Key Terms
rainbow
apparent depth
shimmering
mirage

11.3 Optical Phenomena in Nature

The double rainbow in **Figure 11.23** is an excellent natural example of the refraction and dispersion of light. Your new understanding of the behaviour of light will allow you to analyze the paths of the light rays that bring this double rainbow to your eyes.

Rainbows

rainbow an arc of colours of the visible spectrum appearing opposite the Sun, caused by reflection, refraction, and dispersion of the Sun's rays as they pass through raindrops

The Sun must be behind you if you are to see a **rainbow**. It must also reflect off something for it to return to your eyes. After a rainstorm, the sky is filled with tiny water droplets. The sunlight reflects off these water droplets.

Now consider the sequence of colours in the two parts of the double rainbow. Red is the top colour of the inner rainbow, but it is the lowest colour of the secondary rainbow. Notice that much more light is coming from the area inside the inner rainbow than the area outside the inner rainbow. All of these factors can be explained by the reflection, refraction, and dispersion of light in raindrops. A secondary rainbow is caused when sunlight reflects twice inside rain droplets. This explains why the secondary bow is less bright, with red at the bottom and blue at the top.

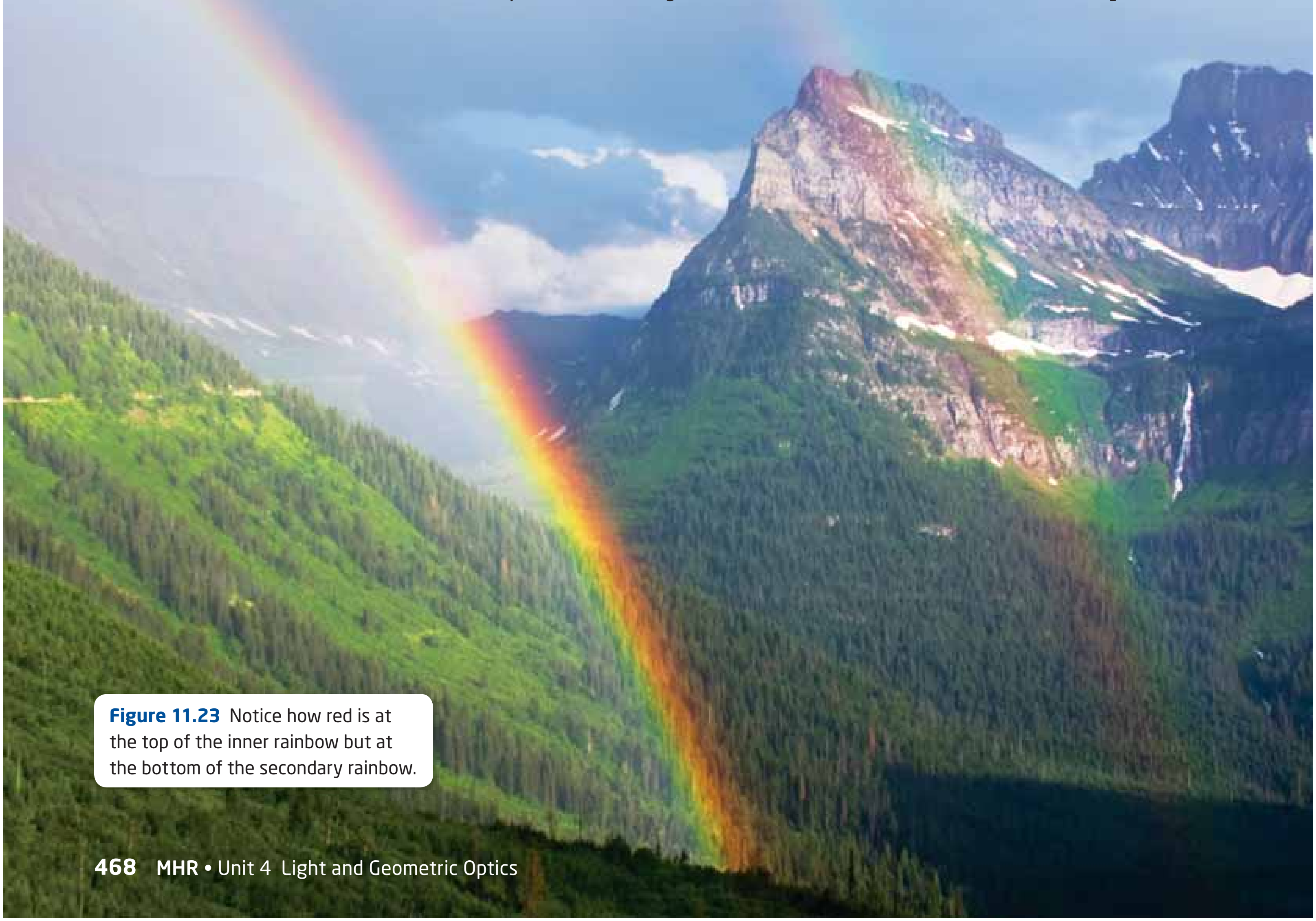


Figure 11.23 Notice how red is at the top of the inner rainbow but at the bottom of the secondary rainbow.

Formation of a Rainbow

A rainbow forms when sunlight enters a water droplet and refracts, reflects off the inner surface of the droplet, and then refracts again when leaving the droplet. The two refractions result in dispersion of the light. Notice in **Figure 11.24A** that within the droplet itself, the different colours cross each other, and then spread out as they leave the droplet.

Compare the colours leaving the single water droplet in **Figure 11.24A** with the colours in the inner rainbow in **Figure 11.23**. Notice that the red light leaving the water droplet is the lowest colour, but red is the top colour in the inner rainbow. Although this seems be a contradiction, it is correct. When you see a rainbow, the colours that you see come from different droplets. Because the red light is directed downward more than the other colours of light, you can only see the red light that is coming from droplets higher in the sky. **Figure 11.24B** shows which colours you see from droplets at different heights in the sky.

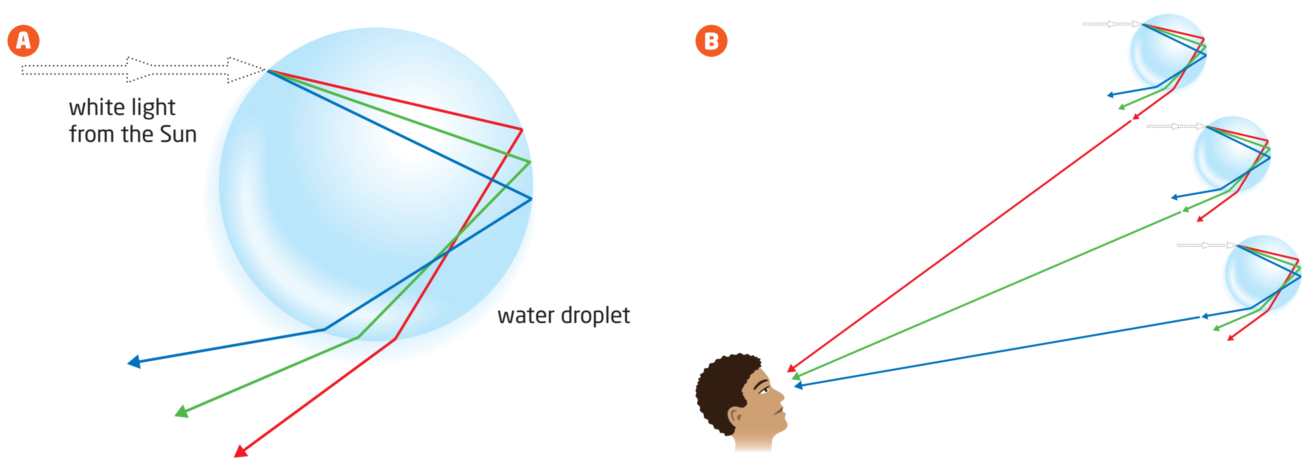


Figure 11.24 **A** The index of refraction is different for each colour of light. When white light leaves a water droplet, refraction causes the colours to disperse. **B** You see the different colours in a rainbow coming from water droplets at different heights in the sky.

Sundogs

At the beginning of this chapter, you saw a photograph of the spectacular atmospheric phenomena known as sundogs, which are bright spots on both sides of the Sun. They are sometimes called "mock suns" for that reason. Their technical name is *parhelia*. Sundogs have something in common with rainbows, but there is a difference. Rainbows are a result from sunlight interacting with water droplets in the atmosphere. Sundogs, however, occur when ice crystals in the atmosphere refract sunlight. The most stunning sundogs occur on cold, clear sunny mornings and evenings, when there are ice crystals in the air, such as in cirrus clouds. (Cirrus clouds are at a high altitude, over 6000 m. They are composed of ice crystals.) Sundogs occur when the Sun is low, near the horizon. These phenomena have been photographed in many provinces and territories of Canada, including Ontario.

Go to **scienceontario** to find out more

The Illusion of Apparent Depth

apparent depth an optical effect in which the image of an object appears closer than the object

Just as an image is formed by reflection in a plane or a curved mirror, an image is formed by the refraction of light. Using ray diagrams, you can determine where the refracted image is located when it is viewed from the air. Light rays from the object, like the box at the bottom of the pool in **Figure 11.25**, travel to your eyes. The rays have refracted at the surface of the water. As in Chapter 10, you can draw a ray diagram to locate the image of the object. Locate the image of the box by tracing the rays backward until they meet. Note that the box on the bottom of the pool looks like it is higher and closer to the observer than it actually is. In fact, the bottom of the pool is deeper than it appears to be. The level at which the object or the bottom of the pool appears to be is called the **apparent depth**.

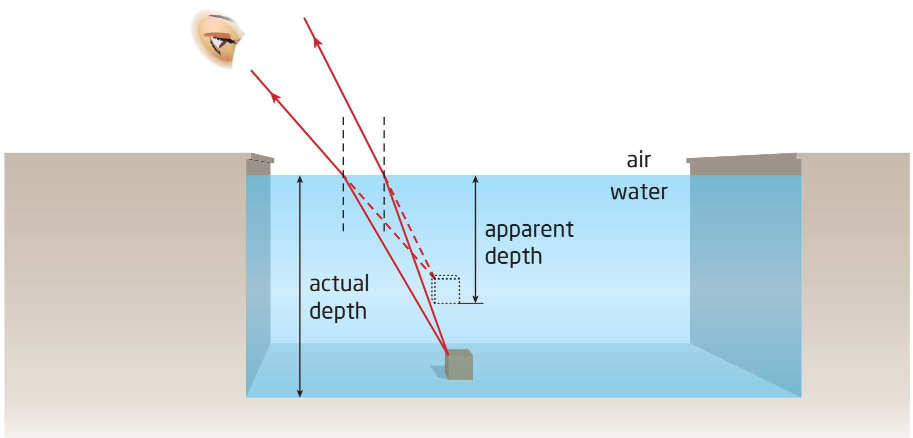


Figure 11.25 The solid lines from the box to the observer show the actual path of the light rays. The dashed lines show where the observer's brain interprets the path to be.

After analyzing **Figure 11.25**, you can understand why a fish in a pond is lower in the water than it appears to be. So, how do water birds, such as the pelican in **Figure 11.26**, actually catch the fish they dive for? A pelican will spot a fish while flying above the water and start into a dive. It will hit the water forcefully, continue into the water, and catch the fish without difficulty. The pelican has found a way to account for the illusion of apparent depth.

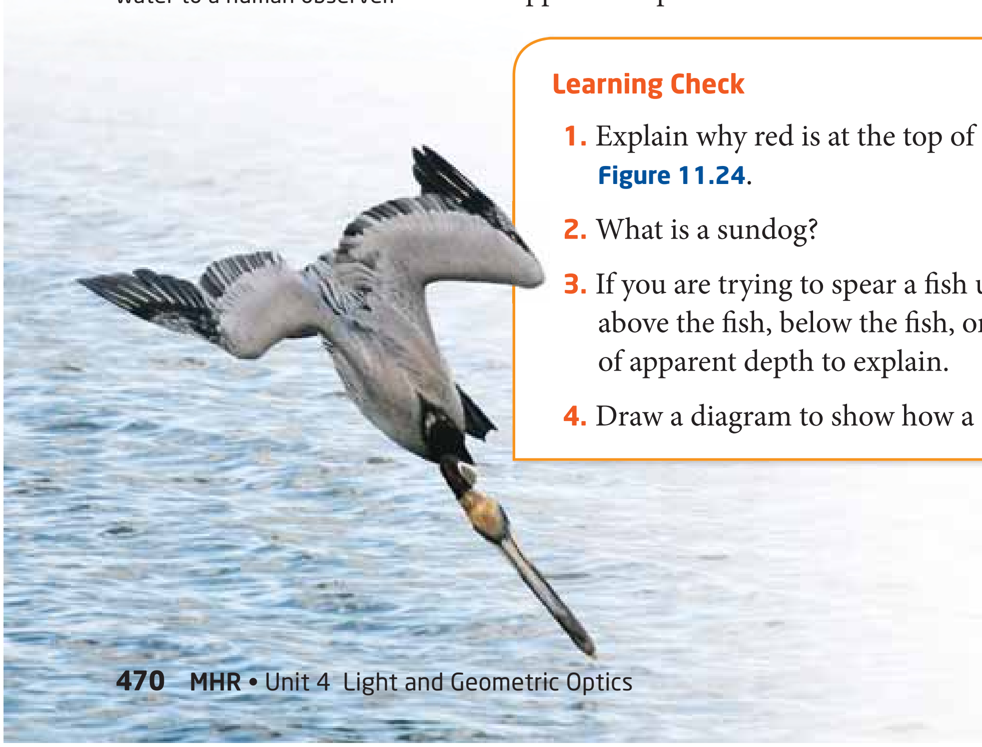


Figure 11.26 Water birds, such as the pelican, dive deeper for a fish than the fish appears in the water to a human observer.

Learning Check

1. Explain why red is at the top of a single rainbow. Review **Figure 11.24**.
2. What is a sundog?
3. If you are trying to spear a fish underwater, should you aim above the fish, below the fish, or at the fish? Use your knowledge of apparent depth to explain.
4. Draw a diagram to show how a double rainbow forms.

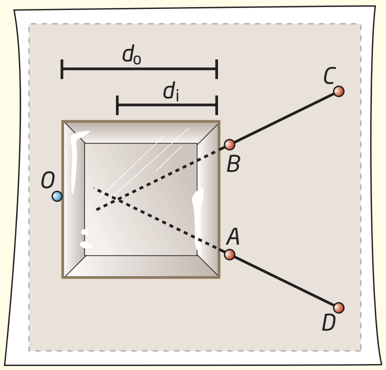
Activity 11-4

Apparent Depth

How does the location of an object appear to change when you observe it through a plastic block? In this activity, you will demonstrate the phenomenon of apparent depth.

Materials

- rectangular plastic block
- thick piece of cardboard
- sheet of blank paper
- 5 straight pins
- ruler



Place the plastic block and pins as shown here.

Procedure

1. Place the cardboard on the desk. Place a sheet of paper on top of the cardboard and the plastic block on the paper.
2. Place a pin at position *O* shown in the diagram above. The pin should be touching the plastic.
3. Place a pin at positions *A* and *B*, as shown in the diagram on the left.
4. Look in the direction shown in the diagram until pin *B* and the pin at *O* appear in a straight line. Place pin *C* so that all three pins appear in a straight line. Similarly, place pin *D* so that the pins at *D*, *A*, and *O* appear in a straight line.
5. Remove the block, and draw dashed lines to show where the lines *CB* and *DA* intersect inside the block at the image of pin *O*. Measure d_i and d_o.
6. Make a ray diagram to illustrate your observation.
7. Switch places with your partner, and repeat steps 3 and 4.

Questions

1. Where do the rays intersect?
2. Explain your observations.
3. Suppose you used a clear container instead of a plastic block. You then positioned the pins before filling the container with water. Predict how your observations would change compared with your observations above. Test your prediction.

Shimmering and Mirages

Shimmering and mirages are caused by the refraction of light in unevenly heated air. When light travels through air at different temperatures, it refracts because hot air is less dense than cooler air. Because there is no distinct boundary between sections of air at different temperatures, the light does not bend at one specific point. Instead, it travels along a curved path. Also, because air is usually moving, the direction and the amount of the bending are constantly changing.

Shimmering

You can see shimmering in air above any very hot surface. For example, the air above the hood of a car that has been travelling for a long time or hot asphalt being laid can become very hot, due to contact with the hot surface. When you look through the hot air, objects look wavy, as shown in **Figure 11.27**. Objects often look like they are moving, as well. This apparent movement of objects is called **shimmering**.

Figure 11.27 When you look through the hot air around the engine at the distant plane in the middle of the photograph, the distant plane looks wavy.

shimmering the apparent movement of objects in hot air over objects and surfaces

Mirages

A mirage occurs on a much larger scale than shimmering. The most common place to see a mirage is in a very hot desert or on a highway. The sand or paved surface becomes extremely hot after being in sunlight for several hours. The hot ground heats the air just above it, making the lower layer of air much hotter than the higher air. When sunlight reaches the hot air near the ground, the sunlight is refracted upward.

Because you are accustomed to assuming that light travels in a straight line, you interpret the origin of the light as being on the ground. An object that appears to be on the ground but is not really there is called a **mirage** [pronounced mi-RAHJ]. **Figure 11.28A** shows how a mirage forms. The solid line shows the real path of the light. The dashed line shows where the blue light from the sky appears to have originated. **Figure 11.28B** is a photograph of a mirage on a highway formed in this way.

mirage an optical effect caused by the bending of light rays passing through layers of air that have extremely different temperatures

STSE Case Study

Protecting Your Eyes from UV Radiation

You may wear sunglasses for style and protection from the Sun. Whatever the reason, it may surprise you to learn that your sunglasses could be letting through radiation that is harmful to your eyes.

The brightness of light is illustrated in the bar graph on page 473. Sunglasses are tinted to reduce the amount of visible light that reaches your eyes. The tinting, which is applied as a coating on the lens, is made up of light-absorbing molecules. The thicker the coating is, the darker the lens is. The coating does not block ultraviolet (UV) radiation, however.

UV Radiation

UV radiation is one of the more energetic types of light in the electromagnetic spectrum. UV radiation causes your skin to tan. If you expose your skin to sunlight for too long, you will get a sunburn. Imagine, therefore, what UV radiation can do to your eyes!

Effects of UV Radiation

- Long-term exposure to UV radiation can damage your eyes.
- Damage from UV radiation cannot be reversed.
- Exposure to UV radiation can contribute to the development of cataracts (a clouding of the natural lens of the eye), cancer, and snow blindness. Snow blindness is a temporary but painful sunburn on the surface of the eyes.

When you buy sunglasses, check the tags to see how much light is blocked. Look for sunglasses that block 99 to 100 percent of UV radiation and 75 to 90 percent of visible light.

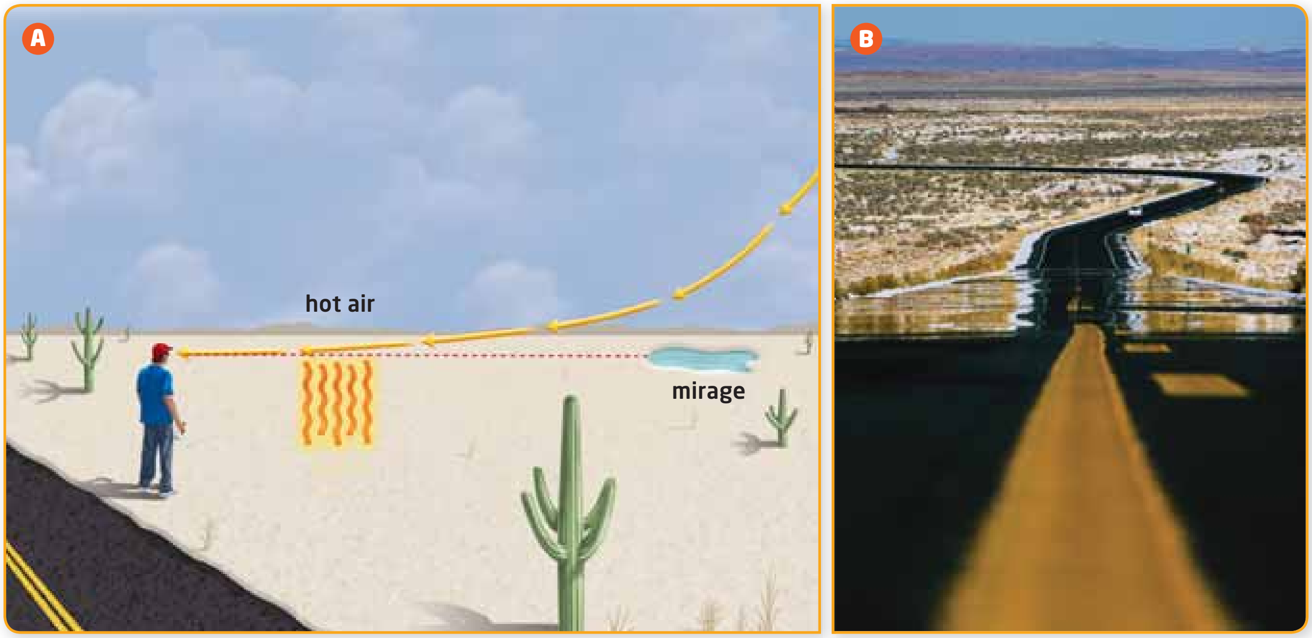
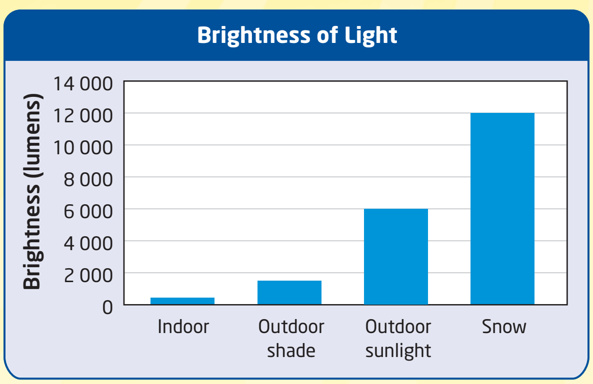


Figure 11.28 **A** The solid, curved line shows the path of light from the sky. The dashed line shows how your brain interprets the scene. **B** The watery area on the road is really a mirage.



The brightness of light is measured in *lumens*. Your eyes are comfortable up to 4000 lumens. After that, you begin to squint. Sunglasses allow an acceptable amount of light to reach your eyes.

How can you protect your eyes from UV radiation? By simply wearing a cap or a wide-brimmed hat, you can prevent 50 percent of the UV radiation from reaching your eyes. Wearing sunglasses with a special coating will prevent even more UV radiation from reaching your eyes. UV-filtering lenses are coated with special chemicals. These chemicals have a structure that allows visible light to pass through them while reflecting UV radiation away from your eyes.

Wraparound sunglasses offer even more protection because they protect your eyes from UV radiation that enters from the side. Wraparound sunglasses are particularly useful when skiing and when at the beach, where the reflection of sunlight is particularly strong.

Over to You

1. According to the bar graph on the left, how bright is light reflected from snow? Is that level of brightness comfortable for your eyes?
2. Survey your friends and family members to find out how many wear sunglasses and when. What argument could you make to persuade people who do not wear sunglasses to buy a pair to protect their eyes?
3. The lenses of some eyeglasses have features that provide enhanced eye protection. These features include anti-glare coatings, anti-reflective coatings, polarization, and photochromic lenses. Choose one of these features. Research how it protects the eyes. Then design a brochure for an optometrist's office to encourage clients to buy prescription sunglasses that have this feature.

Mirages and Temperature Inversions

Although much less common, a mirage can also be caused by the opposite combination of temperatures. Sometimes, a wind brings warm air over a very cold ocean. This weather condition is called a temperature inversion. Light from an object on the ground starts to travel upward, but it curves and starts back down when it reaches warmer air. The light that reaches an observer can even come from beyond the horizon. When this type of mirage occurs, you think that you are seeing the object in the air. People have seen ships and icebergs, and even buildings from a distant city that appear to be sitting above the ocean.

Depending on the exact paths of the light through the different temperatures of air, part of the object sometimes appears to be upside down. **Figure 11.29** shows a diagram and a mirage in which the object appears to be upright, as well as a diagram and a mirage in which part of the object appears to be upside down.

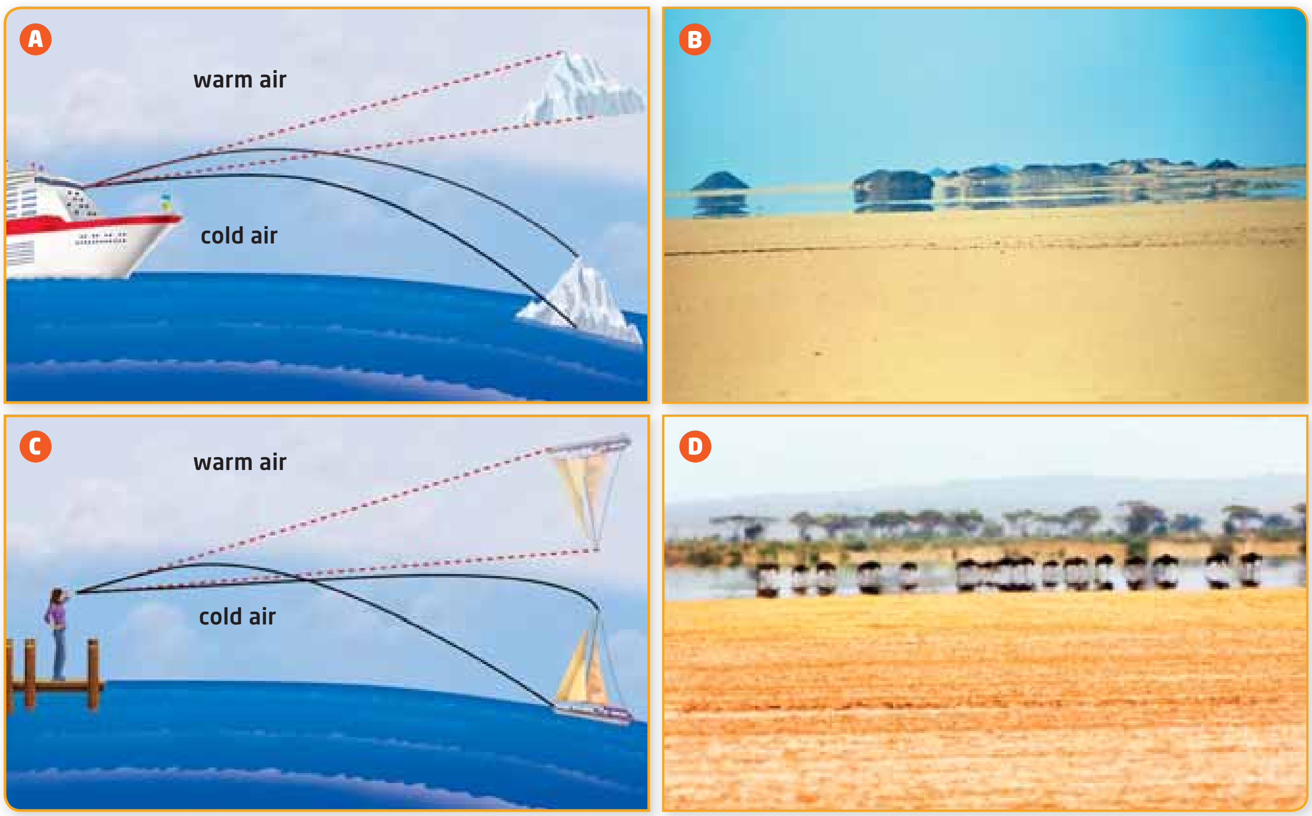


Figure 11.29 **A** The solid, curved lines show the path of light from an object, such as an iceberg. The dashed lines show where the object seems to be. **B** The mountains in this hot desert are a mirage. **C** The curved, solid lines show the path of light from an object, such as a boat. The atmospheric conditions caused the light rays to cross, so the boat appears to be upside down. **D** In this photograph, it looks like the animals are reflected in water, but there is no water. This is a mirage.

Section 11.3 Review

Section Summary

- A rainbow is formed by the refraction and total internal reflection of light and the resulting dispersion of the light by spherical water droplets in the sky.
- As a result of the refraction of light at the surface of water, objects under the water are not where they appear to be when you are looking at them from above the water. The level at which they appear to be is called their apparent depth.
- Shimmering is the apparent movement of objects seen through air that is unevenly heated and moving.
- A mirage is the appearance of water or another object that is not really there. A mirage is caused by light being continuously refracted by layers of air that are at extremely different temperatures.

Review Questions

K/U **1.** Under what atmospheric conditions are sundogs likely to appear, and where would they be in the sky?

K/U **2.** Use **Figure 11.24B** to explain the sequence of colours that you see in a rainbow.

C **3.** Sketch all the conditions that are necessary for you to see a single rainbow. Include the position of the Sun relative to your position.

C **4.** Review **Figure 11.25**. Sketch the apparent depth of a fish in a pond when you are looking at the fish from above the water and to the side, at an angle. Explain your sketch.

A **5.** An archer fish catches an insect by spitting a stream of water at it to knock it off an overhanging branch. The insect then falls in the water, and the fish eats it. The eyes of the fish remain underwater when it hunts. Only the fish's mouth projects out of the water. Draw a ray diagram based on the photograph on the right to show where the fish must aim to strike the insect.

Use this photograph to answer question 5.

K/U **6.** Explain how understanding the properties of light allows you to explain shimmering images.

K/U **7.** What conditions are necessary for a mirage to appear?

C **8.** Suppose you are in a hot desert and you see a mirage in which the object is upside down. Sketch the mirage. Show the path that the light rays actually take as well as the path that you assume the light rays take. Refer to **Figure 11.28**.