Phenomena Related to Refraction

12.7

Nature has many interesting phenomena involving light. Geometric optics is a useful tool that we can use to explain many of these phenomena.

Apparent Depth

A pencil partly under water looks bent when viewed from above (Figure 1). We can explain this using the concept of refraction and the knowledge that our brains perceive light rays to always travel in a straight line. Light from the submerged pencil tip reaches your eyes. Your brain then projects the rays backwards in a straight line to create a virtual image in the water. This virtual image is higher than the actual pencil tip, resulting in the pencil appearing to be bent. The pencil tip appears to be at a shallower depth than it really is. The distance from the surface of the water to where the object appears to be (the virtual image) is called the **apparent depth** (Figure 2). A paddle in the water also appears to be closer to the surface for the same reason.

Figure 1 A "bent" pencil in water

apparent depth the depth that an object appears to be at due to the refraction of light in a transparent medium

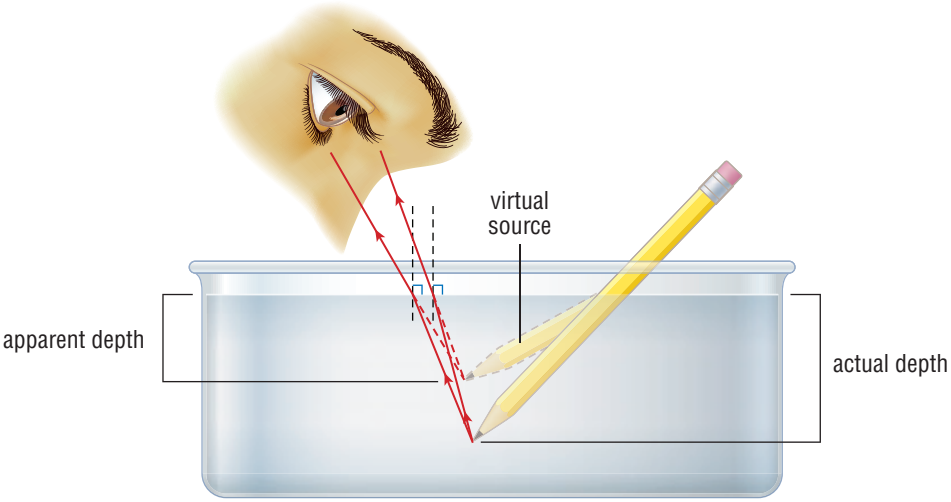


Figure 2 Refraction causes the pencil to appear closer to the surface than it actually is.

Objects under water always appear to be nearer to the surface than they actually are. Apparent depth is an optical illusion. This is what makes fish in water appear to be closer to the surface than they actually are (Figure 3).

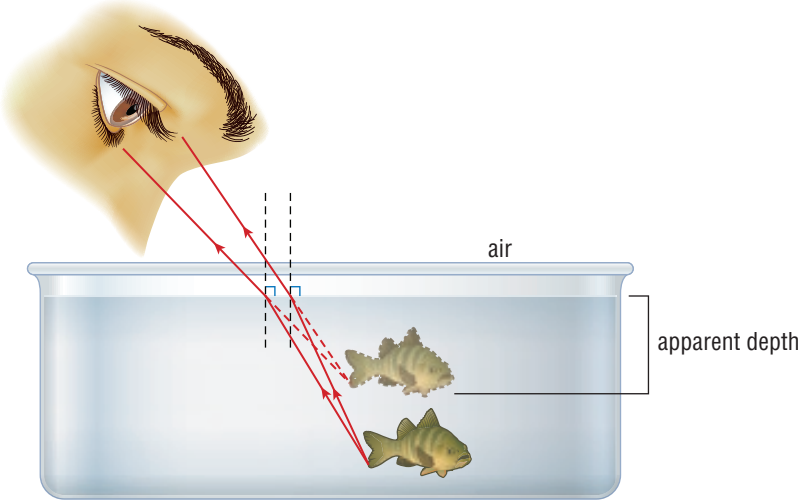


Figure 3 The illusion of apparent depth

For the same reason, the legs of someone standing in water appear to be shorter. Figure 4 is an illustration of refraction and apparent depth.

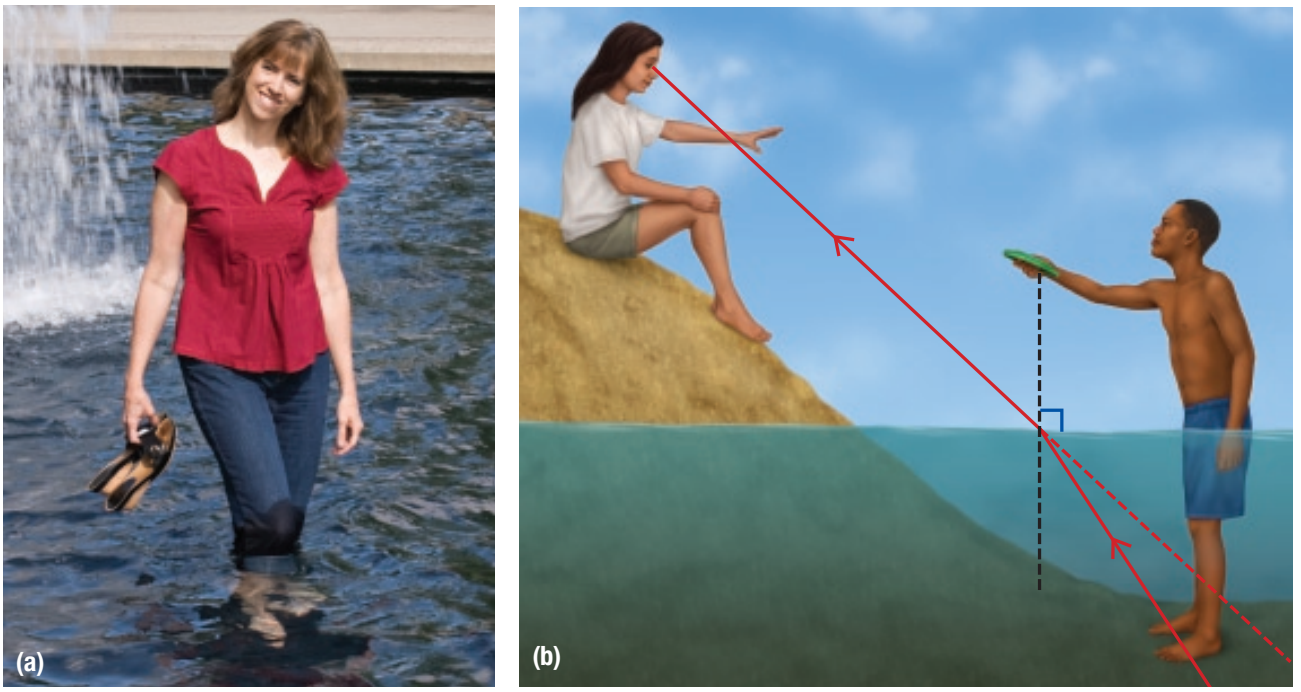


Figure 4 Refraction causes a person's legs to appear shorter under water than they really are.

The "Flattened" Sun

Sunsets offer a unique opportunity to see an unusual image due to refraction. People notice that when the Sun is near the horizon during sunset, it appears to be flattened. The Sun, of course, is not really flattened (Figure 5). When the Sun is close to the horizon, light from the bottom of the Sun is refracted more than light from the top of the Sun. Part of the reason is that air is more dense near Earth's surface than higher up in the atmosphere. So the increased density of air closer to Earth results in greater bending of the Sun's rays. In addition, the light rays from the bottom of the Sun have a greater angle of incidence than the light rays from the top of the Sun. This results in the Sun having a flattened appearance rather than its familiar round shape.

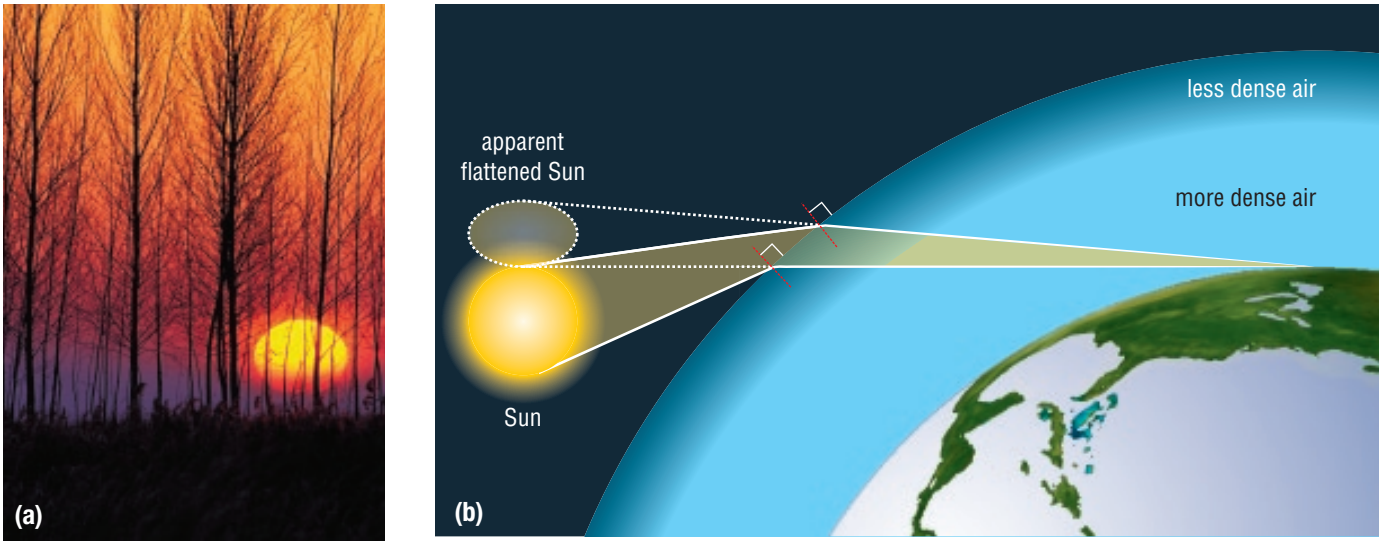


Figure 5 The flattening of the Sun is the result of refraction in Earth's atmosphere.

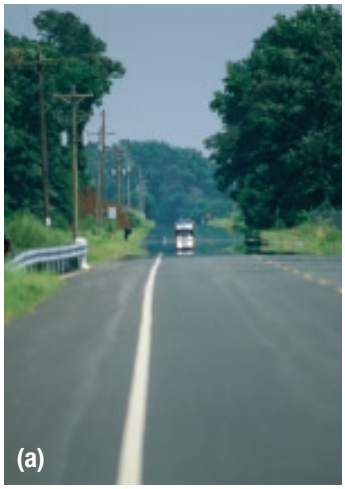
Water on Pavement—The Mirage

Many people have noticed what appears to be a pool of water in front of them as they drive along a highway (Figure 6(a)). This pool of water seems to be only a short distance away, yet the car never seems to reach it. The pool appears to be constantly moving away.

The pool of water on a highway is a **mirage**. A mirage can appear when light is travelling from cool air into warmer air. The index of refraction for air decreases as the air gets warmer. This results in light bending farther away from the normal as the air temperature continues to increase. Eventually, total internal reflection occurs in the lowest (hottest) air layer (Figure 6(b)). The light ray now travels up from the hottest layer to the cooler layer above and is gradually refracted toward the normal as the air temperature decreases. This light ray eventually enters your eyes. A motorist who sees this curved light forms a virtual image on the highway.

mirage a virtual image that forms as a result of refraction and total internal reflection in Earth's atmosphere

In reality, the pool of water is a virtual image of the sky on the highway. Because the human brain perceives light to travel in a straight line, the motorist projects the image of the sky onto the highway.



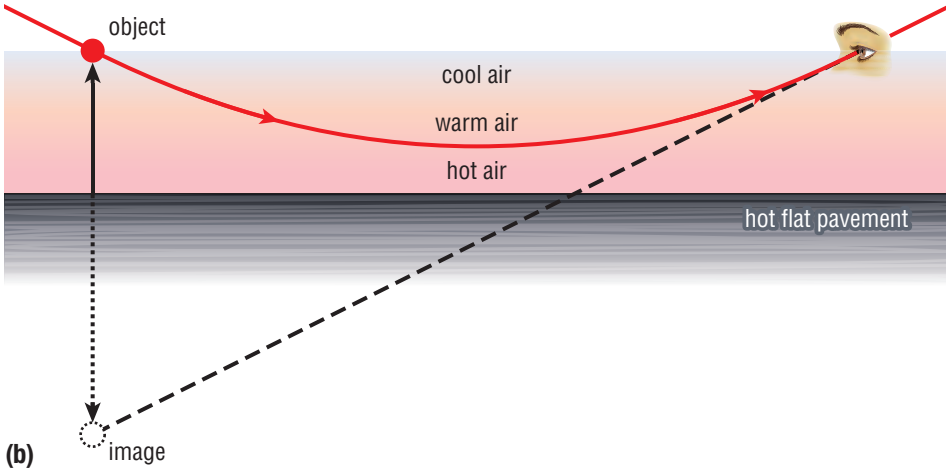


Figure 6 There appears to be a pool of water on the highway. This illusion is caused by the refraction and reflection of light as it goes through air of different temperatures.

Shimmering

You may have noticed that when the Moon is out at night above a lake, you can see a shimmering image of the Moon on the water's surface (Figure 7). As with a mirage, shimmering is caused by light being refracted as it passes through air of different temperatures.

At night, the air just above a lake is much warmer than air farther away from the water's surface. Moonlight passes through layers of air that have different temperatures. In the coldest air layer, light travels more slowly so a light ray going through this layer bends toward the normal. As the light ray continues travelling downward toward the warmest air layer (just above the lake), its speed increases, so the light ray bends farther and farther away from the normal. Eventually, total internal reflection occurs in the lowest warm air layer. This results in multiple virtual images of the Moon on the water's surface.

Figure 7 Shimmering on a lake is caused by light travelling at slightly different speeds through air layers of different temperatures.

The Rainbow

dispersion the separation of white light into its constituent colours

In the previous chapter, you learned how Isaac Newton used a triangular prism to separate white light into a continuous sequence of colours. The separation of white light into its spectrum is called **dispersion**. Dispersion occurs because each colour of visible light travels at a slightly different speed when it goes through the glass prism. Violet light slows down more than red light when it enters the prism. That is why you see violet light being refracted more than any other colour (that is, bending more toward the normal than any other colour). Red light is refracted the least (Figure 8).

READING TIP

Challenging Beliefs
The explanation of a natural phenomenon or an optical illusion may challenge a belief that you hold about something you have experienced. For example, the explanation of a rainbow or a mirage may convince you that you cannot always believe what you see, or think you see.

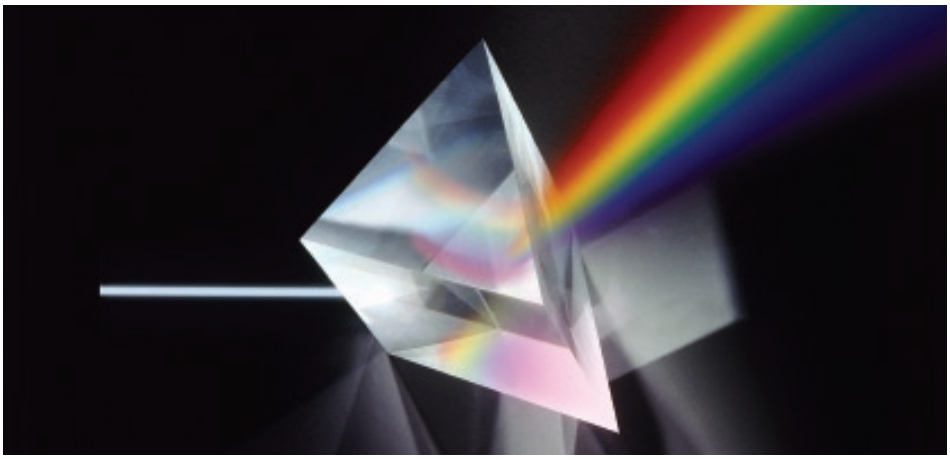


Figure 8 The colours in visible light travel at different speeds through a triangular glass prism.

The rainbow is an optical phenomenon that is produced by water droplets in Earth's atmosphere (Figure 9). The first step in the process involves refraction as light enters the raindrop (going from air into water), resulting in dispersion. The second step is partial internal reflection when this light hits the back of the raindrop. The third step is refraction as the light now exits the raindrop (going from water into air). This is the light that your eyes see, which you perceive as a rainbow. Your brain projects these light rays backwards and forms a virtual image of the spectrum: a rainbow (Figure 10). You can only see a rainbow when the Sun is behind you.

DID YOU KNOW?

Over the Rainbow
The geometry of a rainbow is very precise. The angle between the rainbow and the viewer is always the same: about 42°. All rainbows would form complete circles if the ground were not in the way.

Figure 9 As long as the Sun remains behind you, a rainbow moves as you move.

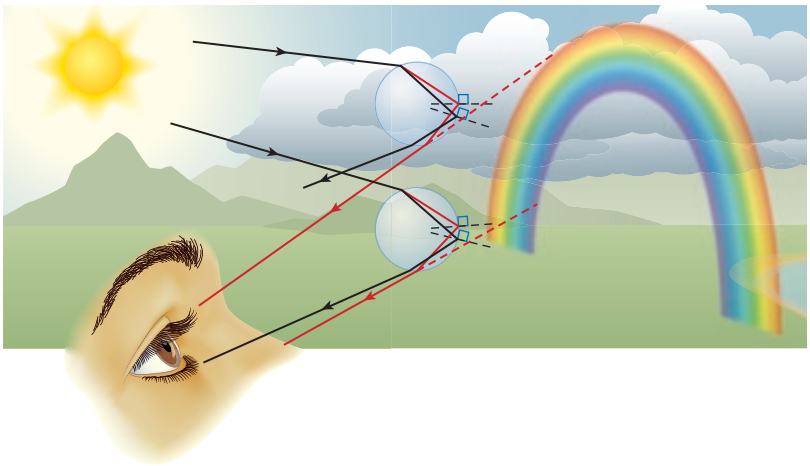


Figure 10 The rainbow is caused by a combination of dispersion and partial internal reflection in water droplets in the atmosphere. Millions of raindrops are necessary to produce a rainbow.

RESEARCH THIS OTHER ATMOSPHERIC OPTICAL PHENOMENA

SKILLS: Researching, Communicating

SKILLS HANDBOOK 4.A., 4.B.

Light produces far more atmospheric phenomena than the few mentioned in this section (Figure 11). In this activity you will research one of these phenomena.

Figure 11 The belt of Venus (the dark blue band above the horizon) is another natural optical phenomena.

Complete *one* of these research questions.

1. Research how a sun dog or a moon dog is produced.
2. Research how an icebow is formed.
3. Research how a "green flash" is produced.
4. Research another interesting atmospheric light phenomenon that has not been mentioned in this section.

Answer the question that matches the phenomenon you chose.

A. What conditions are necessary to produce a sun dog or a moon dog? T/I

B. What is the primary difference between a rainbow and an icebow? T/I

C. Explain how a "green flash" is produced in the atmosphere. Why is the "green flash" so difficult to see? T/I

D. Briefly explain how the other light phenomenon you researched is produced in the atmosphere. T/I

IN SUMMARY

- Objects in water appear to be at a shallower depth (an apparent depth) than they really are as a result of the refraction of light.
- The Sun appears flattened near the horizon because light from the bottom of the Sun is refracted more through Earth's atmosphere than light from the top of the Sun.
- Shimmering is caused by light travelling at slightly different speeds through air layers of different temperatures.
- A mirage is the result of refraction and total internal reflection in layers of air of different temperatures.
- A rainbow is caused by refraction of sunlight and partial internal reflection in water droplets in Earth's atmosphere.

CHECK YOUR LEARNING

1. (a) Explain what is meant by the term "apparent depth."
   (b) What causes this phenomenon? K/U
2. You want to scoop a fish out of water. Where should you aim relative to the fish image in order to really capture it? Explain. K/U
3. In the explanation of a mirage, the text mentioned that the index of refraction for air decreases as the air gets warmer. What does this tell you about the speed of light in cold air compared with the speed of light in warm air? Explain. K/U
4. What are you really looking at when you see a pool of water on a highway that you know is dry? Explain. K/U
5. In dispersion, violet light is refracted more than red light. What does this tell you about how the index of refraction for violet light compares with that for red light? Explain. K/U
6. What three changes in direction does a light ray undergo when it interacts with a raindrop to form a rainbow? K/U
7. Would a rainbow still form if the speed of light did not change for different colours in a raindrop? Explain. K/U