues in its orbit, it begins to uncover the Sun, and in the first moments after totality, the partially eclipsed Sun looks a little like a diamond ring (fig. 1.24E). Now the cycle continues in reverse. The sky rapidly brightens, and the shadow of the Moon, racing away to the east, may be glimpsed on distant clouds or mountains.

Q: According to the map, when will the next total solar eclipse occur after 2017 in North America? In South America?

Answer

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Total solar eclipses can be seen only within a narrow path where the Moon's shadow crosses the Earth (fig. 1.25A). Because the Moon is physically smaller than the Sun, the Moon's shadow grows narrower farther from the Moon, as illustrated in figure 1.24A, and is at most a few hundred kilometers wide at the distance of the Earth. The locations of the paths of totality are shown for total eclipses from 2008 to 2035 in figure 1.25B. The first total solar eclipse visible in the continental United States since 1979 will occur in 2017, with a path crossing from the northwest to the southeast. If you have the chance to travel to the path of totality, do it!

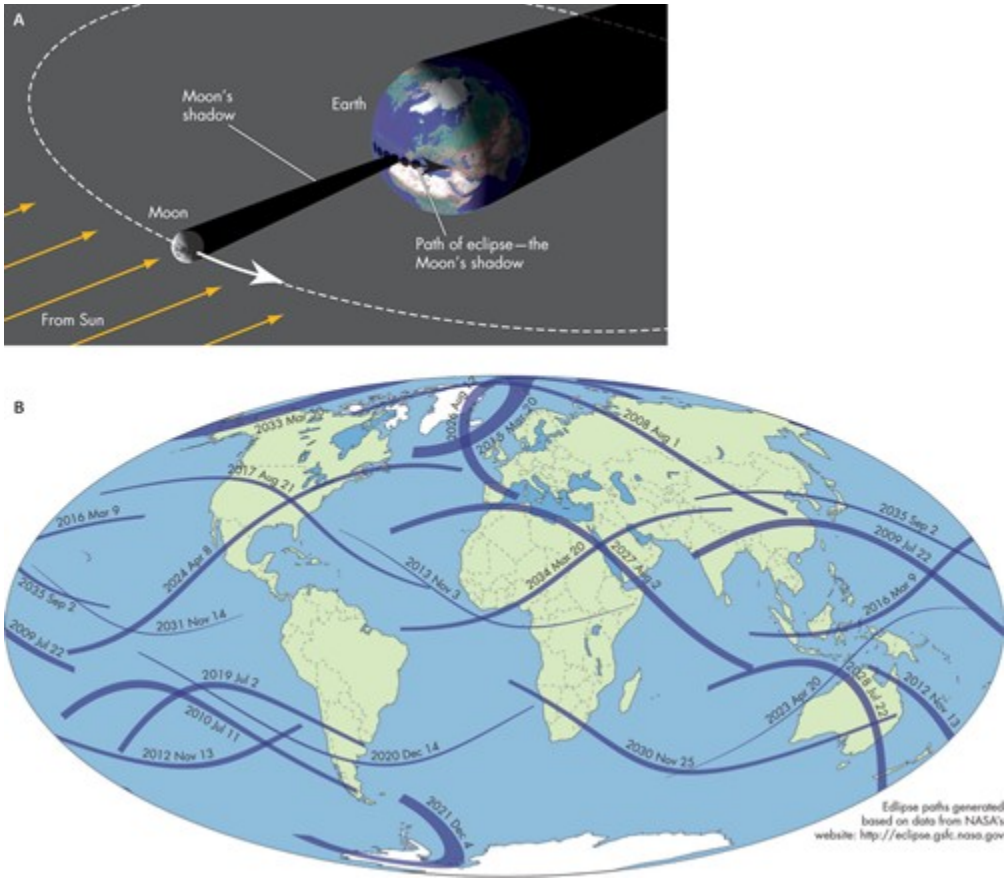

FIGURE 1.25
(A) When the Moon casts a shadow on the Earth, the Moon's orbit shifts it from west to east along a narrow line. (B) The locations of recent and upcoming total solar eclipses are shown through 2035. The paths show where totality can be observed. In regions outside of these paths, a partial eclipse may be visible.

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Sometimes the Moon is so far away that its shadow does not reach the Earth. What we see when this happens is that the Moon does not completely cover the Sun, even though it is precisely in line with the Sun. An example is shown in figure 1.26, where a ring of sunlight is seen as the Sun is setting. This is called an **annular eclipse** because it leaves an *annulus* of the Sun's surface still visible.

FIGURE 1.26
An annular eclipse of the Sun in 1992 occurring near sunset. The Moon is at a distant point in its orbit, so it cannot block the Sun entirely.

Rarity of Eclipses

Given that the lunar cycle is about 29.5 days, you may wonder why we do not have eclipses every month. The answer is that the Moon's orbit is tipped with respect to the Earth's orbit (fig. 1.27). Because of this tip, even if the Moon is new, the Moon's shadow may pass above or below Earth, as you can see in figure 1.27A. As a result, no eclipse occurs. Similarly, when the Moon is full, the Earth's shadow may pass above or below the Moon so that again no eclipse occurs. Only a nearly exact alignment of the Earth, Moon, and Sun leads to eclipses, a point that is easier to appreciate if you look at figure 1.27B, which shows the Earth and Moon and their shadows drawn to scale.

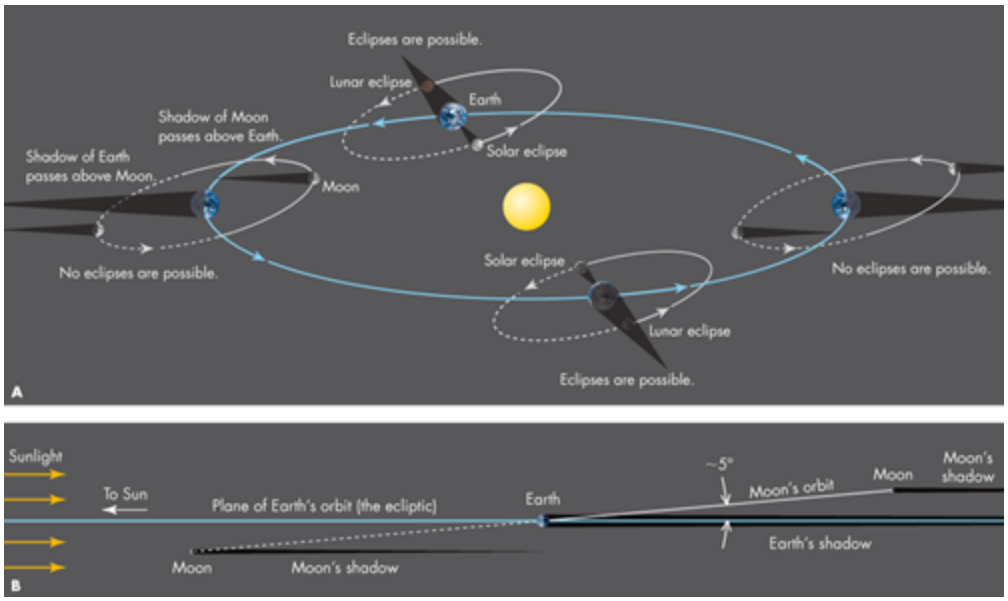

FIGURE 1.27
(A) The Moon's orbit keeps approximately the same orientation as the Earth orbits the Sun. Because of its orbital tilt, the Moon generally is either above or below the Earth's orbit. Thus, the Moon's shadow rarely hits the Earth, and the Earth's shadow rarely hits the Moon. Eclipse seasons are when the Earth is in either of two places in its orbit, about 6 months apart, when the Moon's orbital plane, if extended, intersects the Sun. (B) The Earth and Moon are drawn to correct relative size and separation, with their orbits seen here edge on. Note how thin their shadows are.

Eclipses and the Moon's orbital inclination

The tilt of the Moon's orbit remains fixed—like that of the spinning Earth—by a gyroscopic effect or, more technically, by the conservation of angular momentum. The result is that twice each year, the Moon's orbital plane (if extended) passes through the Sun, as shown in figure 1.27A. At those times—**eclipse seasons**—eclipses will happen when the Moon crosses the Earth's orbital plane, the ecliptic. In 2012 the eclipse seasons were within about two weeks of the end of May and November. Only at those times could eclipses happen: at other times, the shadows of the Earth and Moon fall on empty space. You can also see from figure 1.27A that when a solar eclipse occurs at new moon, conditions are right for a lunar eclipse to happen at either the previous or the following full moon. Thus, eclipses can occur in pairs or triplets, with a solar eclipse followed approximately 14 days later by a lunar eclipse, or vice versa. This can be seen in table 1.1 where several upcoming solar and lunar eclipses are listed.

Table 1.1
Some Upcoming Solar and Lunar Eclipses

Solar Eclipses			**Lunar Eclipses**		
2016 March 9	Total	Sumatra, central Pacific	2017 August 7	Partial	Europe, Africa, Asia, Australia
2016 September 1	Annular	Africa, Madagascar	2018 January 31	Total	Asia, Australia, Pacific, w. Americas

2017 February 26	Annular	S. America, Atlantic, Africa	2018 July 27	Total	S. America, Europe, Africa, Asia, Aus.
2017 August 21	Total	N. America	2019 January 21	Total	Asia, Australia, Pacific, N. America
2019 July 2	Total	S. Pacific, S. America	2019 July 16	Partial	S. America, Europe, Africa, Asia, Aus.
2019 December 26	Annular	Asia, Australia	2021 May 26	Total	Asia, Australia, Pacific, Americas
2020 June 21	Annular	Africa, S. Europe	2021 November 19	Partial	Americas, Europe, Asia, Aus., Pacific
2020 December 14	Total	Pacific, S. America	2022 May 16	Total	Americas, Europe, Africa

Data from NASA's eclipse website: http://eclipse.gsfc.nasa.gov/. Partial solar eclipses and "penumbral" lunar eclipses, are not listed.

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Precession of the Moon's Orbit

Eclipse seasons do not always remain in the same months, because the orientation of the Moon's orbit does not remain exactly the same over time. The plane of the orbit slowly changes orientation, as illustrated in figure 1.28. That is, the Moon's orbit *precesses*, swinging once around about every 18.6 years. This orbital **precession** makes the dates of the eclipse seasons shift by 1/18.6 of a year (about 20 days) each year. Thus, eclipses occurred about 3 weeks earlier in 2015, on average, than in 2014.

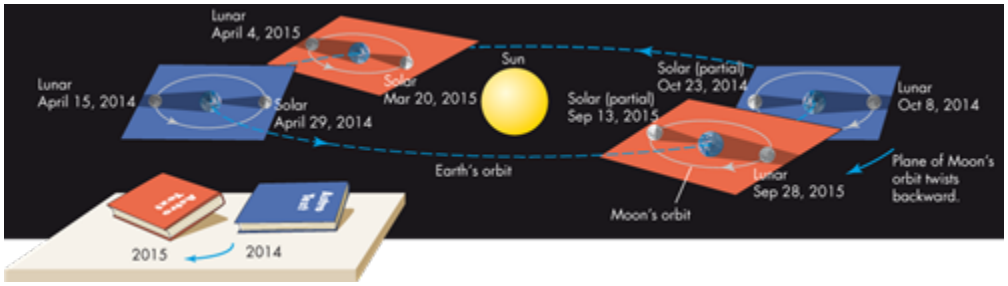

FIGURE 1.28
Precession of the Moon's orbit causes eclipses to come a few weeks earlier (on average) each year. The shift of the orbital plane is similar to twisting a tilted book that has one edge resting on a table, as illustrated in the inset diagram. (Sizes and separations are not to scale.)

If one of the eclipse seasons occurs in early January with the next in June, a third eclipse season may sometimes happen in late December. As a result, as many as seven eclipses, solar and lunar combined, can occur each year. No matter when the eclipse season falls, at least two solar and two lunar eclipses must happen each year, but that does not mean they will be visible to an observer at a given location, since the eclipse may be visible only from another part of the Earth. Most of these eclipses are partial, only partially dimming the Sun or Moon, so they may go unnoticed even where they are visible.