CHAPTER ONE

TWILIGHT

מֵאֵימָתַי קוֹרִין אֶת שְׁמַע בְּעַרְבִית? מִשָּׁעָה שֶׁהַכֹּהֲנִים נִכְנָסִים לֶאֱכֹל בִּתְרוּמָתָן, עַד סוֹף הָאַשְׁמוּרָה הָרִאשׁוֹנָה; דִּבְרֵי רַבִּי אֱלִיעֶזֶר. וַחֲכָמִים אוֹמְרִים: עַד חֲצוֹת. רַבָּן גַּמְלִיאֵל אוֹמֵר: עַד שֶׁיַּעֲלֶה עַמּוּד הַשָּׁחַר.

From when may one recite the *Shema* in the evening? From the time that the Kohanim enter to eat their *terumah* until the end of the first watch—[these are] the words of Rabbi Eliezer. But the Sages say: Until midnight. Rabban Gamliel says: Until the break of dawn.

Berachos 1:1

FIGURE 1.1. Yerushalayim at dawn, a short time before sunrise. Where do those beautiful colors in the sky come from?

WHY DOES THE SKY LIGHT UP BEFORE THE SUN HAS RISEN?

Twilight is that special time of day when the sky is not dark, yet the **Sun** is not visible above the **horizon**. It actually happens twice every day: at dawn, before the Sun has risen, and at dusk, immediately after the Sun has set. In halachah, it is not sunrise, but rather the break of dawn (עַמּוּד הַשַּׁחַר) that marks the beginning of a new day.[1] This happens more than an hour before sunrise when the first rays of sunlight become visible in the eastern sky.[2]

FIGURE 1.2. This is NASA's Juno planetary probe launching atop an Atlas V rocket. About one minute after takeoff, a rocket like this will have traveled through the 100 kilometers (about 62 miles) of Earth's atmosphere and be in empty space.

We have all enjoyed the wonder of the dawn. It is one of the most beautiful and peaceful times of the day. The gradual transition from darkness to light is actually a *chessed* from Hashem to allow our eyes to adjust to the changing brightness so they won't be damaged.[3] The first blessing of the *Shema*, which we recite in the early morning and early evening, alludes to this with the words "הַמֵּאִיר לָאָרֶץ וְלַדָּרִים עָלֶיהָ בְּרַחֲמִים—He Who illuminates the Earth and those upon it with compassion."[4] But have you ever wondered where the light of dawn comes from if the Sun isn't visible over the horizon?

1 *Megillah* 20a–b.
2 *Mishnah Berurah* 89:2.
3 *Kitzur Shulchan Aruch* 32:27.
4 Ibid.

It's not at all as simple as you may have thought. For example, there is no such thing as dawn on the **Moon** or on a **planet** like Mercury. So why does it happen here on Earth?

Hashem custom-made our planet Earth with love in every way. One of those ways was to wrap it in a blanket of air. It may sound strange to compare the air around us to something as thin as a blanket, but it shouldn't. The layer of air around us is actually much thinner than most people think. It hardly takes a minute before a rocket launched from Earth leaves this layer and is no longer surrounded by any air at all—just empty space (see Figure 1.2). And as we shall see, empty space is very different from air!

The layer of air around us isn't just thin like a blanket. It also works like a blanket, ensuring that we never get too hot or too cold. This layer has a special name: the Earth's **atmosphere** (see Figure 1.3).

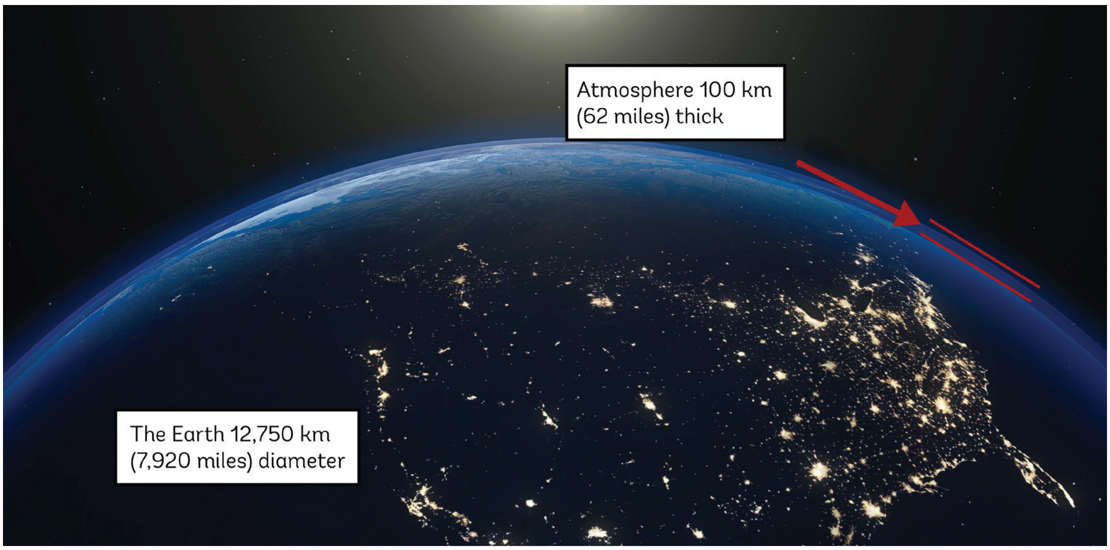

FIGURE 1.3. This is an actual photograph of the Earth at night. All those light blotches in the darkness are city lights throughout North America. On the far right you can see an outline of much of the State of Florida. The strip of lights on the left are cities along the Pacific coast, with Vancouver, British Columbia (Canada) as the most northerly large blotch, and San Diego, California (and even some lights from Tijuana, Mexico) at the bottom of it. Most of the surface of the Earth (especially the Pacific Ocean on the left and Atlantic Ocean on the far right) is entirely dark at night. The blue arc of light surrounding the planet is our atmosphere. Above it, the atmosphere ends and the blackness of space begins. In this picture, you can get an idea of how thin the Earth's atmosphere is relative to the size of the entire planet.

OUR ATMOSPHERE

Our atmosphere does a lot of things. Perhaps the most obvious one is that it provides us with the air we breathe. But it does other things as well. Imagine you were on the Moon. You would need a spacesuit to provide you with air to breathe, since there is no atmosphere on the Moon. Picture yourself looking out of your Moon home's window: It is nighttime and completely dark outside, except for the faint starlight. Without warning, a moment later, the edge of the Sun appears over the nearby mountains. Sunrise! Everything lights up as bright as day—because it is day! On the Moon, there is no such thing as dawn. No עַמּוּד הַשַּׁחַר. One moment it is black night, and hardly a moment later the surface of the Moon is fully lit up.

So why is there a dawn every day on Earth, but never on the Moon? Because of our atmosphere!

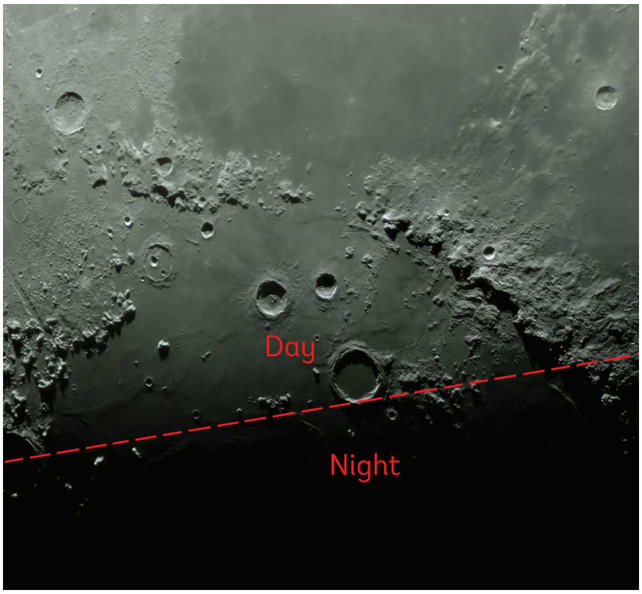

FIGURE 1.4. This is an actual photograph of the Moon. The dotted line divides between where sunrise has occurred and where it hasn't yet.

Our atmosphere is filled with air, which makes it very different from empty space. When we look at air, we don't see anything, but that doesn't mean that nothing is there. Air (like almost everything) is made of countless very tiny particles (pieces) called **molecules**. Even if you can't see air molecules, you can feel them simply by moving your hand quickly and feeling a gentle wind of air molecules press against your hand. You wouldn't feel that on the Moon.

LIGHT

One way to imagine light is as countless extremely tiny balls (scientists call these balls **photons**). When these little balls bump into something, they can either be absorbed or bounce off. For example, look in a mirror and you will see a reflection of your face. What you are seeing is light that bounced off your face onto the mirror and then bounced off the mirror and into your eyes (see Figure 1.5). Light bouncing off something is called **reflection**. When all the light coming from any one particular direction reflects off a smooth surface at the same angle, such as off a mirror, then all the photons "stay together" in their original formation, and we see a copy of the original object. Mirrors, however, are special cases of reflection. Usually, photons bounce off objects in every direction, so our eyes just see the color of the photons that bounced off, without seeing a recognizable image of the original light source.

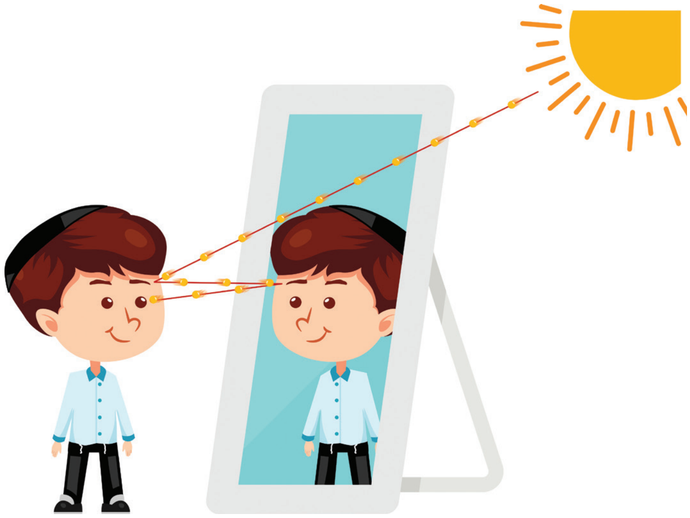

FIGURE 1.5. You can see your forehead in the mirror, even though it isn't actually there. This is because of photons that reflected off your forehead, toward the mirror, and then reflected back off the mirror's surface into your eyes.

The reflection of light off a mirror is something like a ball bouncing off a smooth wall. When you throw a ball against a smooth surface, it bounces back in a very predictable direction. If you have good aim, you could probably throw a ball against a wall ten times and catch it again each time without ever moving your feet. Now imagine that instead of a wall, you were throwing a small bouncy ball against a basketball. Do you think you could guess which direction it would bounce off the basketball? If you think you could, why not try it? Throw a small ball a few times against a basketball and see just how unpredictably it rebounds. If you threw a thousand small bouncy balls against a pile of basketballs, can you picture how the balls would bounce back, scattering in every direction?

A simplified way of thinking about what happens when the Sun's light passes through our atmosphere is to imagine the light from the Sun as being made of countless photons, each like a tiny bouncy ball, and the atmosphere as countless air molecules, each like a basketball. In our atmosphere, there is a lot of empty space between each molecule, so most of the photons coming from the Sun pass straight through the atmosphere without bumping into any air molecules (see Figure 1.6). However, some of the photons from the Sun do bump into the atmosphere's air molecules. When this happens, the photon is knocked into a totally different, unpredictable direction. Since there are actually many, many photons bouncing off the molecules in the atmosphere, the overall effect is to spread some of the Sun's light over the entire sky. This is called **scattering** of the light.

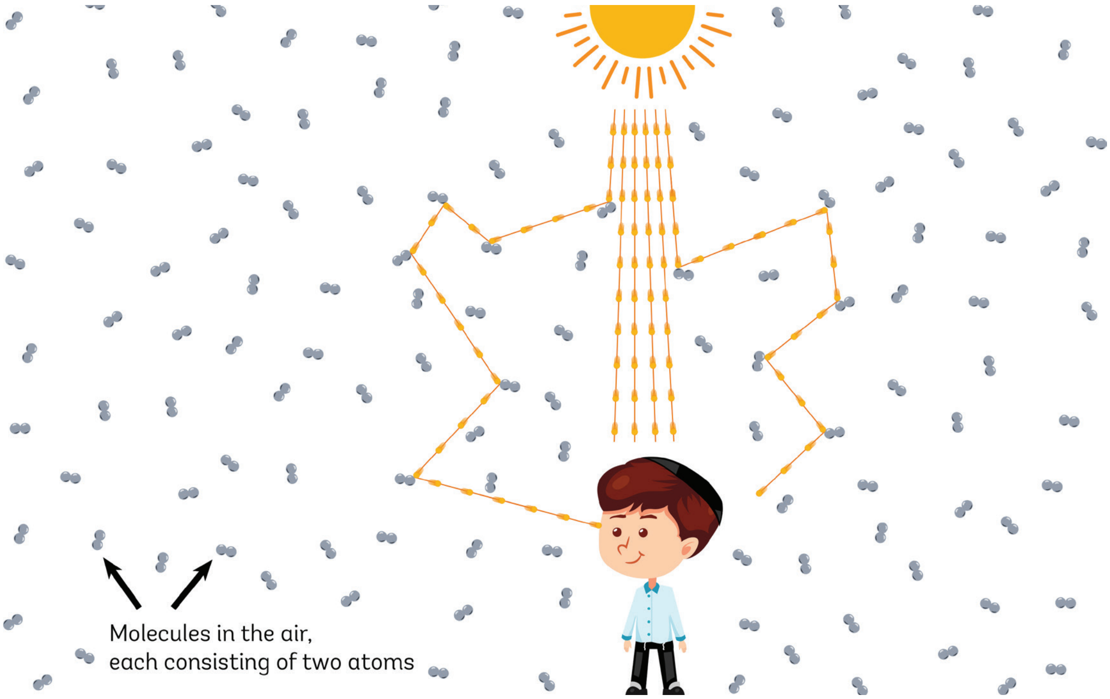

FIGURE 1.6. This is an illustration of how you might imagine most photons from the Sun passing directly through the atmosphere, while some collide with air molecules and are scattered in unpredictable directions.

The light that we see in the sky before sunrise is scattered sunlight that spreads around the atmosphere. It is probably easier to make sense of this with an illustration. Look at Figure 1.7. The person standing at Position A on the Earth's surface will not be able to see the Sun directly. In other words, sunrise has not yet

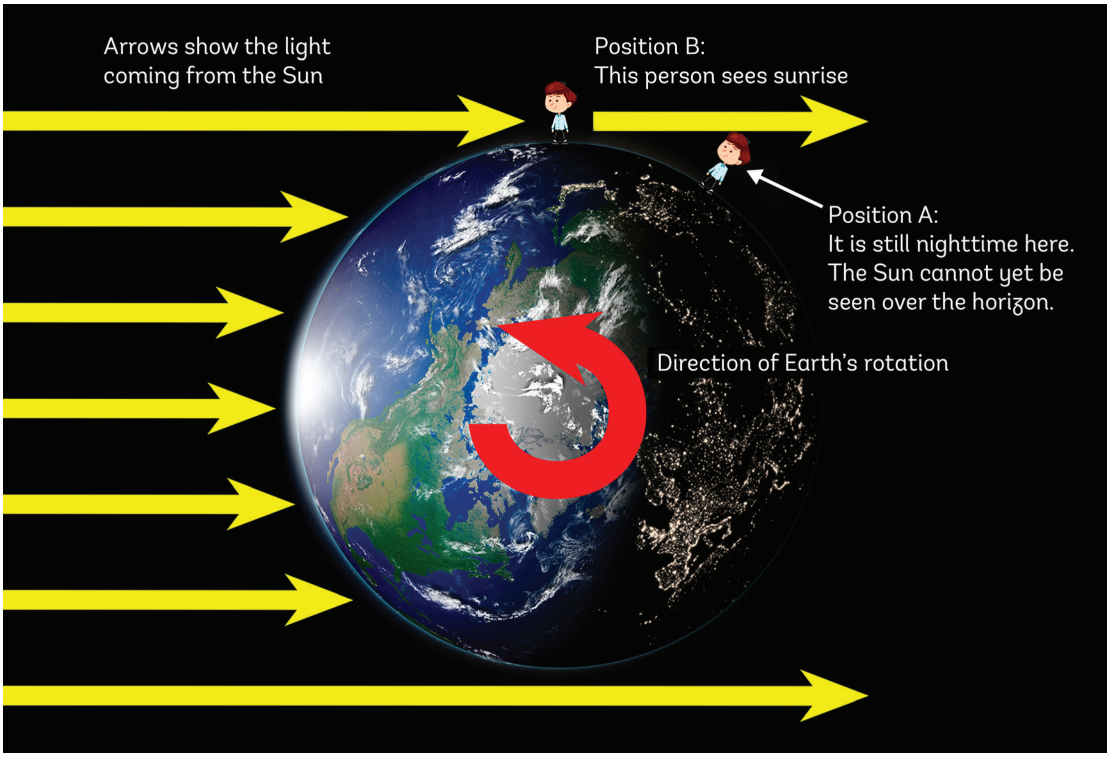

FIGURE 1.7. A view of the Earth from above the North **Pole**. From the direction of the Earth's rotation (as signified by the red arrow), you can see that it is currently nearing the end of the night for the person standing at Position A. In an hour or so he will have moved to Position B. (The Earth rotates 360° in 24 hours, so each hour it rotates 15°.) The person currently standing at Position B would have just been able to see the Sun rise over the horizon.

occurred where he is standing. If he looks at the sky in the direction of the Sun, soon he will be able to detect the break of dawn (עַמּוּד הַשָּׁחַר) as the sky begins to fill with scattered sunlight. It is almost like the light is "sneaking around the corner." As the Earth rotates and he moves toward Position B, the sky will brighten with more and more scattered light. When he finally reaches Position B, the Sun will be in a direct line of sight, and sunrise will occur as the ball of the Sun appears on the horizon.[5]

5 Technical point: There is another atmospheric effect called "refraction," which slightly bends light from the Sun toward the Earth. Refraction bends light uniformly in a single direction; it is something entirely different from the scattering we have been discussing, in which light spreads out in all directions. When we view light refracted through our atmosphere, it retains a coherent image (i.e., the Sun can still be seen

We have answered our initial question regarding why the sky lights up before the Sun has risen. Before we conclude this topic, we should consider one more question that almost every person has wondered about some time in their life, since we are most of the way to the answer already: Why is the sky blue?

WHY IS THE SKY BLUE?

Up until now, we have been discussing the scattering of the Sun's light in the atmosphere, but not all of the Sun's light scatters in the same way. This is because not all photons are the same. Depending on how much **energy** they have, we perceive photons as having a different colors. Thus, we might say that blue light is made of blue photons, and red light is made up of red photons. The light that comes from the Sun is actually a mixture of many different colors that all combine to make it the yellow-white color that we usually see. The chances that an individual photon will be scattered in the atmosphere depends very strongly on its color. Blue photons scatter much more readily than photons of the other colors.

During most of the day, when the Sun is high in the sky, its red light doesn't travel through enough atmosphere to be scattered significantly. At the same time, a lot of blue light is scattered and spreads around the atmosphere (see Figure 1.8). This is the source of our midday blue sky (Figure 1.9). The strong scattering of blue photons also means that they travel very far around the atmosphere, so blues are the first colors we see at dawn (עַמּוּד הַשָּׁחַר) and the last colors we see at dusk (צֵאת הַכּוֹכָבִים) (Figure 1.10).

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as a sharply defined ball, despite the refraction). This is in contrast to scattered light, as we have described above. Refraction's net effect is to make sunrise visible about two minutes earlier than it would have been if the Earth had no atmosphere. The precise amount of refraction that occurs depends on latitude, elevation, **temperature**, and **humidity** at the time of sunrise.

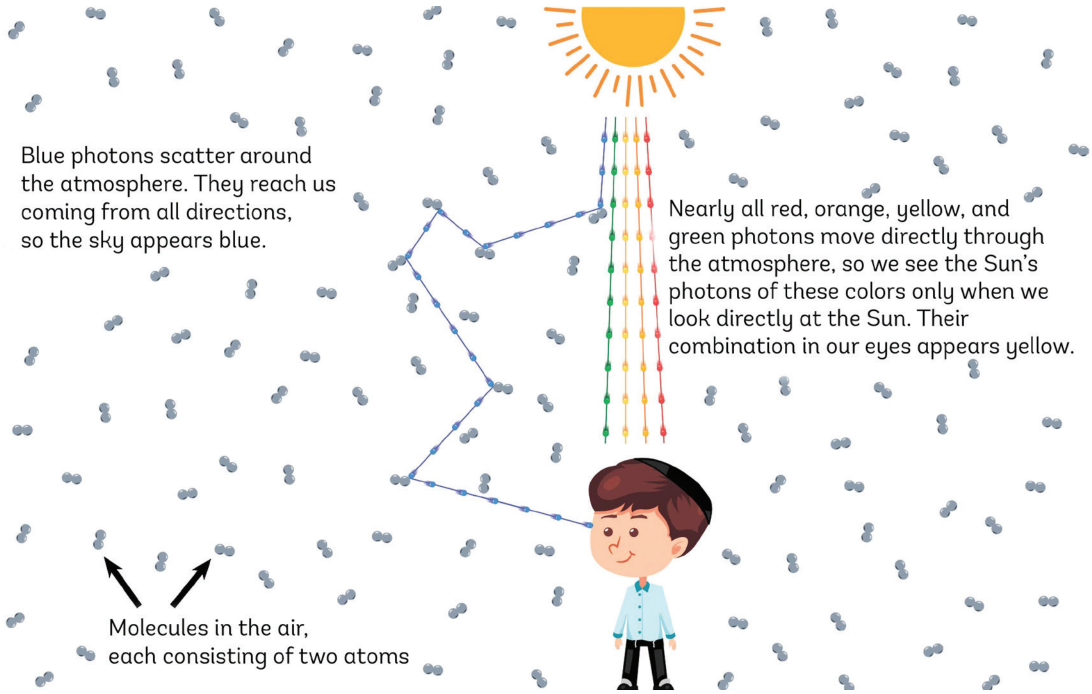

FIGURE 1.8. Blue photons are much more likely to be scattered, so we see them coming from all directions.

FIGURE 1.9. During most of the day, only some of the blue light is scattered around the sky. Most of the rest of the Sun's light goes straight through the atmosphere, combining to make the familiar yellow-white color of the Sun. (Caution: you should protect your eyes and try to never look directly at the Sun!)

FIGURE 1.10. After the Sun sets and moves further and further below the horizon, fewer and fewer colors are able to scatter widely enough to be seen, until only blue light is left. This means that from about half an hour after sunset, the sky is just ever-darkening shades of blue.

Since red light scatters less easily, the only time we see red in the sky is when the Sun is low in the sky and its light must go through a much thicker section of atmosphere before reaching us (Figure 1.11). This happens around sunset and sunrise (Figure 1.12). At these times, when the Sun is low in the horizon, sunlight passes through up to thirty times more atmosphere than it does at noon.

All the light other than the red is scattered to such a degree that it is lost. Even much of the red light is scattered, causing the sky around the Sun to appear reddish, instead of its usual blue. The remaining red photons from the Sun that are not scattered travel straight through the atmosphere, so the Sun also appears deep red.

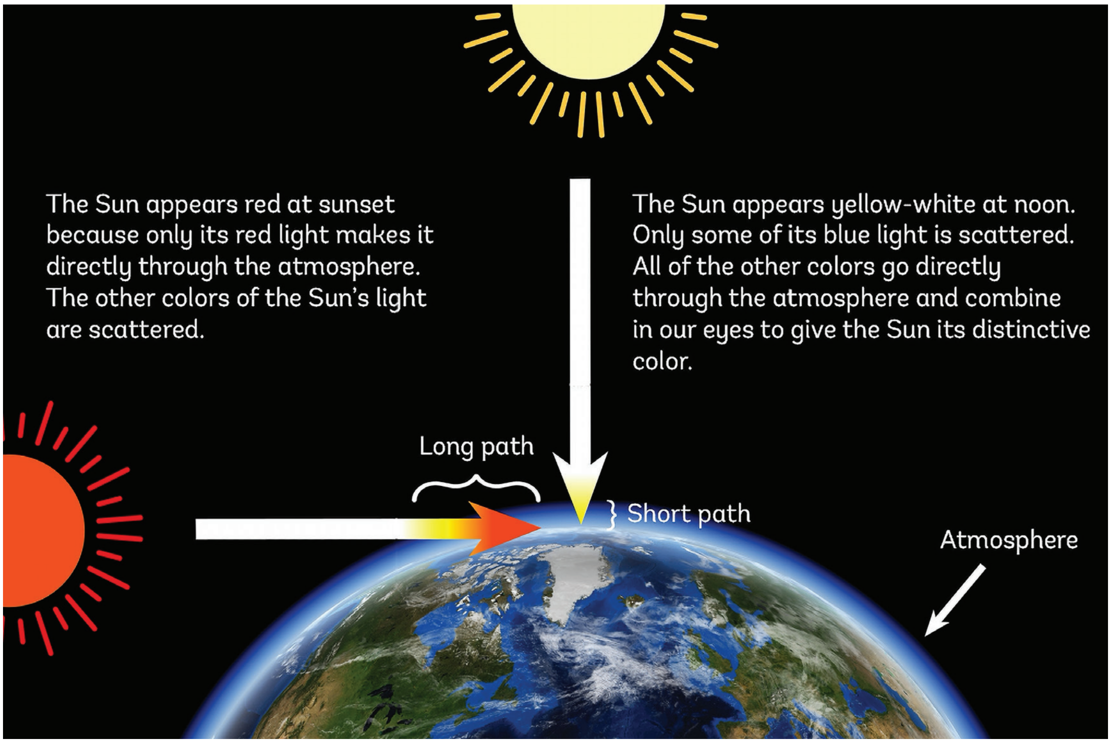

FIGURE 1.11. The Sun's rays must travel through a thicker section of atmosphere at sunrise and sunset (when the Sun appears low in the sky) than they do during the middle of the day.

FIGURE 1.12. The distinctive deep reds of a beautiful sunset