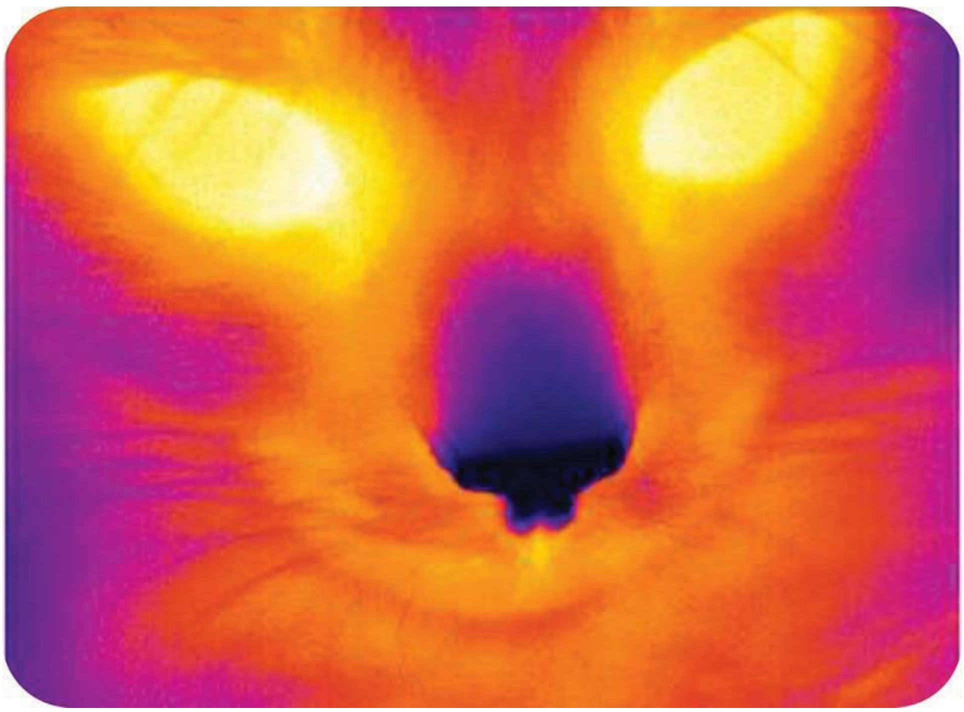
CHAPTER 8 Electromagnetic Radiation

Chapter Outline



Why is this picture of a cat so colorful? No cat looks like this to the human eye. The picture was taken with a special camera that senses infrared light. This is a form of energy given off by warm objects. Areas that appear yellow are the warmest, and areas that appear purple are the coolest. The picture shows that the cat's eyes are the warmest part of its head. Why can't people see images like this without a camera? The answer has to do with the wavelengths of infrared light. Its wavelengths are too long for the human eye to detect. In fact, the human eye can detect light only in a very narrow range of wavelengths, called visible light. You'll learn more about infrared light, visible light, and other forms of electromagnetic radiation in this chapter.

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8.1 Electromagnetic Waves

Lesson Objectives

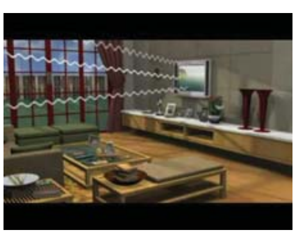
- Describe electromagnetic waves.
- Explain how electromagnetic waves begin.
- State how electromagnetic waves travel.
- Summarize the wave-particle theory of light.
- Identify sources of electromagnetic waves.

Lesson Vocabulary

- electromagnetic radiation
- electromagnetic wave
- photon

Introduction

Both infrared light and visible light are examples of electromagnetic radiation. **Electromagnetic radiation** is the transfer of energy by waves traveling through matter or across empty space. The waves that transfer this energy are called electromagnetic waves. In this lesson, you'll learn how electromagnetic waves differ from mechanical waves such as ocean waves and sound waves. For an excellent video introduction to electromagnetic waves, go to this URL: http://www.youtube.com/watch?v=cfXzwh3KadE (5:20).



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What Are Electromagnetic Waves?

An **electromagnetic wave** is a wave that consists of vibrating electric and magnetic fields. A familiar example will help you understand the fields that make up an electromagnetic wave. Think about a common bar magnet. It exerts magnetic force in an area surrounding it, called the magnetic field. You can see the magnetic field of a bar magnet in **Figure** 8.1. Because of this force field, a magnet can exert force on objects without touching them. They just have to be in its magnetic field. An electric field is similar to a magnetic field (see **Figure** 8.1). An electric field is an area of electrical force surrounding a charged particle. Like a magnetic field, an electric field can exert force on objects over a distance without actually touching them.

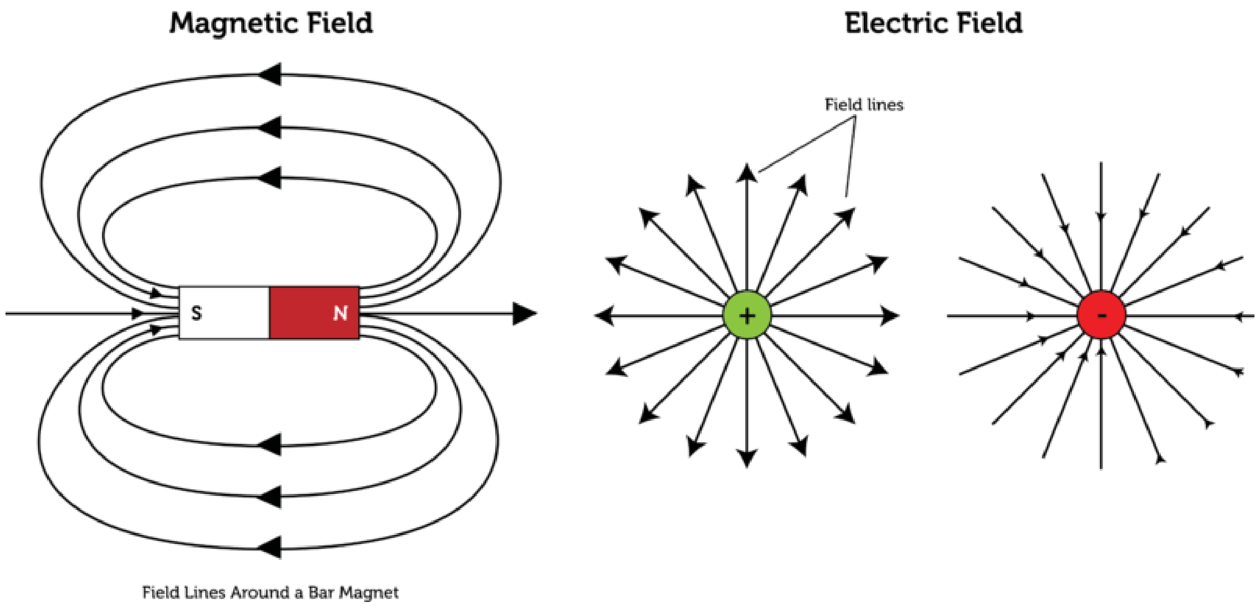
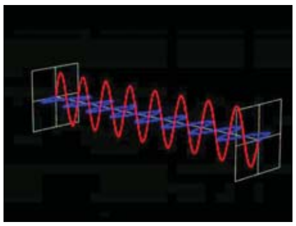


FIGURE 8.1

Magnetic and electric fields are invisible areas of force surrounding magnets and charged particles. The field lines in the diagrams represent the direction and location of the force.

How Electromagnetic Waves Begin

An electromagnetic wave begins when an electrically charged particle vibrates. This is illustrated in **Figure** 8.2. When a charged particle vibrates, it causes the electric field surrounding it to vibrate as well. A vibrating electric field, in turn, creates a vibrating magnetic field (you can learn how this happens in the chapter "Electromagnetism"). The two types of vibrating fields combine to create an electromagnetic wave. You can see an animation of an electromagnetic wave at this URL: http://www.youtube.com/watch?v=Qju7QnbrOhM&feature=related (1:31).



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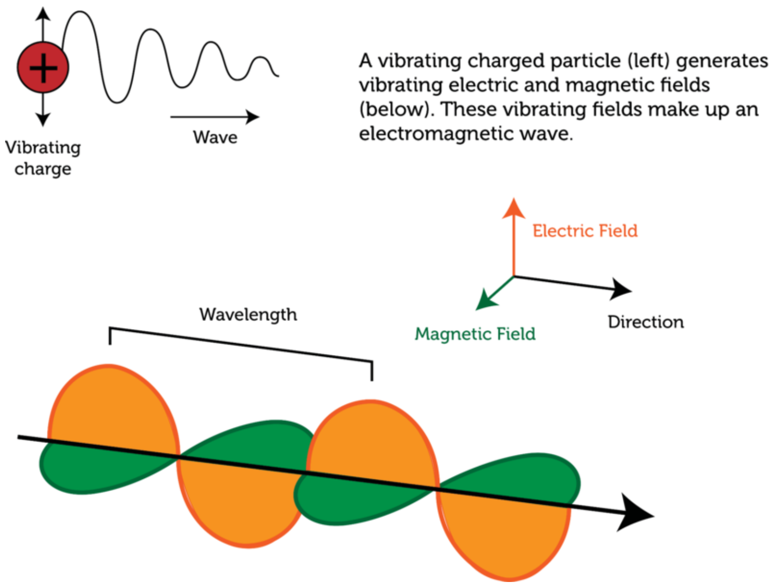


FIGURE 8.2
An electromagnetic wave starts with a vibrating charged particle.

How Electromagnetic Waves Travel

As you can see in **Figure** 8.2, the electric and magnetic fields that make up an electromagnetic wave occur are at right angles to each other. Both fields are also at right angles to the direction that the wave travels. Therefore, an electromagnetic wave is a transverse wave.

No Medium Required

Unlike a mechanical transverse wave, which requires a medium, an electromagnetic transverse wave can travel through space without a medium. Waves traveling through a medium lose some energy to the medium. However, when an electromagnetic wave travels through space, no energy is lost, so the wave doesn't get weaker as it travels. However, the energy is "diluted" as it spreads out over an ever-larger area as it travels away from the source. This is similar to the way a sound wave spreads out and becomes less intense farther from the sound source.

Wave Interactions

Electromagnetic waves can travel through matter as well as across space. When they strike matter, they interact with it in the same ways that mechanical waves interact with matter. They may reflect (bounce back), refract (bend when traveling through different materials), or diffract (bend around objects). They may also be converted to other forms of energy. Microwaves are a familiar example. They are a type of electromagnetic wave that you can read about later on in this chapter, in the lesson "The Electromagnetic Spectrum." When microwaves strike food in a microwave oven, they are converted to thermal energy, which heats the food.

Wave or Particle?

Electromagnetic radiation behaves like waves of energy most of the time, but sometimes it behaves like particles. As evidence accumulated for this dual nature of electromagnetic radiation, the famous physicist Albert Einstein developed a new theory about electromagnetic radiation, called the wave-particle theory. This theory explains how electromagnetic radiation can behave as both a wave and a particle. In brief, when an electron returns to a lower energy level, it is thought to give off a tiny "packet" of energy called a **photon** (see **Figure** 8.3). The amount of energy in a photon may vary. It depends on the frequency of electromagnetic radiation. The higher the frequency is, the more energy a photon has.

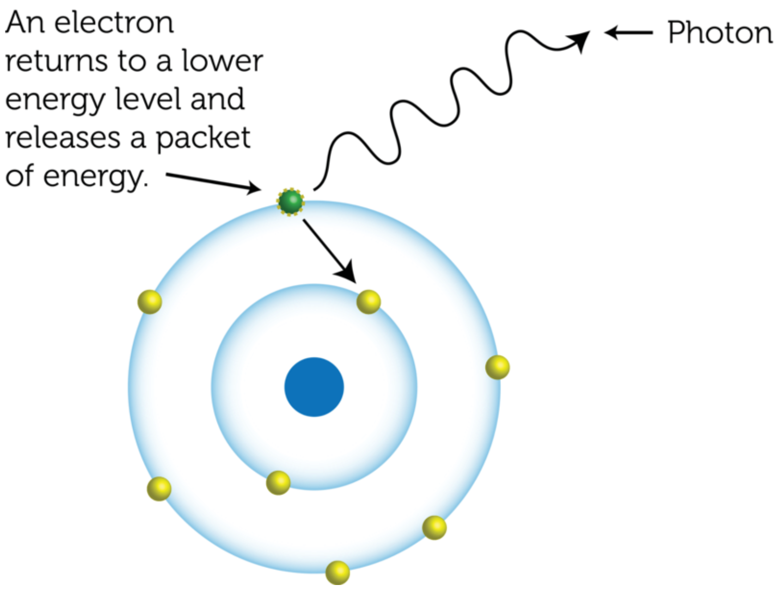


FIGURE 8.3
A photon of light energy is given off when an electron returns to a lower energy level.

Sources of Electromagnetic Radiation

The most important source of electromagnetic radiation on Earth is the sun. Electromagnetic waves travel from the sun to Earth across space and provide virtually all the energy that supports life on our planet. Many other sources of electromagnetic waves that people use depend on technology. Radio waves, microwaves, and X rays are examples. We use these electromagnetic waves for communications, cooking, medicine, and many other purposes. You'll learn about all these types of electromagnetic waves in this chapter's lesson on "The Electromagnetic Spectrum."

Lesson Summary

- An electromagnetic wave consists of vibrating electric and magnetic fields.
- An electromagnetic wave begins when an electrically charged particle vibrates.
- Electromagnetic waves are transverse waves that can travel across space without a medium. When the waves strike matter, they may reflect, refract, or diffract, or they may be converted to other forms of energy.
- Electromagnetic radiation behaves like particles as well as waves. This prompted Albert Einstein to develop his wave-particle theory.
- The most important source of electromagnetic waves on Earth is the sun, which provides virtually all the energy that supports life on Earth. Other sources of electromagnetic radiation depend on technology and are used for communications, cooking, and other purposes.

Lesson Review Questions

Recall

1. Define electromagnetic radiation.
2. What is an electromagnetic wave?
3. How do electromagnetic waves interact with matter?
4. What is a photon?
5. Identify sources of electromagnetic waves.

Apply Concepts

6. Create a diagram to represent an electromagnetic wave. Explain your diagram to another student who has no prior knowledge of electromagnetic waves.

Think Critically

7. Explain how an electromagnetic wave begins.
8. Compare and contrast mechanical transverse waves and electromagnetic transverse waves.

Points to Consider

In this lesson, you learned that electromagnetic waves are transverse waves. Like other transverse waves, electromagnetic waves have certain properties.

- Based on your knowledge of other transverse waves, such as waves in a rope, what is the wavelength of an electromagnetic wave? How is it measured?
- How do you think the wavelengths of electromagnetic waves are related to their frequencies? (*Hint:* How is the speed of waves calculated?)

8.2 Properties of Electromagnetic Waves

Lesson Objectives

- Describe the speed of electromagnetic waves.
- Relate wavelength and frequency of electromagnetic waves.

Lesson Vocabulary

- speed of light

Introduction

Some electromagnetic waves are harmless. The light we use to see is a good example. Other electromagnetic waves are very harmful. They can penetrate virtually anything and destroy living cells. Why do electromagnetic waves vary in these ways? It depends on their properties. Like other waves, electromagnetic waves have properties of speed, wavelength, and frequency.

Speed of Electromagnetic Waves

All electromagnetic waves travel at the same speed through empty space. That speed, called the **speed of light**, is 300 million meters per second (3.0×10^8 m/s). Nothing else in the universe is known to travel this fast. If you could move that fast, you would be able to travel around Earth 7.5 times in just 1 second! The sun is about 150 million kilometers (93 million miles) from Earth, but it takes electromagnetic radiation only 8 minutes to reach Earth from the sun. Electromagnetic waves travel more slowly through a medium, and their speed may vary from one medium to another. For example, light travels more slowly through water than it does through air (see **Figure** 8.4). You can learn more about the speed of light at this URL: http://videos.howstuffworks.com/discovery/29407-assignment-discovery-speed-of-light-video.htm .

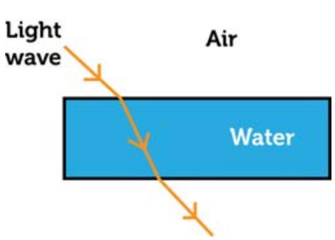


FIGURE 8.4

Light slows down when it enters water from the air. This causes the wave to refract, or bend.

Wavelength and Frequency of Electromagnetic Waves

Although all electromagnetic waves travel at the same speed, they may differ in their wavelength and frequency.

Defining Wavelength and Frequency

Wavelength and frequency are defined in the same way for electromagnetic waves as they are for mechanical waves. Both properties are illustrated in **Figure** 8.5.

- Wavelength is the distance between corresponding points of adjacent waves. Wavelengths of electromagnetic waves range from many kilometers to a tiny fraction of a millimeter.
- Frequency is the number of waves that pass a fixed point in a given amount of time. Frequencies of electromagnetic waves range from thousands to trillions of waves per second. Higher frequency waves have greater energy.

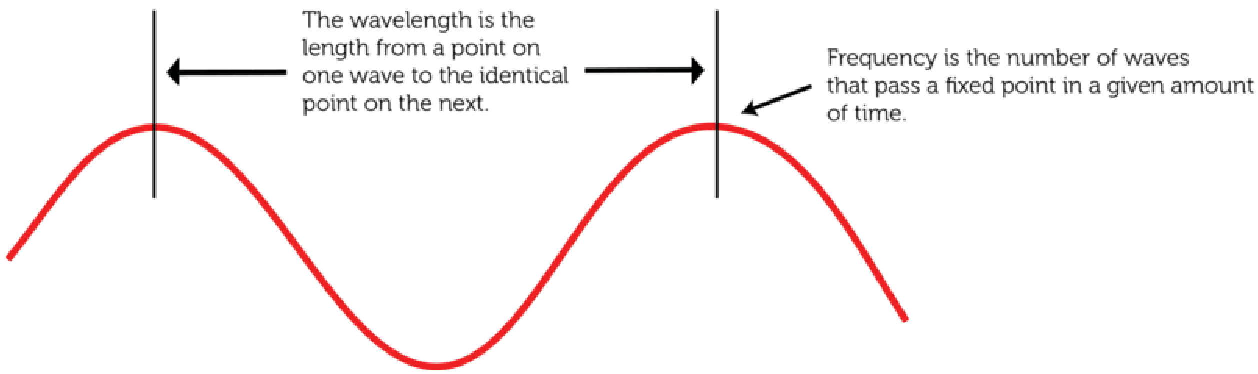


FIGURE 8.5
Wavelength and frequency of electromagnetic waves.

Speed, Wavelength, and Frequency

The speed of a wave is a product of its wavelength and frequency. Because all electromagnetic waves travel at the same speed through space, a wave with a shorter wavelength must have a higher frequency, and vice versa. This relationship is represented by the equation:

$$\text{Speed} = \text{Wavelength} \times \text{Frequency}$$

The equation for wave speed can be rewritten as:

$$\text{Frequency} = \frac{\text{Speed}}{\text{Wavelength}} \text{ or Wavelength} = \frac{\text{Speed}}{\text{Frequency}}$$

Therefore, if either wavelength or frequency is known, the missing value can be calculated. Consider an electromagnetic wave that has a wavelength of 3 meters. Its speed, like the speed of all electromagnetic waves, is 3.0×10^8 meters per second. Its frequency can be found by substituting these values into the frequency equation:

$$\text{Frequency} = \frac{3.0 \times 10^8 \text{ m/s}}{3.0 \text{ m}} = 1.0 \times 10^8 \text{ waves/s, or } 1.0 \times 10^8 \text{ hertz (Hz)}$$

You Try It!

Problem: What is the wavelength of an electromagnetic wave that has a frequency of 3.0×10^8 hertz?

For more practice calculating the frequency and wavelength of electromagnetic waves, go to these URLs:

- http://www.youtube.com/watch?v=GwZvtfZRNKk
- http://www.youtube.com/watch?v=wjPk108Ua8k&feature=related

Lesson Summary

- All electromagnetic waves travel at the same speed through space, called the speed of light, which equals 3.0×10^8 meters per second. Electromagnetic waves travel more slowly through a medium.
- Electromagnetic waves differ in their wavelengths and frequencies. The higher the frequency of an electromagnetic wave, the greater its energy. The speed of an electromagnetic wave is the product of its wavelength and frequency, so a wave with a shorter wavelength has a higher frequency, and vice versa.

Lesson Review Questions

Recall

1. What is the speed of light?
2. What is the wavelength of an electromagnetic wave?
3. Describe the range of frequencies of electromagnetic waves.

Apply Concepts

4. If an electromagnetic wave has a wavelength of 1 meter, what is its frequency?

Think Critically

5. Explain why light waves bend when they pass from air to water at an angle.
6. Explain the relationship between frequency and wavelength of electromagnetic waves.

Points to Consider

In this lesson, you learned that electromagnetic waves vary in their wavelength and frequency. The complete range of wavelengths and frequencies of electromagnetic waves is outlined in the next lesson, "The Electromagnetic

Spectrum."

- What do you think are the longest-wavelength electromagnetic wave?
- What might be the electromagnetic waves with the highest frequencies?

8.3 The Electromagnetic Spectrum

Lesson Objectives

- Define the electromagnetic spectrum.
- Describe radio waves and their uses.
- Identify three forms of light.
- Describe X rays and gamma rays.

Lesson Vocabulary

- electromagnetic spectrum
- gamma ray
- infrared light
- microwave
- radar
- radio wave
- ultraviolet light
- visible light
- X ray

Introduction

Imagine playing beach volleyball, like the young men in **Figure** 8.6. They may not realize it, but they are being bombarded by electromagnetic radiation as play in the sunlight. The only kinds of radiation they can detect are visible light, which allows them to see, and infrared light, which they feel as warmth on their skin. What other kinds of electromagnetic radiation are they being exposed to in sunlight? In this lesson, you'll find out.

What Is The Electromagnetic Spectrum?

Electromagnetic radiation occurs in waves of different wavelengths and frequencies. Infrared light and visible light make up just a small part of the full range of electromagnetic radiation, which is called the **electromagnetic spectrum**. The electromagnetic spectrum is summarized in the diagram in **Figure** 8.7.

- On the far left of the diagram are radio waves, which include microwaves. They have the longest wavelengths and lowest frequencies of all electromagnetic waves. They also have the least amount of energy.
- On the far right are X rays and gamma rays. The have the shortest wavelengths and highest frequencies of all electromagnetic waves. They also have the greatest amount of energy.

FIGURE 8.6
Electromagnetic radiation from the sun reaches Earth across space. It strikes everything on Earth's surface, including these volleyball players.

- Between these two extremes, wavelength, frequency, and energy change continuously from one side of the spectrum to the other. Waves in this middle section of the electromagnetic spectrum are commonly called light.

As you will read below, the properties of electromagnetic waves influence how the different waves behave and how they can be used.

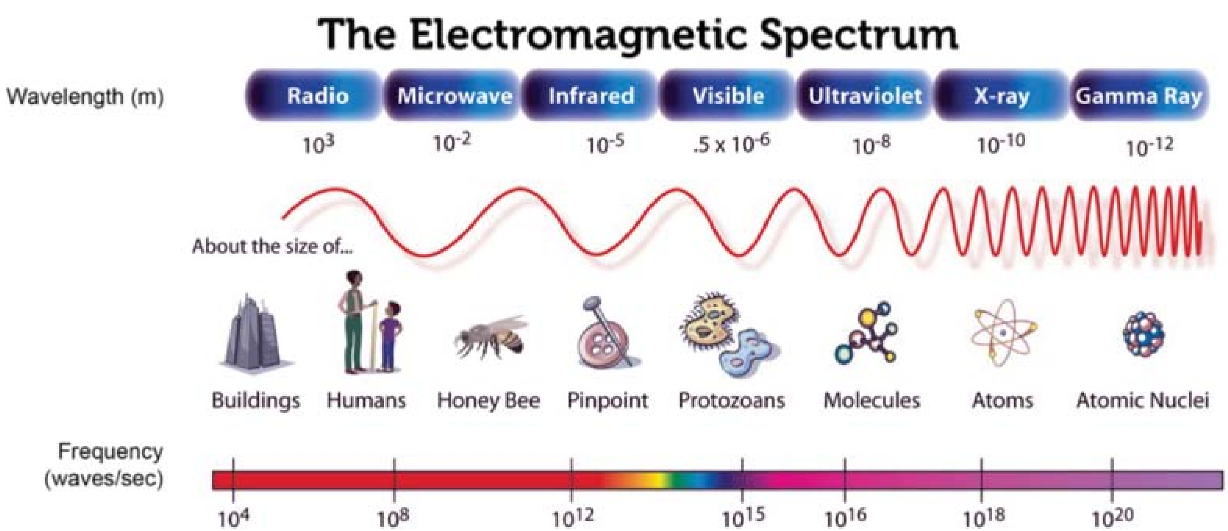
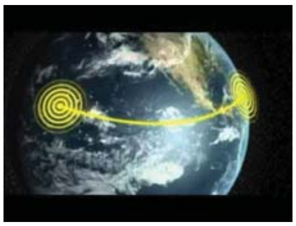


FIGURE 8.7
How do the wavelength and frequency of waves change across the electromagnetic spectrum?

Radio Waves

Radio waves are the broad range of electromagnetic waves with the longest wavelengths and lowest frequencies. In **Figure** 8.7, you can see that the wavelength of radio waves may be longer than a soccer field. With their low frequencies, radio waves have the least energy of electromagnetic waves, but they still are extremely useful. They are used for radio and television broadcasts, microwave ovens, cell phone transmissions, and radar. You can learn more about radio waves, including how they were discovered, at this URL: http://www.youtube.com/watch?v=al7sFP4C2TY (3:58).



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AM and FM Radio

In radio broadcasts, sounds are encoded in radio waves that are sent out through the atmosphere from a radio tower. A receiver detects the radio waves and changes them back to sounds. You've probably listened to both AM and FM radio stations. How sounds are encoded in radio waves differs between AM and FM broadcasts.

- AM stands for amplitude modulation. In AM broadcasts, sound signals are encoded by changing the amplitude of radio waves. AM broadcasts use longer–wavelength radio waves than FM broadcasts. Because of their longer wavelengths, AM radio waves reflect off a layer of the upper atmosphere called the ionosphere. You can see how this happens in **Figure** 8.8. This allows AM radio waves to reach radio receivers that are very far away from the radio tower.
- FM stands for frequency modulation. In FM broadcasts, sound signals are encoded by changing the frequency of radio waves. Frequency modulation allows FM waves to encode more information than does amplitude modulation, so FM broadcasts usually sound clearer than AM broadcasts. However, because of their shorter wavelength, FM waves do not reflect off the ionosphere. Instead, they pass right through it and out into space (see **Figure** 8.8). As a result, FM waves cannot reach very distant receivers.

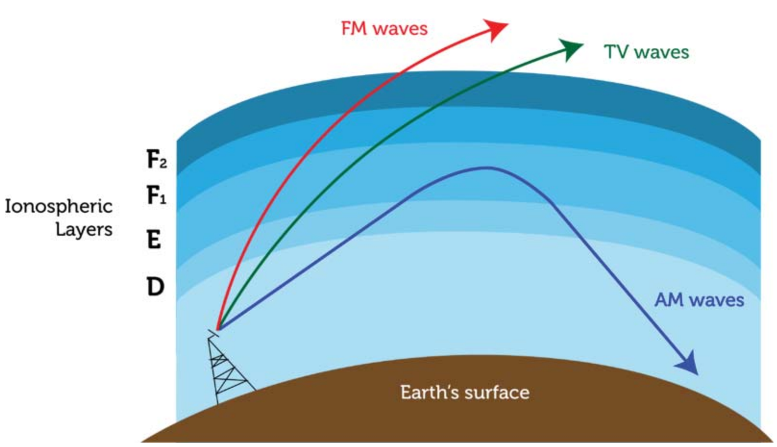

FIGURE 8.8
AM radio waves reflect off the ionosphere and travel back to Earth. Radio waves used for FM radio and television pass through the ionosphere and do not reflect back.

Television

Television broadcasts also use radio waves. Sounds are encoded with frequency modulation, and pictures are encoded with amplitude modulation. The encoded radio waves are broadcast from a TV tower like the one in **Figure** 8.9. When the waves are received by television sets, they are decoded and changed back to sounds and pictures.

FIGURE 8.9
This television tower broadcasts signals using radio waves.

Microwaves

The shortest wavelength, highest frequency radio waves are called **microwaves** (see **Figure** 8.7). Microwaves have more energy than other radio waves. That's why they are useful for heating food in microwave ovens. Microwaves have other important uses as well, including cell phone transmissions and **radar**, which is a device for determining the presence and location of an object by measuring the time for the echo of a radio wave to return from it and the direction from which it returns. These uses are described in **Figure** 8.10. You can learn more about microwaves and their uses in the video at this URL: http://www.youtube.com/watch?v=YgQQb1BVnu8 (3:23).

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Light

Mid-wavelength electromagnetic waves are commonly called light. This range of electromagnetic waves has shorter wavelengths and higher frequencies than radio waves, but not as short and high as X rays and gamma rays. Light includes visible light, infrared light, and ultraviolet light. If you look back at **Figure** 8.7, you can see where these different types of light waves fall in the electromagnetic spectrum.

Visible Light

The only light that people can see is called **visible light**. It refers to a very narrow range of wavelengths in the electromagnetic spectrum that falls between infrared light and ultraviolet light. Within the visible range, we see light

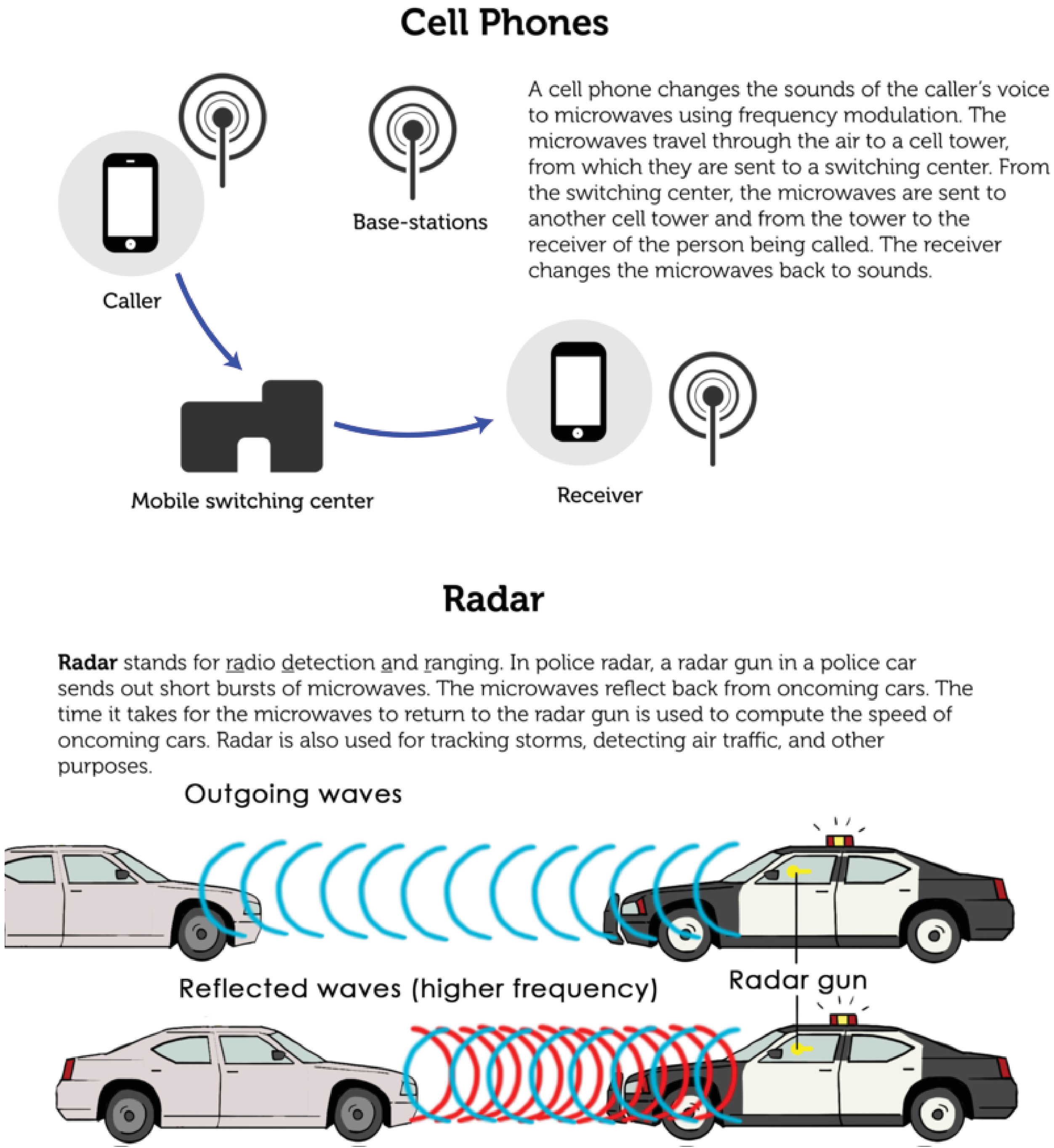

FIGURE 8.10

Microwaves are used for cell phones and radar.

of different wavelengths as different colors of light, from red light, which has the longest wavelength, to violet light, which has the shortest wavelength. You can see the spectrum of colors of visible light in **Figure** 8.11. When all of the wavelengths are combined, as they are in sunlight, visible light appears white. You can learn more about visible light in the chapter "Visible Light" and at the URL below.

http://www.youtube.com/watch?v=PMtC34pzKGc (4:50)

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FIGURE 8.11
Red light (right) has the longest wavelength, and violet light (left) has the shortest wavelength.

Infrared Light

Light with the longest wavelengths is called **infrared light**. The term *infrared* means "below red." Infrared light is the range of light waves that have longer wavelengths than red light in the visible spectrum. You can't see infrared light waves, but you can feel them as heat on your skin. The sun gives off infrared light as do fires and living things. The picture of a cat that opened this chapter was made with a camera that detects infrared light waves and changes their energy to colored light in the visible range. Night vision goggles, which are used by law enforcement and the military, also detect infrared light waves. The goggles convert the invisible waves to visible images. For a deeper understanding of infrared light, watch the video at this URL: http://www.youtube.com/watch?v=2–0q0XlQJ0 (6:46).

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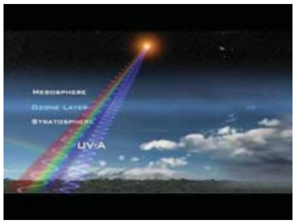
Ultraviolet Light

Light with wavelengths shorter than visible light is called **ultraviolet light**. The term *ultraviolet* means "above violet." Ultraviolet light is the range of light waves that have shorter wavelengths than violet light in the visible spectrum. Humans can't see ultraviolet light, but it is very useful nonetheless. It has higher-frequency waves than visible light, so it has more energy. It can be used to kill bacteria in food and to sterilize laboratory equipment (see **Figure** 8.12). The human skin also makes vitamin D when it is exposed to ultraviolet light. Vitamin D is needed for strong bones and teeth. You can learn more about ultraviolet light and its discovery at this URL: http://www.youtube.com/watch?v=QW5zeVy8aE0&feature=related (3:40).



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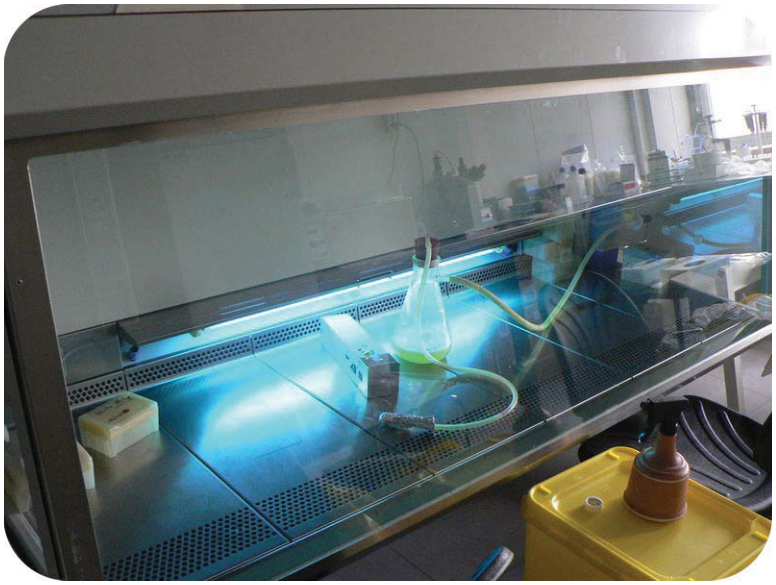

FIGURE 8.12
This sterilizer for laboratory equipment uses ultraviolet light to kill bacteria.

Too much exposure to ultraviolet light can cause sunburn and skin cancer. You can protect your skin from ultraviolet light by wearing clothing that covers your skin and by applying sunscreen to any exposed areas. The SPF, or sun-protection factor, of sunscreen gives a rough idea of how long it protects the skin from sunburn (see **Figure** 8.13). A sunscreen with a higher SPF protects the skin longer. You should use sunscreen with an SPF of at least 15 even on cloudy days, because ultraviolet light can travel through clouds. Sunscreen should be applied liberally and often. You can learn more about the effects of ultraviolet light on the skin at this URL: http://www.youtube.com/watch?v=np-BBJyl-go (5:59).

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X Rays and Gamma Rays

The shortest-wavelength, highest-frequency electromagnetic waves are X rays and gamma rays. These rays have so much energy that they can pass through many materials. This makes them potentially very harmful, but it also makes them useful for certain purposes.

FIGURE 8.13

If your skin normally burns in 10 minutes of sun exposure, using sunscreen with an SPF of 30 means that, ideally, your skin will burn only after 30 times 10 minutes, or 300 minutes, of sun exposure. How long does sunscreen with an SPF of 50 protect skin from sunburn?

X Rays

X rays are high-energy electromagnetic waves. They have enough energy to pass through soft tissues such as skin but not enough to pass through bones and teeth, which are very dense. The bright areas on the X ray film in **Figure** 8.14 show where X rays were absorbed by the teeth. X rays are used not only for dental and medical purposes but also to screen luggage at airports (see **Figure** 8.14). Too much X ray exposure may cause cancer. If you've had dental X rays, you may have noticed that a heavy apron was placed over your body to protect it from stray X rays. The apron is made of lead, which X rays cannot pass through. You can learn about the discovery of X rays as well as other uses of X rays at this URL: http://www.guardian.co.uk/science/blog/2010/oct/26/x-ray-visions-disease-forgeries .

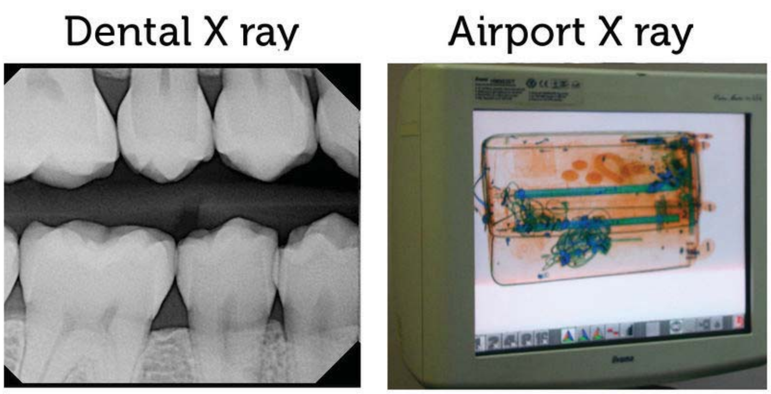


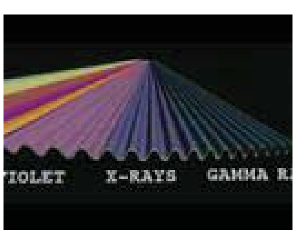
FIGURE 8.14

Two common uses of X rays are illustrated here.

Gamma Rays

Gamma rays are the most energetic of all electromagnetic waves. They can pass through most materials, including bones and teeth. Nonetheless, even these waves are useful. For example, they can be used to treat cancer. A medical device sends gamma rays the site of the cancer, and the rays destroy the cancerous cells. If you want to learn more about gamma rays, watch the video at the URL below.

http://www.youtube.com/watch?v=okyynBaSOtA (2:45)



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Lesson Summary

- The electromagnetic spectrum is the full range of wavelengths and frequencies of electromagnetic radiation. Wavelength, frequency, and energy change continuously across the electromagnetic spectrum.
- Radio waves are the broad range of electromagnetic waves with the longest wavelengths and lowest frequencies. They are used for radio and television broadcasts, microwave ovens, cell phone transmissions, and radar.
- Mid-wavelength electromagnetic waves are called light. Light consists of visible, infrared, and ultraviolet light. Humans can see only visible light. Infrared light has longer wavelengths than visible light and is perceived as warmth. Ultraviolet light has shorter wavelengths than visible light and has enough energy to kill bacteria. It can also harm the skin.
- X rays and gamma rays are the electromagnetic waves with the shortest wavelengths and highest frequencies. X rays are used in medicine and dentistry and to screen luggage at airports. Gamma rays are used to kill cancer cells.

Lesson Review Questions

Recall

1. What is the electromagnetic spectrum?
2. Describe how wave frequency changes across the electromagnetic spectrum, from radio waves to gamma rays.
3. List three uses of radio waves.
4. How are X rays and gamma rays used in medicine?

Apply Concepts

5. Create a public service video warming people of the dangers of ultraviolet light. Include tips for protecting the skin from ultraviolet light.

Think Critically

6. Explain two ways that sounds can be encoded in electromagnetic waves.
7. Explain how radar works.
8. Compare and contrast infrared, visible, and ultraviolet light.

Points to Consider

This chapter introduces visible light. The chapter "Visible Light" discusses visible light in greater detail.

- In this lesson, you read that visible light consists of light of different colors. Do you know how visible light can be separated into its different colors? (*Hint:* How does a rainbow form?)
- In the next chapter, *Visible Light*, you'll read that visible light interacts with matter in certain characteristic ways. Based on your own experiences with visible light, how does it interact with matter? (*Hint:* What happens to visible light when it strikes a wall, window, or mirror?)

8.4 References

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CHAPTER 9 Visible Light

Chapter Outline

There is no pot of gold at the end of this rainbow, but it's pretty special nonetheless. Rainbows don't form very often, and they usually don't last very long. Maybe because they are relatively rare or because they often signal the end of a rainstorm, some people think rainbows are a sign of good luck. You may have noticed that rainbows form when the sun starts to come out while raindrops are still falling. What do the sun and raindrops have to do with rainbows? In this chapter, you'll find out.

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9.1 The Light We See

Lesson Objectives

- Identify common sources of visible light.
- Explain how light interacts with matter.
- Describes the colors of visible light.

Lesson Vocabulary

- absorption
- incandescence
- luminescence
- opaque
- pigment
- primary color
- scattering
- translucent
- transmission
- transparent

Introduction

We can see rainbows because they are formed by visible light. Visible light includes all the wavelengths of light that the human eye can detect. It allows us to see objects in the world around us. Without visible light, we would only be able to sense most objects by sound or touch, and we would never see rainbows. Like humans, most other organisms also depend on visible light, either directly or indirectly. Many animals use it to see. All plants use it to make food in the process of photosynthesis. Without the food made by plants, most other organisms could not survive.

Sources of Visible Light

Look at the classroom in **Figure** 9.1. It has several sources of visible light. One source of visible light is the sun. Sunlight enters the classroom through the windows. The sun provides virtually all of the visible light that living things need. Visible light travels across space from the sun to Earth in electromagnetic waves. But how does the sun produce light? Read on to find out.

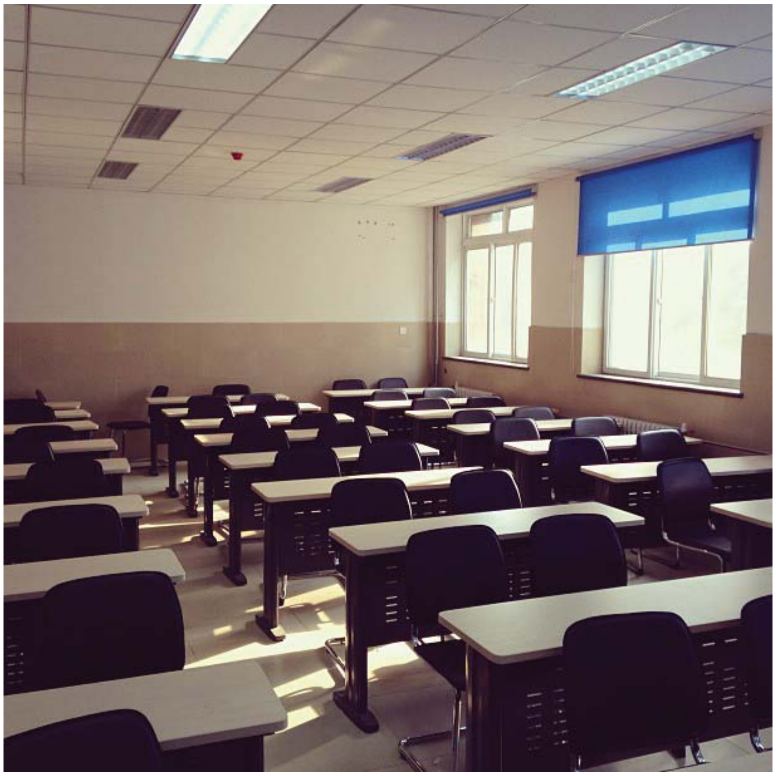

FIGURE 9.1
This classroom has three obvious sources of visible light. Can you identify all of them?

How Visible Light Is Produced

The sun and other stars produce light because they are so hot. They glow with light due to their extremely high temperatures. This way of producing light is called **incandescence**. Some objects produce light without becoming very hot. They generate light through chemical reactions or other processes. Producing light without heat is called **luminescence**. Objects that produce light by luminescence are said to be luminous. Luminescence, in turn, can occur in different ways:

- One type of luminescence is called fluorescence. In this process, a substance absorbs shorter-wavelength light, such as ultraviolet light, and then gives off light in the visible range of wavelengths. Certain minerals produce light in this way.
- Another type of luminescence is called electroluminescence. In this process, a substance gives off light when an electric current runs through it. Some gases produce light in this way.
- A third type of luminescence is called bioluminescence. This is the production of light by living things as a result of chemical reactions. Examples of bioluminescent organisms are pictured in **Figure** 9.2. You can learn more about bioluminescence in the video at this URL: http://www.ted.com/talks/edith_widder_glowing_life_in_an_underwater_world.html .

Many other objects appear to produce their own light, but they actually just reflect light from another source. The moon is a good example. It appears to glow in the sky from its own light, but in reality it is just reflecting light from the sun. Objects like the moon that are lit up by another source of light are said to be illuminated. Everything you can see that doesn't produce its own light is illuminated.

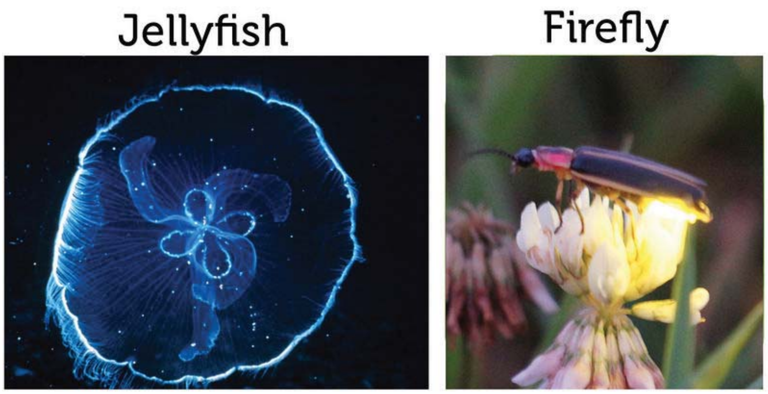

FIGURE 9.2
Bioluminescent organisms include jellyfish and fireflies. Jellyfish give off visible light to startle predators. Fireflies give off visible light to attract mates.

Artificial Lights

The classroom in **Figure** 9.1 has artificial light sources in addition to natural sunlight. There are fluorescent lights on the ceiling of the room. There are also projectors on the ceiling that are shining light on screens. In these and most other artificial light sources, electricity provides the energy and some type of light bulb converts the electrical energy to visible light. How a light bulb produces visible light varies by type of bulb, as you can see in **Table** 9.1. Incandescent light bulbs, which produce light by incandescence, give off a lot of heat as well as light, so they waste energy. Other light bulbs produce light by luminescence, so they produce little if any heat. These light bulbs use energy more efficiently. Which types of light bulbs do you use?

TABLE 9.1: Different types of light bulbs produce visible light in different ways.

Type of Light Bulb	Description
Incandescent Light 	An incandescent light bulb produces visible light by incandescence. The bulb contains a thin wire filament made of tungsten. When electric current passes through the filament, it gets extremely hot and glows. You can learn more about incandescent light bulbs at the URL below. http://science.discovery.com/videos/deconstructed-how-incandescent-light-bulbs-work.html
Fluorescent Light 	A fluorescent light bulb produces visible light by fluorescence. The bulb contains mercury gas that gives off ultraviolet light when electricity passes through it. The inside of the bulb is coated with a substance called phosphor. The phosphor absorbs the ultraviolet light and then gives off most of the energy as visible light. You can learn more about fluorescent light bulbs at this URL: http://science.discovery.com/videos/deconstructed-compact-fluorescent-light-bulb.html .

TABLE 9.1: (continued)

Type of Light Bulb	Description
Neon Light 	A neon light produces visible light by electroluminescence. The bulb is a glass tube that contains the noble gas neon. When electricity passes through the gas, it excites electrons of neon atoms, causing them to give off visible light. Neon produces red light. Other noble gases are also used in lights, and they produce light of different colors. For example, krypton produces violet light, and argon produces blue light.
Vapor Light 	A vapor light produces visible light by electroluminescence The bulb contains a small amount of solid sodium or mercury as well as a mixture of neon and argon gases. When an electric current passes through the gases, it causes the solid sodium or mercury to change to a gas and emit visible light. Sodium vapor lights, like these streetlights, produce yellowish light. Mercury vapor lights produce bluish light. Vapor lights are very bright and energy efficient. The bulbs are also long lasting.
LED Light 	LED stands for "light-emitting diode." This type of light contains a material, called a semi-conductor, which gives off visible light when a current runs through it. LED lights are used for traffic lights and indicator lights on computers, cars, and many other devices. This type of light is very reliable and durable.

Light and Matter

When visible light strikes matter, it interacts with it. How light interacts with matter depends on the type of matter.

How Light Interacts with Matter

Light may interact with matter in several ways.

- Light may be reflected by matter. Reflected light bounces back when it strikes matter. Reflection of light is similar to reflection of sound waves. You can read more about reflection of light later on in this chapter in the lesson "Optics."
- Light may be refracted by matter. The light is bent when it passes from one type of matter to another. Refraction of light is similar to refraction of sound waves. You can also read more about refraction of light in

the lesson "Optics."
- Light may pass through matter. This is called **transmission** of light. As light is transmitted, it may be scattered by particles of matter and spread out in all directions. This is called **scattering** of light.
- Light may be absorbed by matter. This is called **absorption** of light. When light is absorbed, it doesn't reflect from or pass through matter. Instead, its energy is transferred to particles of matter, which may increase the temperature of matter.

Classifying Matter in Terms of Light

Matter can be classified on the basis of how light interacts with it. Matter may be transparent, translucent, or opaque. Each type of matter is illustrated in **Figure** 9.3.

- **Transparent** matter is matter that transmits light without scattering it. Examples of transparent matter include air, pure water, and clear glass. You can see clearly through a transparent object, such as the revolving glass doors in the figure, because all the light passes straight through it.
- **Translucent** matter is matter that transmits but scatters light. Light passes through a translucent object but you cannot see clearly through the object because the light is scattered in all directions. The frosted glass doors in the figure are translucent.
- **Opaque** matter is matter that does not let any light pass through it. Matter may be opaque because it absorbs light, reflects light, or does both. Examples of opaque objects are solid wooden doors and glass mirrors. A wooden door absorbs most of the light that strikes it and reflects just a few wavelengths of visible light. A mirror, which is a sheet of glass with a shiny metal coating on the back, reflects all the light that strikes it.

Colors of Light

Visible light consists of a range of wavelengths. The wavelength of visible light determines the color that the light appears. As you can see in **Figure** 9.4, light with the longest wavelength appears red, and light with the shortest wavelength appears violet. In between is a continuum of all the other colors of light. Only a few colors of light are represented in the figure.

Separating Colors of Light

A prism, like the one in **Figure** 9.5, can be used to separate visible light into its different colors. A prism is a pyramid-shaped object made of transparent matter, usually clear glass. It transmits light but slows it down. When light passes from the air to the glass of the prism, the change in speed causes the light to bend. Different wavelengths of light bend at different angles. This causes the beam of light to separate into light of different wavelengths. What we see is a rainbow of colors. Look back at the rainbow that opened this chapter. Do you see all the different colors of light, from red at the top to violet at the bottom? Individual raindrops act as tiny prisms. They separate sunlight into its different wavelengths and create a rainbow.

For an animated version of **Figure** 9.5, go to the URL: http://en.wikipedia.org/wiki/File:Light_dispersion_conceptual_waves.gif .

Colors of Objects

We see an opaque object, such as the apple in **Figure** 9.6, because it reflects some wavelengths of visible light. The wavelengths that are reflected determine the color that the object appears. For example, the apple in the figure appears red because it reflects red light and absorbs light of other wavelengths. We see a transparent or translucent

FIGURE 9.3
The objects pictured here differ in the way light interacts with them.

object, such as the bottle in **Figure** 9.6, because it transmits light. The wavelength of the transmitted light determines the color that the object appears. For example, the bottle in the figure appears blue because it transmits blue light.

The color of light that strikes an object may also affect the color that the object appears. For example, if only blue light strikes a red apple, the blue light is absorbed and no light is reflected. When no light reflects from an object, it looks black. Black isn't a color. It is the absence of light.

The Colors We See

The human eye can distinguish only red, green, and blue light. These three colors of light are called **primary colors**. All other colors of light can be created by combining the primary colors. As you can see in **Figure** 9.7, when red and green light combine, they form yellow. When red and blue light combine, they form magenta, a dark pinkish color, and when blue and green light combine, they form cyan, a bluish green color. Yellow, magenta, and cyan are called the secondary colors of light. Look at the center of the diagram in **Figure** 9.7. When all three primary colors combine, they form white light. White is the color of the full spectrum of visible light when all of its wavelengths are combined. You can explore the colors of visible light and how they combine with the interactive animations at this URL: http://www.phy.ntnu.edu.tw/oldjava/color/color_e.html .

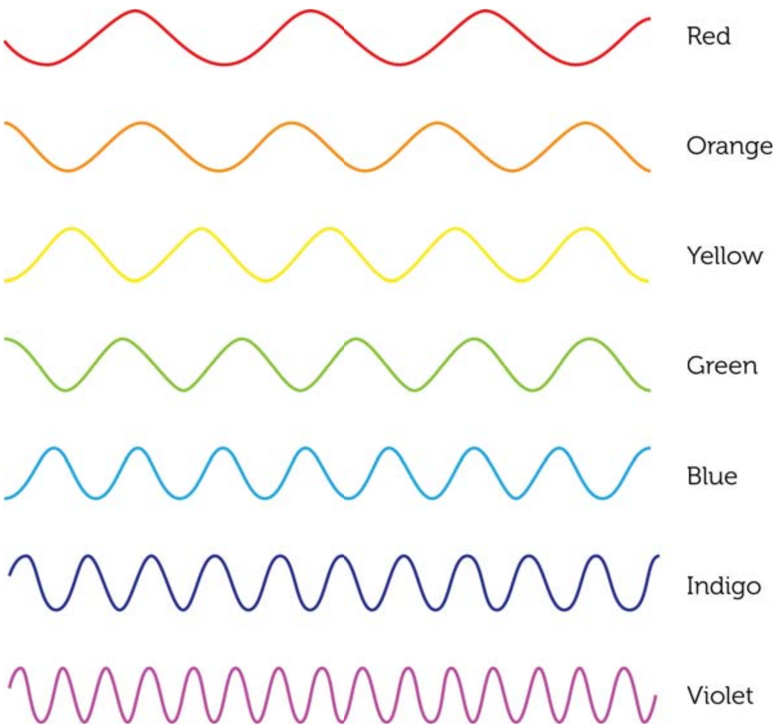

FIGURE 9.4
The color of light depends on its wavelength.

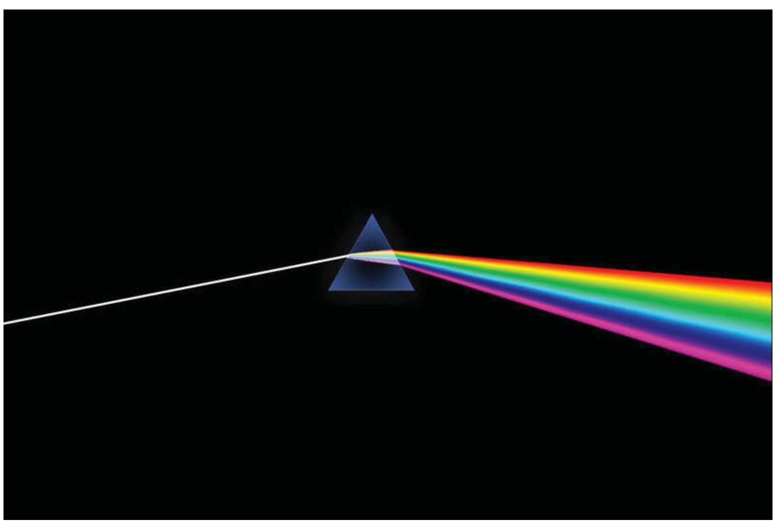

FIGURE 9.5
A prism separates visible light into its different wavelengths.

FIGURE 9.6
The color that objects appear depends on the wavelengths of light they reflect or transmit.

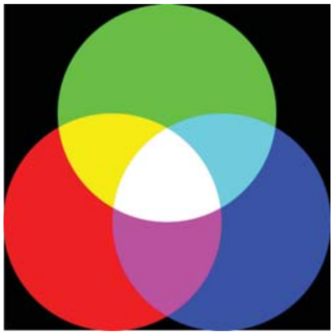

FIGURE 9.7
The three primary colors of light—red, green, and blue—combine to form white light in the center of the figure. What are the secondary colors of light? Can you find them in the diagram?

Pigments

Many objects have color because they contain pigments. A **pigment** is a substance that colors materials by reflecting light of certain wavelengths and absorbing light of other wavelengths. A very common pigment is chlorophyll, which is found in plants. This dark green pigment absorbs all but green wavelengths of visible light. It is responsible for "capturing" the light energy needed for photosynthesis. Pigments are also found in paints, inks, and dyes. Just three pigments, called primary pigments, can be combined to produce all other colors. The primary pigment colors are the same as the secondary colors of light: cyan, magenta, and yellow. The printer ink cartridges in **Figure** 9.8 come in just these three colors. They are the only colors needed for full-color printing.

FIGURE 9.8
Printer ink comes in three primary pigment colors: cyan, magenta, and yellow.

Lesson Summary

- Visible light can be produced by incandescence or luminescence. Incandescence is the production of light by an object that is so hot it glows. Luminescence is the production of light by other means, such as chemical reactions.

- Light may interact with matter in several ways, including reflection, refraction, transmission, and absorption. Matter can be classified on the basis of how light interacts with it as transparent, translucent, or opaque.
- The wavelength of visible light determines the color that the light appears. Red light has the longest wavelength, and violet light has the shortest wavelength. The primary colors of light are red, green, and blue. All other colors of light can be created by combining the primary colors.

Lesson Review Questions

Recall

1. What is incandescence?
2. Define luminescence.
3. Identify two types of light bulbs and describe how they produce visible light.
4. What determines the color of visible light?
5. List four ways that light interacts with matter.

Apply Concepts

6. If only blue light were to strike the bottle in **Figure** 9.6, what color would the bottle appear?

Think Critically

7. Compare and contrast transparent, translucent, and opaque matter.
8. Explain why snow appears white to the human eye.

Points to Consider

In this lesson, you were introduced to the reflection and refraction of light. The next lesson "Optics" describes how mirrors reflect light and how lenses refract light.

- Based on your own experiences with mirrors, how do you think a mirror forms an image of the person in front of it?
- An example of a lens is a hand lens, also called a magnifying glass. This type of lens makes objects look bigger than they really are. How do you think this happens?

9.2 Optics

Lesson Objectives

- Outline how light is reflected.
- Describe how mirrors reflect light and form images.
- Explain the refraction of light.
- Describe how lenses refract light and form images.
- Explain how mirrors and lenses are used in optical instruments.

Lesson Vocabulary

- concave
- convex
- image
- laser
- law of reflection
- lens
- optics

Introduction

Did you ever see trees or other objects reflected in the still waters of a lake, like the one in **Figure** 9.9? The water in the lake is so calm that it reflects visible light almost as clearly as a mirror. A mirror is one of many devices that people use to extend their ability to see. Mirrors allow people to see themselves as other people see them and also to see behind their back. Mirrors are also used in instruments such as telescopes, which you will read about in this lesson. The use of light in devices such as these is possible because of optics. **Optics** is the study of visible light and the ways it can be used to extend human vision and do other tasks.

Reflection of Light

Almost all surfaces reflect some of the light that strikes them. The still water of the lake in **Figure** 9.9 reflects almost all of the light that strikes it. The reflected light forms an image of nearby objects. An **image** is a copy of an object that is formed by reflected or refracted light.

FIGURE 9.9
Still waters of a lake create a mirror image of the surrounding scenery.

Regular and Diffuse Reflection

If a surface is extremely smooth, like very still water, then an image formed by reflection is sharp and clear. This is called regular reflection. If the surface is even slightly rough, an image may not form, or if there is an image, it is blurry or fuzzy. This is called diffuse reflection. Both types of reflection are represented in **Figure** 9.10. You can also see animations of both types of reflection at this URL: http://toolboxes.flexiblelearning.net.au/demosites/series5/508/laboratory/studynotes/snReflectionMirrors.htm .

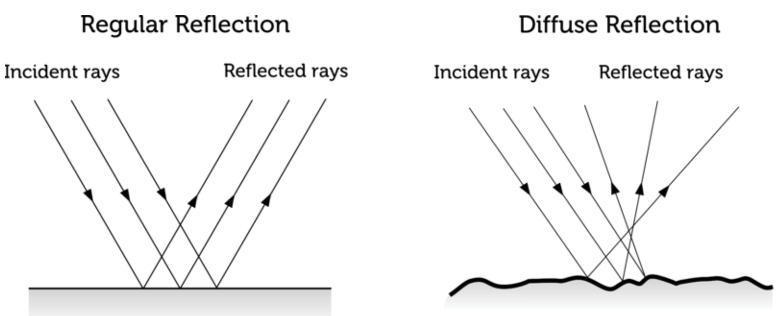

FIGURE 9.10
Whether reflection is regular or diffuse depends on the smoothness of the reflective surface.

In **Figure** 9.10, the waves of light are represented by arrows called rays. Rays that strike the surface are referred to as incident rays, and rays that reflect off the surface are known as reflected rays. In regular reflection, all the rays are reflected in the same direction. This explains why regular reflection forms a clear image. In diffuse reflection, in contrast, the rays are reflected in many different directions. This is why diffuse reflection forms, at best, a blurry image.

Law of Reflection

One thing is true of both regular and diffuse reflection. The angle at which the reflected rays bounce off the surface is equal to the angle at which the incident rays strike the surface. This is the **law of reflection**, and it applies to the reflection of all light. The law is illustrated in **Figure** 9.11 and in the animation at this URL: http://www.physicsclassroom.com/mmedia/optics/lr.cfm .

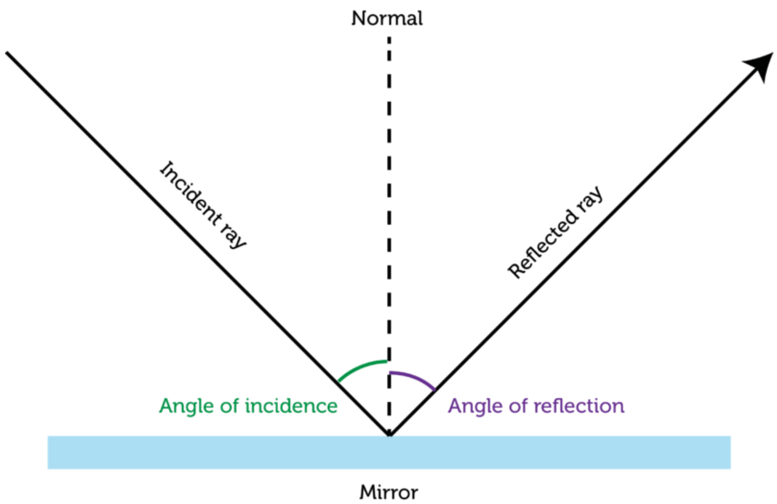

FIGURE 9.11
According to the law of reflection, the angle of reflection always equals the angle of incidence. The angles of both reflected and incident light are measured relative to an imaginary line, called normal, that is perpendicular (at right angles) to the reflective surface.

Mirrors

Mirrors are usually made of glass with a shiny metal backing that reflects all the light that strikes it. Mirrors may have flat or curved surfaces. The shape of a mirror's surface determines the type of image the mirror forms. For example, the image may be real or virtual. A real image forms in front of a mirror where reflected light rays actually meet. It is a true image that could be projected on a screen. A virtual image appears to be on the other side of the mirror. Of course, reflected rays don't actually go behind a mirror, so a virtual image doesn't really exist. It just appears to exist to the human eye and brain.

Plane Mirrors

Most mirrors are plane mirrors. A plane mirror has a flat reflective surface and forms only virtual images. The image formed by a plane mirror is also life sized. But something is different about the image compared with the real object in front of the mirror. Left and right are reversed. Look at the man shaving in **Figure** 9.12. He is using his right hand to hold the razor, but his image appears to be holding the razor in the left hand. Almost all plane mirrors reverse left and right in this way.

Concave Mirrors

Some mirrors have a curved rather than flat surface. Curved mirrors can be concave or convex. A **concave** mirror is shaped like the inside of a bowl. This type of mirror forms either real or virtual images, depending on where the object is placed relative to the focal point. The focal point is the point in front of the mirror where the reflected rays intersect. You can see how concave mirrors form images in **Figure** 9.13 and in the interactive animation at the URL below. The animation allows you to move an object to see how its position affects the image. Concave mirrors are used behind car headlights. They focus the light and make it brighter. They are also used in some telescopes.

http://www.splung.com/content/sid/4/page/concavemirrors

FIGURE 9.12
The term "mirror image" refers to how left and right are reversed in the image compared with the real object.

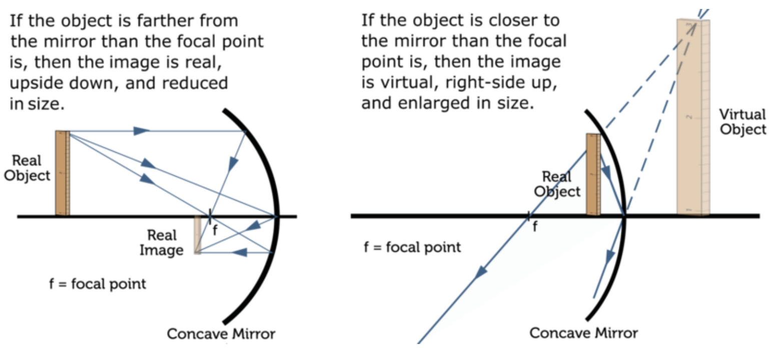

FIGURE 9.13
The image created by a concave mirror depends on how far the object is from the mirror.

Convex Mirrors

The other type of curved mirror, a **convex** mirror, is shaped like the outside of a bowl. This type of mirror forms only virtual images. The image is always right-side up and smaller than the actual object, which makes the object appear farther away than it really is. You can see how a convex mirror forms an image in **Figure** 9.14 and in the animation at the URL below. Because of their shape, convex mirrors can gather and reflect light from a wide area. This is why they are used as side mirrors on cars. They give the driver a wider view of the area around the vehicle than a plane mirror would.

http://physics.slss.ie/resources/convex%20mirror.swf

Refraction of Light

Although the speed of light is constant in a vacuum, light travels at different speeds in different kinds of matter. For example, light travels more slowly in glass than in air. Therefore, when light passes from air to glass, it slows down. If light strikes a sheet of glass straight on, or perpendicular to the glass, it slows down but passes straight through. However, if light enters the glass at an angle other than 90°, the wave refracts, or bends. This is illustrated in **Figure** 9.15. How much light bends when it enters a new medium depends on how much it changes speed. The greater the change in speed, the more light bends.

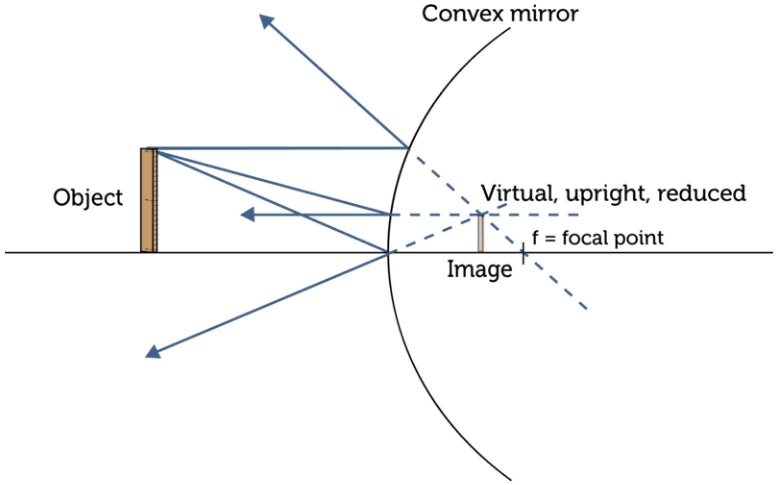

FIGURE 9.14
A convex mirror forms a virtual image that appears to be on the opposite side of the mirror from the object. How is the image different from the object?

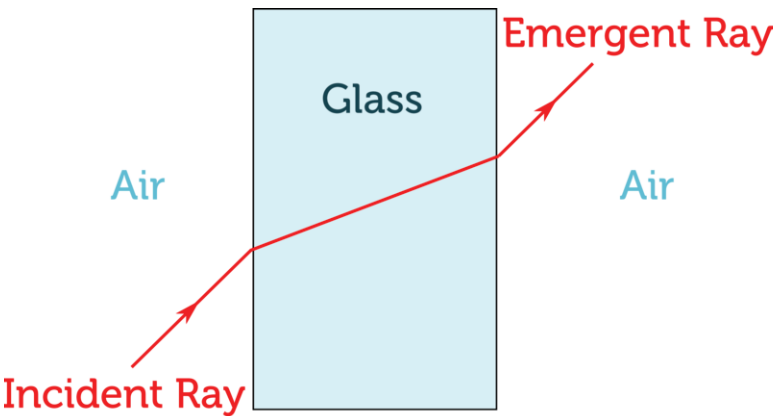

FIGURE 9.15
Light refracts when it passes from one medium to another at an angle other than 90°. Can you explain why?

Lenses

Lenses make use of the refraction of light to create images. A **lens** is a transparent object, typically made of glass, with one or two curved surfaces. The more curved the surface of a lens is, the more it refracts light. Like mirrors, lenses may be concave or convex.

Concave Lenses

Concave lenses are thicker at the edges than in the middle. They cause rays of light to diverge, or spread apart. **Figure** 9.16 shows how a concave lens forms an image. The image is always virtual and on the same side of the lens as the object. The image is also right-side up and smaller than the object. Concave lenses are used in cameras. They focus reduced images inside the camera, where they are captured and stored. You can explore the formation of images by a concave lens with the interactive animation at this URL: http://phet.colorado.edu/sims/geometric-optics/geometric-optics_en.html .

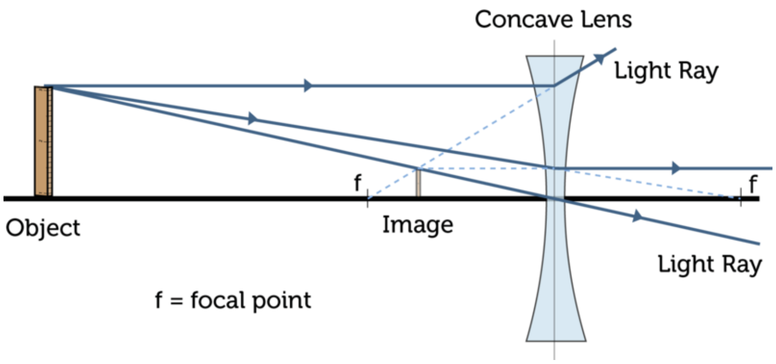

FIGURE 9.16
The image formed by a concave lens is a virtual image.

Convex Lenses

Convex lenses are thicker in the middle than at the edges. They cause rays of light to converge, or meet, at a point called the focus (F). Convex lenses form either real or virtual images. It depends on how close an object is to the lens relative to the focus. **Figure** 9.17 shows how a convex lens works. You can also interact with an animated convex lens at the URL below. An example of a convex lens is a hand lens.

http://www.phy.ntnu.edu.tw/ntnujava/index.php?topic=1395.msg5241#msg5241

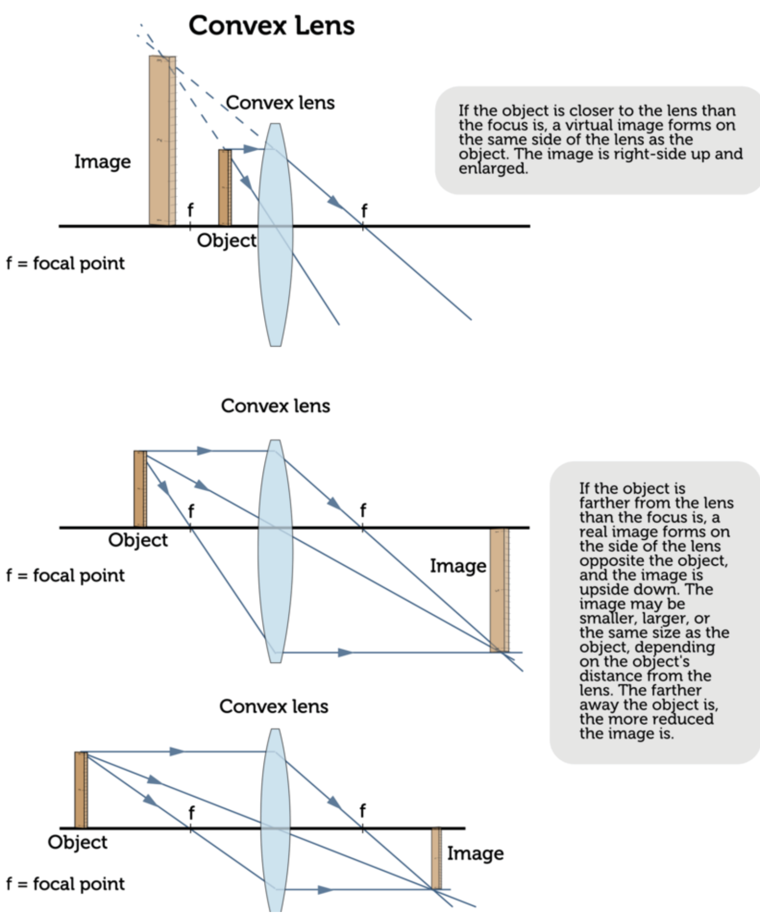

FIGURE 9.17
The type of image made by a convex lens depends on how close the object is to the lens. Which diagram shows how a hand lens makes an image?

Optical Instruments

Mirrors and lenses are used in optical instruments to reflect and refract light. Optical instruments include microscopes, telescopes, cameras, and lasers.

Light Microscopes

A light microscope is an instrument that uses lenses to make enlarged images of objects that are too small for the unaided eye to see. A common type of light microscope is a compound microscope, like the one in **Figure** 9.18. A compound microscope has at least two convex lenses: one or more objective lenses and one or more eyepiece lenses. The objective lenses are close to the object being viewed. They form an enlarged image of the object inside the microscope. The eyepiece lenses are close to the viewer's eyes. They form an enlarged image of the first image. The magnifications of all the lenses are multiplied together to yield the overall magnification of the microscope. Some light microscopes can magnify objects more than 1000 times! For more on light microscopes and the images they create, watch the video at this URL: http://www.youtube.com/watch?v=Xo7mr90GYLA (7:29).

MEDIA

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Telescopes

Like microscopes, telescopes use convex lenses to make enlarged images. However, telescopes make enlarged images of objects—such as distant stars—that only appear tiny because they are very far away. There are two basic types of telescopes: reflecting telescopes and refracting telescopes. The two types are compared in **Figure** 9.19. You can learn more about telescopes and how they evolved in the video at this URL: http://www.videojug.com/film/how-does-a-telescope-work .

Cameras

A camera is an optical instrument that records an image of an object. The image may be recorded on film or it may be detected by an electronic sensor that stores the image digitally. Regardless of how the image is recorded, all cameras form images in the same basic way, as demonstrated in **Figure** 9.20 and at the URL below. Light passes through the lens at the front of the camera and enters the camera through an opening called the aperture. As light passes through the lens, it forms a reduced real image. The image focuses on film (or a sensor) at the back of the camera. The lens may be moved back and forth to bring the image into focus. The shutter controls the amount of light that strikes the film (or sensor). It stays open longer in dim light to let more light in. For a series of animations showing how a camera works, go to this URL: http://www.shortcourses.com/guide/guide1-3.html .

Lasers

Did you ever see a cat chase after a laser light, like the one in **Figure** 9.21? A **laser** is a device that produces a very focused beam of light of just one wavelength and color. Waves of laser light are synchronized so the crests and troughs of the waves line up (see **Figure** 9.21).

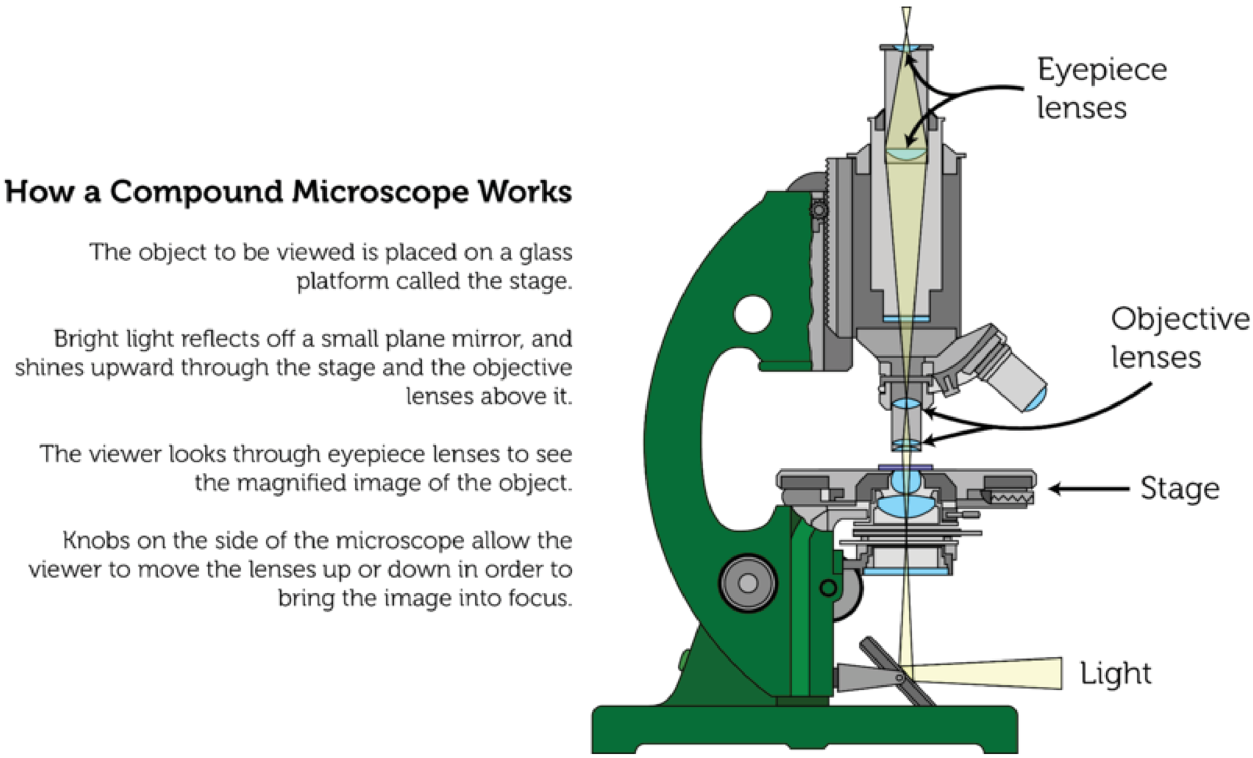
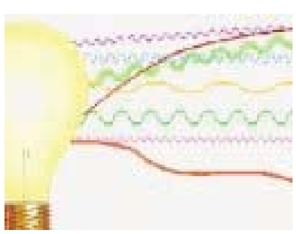


FIGURE 9.18

A compound microscope uses convex lenses to make enlarged images of tiny objects.

Laser light is created in a tube like the one shown in **Figure** 9.22. Electrons in a material such as a ruby crystal are stimulated to radiate photons of light of one wavelength. At each end of the tube is a concave mirror. The photons of light bounce back and forth in the tube off the mirrors. This focuses the light. The mirror at one end of the tube is partly transparent. A constant stream of photons passes through the transparent part, forming the laser beam. You can see an animation showing how a laser works at this URL: http://www.youtube.com/watch?v=gUbBzEXlEho (1:12).



MEDIA

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Besides entertaining a cat, laser light has many other uses. It is used to scan bar codes, for example, and to carry communication signals in optical fibers. Optical fibers are extremely thin glass tubes that are used to guide laser light (see **Figure** 9.23). Sounds or pictures are encoded in pulses of laser light, which are then sent through an optical fiber. All of the light reflects off the inside of the fiber, so none of it escapes. As a result, the signal remains strong even over long distances. More than one signal can travel through an optic fiber at the same time, as you can see in **Figure** 9.23. Optical fibers are used to carry telephone, cable TV, and Internet signals.

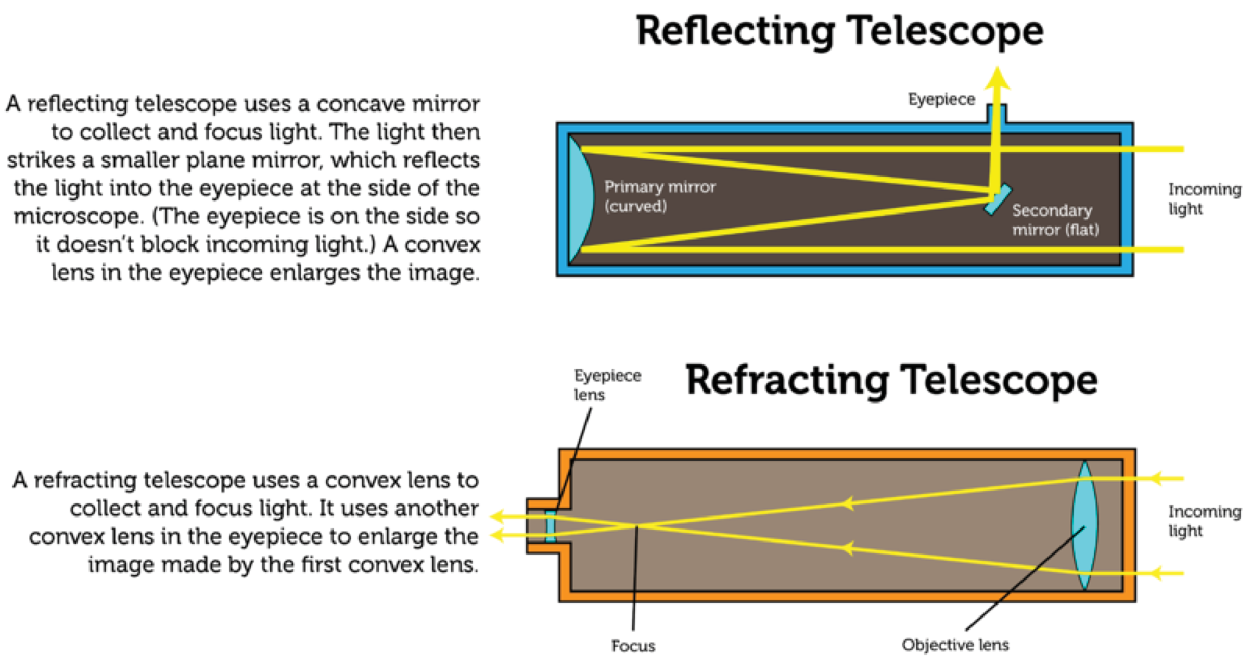

FIGURE 9.19
These telescopes differ in how they collect light, but both use convex lenses to enlarge the image.

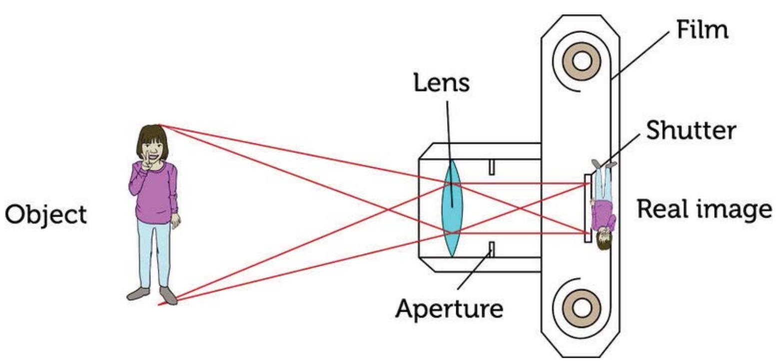

FIGURE 9.20
A camera uses a convex lens to form an image on film or a sensor.

Lesson Summary

- Objects that reflect or refract light may form images. An image is a copy of an object that is formed by reflected or refracted light. According to the law of reflection, light is reflected at the same angle that it strikes a reflective surface.
- Mirrors reflect all of the light that strikes them and form images. A plane, or flat, mirror forms virtual, life-sized images. A concave mirror forms either enlarged virtual images or reduced real images. A convex mirror forms only reduced virtual images.
- Refraction, or bending, of light occurs when light passes from one medium to another at an angle other than

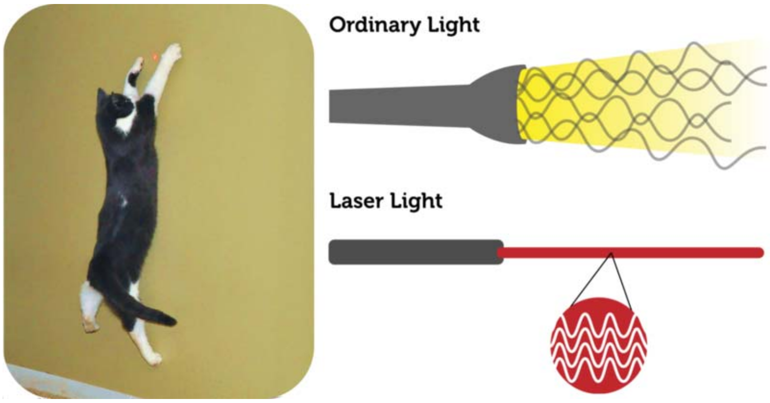

FIGURE 9.21
A very focused beam of bright laser light moves around the room for the cat to chase. The diagram shows why the beam of laser light is so focused compared with ordinary light from a flashlight.

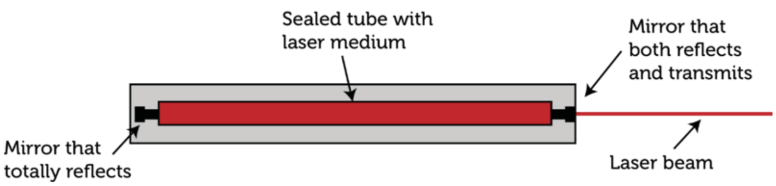

FIGURE 9.22
A laser light uses two concave mirrors to focus photons of colored light.

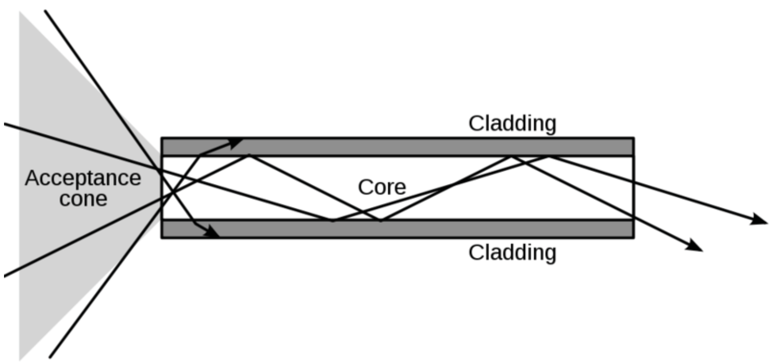

FIGURE 9.23
An optical fiber carries pulses of laser light. The outer cladding and inner core refract light by different amounts, so that all of the light is reflected back into the core. The optical fiber in the diagram is much larger than a real optical fiber, which is only about as wide as a human hair.

90° and the speed of light changes in the new medium. The greater the change in speed, the more light bends.
- Lenses are transparent objects with curved surfaces that refract light and form images. Concave lenses form only reduced virtual images. Convex lenses form either enlarged virtual images or real images that may be enlarged or reduced.
- Mirrors and lenses are used in optical instruments to reflect or refract light. Optical instruments include microscopes, telescopes, cameras, and lasers.

Lesson Review Questions

Recall

1. Define optics.

2. State the law of reflection.
3. What type of images does a convex mirror form?
4. What type of images does a concave lens form?
5. Choose an optical instrument described in this lesson and state how it uses lenses and/or mirrors to focus visible light.

Apply Concepts

6. Assume that a light shines upward through the water of a swimming pool. Create a diagram to show what happens to the light when it passes from the water to the air above the water's surface. The light should enter the air at an angle other than 90°. Explain your diagram to another student.

Think Critically

7. Compare and contrast regular and diffuse reflection.
8. Explain how concave mirrors form real and virtual images.
9. Relate focus and position of an object to the image formed by a convex lens.

Points to Consider

In this lesson, you read how convex and concave lenses refract light. The human eye, which you can read about in the next lesson "Vision," also contains a lens.

- How do you think the lens in the eye works? What is its role in vision?
- Do you think the lens in the eye is a concave lens or a convex lens?

9.3 Vision

Lesson Objectives

- Describe the structure and function of the eye.
- Explain how the eyes and brain work together to enable vision.
- Identify common vision problems and how they can be corrected.

Introduction

A certain optical instrument uses a convex lens to focus an image on a surface, where the image is encoded in electrical signals. The signals are then transmitted to an extremely fast and complex computer, which interprets the signals as an image. Can you guess what the optical instrument is? The "instrument" is the human eye. And the "computer"? It's the human brain. In this lesson, you'll learn how the eyes and brain work together to enable human vision.

Structure and Function of the Eye

The structure of the human eye is shown in **Figure** 9.24. Find each structure in the diagram as you read about it below. You can also watch a video about the eye at this URL: http://www.youtube.com/watch?v=JadaWSDxBYk (5:28).

MEDIA

Click image to the left for more content.

Structures of the Eye

- The cornea is the transparent outer covering of the eye. It protects the eye and also acts as a convex lens, helping to focus light that enters the eye.
- The pupil is an opening in the front of the eye. It looks black because it doesn't reflect any light. It allows light to enter the eye. The pupil automatically gets bigger or smaller to let more or less light in as needed.
- The iris is the colored part of the eye. It controls the size of the pupil.
- The lens is a convex lens that fine-tunes the focus so an image forms on the back of the eye. Tiny muscles control the shape of the lens to focus images of close or distant objects.
- The retina is a membrane lining the back of the eye. The retina has nerve cells called rods and cones that change images to electrical signals. Rods are good at sensing dim light but can't distinguish different colors of

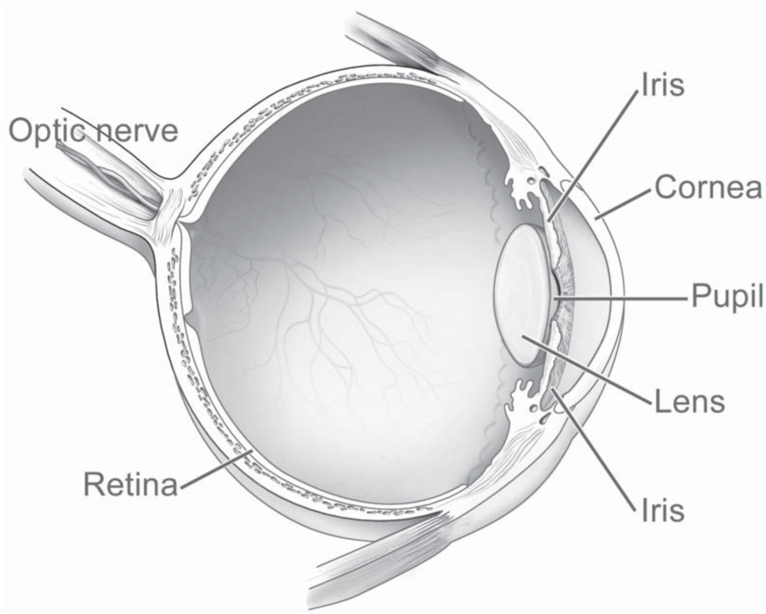

FIGURE 9.24
The human eye is the organ specialized to collect light and focus images.

light. Cones can sense colors but not in dim light. There are three different types of cones. Each type senses one of the three primary colors of light.

- The optic nerve carries electrical signals from the rods and cones to the brain.

How We See

As just described, the eyes collect and focus visible light. The lens and other structures of the eye work together to focus a real image on the retina. The image is upside-down and reduced in size, as you can see in **Figure** 9.25. The image reaches the brain as electrical signals that travel through the optic nerve. The brain interprets the signals as shape, color, and brightness. It also interprets the image as though it were right-side up. The brain does this automatically, so what we see is always right-side up. The brain also "tells" us what we are seeing.

Vision Problems

Many people have vision problems. The problems often can be corrected with contact lenses or lenses in eyeglasses. Some vision problems can also be corrected with laser surgery, which reshapes the cornea. Two of the most common vision problems are nearsightedness and farsightedness. You may even have one of these conditions yourself. Both are illustrated in **Figure** 9.26 and in the video at this URL: http://www.youtube.com/watch?v=ekSGbXt4XdI (1:08).

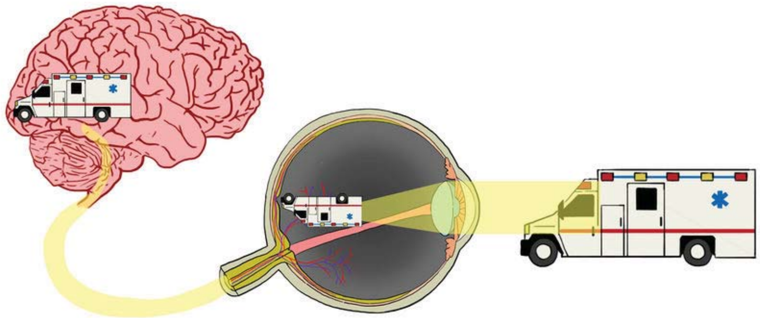

FIGURE 9.25
The brain and eyes work together to allow us to see.

MEDIA
Click image to the left for more content.

- Nearsightedness, or myopia, is the condition in which nearby objects are seen clearly, but distant objects are blurry. It occurs when the eyeball is longer than normal. This causes images to be focused in front of the retina. Myopia can be corrected with concave lenses. The lenses focus images farther back in the eye, so they are on the retina instead of in front of it.
- Farsightedness, or hyperopia, is the condition in which distant objects are seen clearly, but nearby objects are blurry. It occurs when the eyeball is shorter than normal. This causes images to be focused in back of the retina. Hyperopia can be corrected with convex lenses. The lenses focus images farther forward in the eye, so they are on the retina instead of behind it.

Lesson Summary

- The structures of the human eye collect and focus light. They form a reduced, upside-down image on the retina at the back of the eye.
- The image focused by the eye travels through the optic nerve to the brain as electrical signals. The brain interprets the signals and “tells” us what we are seeing.
- Common vision problems include nearsightedness (myopia), which can be corrected with concave lenses, and farsightedness (hyperopia), which can be corrected with convex lenses.

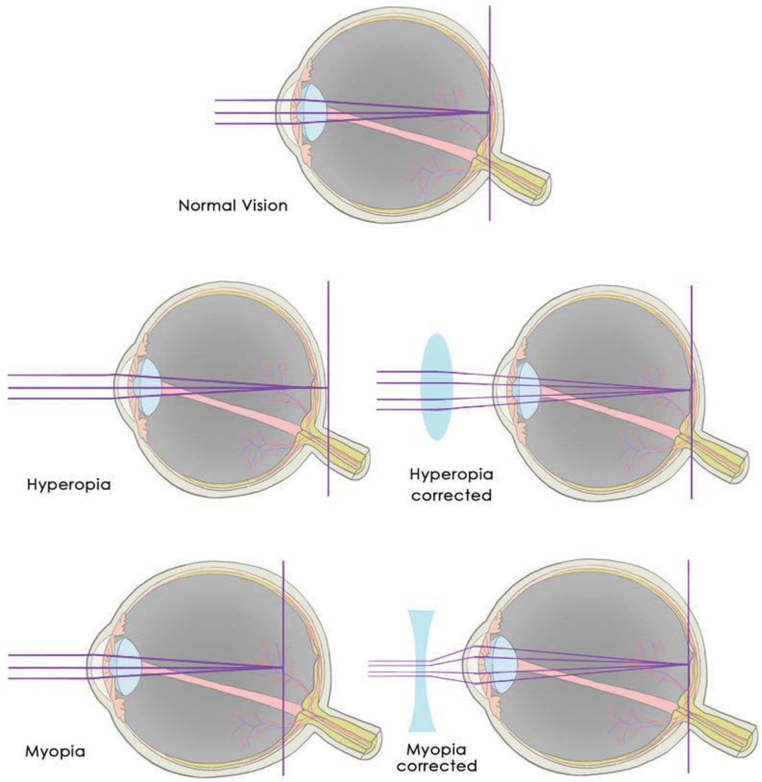

FIGURE 9.26
Myopia and hyperopia can be corrected with lenses.

Lesson Review Questions

Recall

1. How are the pupil and iris related?
2. Which parts of the eye focus light?
3. Describe the retina.
4. What is the function of the optic nerve?
5. In an eye with normal vision, where are images focused?

Apply Concepts

6. Create a lesson for younger students to teach them how the eye works. With your teacher's approval, present your lesson to a class in a lower grade.

Think Critically

7. Compare and contrast rods and cones.
8. Why is the brain needed for vision?
9. Identify a common vision problem and explain how lenses can be used to correct it.

Points to Consider

This chapter focuses on energy in the form of visible light. Another common form of energy, electrical energy, is the focus of the chapter *Electricity*.

- What are some ways you use electrical energy?
- Where does the electrical energy you use come from?

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9.4 References

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