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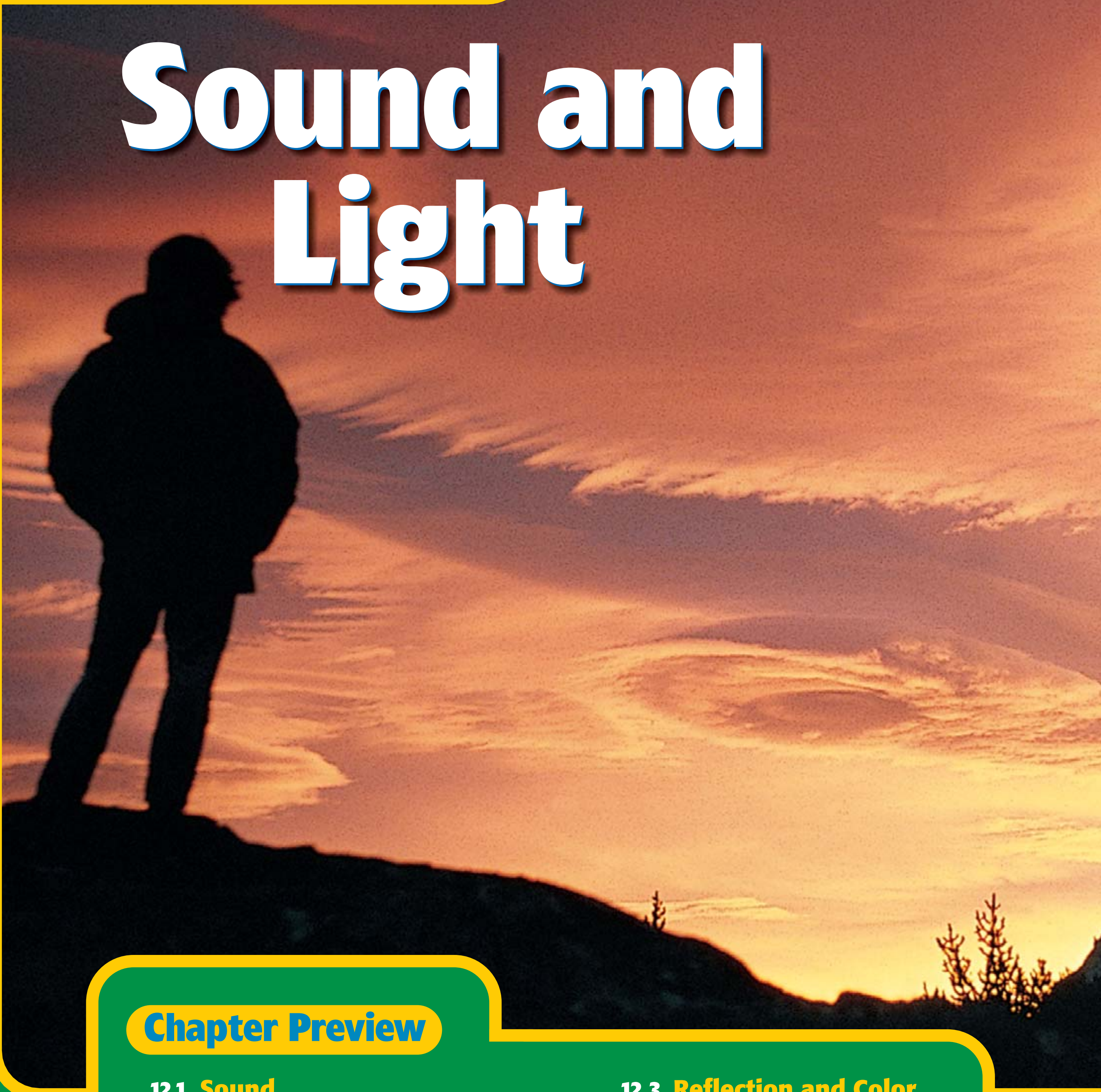
Sound and Light



Chapter Preview

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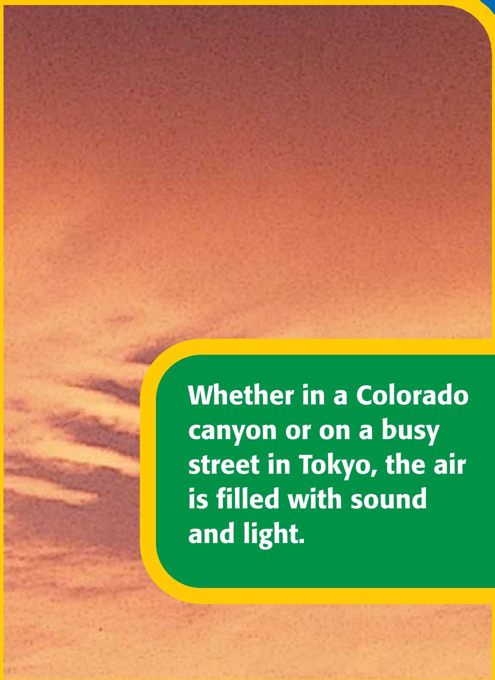

Whether in a Colorado canyon or on a busy street in Tokyo, the air is filled with sound and light.

Focus ACTIVITY

Background Imagine that you are walking through a canyon at sunset. As the red light of the setting sun fades, you see the first stars of the night sky. Your footsteps make a faint echo that bounces around the rocky canyon walls. As you approach your destination, you hear the sounds of people talking around a campfire.

Now imagine that you are walking down a street in a big city. You see the flash of neon signs and the colors of street lights. You hear the sound of cars, and you hear music from a car radio. Through the open door of a restaurant, you hear dishes clanking and people laughing.

Sound and light carry information about the world around us. In Chapter 11, you learned that sound waves are longitudinal waves, which require a medium, while light waves are transverse waves that can pass through empty space. You also learned some of the ways that waves behave in different situations.

This chapter will focus on the behavior of sound waves and light waves. You will learn how sound is produced, how mirrors and lenses work, how we see and hear, and how sound and light are used in different applications, ranging from music to medicine.

Activity 1 Stand outside in front of a large wall, and clap your hands. Do you hear an echo? How much time passes between the time you clap your hands and the time you hear the echo? Use this estimated time to estimate the distance to the wall. You will need two other pieces of information: the speed of sound in air, about 340 m/s, and the speed equation, $v = d/t$.

Activity 2 Find a crosswalk with a crossing signal. Watch as the signal changes from "Walk" to "Don't Walk" and back again. Does the crossing signal ever produce a sound? If so, why? If not, why would it be a good idea for the signal to produce a sound?

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TOPIC: Transfer of sound and light energy
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12.1

Sound

KEY TERMS
pitch
ultrasound
infrasound
resonance
sonar

OBJECTIVES
- Recognize what factors affect the speed of sound.
- Relate loudness and pitch to properties of sound waves.
- Explain how harmonics and resonance affect the sound from musical instruments.
- Describe the function of the ear.
- Explain how sonar and ultrasound imaging work.

When you listen to your favorite musical group, you hear a variety of sounds. You may hear the steady beat of a drum, the twang of guitar strings, the wail of a saxophone, chords from a keyboard, or human voices.

Although these sounds all come from different sources, they are all longitudinal waves produced by vibrating objects. How does a musical instrument or a stereo speaker make sound waves in the air? What happens when those waves reach your ears? Why does a guitar sound different from a violin?

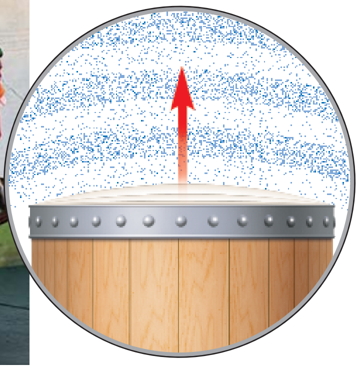
Properties of Sound

When a drummer hits a drum, the head of the drum vibrates up and down, as shown in **Figure 12-1A.** Each time the drumhead moves upward, it compresses the air above it. As the head moves back down again, it leaves a small region of air that has a lower pressure. As this happens over and over, the drumhead creates a series of compressions and rarefactions in the air, as shown in **Figure 12-1B.**

The sound waves from a drum are longitudinal waves, like the waves along a stretched spring that were discussed in Chapter 11. Sound waves are caused by vibrations, and carry energy through a medium. Unlike waves along a spring, however, sound waves in air spread out in all directions away from the source. When sound waves from the drum reach your ears, the waves cause your eardrums to vibrate.

Figure 12-1

A The head of a drum vibrates up and down when it is struck by the drummer's hand.



B The vibrations of the drumhead create sound waves in the air.

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Table 12-1 Speed of Sound in Various Mediums

Medium	Speed of sound (m/s)	Medium	Speed of sound (m/s)
Gases		**Liquids at 25°C**	
air (0°C)	331	water	1490
air (25°C)	346	sea water	1530
air (100°C)	386	**Solids**	
helium (0°C)	972	copper	3813
hydrogen (0°C)	1290	iron	5000
oxygen (0°C)	317	rubber	54

The speed of sound depends on the medium

If you stand a few feet away from a drummer, it may seem that you hear the sound from the drum at the same time that the drummer's hand strikes the drum head. Sound waves travel very fast, but not infinitely fast. The speed of sound in air at room temperature is about 346 m/s (760 mi/h).

Table 12-1 shows the speed of sound in various materials and at various temperatures. The speed of sound in a particular medium depends on how well the particles can transmit the compressions and rarefactions of sound waves. In a gas, such as air, the speed of sound depends on how often the molecules of the gas collide with one another. At higher temperatures, the molecules move around faster and collide more frequently. An increase in temperature of 10°C increases the speed of sound in a gas by about 6 m/s.

Sound waves travel faster through liquids and solids than through gases. In a liquid or solid the particles are much closer together than in a gas, so the vibrations are transferred more rapidly from one particle to the next. However, some solids, such as rubber, dampen vibrations so that sound travels very slowly. Materials like rubber can be used for soundproofing.

Loudness is determined by intensity

How do the sound waves change when you increase the volume on your stereo or television? The loudness of a sound depends partly on the energy contained in the sound waves. The energy of a mechanical wave is determined by its amplitude. So the greater the amplitude of the sound waves, the louder the sound. For more on the energy of waves, review Section 11.1.

Loudness also depends on your distance from the source of the sound waves. The *intensity* of a sound describes its loudness at a particular distance from the source of the sound.

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TOPIC: Properties of sound
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Quick ACTIVITY

Sound in Different Mediums

1. Tie a spoon or other utensil to the middle of a 1–2 m length of string.
2. Wrap the loose ends of the string around your index fingers and place your fingers against your ears.
3. Swing the spoon so that it strikes a tabletop, and compare the volume and quality of the sound received with those received when you listen to the sound directly through the air.
4. Does sound travel better through the string or through the air?

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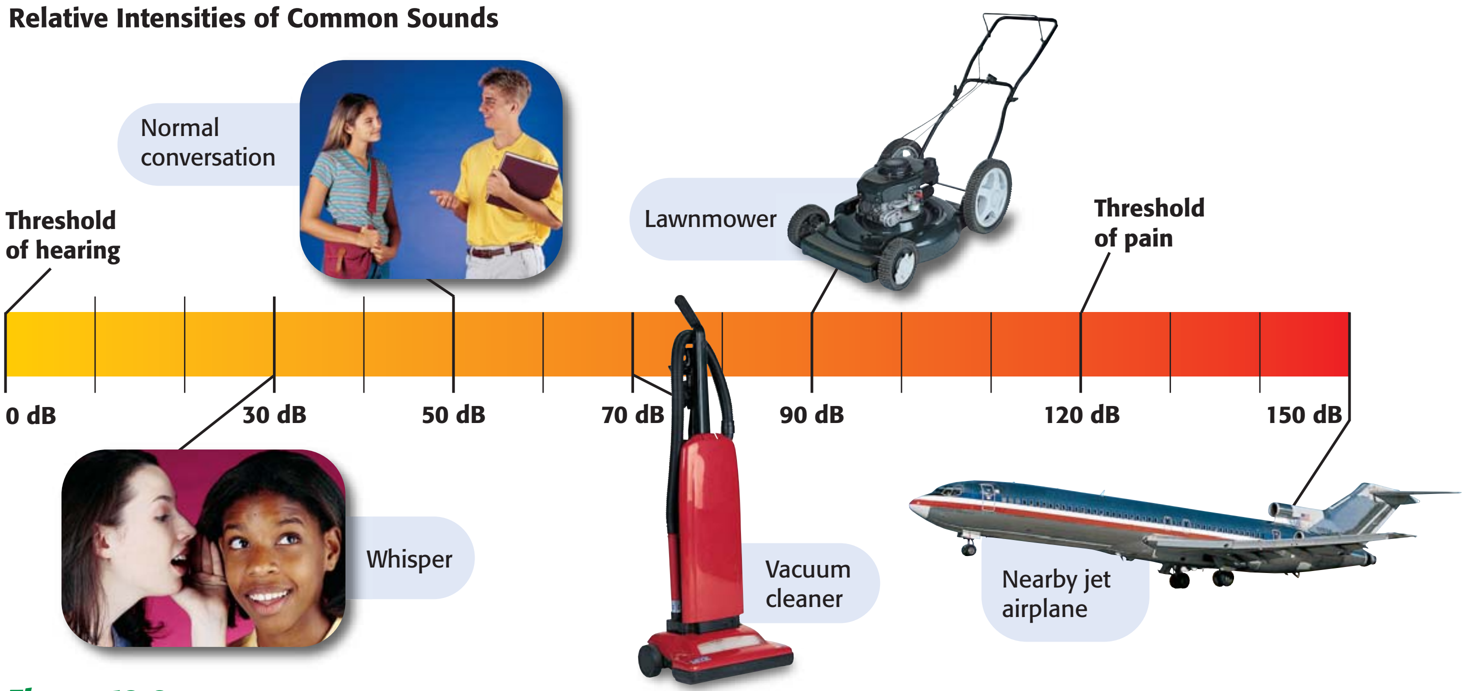

Figure 12-2
Sound intensity is measured on a logarithmic scale of decibels.

However, a sound with twice the intensity of another sound does not seem twice as loud. Humans perceive loudness on a logarithmic scale. This means that a sound seems twice as loud when its intensity is 10 times the intensity of another sound.

The *relative intensity* of sounds is found by comparing the intensity of a sound with the intensity of the quietest sound a person can hear, the threshold of hearing. Relative intensity is measured in units called *decibels,* dB. A difference in intensity of 10 dB means a sound seems about twice as loud. **Figure 12-2** shows some common sounds and their decibel levels.

The quietest sound a human can hear is 0 dB. A sound of 120 dB is at the threshold of pain. Sounds louder than this can hurt your ears and give you headaches. Extensive exposure to sounds above 120 dB can cause permanent deafness.

pitch the perceived highness or lowness of a sound, depending on the frequency of sound waves

Pitch is determined by frequency

Musicians use the word **pitch** to describe how high or low a note sounds. The pitch of a sound is related to the frequency of sound waves. Small instruments generally produce higher-pitched sounds than large instruments. A high-pitched note is made by something vibrating very rapidly, like a violin string or the air in a flute. A low-pitched sound is made by something vibrating more slowly, like a cello string or the air in a tuba.

In other words, a high-pitched sound corresponds to a high frequency, and a low-pitched sound corresponds to a low frequency. Trained musicians are capable of detecting subtle differences in frequency, even as slight as a change of 2 Hz.

Quick ACTIVITY

Frequency and Pitch

1. Hold one end of a flexible metal or plastic ruler on a desk with about half of the ruler hanging off the edge. Bend the free end of the ruler and then release it. Can you hear a sound?
2. Try changing the position of the ruler so that less hangs over the edge. How does that change the sound produced?

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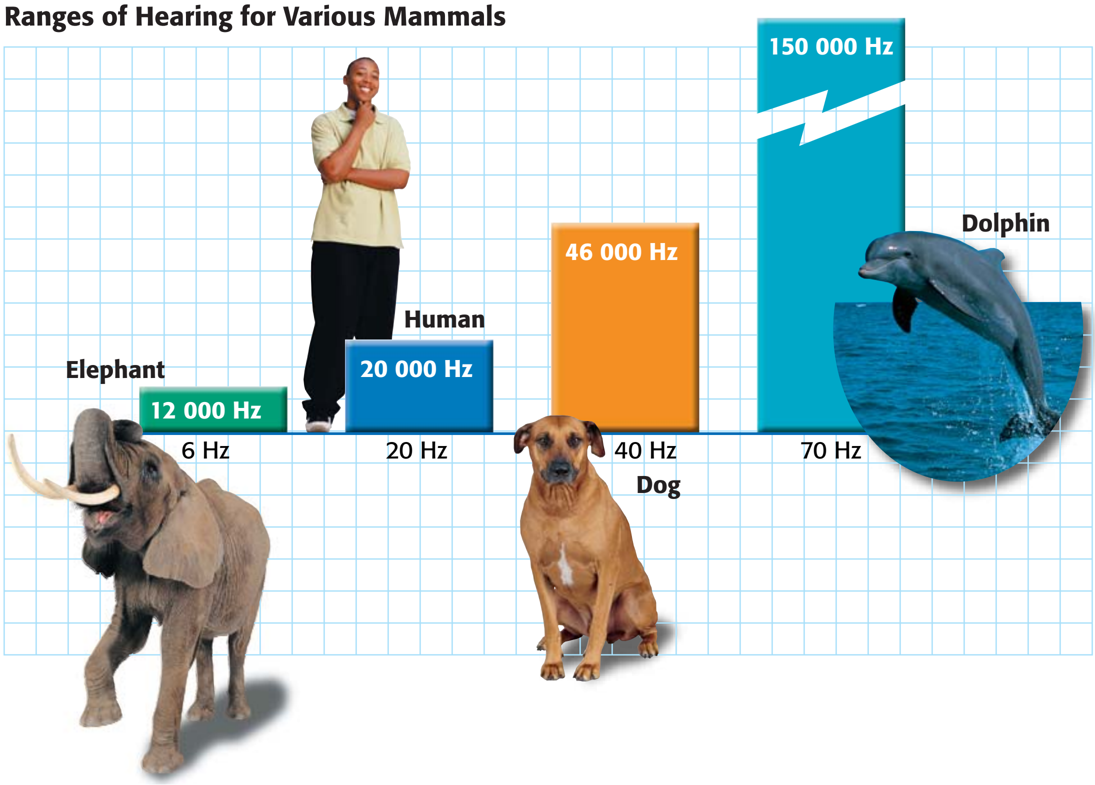

Figure 12-3
Humans can hear sounds ranging from 20 Hz to about 20 000 Hz, but many other animals can hear sounds well into the infrasound and ultrasound ranges.

Humans hear sound waves in a limited frequency range

The human ear can hear sounds from sources that vibrate as slowly as 20 vibrations per second (20 Hz) and as rapidly as 20 000 Hz. Any sound with a frequency below the range of human hearing is known as **infrasound;** any sound with a frequency above human hearing range is known as **ultrasound.** Many animals can hear frequencies of sound outside the range of human hearing, as shown in **Figure 12-3.**

infrasound any sound consisting of waves with frequencies lower than 20 Hz

ultrasound any sound consisting of waves with frequencies higher than 20 000 Hz

Musical Instruments

Musical instruments, from deep bassoons to twangy banjos, come in a wide variety of shapes and sizes and produce a wide variety of sounds. But musical instruments can be grouped into a small number of categories based on how they make sound. Most instruments produce sound through the vibration of strings, air columns, or membranes.

Musical instruments rely on standing waves

When you pluck the string of a guitar, particles in the string start to vibrate. Waves travel out to the ends of the string, and then reflect back toward the middle. These vibrations cause a standing wave on the string, as shown in **Figure 12-4.** The two ends of the strings are nodes, and the middle of the string is an antinode.

Figure 12-4
Vibrations on a guitar string produce standing waves on the string. These standing waves in turn produce sound waves in the air.

Figure 12-5
Colored dust lies along the nodes of the two-dimensional standing waves on the head of this drum.

By placing your finger on the string somewhere along the neck of the guitar, you can change the pitch of the sound. This happens because a shorter length of string vibrates more rapidly, or in other words, at a higher frequency.

Recall from Section 11.3 that standing waves can exist only at certain frequencies on a string. The primary standing wave on a vibrating string has a wavelength that is twice the length of the string. The frequency of this wave, which is also the frequency of the string's vibrations, is called the *fundamental frequency*.

All musical instruments use standing waves to produce sound. In a flute, standing waves are formed in the column of air inside the flute. The wavelength and frequency of the standing waves can be changed by opening or closing holes in the flute body, which changes the length of the air column. Standing waves also form on the head of a drum, as shown in **Figure 12-5.**

Harmonics give every instrument a unique sound

If you play notes of the same pitch on a tuning fork and a clarinet, the two notes will sound different from each other. If you listen carefully, you may be able to hear that the clarinet is actually producing sounds at several different pitches, while the tuning fork produces a pure tone of only one pitch.

A tuning fork vibrates only at its fundamental frequency. The air column in a clarinet, however, vibrates at its fundamental frequency and at certain whole-number multiples of that frequency, called *harmonics*. **Figure 12-6** shows the harmonics present in a tuning fork and a clarinet when each sounds the note A-natural.

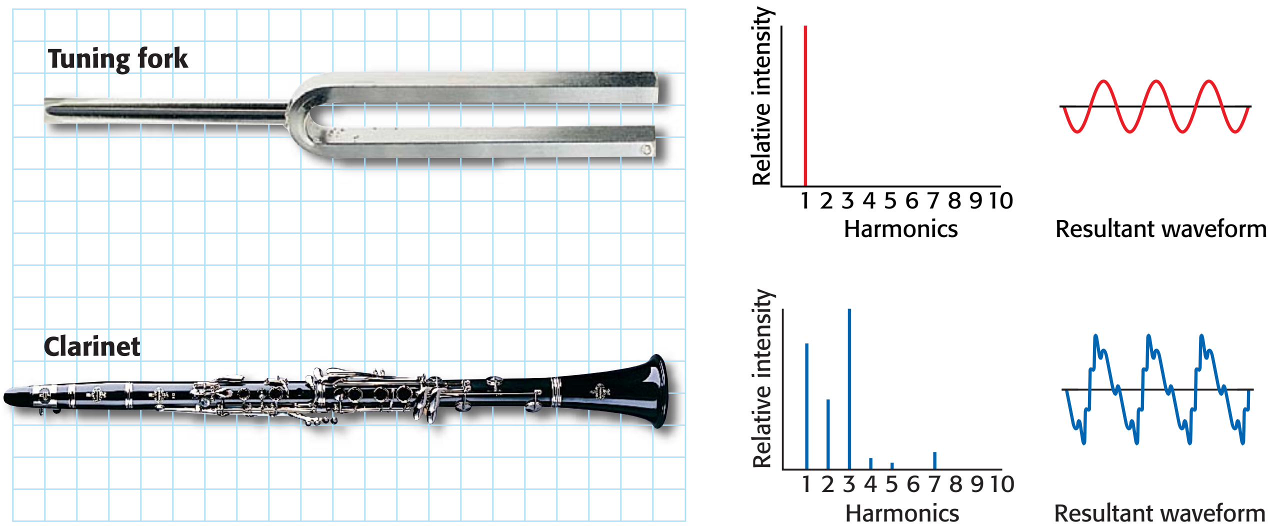

Figure 12-6
The note A-natural on a clarinet sounds different from the same note on a tuning fork due to the relative intensity of harmonics.

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In the clarinet, several harmonics combine to make a complex wave. Note, however, that this wave still has a primary frequency that is the same as the frequency of the wave produced by the tuning fork. This is the fundamental frequency, which makes the note sound a certain pitch. The unique sound quality of a clarinet results from the relative intensity of different harmonics in each note that it plays. Every musical instrument has a characteristic sound quality resulting from the mixture of harmonics.

Instruments use resonance to amplify sound

When you pluck a guitar string, you can feel that the bridge and the body of the guitar also vibrate. These vibrations, which are a response to the vibrating string, are called *forced vibrations*. The body of the guitar is more likely to vibrate at certain specific frequencies called *natural frequencies*.

The sound produced by the guitar will be loudest when the forced vibrations cause the body of the guitar to vibrate at a natural frequency. This effect is called **resonance.** When resonance occurs, the sound is amplified because both the string and the guitar itself are vibrating at the same frequency.

resonance an effect in which the vibration of one object causes the vibration of another object at a natural frequency

Inquiry Lab

How can you amplify the sound of a tuning fork?

Materials

- *tuning forks of various frequencies*
- *rubber block for activating forks*
- *various objects made of metal and wood*

Procedure

1. Activate a tuning fork by striking the tongs of the fork against a rubber block.
2. Touch the base of the tuning fork to different wood or metal objects, as shown in the figure at right. Listen for any changes in the sound of the tuning fork.
3. Activate the fork again, but now try touching the end of the tuning fork to the ends of other tuning forks (make sure that the tongs of the forks are free to vibrate, not touching anything). Can you make another tuning fork start vibrating in this way?
4. If you find two tuning forks that resonate with each other, try activating one and holding it near the tongs of the other one. Can you make the second fork vibrate without touching it?

Analysis

1. What are some characteristics of the objects that helped to amplify the sound of the tuning fork in step 2?
2. What is the relationship between the frequencies of tuning forks that resonate with each other in steps 3 and 4?

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The natural frequency of an object depends on its shape, size, and mass, as well as the material it is made of. Complex objects such as a guitar have many natural frequencies, so they resonate well at many different pitches. However, some musical instruments, such as an electric guitar, do not resonate well and must be amplified electronically.

Hearing and the Ear

The head of a drum or the strings and body of a guitar vibrate to create sound waves in air. But how do you hear these waves and interpret them as different sounds?

The human ear is a very sensitive organ that senses vibrations in the air, amplifies them, and then transmits signals to the brain. In some ways, the process of hearing is the reverse of the process by which a drum head makes a sound. In the ear, sound waves cause membranes to vibrate.

Vibrations pass through three regions in the ear

Your ear is divided into three regions—outer, middle, and inner—as shown in **Figure 12-7.** Sound waves are funneled through the fleshy part of your outer ear and down the ear canal. The ear canal ends at the eardrum, a thin, flat piece of tissue.

When sound waves strike the eardrum, they cause the eardrum to vibrate. These vibrations pass from the eardrum through the three small bones of the middle ear—known as the hammer, the anvil, and the stirrup. When the vibrations reach the stirrup, the stirrup strikes a membrane at the opening of the inner ear, sending waves through the spiral-shaped cochlea.

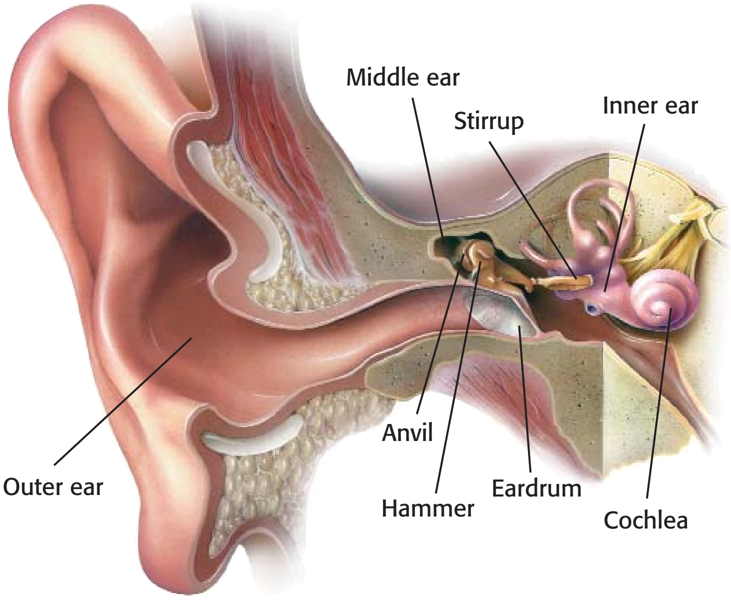

Figure 12-7
Sound waves are transmitted as vibrations through the ear. Vibrations in the cochlea stimulate nerves that send impulses to the brain.

Resonance occurs in the inner ear

The cochlea contains a long, flexible membrane called the *basilar membrane.* Different parts of the basilar membrane vibrate at different natural frequencies. As waves pass through the cochlea, they resonate with specific parts of the basilar membrane.

A wave of a particular frequency causes only a small portion of the basilar membrane to vibrate. Hair cells near that part of the membrane then stimulate nerve fibers that send an impulse to the brain. The brain interprets this impulse as a sound with a specific frequency.

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Ultrasound and Sonar

If you shout over the edge of a rock canyon, you may hear the sound reflected back to you in an echo. Like all waves, sound waves can be reflected. The reflection of sound waves can be used to determine distances and to create maps and images.

Figure 12-8
Bats use ultrasound echoes to navigate in flight.

Sonar is used for underwater location

How can a person on a ship measure the distance to the ocean floor, which may be thousands of meters from the surface of the water? One way is to use **sonar.**

sonar a system that uses reflected sound waves to determine the distance to, and location of, objects

A sonar system determines distance by measuring the time it takes for sound waves to be reflected back from a surface. A sonar device on a ship sends a pulse of sound downward, and measures the time, t, that it takes for the sound to be reflected back from the ocean floor. Using the average speed of the sound waves in water, v, the distance, d, can be calculated using a form of the speed equation from Section 8.1.

$$d = vt$$

If a school of fish or a submarine passes under the ship, the sound pulse will be reflected back much sooner.

Ultrasound waves—sound waves with frequencies above 20 000 Hz—work particularly well in sonar systems because they can be focused into narrow beams and can be directed more easily than other sound waves. Bats, like the one in **Figure 12-8,** use reflected ultrasound waves to navigate in flight and to locate insects for food.

VOCABULARY Skills Tip

Sonar stands for **so***und* **n***avigation* **a***nd* **r***anging.*

Ultrasound imaging is used in medicine

The echoes of very high frequency ultrasound waves, between 1 million and 15 million Hz, are used to produce computerized images called *sonograms*. Using sonograms, doctors can safely view organs inside the body without having to perform surgery. Sonograms can be used to diagnose problems, to guide surgical procedures, or even to view unborn fetuses, as shown in **Figure 12-9.**

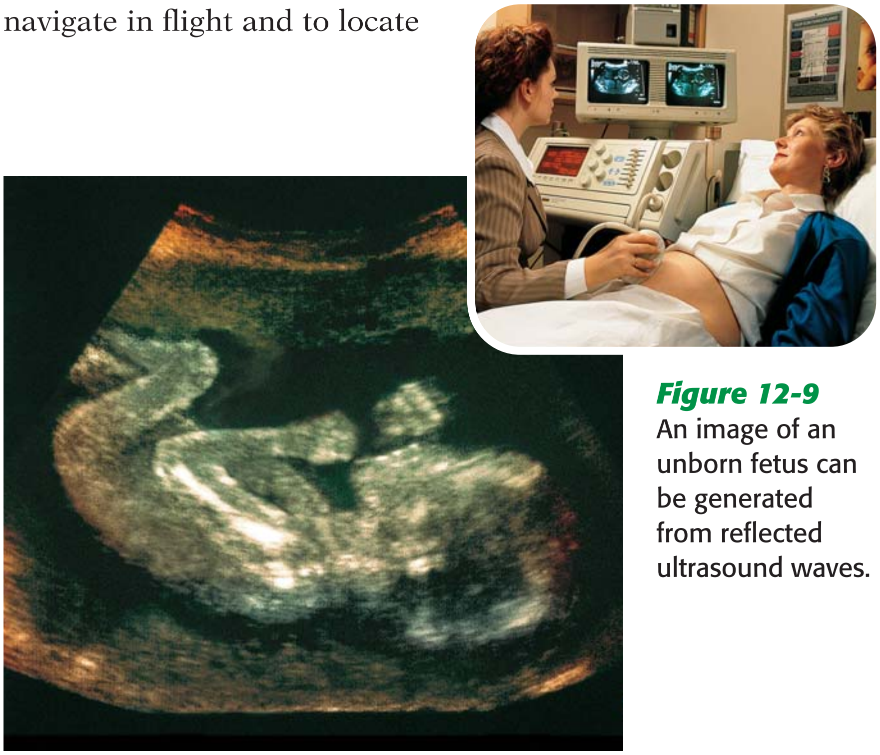

Figure 12-9
An image of an unborn fetus can be generated from reflected ultrasound waves.

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At high frequencies, ultrasound waves can travel through most materials. But some sound waves are reflected when they pass from one type of material into another. How much sound is reflected depends on the density of the materials at each boundary. The reflected sound waves from different boundary surfaces are compiled into a sonogram by a computer.

The advantage of using sound to see inside the human body is that it doesn't harm living cells as X rays may do. However, to see details, the wavelengths of the ultrasound must be slightly smaller than the smallest parts of the object being viewed. That is another reason that such high frequencies are used. According to the wave speed equation from Section 11.2, the higher the frequency of waves in a given medium, the shorter the wavelength will be. Sound waves with a frequency of 15 million Hz have a wavelength of less than 1 mm when they pass through soft tissue.

SECTION 12.1 REVIEW

SUMMARY

- The speed of sound waves depends on temperature, density, and other properties of the medium.
- Pitch is determined by the frequency of sound waves.
- Infrasound and ultrasound lie beyond the range of human hearing.
- The loudness of a sound depends on intensity. Relative intensity is measured in decibels (dB).
- Musical instruments use standing waves and resonance to produce sound.
- The ear converts vibrations in the air into nerve impulses to the brain.
- Reflection of sound or ultrasound waves can be used to determine distances or to create sonograms.

CHECK YOUR UNDERSTANDING

1. **Identify** two factors that affect the speed of sound.
2. **Explain** why sound travels faster in water than in air.
3. **Distinguish** between infrasound, audible sound, and ultrasound waves.
4. **Determine** which of the following must change when pitch gets higher.
   a. amplitude
   b. frequency
   c. wavelength
   d. intensity
   e. speed of the sound waves
5. **Determine** which of the following must change when a sound gets louder.
   a. amplitude
   b. frequency
   c. wavelength
   d. intensity
   e. speed of the sound waves
6. **Explain** why the note middle C played on a piano sounds different from the same note played on a violin.
7. **Explain** why an acoustic guitar generally sounds louder than an electric guitar without an electronic amplifier.
8. **Describe** the process through which sound waves in the air are translated into nerve impulses to the brain.
9. **Critical Thinking** Why are sonograms made with ultrasound waves instead of audible sound waves?
10. **Creative Thinking** Why do most pianos contain a large *sounding board* underneath the strings? (**Hint:** The piano would be harder to hear without it.)

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12.2

The Nature of Light

OBJECTIVES

- Recognize that light has both wave and particle characteristics.
- Relate the energy of light to the frequency of electromagnetic waves.
- Describe different parts of the electromagnetic spectrum.
- Explain how electromagnetic waves are used in communication, medicine, and other areas.

KEY TERMS

photon
intensity
radar

Most of us see and feel light almost every moment of our lives, from the first rays of dawn to the warm glow of a campfire. Even people who cannot see can feel the warmth of the sun on their skin, which is an effect of infrared light. We are very familiar with light, but how much do we understand about what light really is?

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TOPIC: Properties of light
GO TO: www.scilinks.org
KEYWORD: HK1123

Waves and Particles

It is difficult to describe all of the properties of light with a single scientific model. The two most commonly used models describe light either as a wave or as a stream of particles.

Light produces interference patterns like water waves

In 1801, the English scientist Thomas Young devised an experiment to test the nature of light. He passed a beam of light through two narrow openings and then onto a screen on the other side. He found that the light produced a striped pattern on the screen, like the pattern in **Figure 12-10A.** This pattern is similar to the pattern caused by water waves interfering in a ripple tank, as shown in **Figure 12-10B.**

Figure 12-10

A Light passed through two small openings produces light and dark bands on a screen.

B Two water waves in a ripple tank also produce an interference pattern with light and dark bands.

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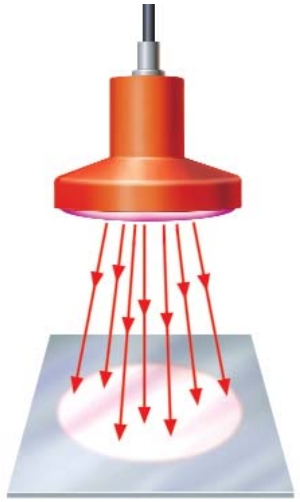
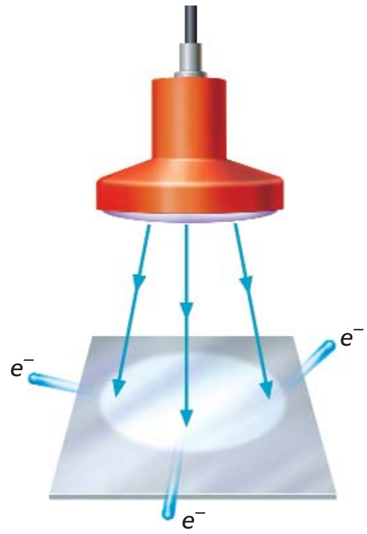
Figure 12-11



A Bright red light cannot knock electrons off this metal plate.



B Dim blue light can knock electrons off the plate. The wave model of light cannot explain this effect, but the particle model can.

photon a particle of light

Light can be modeled as a wave

Because the light in Young's experiment produced interference patterns, Young concluded that light must consist of waves. The model of light as a wave is still used today to explain many of the basic properties of light and its behavior.

Chapter 11 describes light waves as transverse waves that do not require a medium in which to travel. Light waves are also called electromagnetic waves because they consist of changing electric and magnetic fields, which will be discussed further in Chapter 13 and Chapter 14. The properties of transverse waves that you have already learned are all that you need to know to understand the wave model of light as it is used in this chapter.

The wave model of light explains much of the observed behavior of light. For example, light waves may reflect when they meet a mirror, refract when they pass through a lens, or diffract when they pass through a narrow opening.

The wave model of light cannot explain some observations

In the early part of the twentieth century, physicists began to realize that some observations could not be explained with the wave model of light. For example, when light strikes a piece of metal, electrons may fly off the metal's surface. Experiments show that in some cases, dim blue light may knock some electrons off a metal plate, while very bright red light cannot knock off any electrons, as shown in **Figure 12-11.**

According to the wave model, very bright red light should have more energy than dim blue light because the waves in bright light should have greater amplitude. But this does not explain how the blue light can knock electrons off the plate while the red light cannot.

Light can be modeled as a stream of particles

One way to explain the effects of light striking a metal plate is to assume that the energy of the light is contained in small packets. A packet of blue light carries more energy than a packet of red light, enough to knock an electron off the plate. Bright red light contains many packets, but no single one has enough energy to knock an electron off the plate.

In the particle model of light, these packets are called **photons,** and a beam of light is considered to be a stream of photons. Photons are considered particles, but they are not like ordinary particles of matter. Photons do not have mass; they are more like little bundles of energy. But unlike the energy in a wave, the energy in a photon is located in a particular place.

The model of light used depends on the situation

Light can be modeled as either waves or particles; so which explanation is correct? The success of any scientific theory depends on how well it can explain different observations. Some effects, such as the interference of light, are more easily explained with the wave model. Other cases, like light knocking electrons off a metal plate, are explained better by the particle model. The particle model also easily explains how light can travel across empty space without a medium.

Most scientists currently accept both the wave model and the particle model of light, and use one or the other depending on the situation that they are studying. Some believe that light has a “dual nature,” so that it actually has different characteristics depending on the situation. In many cases, using either the wave model or the particle model of light gives good results.

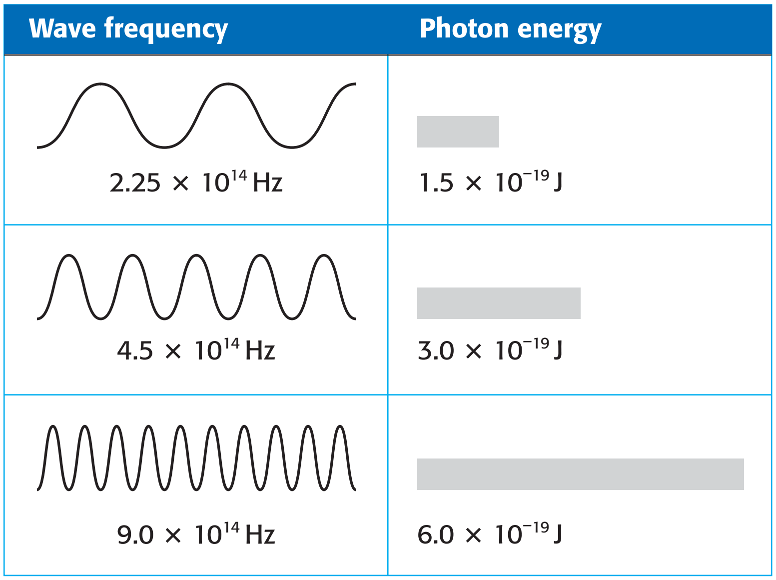


Figure 12-12
The energy of photons of light is related to the frequency of electromagnetic waves.

The energy of light is proportional to frequency

Whether modeled as a particle or as a wave, light is also a form of energy. Each photon of light can be thought of as carrying a small amount of energy. The amount of this energy is proportional to the frequency of the corresponding electromagnetic wave, as shown in **Figure 12-12.**

A photon of red light, for example, carries an amount of energy that corresponds to the frequency of waves in red light, 4.5×10^{14} Hz. A photon with twice as much energy corresponds to a wave with twice the frequency, which lies in the ultraviolet range of the electromagnetic spectrum. Likewise, a photon with half as much energy, which would be a photon of infrared light, corresponds to a wave with half the frequency.

The speed of light depends on the medium

In a vacuum, all light travels at the same speed, called *c*. The speed of light is very large, 3×10^8 m/s (about 186 000 mi/s). Light is the fastest signal in the universe. Nothing can travel faster than the speed of light.

Light also travels through transparent mediums, such as air, water, and glass. When light passes through a medium, it travels slower than it does in a vacuum. **Table 12-2** shows the speed of light in several different mediums.

Table 12-2 **Speed of Light in Various Mediums**

Medium	Speed of light ($\times 10^8$ m/s)
Vacuum	2.997925
Air	2.997047
Ice	2.29
Water	2.25
Quartz (SiO_2)	2.05
Glass	1.97
Diamond	1.24

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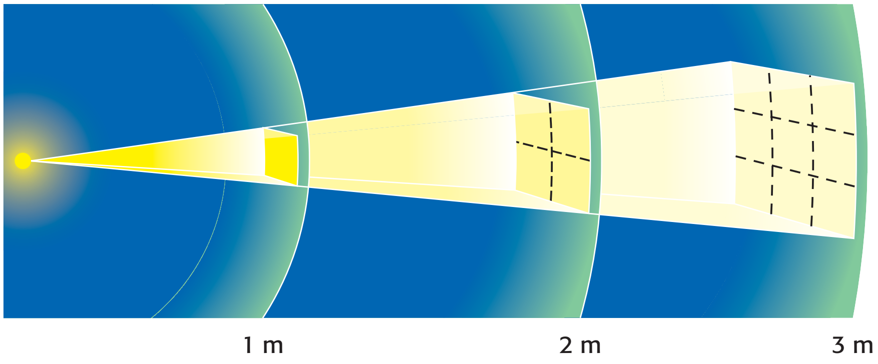

Figure 12-13
Less light falls on each unit square as the distance from the source increases.

intensity the rate at which light or any other form of energy flows through a given area of space

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SCILINKS NSTA

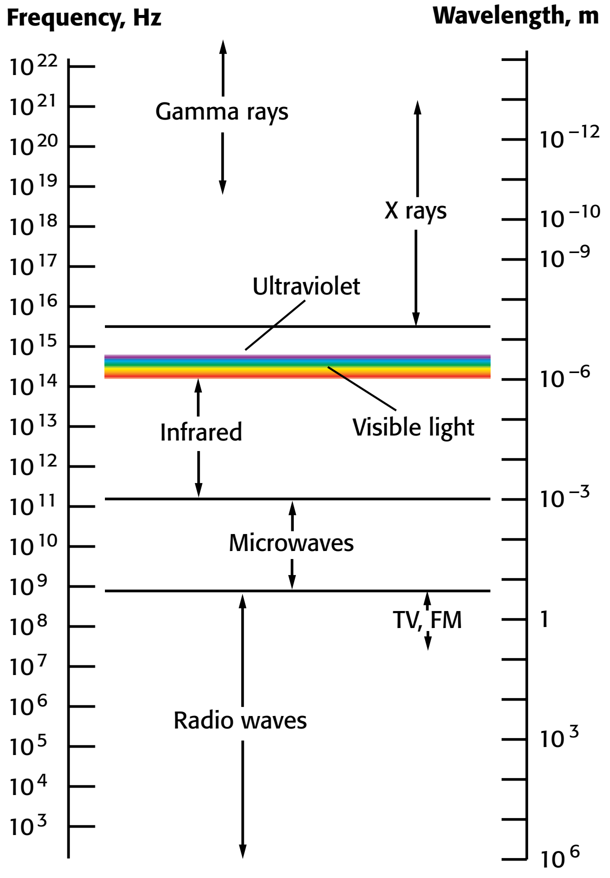
TOPIC: The electromagnetic spectrum
GO TO: www.scilinks.org
KEYWORD: HK1124

The brightness of light depends on intensity

You have probably noticed that it is easier to read near a lamp with a 100 W bulb than near a lamp with a 60 W bulb. That is because a 100 W bulb is brighter than a 60 W bulb. The quantity that measures the amount of light illuminating a surface is called **intensity,** and it depends on the amount of light—the number of photons or waves—that passes through a certain area of space.

Like the intensity of sound, the intensity of light from a light source decreases as the light spreads out in spherical wave fronts. Imagine a series of spheres centered around a source of light, as shown in **Figure 12-13.** As light spreads out from the source, the number of photons or waves passing through a given area on a sphere, say 1 cm^2, decreases. An observer farther from the light source will therefore see the light as dimmer than will an observer closer to the light source.

Figure 12-14
The electromagnetic spectrum includes all possible kinds of light.



The Electromagnetic Spectrum

Light fills the air and space around us. Our eyes can detect light waves ranging from 400 nm (violet light) to 700 nm (red light). But the visible spectrum is only one small part of the entire electromagnetic spectrum, shown in **Figure 12-14.** We live in a sea of electromagnetic waves, ranging from the sun's ultraviolet light to radio waves transmitted by television and radio stations.

The electromagnetic spectrum consists of light at all possible energies, frequencies, and wavelengths. Although all electromagnetic waves are similar in certain ways, each part of the electromagnetic spectrum also has unique properties. Many modern technologies, from radar guns to cancer treatments, take advantage of the different properties of electromagnetic waves.

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Sunlight contains ultraviolet light

The invisible light that lies just beyond violet light falls into the *ultraviolet* (UV) portion of the spectrum. Ultraviolet light has higher energy and shorter wavelengths than visible light does. Nine percent of the energy emitted by the sun is UV light. Because of its high energy, some UV light can pass through thin layers of clouds, causing you to sunburn even on overcast days.

X rays and gamma rays are used in medicine

Beyond the ultraviolet part of the spectrum lie waves known as *X rays,* which have even higher energy and shorter wavelengths than ultraviolet waves. X rays have wavelengths less than 10^{-8} m. The highest energy electromagnetic waves are gamma rays, which have wavelengths as short as 10^{-14} m.

An X-ray image at the doctor's office is made by passing X rays through the body. Most of them pass right through, but a few are absorbed by bones and other tissues. The X rays that pass through the body to a photographic plate produce an image such as the one in **Figure 12-15.**

X rays are useful tools for doctors, but they can also be dangerous. Both X rays and gamma rays have very high energies, so they may kill living cells or turn them into cancer cells. However, gamma rays can also be used to treat cancer by killing the diseased cells.

Figure 12-15
X-ray images are negatives. Dark areas show where the rays passed through, while bright areas show denser structures in the body.

REAL WORLD APPLICATIONS

Sun Protection Short-term exposure to UV light can cause sunburn; prolonged or repeated exposure may lead to skin cancer. To protect your skin, you should shield it from UV light whenever you are outdoors by covering your body with clothing, wearing a hat, and using a sunscreen.

Sunscreen products contain a chemical that blocks some or all UV light, preventing it from penetrating your skin. The Skin Protection Factor (SPF) of sunscreens varies as shown in the table at right.

Applying Knowledge

1. A friend is taking an antibiotic, and his doctor tells him to avoid UV light while on the medication. What SPF factor should he use, and why?
2. You and another friend decide to go hiking on a cloudy day. Your friend claims that she does not need any sunscreen because the sun is not out. What is wrong with her reasoning?

SPF factor	Effect on skin
None	Offers no protection from damage by UV
4 to 6	Offers some protection if you tan easily
7 to 8	Offers extra protection but still permits tanning
9 to 10	Offers excellent protection if you burn easily but would still like to get a bit of a tan
15	Offers total protection from burning
22	Totally blocks UV

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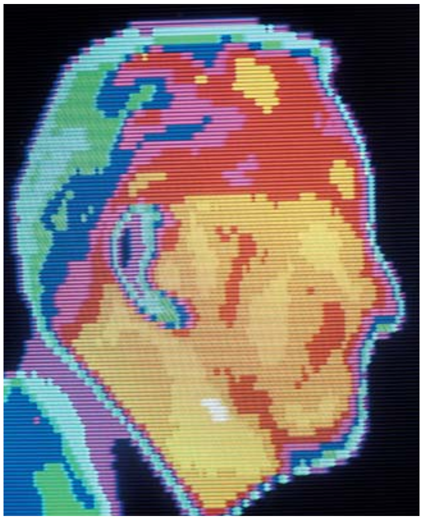

Figure 12-16
An infrared camera reveals the temperatures of different parts of an object.

Infrared light can be felt as warmth

Electromagnetic waves with wavelengths slightly longer than red light fall into the *infrared* (IR) portion of the spectrum. Infrared light from the sun, or from a heat lamp, warms you. Infrared light is used to keep food warm. You might have noticed reddish lamps above food in a cafeteria. The energy provided by the infrared light is just enough to keep the food hot without continuing to cook it.

Devices and photographic film that are sensitive to infrared light can reveal images of objects like the one in **Figure 12-16.** An infrared sensor can be used to measure the heat that objects radiate and then create images that show temperature variations. By detecting infrared radiation, areas of different temperature can be mapped. Remote sensors on weather satellites that record infrared light can track the movement of clouds and record temperature changes in the atmosphere.

Microwaves are used in cooking and communication

Electromagnetic waves with wavelengths in the range of centimeters, longer than infrared waves, are known as *microwaves.* The most familiar application of microwaves today is in cooking.

Microwave ovens in the United States use microwaves with a frequency of 2450 MHz (12.2 cm wavelength). Microwaves are reflected by metals and are easily transmitted through air, glass, paper, and plastic. However, water, fat, and sugar all absorb microwaves. Microwaves can travel about 3–5 cm into most foods.

As microwaves penetrate deeper into food, they are absorbed along with their energy. The rapidly changing electric field of the microwaves causes water and other molecules to vibrate. The energy of these vibrations is delivered to other parts of the food as energy is transferred by heat.

Microwaves are also used to carry telecommunication signals. Communication technologies using microwaves will be discussed in Chapter 15.

Did You Know?

Because microwaves reflect off the inside walls of a microwave oven, they may form standing waves. Food lying at the antinodes, where the vibrations are at a maximum, gets cooked more than food lying at the nodes, where there are no vibrations. For that reason, most microwave ovens rotate food items to ensure even heating.

Radio waves are used in communications and radar

Electromagnetic waves longer than microwaves are classified as *radio waves.* Radio waves have wavelengths that range from tenths of a meter to millions of meters. This portion of the electromagnetic spectrum includes TV signals, AM and FM radio signals, and other radio waves. The ways that these waves are used to transmit signals will be described in Chapter 15.

Air-traffic control towers at airports use **radar** to determine the locations of aircraft. Antennas at the control tower emit radio waves, or sometimes microwaves, out in all directions.

radar a system that uses reflected radio waves to determine the distance to, and location of, objects

VOCABULARY Skills Tip

Radar stands for **ra***dio* **d***etection* **a***nd* **r***anging.*

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When the signal reaches an airplane, a transmitter on the plane sends another radio signal back to the control tower. This signal gives the plane's location and elevation above the ground.

At shorter range, the original signal sent by the antenna may reflect off the plane and back to a receiver at the control tower. A computer then calculates the distance to the plane using the time delay between the original signal and the reflected signal. The locations of various aircraft around the airport are displayed on a screen like the one shown in **Figure 12-17.**

Figure 12-17
The radar system in an air traffic control tower uses reflected radio waves to monitor the location and speed of airplanes.

Radar is also used by police to monitor the speed of vehicles. A radar gun fires a radar signal of known frequency at a moving vehicle and then measures the frequency of the reflected waves. Because the vehicle is moving, the reflected waves will have a different frequency, according to the Doppler effect as described in Section 11.2. A computer chip converts the difference in frequency into a speed and shows the result on a digital display.

SECTION 12.2 REVIEW

SUMMARY

- Light can be modeled as electromagnetic waves or as a stream of particles called photons.
- The energy of a photon is proportional to the frequency of the corresponding light wave.
- The speed of light in a vacuum, *c*, is 3.0×10^8 m/s. Light travels more slowly in a medium.
- The electromagnetic spectrum includes light at all possible values of energy, frequency, and wavelength.

CHECK YOUR UNDERSTANDING

1. **State** one piece of evidence supporting the wave model of light and one piece of evidence supporting the particle model of light.
2. **Name** the regions of the electromagnetic spectrum from the shortest wavelengths to the longest wavelengths.
3. **Determine** which photons have greater energy, those associated with microwaves or those associated with visible light.
4. **Determine** which band of the electromagnetic spectrum has the following:
   - **a.** the lowest frequency
   - **b.** the shortest wavelength
   - **c.** the greatest energy
   - **d.** the least energy
5. **Critical Thinking** You and a friend are looking at the stars, and you notice two stars close together, one bright and one fairly dim. Your friend comments that the bright star must emit much more light than the dimmer star. Is he necessarily right? Explain your answer.

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12.3

Reflection and Color

KEY TERMS

light ray
virtual image
real image

OBJECTIVES

- Describe how light reflects off smooth and rough surfaces.
- Explain the law of reflection.
- Show how mirrors form real and virtual images.
- Explain why objects appear to be different colors.
- Describe how colors may be added or subtracted.

You may be used to thinking about light bulbs, candles, and the sun as objects that send light to your eyes. But everything else that you see, including this textbook, also sends light to your eyes. Otherwise, you would not be able to see them.

Of course, there is a difference between the light from the sun and the light from a book. The sun emits its own light. The light that comes from a book is created by the sun or a lamp, then bounces off the pages of the book to your eyes.

light ray a model of light that represents light traveling through space in an imaginary straight line

Reflection of Light

Every object reflects some light and absorbs some light. Mirrors, such as those on the solar collector in **Figure 12-18,** reflect almost all incoming light. Because mirrors reflect light, it is possible for you to see an image of yourself in a mirror.

Figure 12-18
This solar collector in the French Pyrenees uses mirrors to reflect and focus light into a huge furnace, which can reach temperatures of 3000°C.

Light can be modeled as a ray

To describe reflection, refraction, and many other effects of light at the scale of everyday experience, it is useful to use another model for light, the **light ray.** A light ray is an imaginary line running in the direction that the light travels. It is the same as the direction of wave travel in the wave model of light or the path of photons in the particle model of light.

Although they do not represent a full picture of the complex nature of light, light rays are a good approximation of light in many situations. The study of light in circumstances where it behaves like a ray makes up the science of *geometrical optics.* Using light rays, the path of light can be traced in geometrical drawings called ray diagrams.

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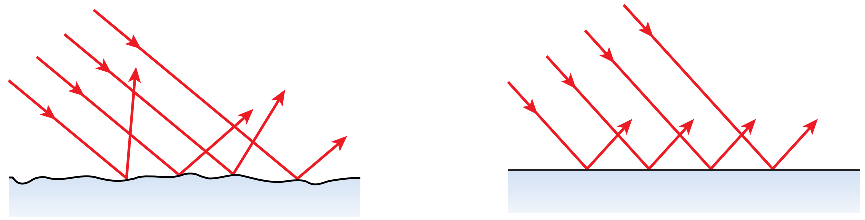
Figure 12-19



A Light rays reflected from a rough surface are reflected in many directions.

B Light rays reflected from a smooth surface are reflected in the same direction.

Rough surfaces reflect light rays in many directions

Many of the surfaces that we see every day, such as paper, wood, cloth, and skin, reflect light but do not appear shiny. When a beam of light is reflected, the path of each light ray in the beam changes from its initial direction to another direction. If a surface is rough, light striking the surface will be reflected at all angles, as shown in **Figure 12-19A.** Such reflection of light into random directions is called *diffuse reflection*.

Smooth surfaces reflect light rays in one direction

When light hits a smooth surface, such as a polished mirror, it does not reflect diffusely. Instead, all the light hitting a mirror from one direction is reflected together into a single new direction, as shown in **Figure 12-19B.**

The new direction of the light rays is related to the old direction in a definite way. The angle of the light rays reflecting off the surface, called the *angle of reflection,* is the same as the angle of the light rays striking the surface, called the *angle of incidence*. This is called the *law of reflection*.

The angle of incidence equals the angle of reflection.

Both of these angles are measured from a line perpendicular to the surface at the point where the light hits the mirror. This line is called the *normal*. **Figure 12-20** is a ray diagram that illustrates the law of reflection.

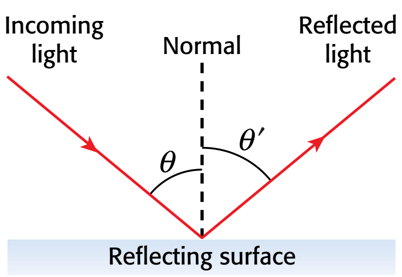


Figure 12-20
When light hits a smooth surface, the angle of incidence (θ) equals the angle of reflection (θ′).

INTEGRATING

SPACE SCIENCE

There are two primary types of telescopes, refracting and reflecting. Refracting telescopes use glass lenses to focus light into an image at the eyepiece; reflecting telescopes use curved mirrors to focus light.

The lens of a refracting telescope cannot be very large, because the weight of the glass would cause the lens to bend out of shape. Curved mirrors are thinner and lighter than lenses, so they are stable at larger diameters.

The largest refracting telescope, at the Yerkes Observatory in Wisconson, has a lens that is 1 m in diameter. The Mauna Kea Observatory in Hawaii houses four of the largest reflecting telescopes. Two of them have single mirrors that are over 8 m in diameter, and two use multiple mirrors for a total diameter of 10 m.

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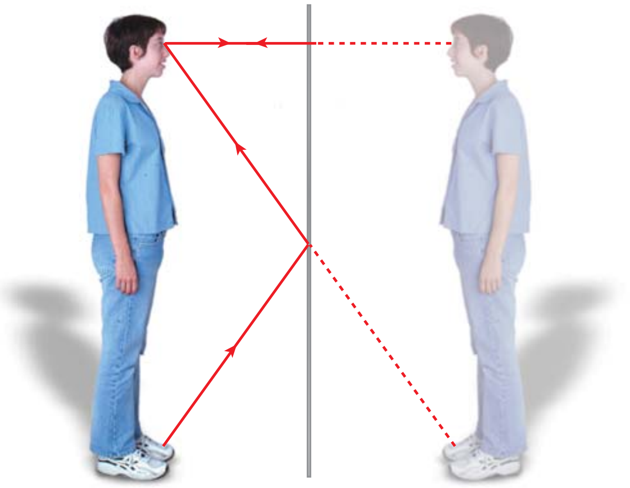
Figure 12-21

A A virtual image appears behind a flat mirror.



B A ray diagram shows where the light actually travels as well as where you perceive that it has come from.

Mirrors

When you look into a mirror, you see an image of yourself behind the mirror, as in **Figure 12-21A.** It is like seeing a twin or copy of yourself standing on the other side of the glass, although flipped from left to right. You also see a whole room, a whole world of space beyond the mirror, even if the mirror is placed against a wall. How is this possible?

Flat mirrors form virtual images by reflection

The ray diagram in **Figure 12-21B** shows the path of light rays striking a flat mirror. When a light ray is reflected by a flat mirror, the angle it is reflected is equal to the angle of incidence, as described by the law of reflection. Some of the light rays reflect off the mirror into your eyes.

However, your eyes do not know where the light rays have been. They simply sense light coming from certain directions, and your brain interprets the light as if it traveled in straight lines from an object to your eyes. As a result, you perceive an image of yourself behind the mirror.

Of course, there is not really a copy of yourself behind the mirror. If someone else looked behind the mirror, they would not see you, an image, or any source of light. The image that you see results from the apparent path of the light rays, not an actual path. An image of this type is called a **virtual image.** The virtual image appears to be as far behind the mirror as you are in front of the mirror.

virtual image an image that forms at a point from which light rays appear to come but do not actually come

Curved mirrors can distort images

If you have ever been to the "fun house" at a carnival, you may have seen a curved mirror like the one in **Figure 12-22.** Your image in a curved mirror does not look exactly like you. Parts of the image may be spread out, making you look wide or tall. Other parts may be compressed, making you look thin or short. How does such a mirror work?

Curved mirrors still create images by reflecting light according to the law of reflection. But because the surface is not flat, the line perpendicular to the mirror (the normal) points in different directions for different parts of the mirror.

Where the mirror bulges out, two light rays that start out parallel are reflected into different directions, making an image that is stretched out. Mirrors that bulge out are called *convex mirrors*.

Similarly, parts of the mirror that are indented reflect two parallel rays in toward one another, making an image that is compressed. Indented mirrors are called *concave mirrors*.

Figure 12-22
A curved mirror produces a distorted image.

Concave mirrors create real images

Concave mirrors are used to focus reflected light. A concave mirror can form one of two kinds of images. It may form a virtual image behind the mirror or a **real image** in front of the mirror. A real image results when light rays from an object are focused onto a single point or small area.

real image an image of an object formed by many light rays coming together in a specific location

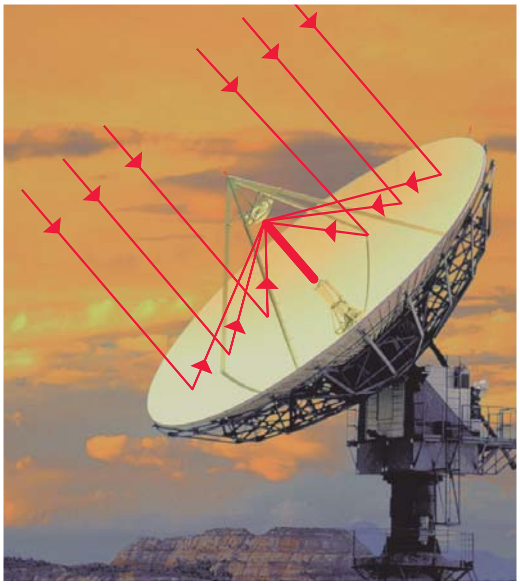
If a piece of paper is placed at the point where the light rays come together, the real image appears on the paper. If you tried this with a virtual image, say by placing a piece of paper behind a mirror, you would not see the image on the paper. That is the primary difference between a real and a virtual image. With a real image, light rays really exist at the point where the image appears; a virtual image appears to exist in a certain place, but there are no light rays there.

Telescopes use curved surfaces to focus light

Many reflecting telescopes use curved mirrors to reflect and focus light from distant stars and planets. Radio telescopes, such as the one in **Figure 12-23,** gather radio waves from extremely distant objects, such as galaxies and quasars.

Because radio waves reflect off almost any solid surface, these telescopes do not need to use mirrors. Instead, parallel radio waves bounce off a curved dish, which focuses the waves onto another, smaller curved surface poised above the dish. The waves are then directed into a receiver at the center of the dish.

Figure 12-23
A radio telescope dish reflects and focuses radio waves into the receiver at the center of the dish.



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Seeing Colors

As you learned in Chapter 11, the different wavelengths of visible light correspond to the colors that you perceive. When you see light with a wavelength of about 550 nm, your brain interprets it as *green*. If the light comes from the direction of a leaf, then you may think, “That leaf is green.”

A leaf does not emit light on its own; in the darkness of night, you may not be able to see the leaf at all. So where does the green light come from?

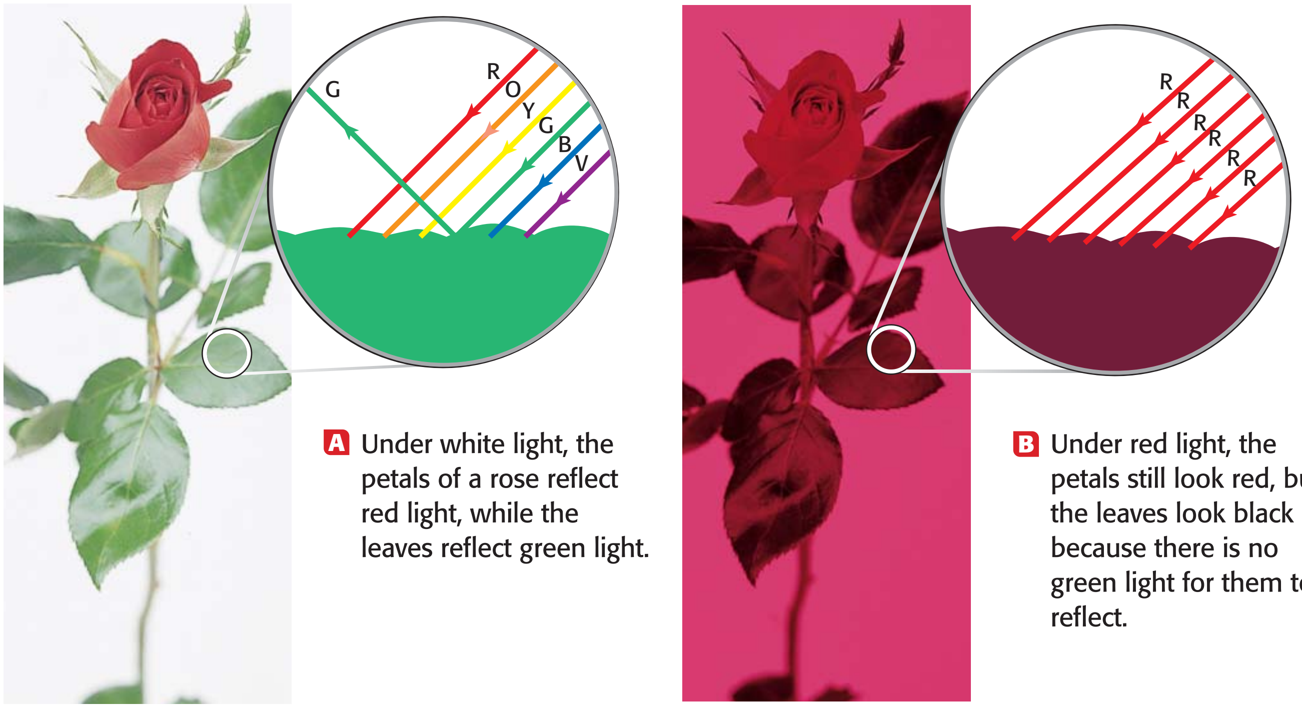
Objects have color because they reflect certain wavelengths of light

If you pass the light from the sun through a prism, the prism separates the light into a rainbow of colors. White light from the sun actually contains light from all the visible wavelengths of the electromagnetic spectrum.

When white light strikes a leaf, as shown in **Figure 12-24A,** the leaf reflects light with a wavelength of about 550 nm, corresponding to the color green. The leaf absorbs light at other wavelengths. When the light reflected from the leaf enters your eyes, your brain interprets it as *green*.

Likewise, the petals of a rose reflect red light and absorb other colors, so the petals appear to be red. If you view a rose and its leaves under red light, as shown in **Figure 12-24B,** the petals will still appear red but the leaves will appear black. Why?

Figure 12-24
A Rose in White and Red Light



A Under white light, the petals of a rose reflect red light, while the leaves reflect green light.

B Under red light, the petals still look red, but the leaves look black because there is no green light for them to reflect.

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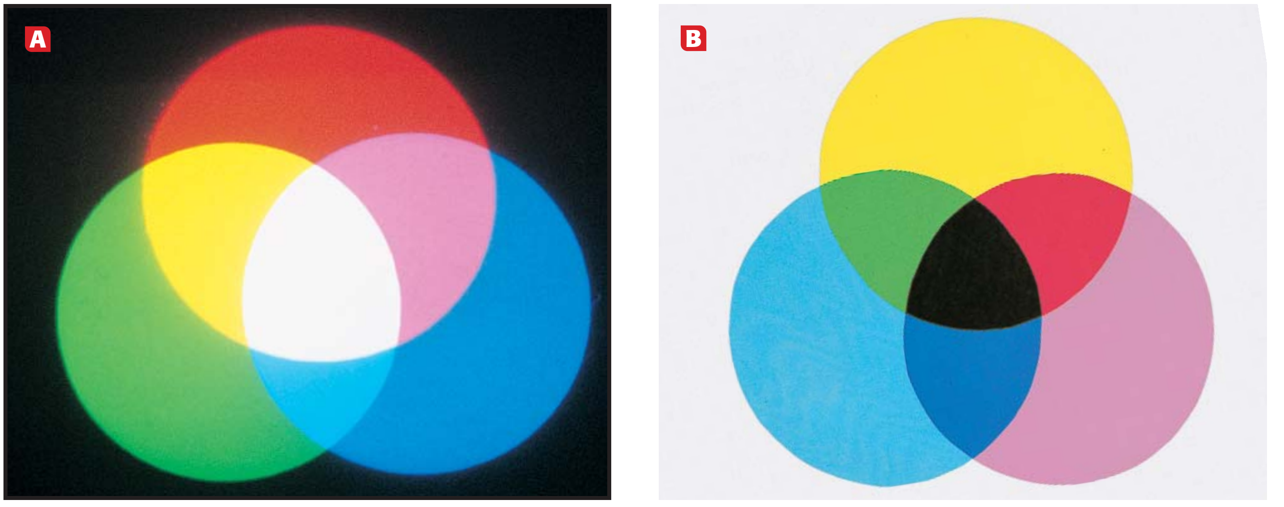


Figure 12-25
(A) Red, green, and blue lights can combine to produce yellow, magenta, cyan, or white.
(B) Yellow, magenta, and cyan filters can be combined to produce red, green, blue, or black.

Colors may add or subtract to produce other colors

Televisions and computer monitors display many different colors by combining light of the *additive primary colors,* red, green, and blue. Adding light of two of these colors together can produce the secondary colors yellow, cyan, and magenta, as shown in **Figure 12-25A.** Mixing all three additive primary colors makes white.

In the reverse process, pigments, paints, or filters of the *subtractive primary colors,* yellow, cyan, and magenta, can be combined to create red, green, and blue as shown in **Figure 12-25B.** If filters or pigments of all three colors are combined in equal proportions, all the light is absorbed, leaving black. Black is not really a color at all; it is the absence of color.

SECTION 12.3 REVIEW

SUMMARY

- Light is reflected when it strikes a boundary between two different mediums.
- When light reflects off a surface, the angle of reflection equals the angle of incidence.
- Mirrors form images according to the law of reflection.
- The color of an object depends on the wavelengths of light that the object reflects.

CHECK YOUR UNDERSTANDING

1. **List** three examples of the diffuse reflection of light.
2. **Describe** the law of reflection in your own words.
3. **Draw** a diagram to illustrate the law of reflection.
4. **Discuss** how a plane mirror forms a virtual image.
5. **Discuss** the difference, in terms of reflection, between objects that appear blue and objects that appear yellow.
6. **Explain** why a plant may look green in sunlight but black under red light.
7. **Critical Thinking** A friend says that only mirrors and other shiny surfaces reflect light. Explain what is wrong with this reasoning.
8. **Creative Thinking** A convex mirror can be used to see around a corner at the intersection of hallways. Draw a simple ray diagram illustrating how this works.

12.4

Refraction, Lenses, and Prisms

KEY TERMS
total internal reflection
lens
magnification
prism
dispersion

OBJECTIVES
- Describe how light is refracted as it passes between mediums.
- Explain how fiber optics use total internal reflection.
- Explain how converging and diverging lenses work.
- Describe the function of the eye.
- Describe how prisms disperse light and how rainbows form.

Light travels in a straight line through empty space. But in our everyday experience, we encounter light passing through various mediums, such as the air, windows, a glass of water, or a pair of eyeglasses. Under these circumstances, the direction of a light wave may be changed by refraction.

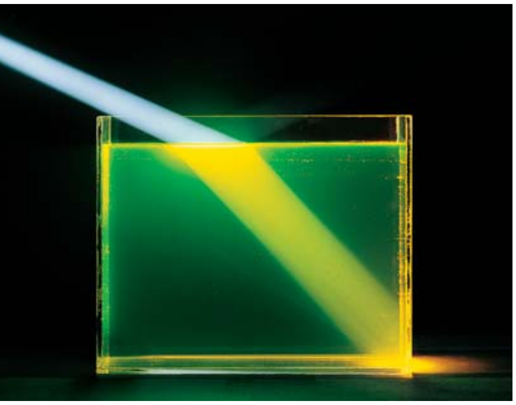


Figure 12-26
Light refracts when it passes from one medium into another.

Refraction of Light

In Chapter 11, you learned that waves bend when they pass from one medium to another. If light travels from one transparent medium to another at any angle other than straight on, the light changes direction when it meets the boundary, as shown in **Figure 12-26.** Light bends when it changes mediums because the speed of light is different in each medium.

Imagine pushing a lawn mower at an angle from a sidewalk onto grass, as in **Figure 12-27.** The wheel that enters the grass first will slow down due to friction. If you keep pushing on the lawn mower, the wheel on the grass will act like a moving pivot, and the lawn mower will turn to a different angle.

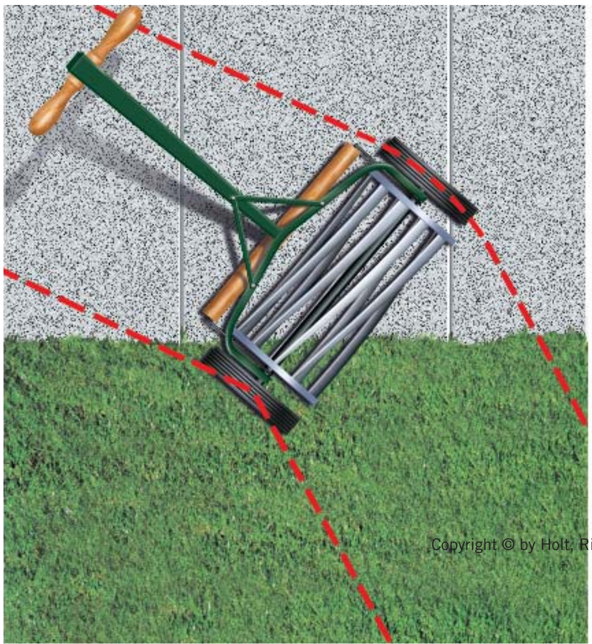


Figure 12-27
This lawn mower changes direction as it passes from the sidewalk onto the grass.

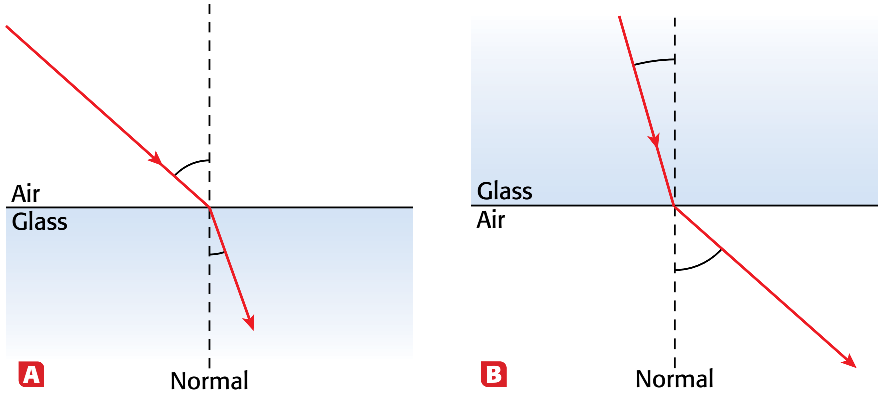


Figure 12-28
(A) When the light ray moves from air into glass, its path is bent toward the normal.
(B) When the light ray passes from glass into air, its path is bent away from the normal.

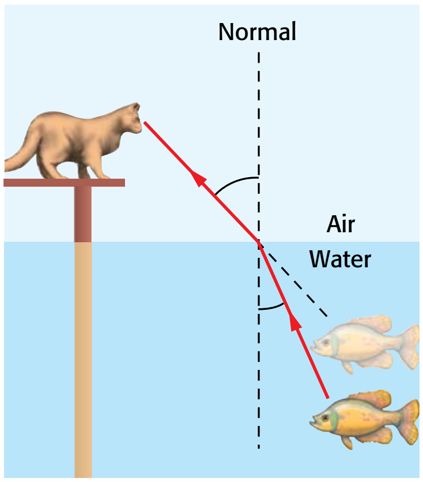
When light moves from a material in which its speed is higher to a material in which its speed is lower, such as from air to glass, the ray is bent toward the normal, as shown in **Figure 12-28A.** This is like the lawnmower moving from the sidewalk onto the grass. If light moves from a material in which its speed is lower to one in which its speed is higher, the ray is bent away from the normal, as shown in **Figure 12-28B.**

Refraction makes objects appear to be in different positions

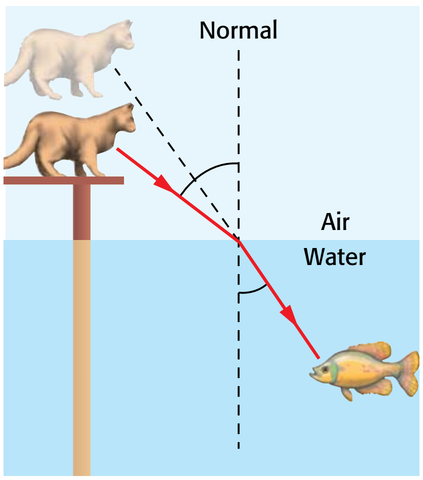
When a cat looks at a fish underwater, the cat perceives the fish as closer than it actually is, as shown in the ray diagram in **Figure 12-29A.** On the other hand, when the fish looks at the cat above the surface, the fish perceives the cat as farther than it really is, as shown in **Figure 12-29B.**

The misplaced images that the cat and the fish see are virtual images like the images that form behind a mirror. The light rays that pass from the fish to the cat bend away from the normal when they pass from water to air. But the cat's brain doesn't know that. It interprets the light as if it traveled in a straight line, and sees a virtual image. Similarly, the light from the cat to the fish bends toward the normal, again causing the fish to see a virtual image.

Figure 12-29



A To the cat on the pier, the fish appears to be closer than it really is.



B To the fish, the cat seems to be farther from the surface than it actually is.

Refraction in the atmosphere creates mirages

Have you ever been on a straight road on a hot, dry summer day and seen what looks like water on the road? If so, then you may have seen a *mirage*. A mirage is a virtual image caused by refraction of light in the atmosphere.

Light travels at slightly different speeds in air of different temperatures. Therefore, when light from the sky passes into the layer of hot air just above the asphalt on a road, it refracts, bending upward away from the road. Because you see an image of the sky coming from the direction of the road, your mind may assume that there is water on the road causing a reflection.

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Figure 12-30
The refraction or internal reflection of light depends on the angle at which light rays meet the boundary between mediums.

Light can be reflected at the boundary between two transparent mediums

Figure 12-30 shows four different beams of light approaching a boundary between air and water. Three of the beams are refracted as they pass from one medium to the other. The fourth beam is reflected back into the water.

If the angle at which light rays meet the boundary between two mediums becomes large enough, the rays will be reflected as if the boundary were a mirror. This angle is called the *critical angle,* and this type of reflection is called **total internal reflection.**

total internal reflection
the complete reflection of light at the boundary between two transparent mediums when the angle of incidence exceeds the critical angle

Fiber optics use total internal reflection

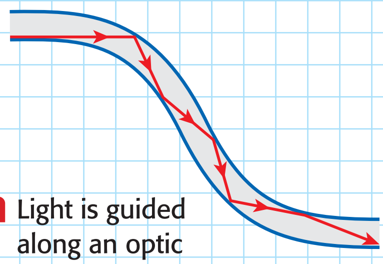
Fiber-optic cables are made by fusing bundles of transparent fibers together, as shown in **Figure 12-31A.** Light inside a fiber in a fiber-optic cable bounces off of the walls of the fiber due to total internal reflection, as shown in **Figure 12-31B.**

If the fibers are arranged in the same pattern at both ends of the cable, the light that enters one end can produce a clear image at the other end. Fiber-optic cables of that sort are used to produce images of internal organs during surgical procedures.

Because fiber-optic cables can carry many different frequencies at once, they transmit computer data or signals for telephone calls more efficiently than standard metal wires. Fiber-optic communications will be discussed further in Chapter 15.

Figure 12-31

A A fiber optic cable consists of several glass or plastic fibers bundled together.



B Light is guided along an optic fiber by multiple internal reflections.

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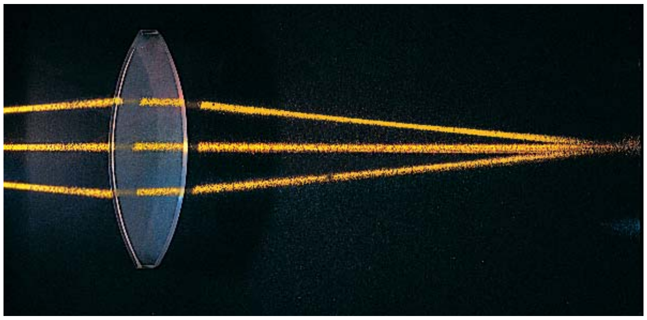
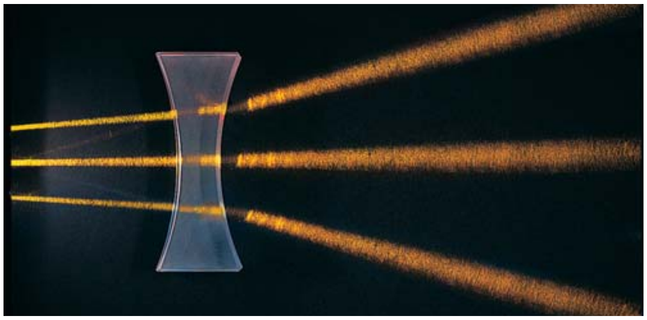
Figure 12-32



A When rays of light pass through a converging lens (thicker at the middle), they are bent inward.



B When they pass through a diverging lens (thicker at the ends), they are bent outward.

Lenses

You are probably already very familiar with one common application of the refraction of light: lenses. From cameras to microscopes, eyeglasses to the human eye, lenses change the way we see the world.

Lenses rely on refraction

Light traveling at an angle through a flat piece of glass is refracted twice—once when it enters the glass and again when it reenters the air. The light ray that exits the glass is still parallel to the original light ray, but it has shifted to one side.

On the other hand, when light passes through a curved piece of glass, a **lens,** there is a change in the direction of the light rays. This is because each light ray strikes the surface of a curved object at a slightly different angle.

A *converging lens,* as shown in **Figure 12-32A,** bends light inward. A lens that bends light outward is a *diverging lens,* as shown in **Figure 12-32B.**

A converging lens can create either a virtual image or a real image, depending on the distance from the lens to the object. A diverging lens, however, can only create a virtual image.

lens a transparent object that refracts light rays, causing them to converge or diverge to create an image

magnification a change in the size of an image compared with the size of an object

Lenses can magnify images

A magnifying glass is a familiar example of a converging lens. A magnifying glass reveals details that you would not normally be able to see, such as the pistils of the flower in **Figure 12-33.** The large image of the flower that you see through the lens is a virtual image. **Magnification** is any change in the size of an image compared with the size of the object. Magnification usually produces an image larger than the object, but not always.

Figure 12-33
A magnifying glass makes a large virtual image of a small object.

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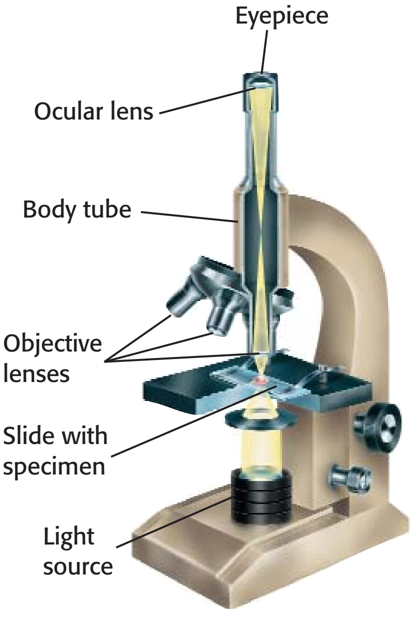


Figure 12-34
A compound microscope uses several lens to produce a highly magnified image.

If you hold a magnifying glass over a piece of paper in bright sunlight, you can see a real image of the sun on the paper. By adjusting the height of the lens above the paper, you can focus the light rays together into a small area or a point, called the *focal point*. At the focal point, the image of the sun may contain enough energy to set the paper on fire.

Microscopes and refracting telescopes use multiple lenses

A compound microscope uses multiple lenses to provide greater magnification than a magnifying glass. **Figure 12-34** illustrates a basic compound microscope. The objective lens first forms a large real image of the object. The eyepiece then acts like a magnifying glass and creates an even larger virtual image that you see when you peer through the microscope.

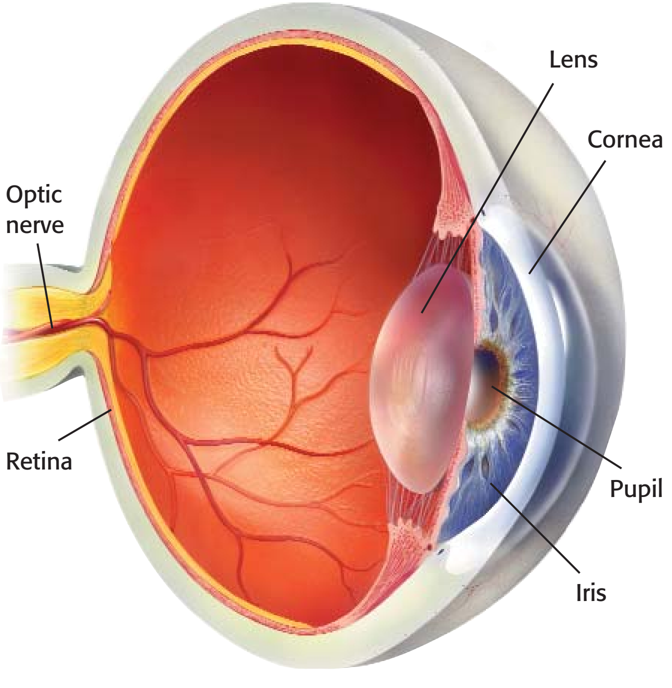
Section 12.3 explained how reflecting telescopes use curved mirrors to create images of distant objects such as planets and galaxies. Refracting telescopes work more like a microscope, focusing light through several lenses. Light first passes through a large lens at the top of the telescope, then through another lens at the eyepiece. The eyepiece focuses an image onto your eye.

The eye depends on refraction and lenses

The refraction of light by lenses is not just used in microscopes and telescopes. Without refraction, you could not see at all.

The operation of the human eye, shown in **Figure 12-35,** is in many ways similar to that of a simple camera. Light enters a camera through a large lens, which focuses the light into an image on the film at the back of the camera.

Figure 12-35
The cornea and lens refract light onto the retina at the back of the eye.



Light first enters the eye through a transparent tissue called the cornea. The cornea is responsible for 70 percent of the refraction of light in the eye. After the cornea, light passes through the pupil, a hole in the colorful iris.

From there, light travels through the lens, which is composed of glassy fibers situated behind the iris. The curvature of the lens determines how much further the lens refracts light. Muscles can adjust the curvature of the lens until an image is focused on the back layer of the eye, the retina.

The retina is composed of tiny structures, called rods and cones, that are sensitive to light. When light strikes the rods and cones, signals are sent to the brain where they are interpreted as images.

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Cones are concentrated in the center of the retina, while rods are mostly located on the outer edges. The cones are responsible for color vision, but they only respond to bright light. That is why you cannot see color in very dim light. The rods are more sensitive to dim light, but cannot resolve details very well. That is why you can glimpse faint movements or see very dim stars out of the corners of your eyes.

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SCILINKS NSTA

TOPIC: Refraction
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KEYWORD: HK1126

Dispersion and Prisms

A **prism,** like the one in **Figure 12-36,** can separate white light into its component colors. Water droplets in the air can also do this, producing a rainbow. But why does the light separate into different colors?

prism a transparent block with a triangular cross section

Different colors of light are refracted differently

In Chapter 11, you learned that all waves travel the same speed in a given medium. That is true for mechanical waves, but not for electromagnetic waves. Light waves at different wavelengths travel at different speeds in a given medium. In the visible spectrum, violet light travels the slowest and red light travels the fastest.

Because violet light travels slower than red light, violet light refracts more than red light when it passes from one medium to another. When white light passes from air to the glass in the prism, violet bends the most, red the least, and the rest of the visible spectrum appears in between. This effect, in which light separates into different colors because of differences in wave speed, is called **dispersion.**

dispersion an effect in which white light separates into its component colors

Figure 12-36
A prism separates white light into its component colors. Notice that violet light is bent more than red light.

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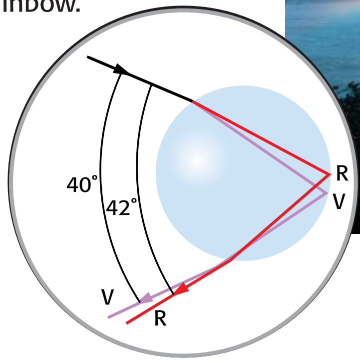
Figure 12-37
Sunlight is dispersed and internally reflected by water droplets to form a rainbow.



Rainbows are caused by dispersion and internal reflection

Rainbows, like the one in **Figure 12-37,** may form any time there is water in the air. When sunlight strikes a droplet of water, the light is dispersed into different colors as it passes from the air into the water. Some of the light then reflects off the back surface of the droplet by total internal reflection. The light disperses further when it passes out of the water back into the air.

When light finally leaves the droplet, violet light emerges at an angle of 40 degrees, red light at 42 degrees, with the other colors in between. We see light from many droplets as arcs of color, forming a rainbow. Red light comes from droplets higher in the air and violet light comes from lower droplets.

SECTION 12.4 REVIEW

SUMMARY

- Light may refract when it passes from one medium to another.
- Light rays may also be reflected at a boundary between mediums.
- Lenses form real or virtual images by refraction.
- Converging lenses cause light rays to converge to a point. Diverging lenses cause light rays to spread apart, or diverge.
- A prism disperses white light into a color spectrum.

CHECK YOUR UNDERSTANDING

1. **Explain** why a lawn mower turns when pushed at an angle from a sidewalk onto the grass.
2. **Draw** a ray diagram showing the path of light when it travels from air into glass.
3. **Explain** how light can bend around corners inside an optical fiber.
4. **Explain** how a simple magnifying glass works.
5. **Describe** the path of light from the time it enters the eye to the time it reaches the retina.
6. **Critical Thinking** Which color of visible light travels the slowest through a glass prism?
7. **Critical Thinking** A spoon partially immersed in a glass of water may appear to be in two pieces. Is the image of the spoon in the water a real image or a virtual image?
8. **Creative Thinking** If light traveled at the same speed in raindrops as it does in air, could rainbows exist? Explain.

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CHAPTER 12 REVIEW

Chapter Highlights

Before you begin, review the summaries of the key ideas of each section, found on pages 398, 405, 411, and 418. The key vocabulary terms are listed on pages 390, 399, 406, and 412.

UNDERSTANDING CONCEPTS

1. All sound waves are __________.
- **a.** longitudinal waves
- **b.** transverse waves
- **c.** electromagnetic waves
- **d.** standing waves

2. The speed of sound depends on ________.
- **a.** the temperature of the medium
- **b.** the density of the medium
- **c.** how well the particles of the medium transfer energy
- **d.** All of the above

3. A sonar device can use the echoes of ultrasound underwater to find the ________.
- **a.** speed of sound
- **b.** depth of the water
- **c.** temperature of the water
- **d.** height of waves on the surface

4. During a thunderstorm, you see lightning before you hear thunder because ________.
- **a.** the thunder occurs after the lightning
- **b.** the thunder is farther away than the lightning
- **c.** sound travels faster than light
- **d.** light travels faster than sound

5. The speed of light __________.
- **a.** depends on the medium
- **b.** is fastest in a vacuum
- **c.** is the fastest speed in the universe
- **d.** All of the above

6. Which of the following forms of light has the most energy?
- **a.** X rays
- **b.** microwaves
- **c.** infrared light
- **d.** ultraviolet light

7. Light can be modeled as _________.
- **a.** electromagnetic waves
- **b.** a stream of particles called photons
- **c.** rays that travel in straight lines
- **d.** All of the above

8. The energy of light is proportional to ____.
- **a.** amplitude
- **b.** wavelength
- **c.** frequency
- **d.** the speed of light

9. A flat mirror forms an image that is _____.
- **a.** smaller than the object
- **b.** larger than the object
- **c.** virtual
- **d.** real

10. Which of the following wavelengths of visible light bends the most when passing through a prism?
- **a.** red
- **b.** yellow
- **c.** green
- **d.** blue

Using Vocabulary

11. How is the loudness of a sound related to *amplitude* and *intensity*?

12. How is *pitch* related to *frequency*?

13. Explain how a guitar produces sound. Use the following terms in your answer: *standing waves, resonance.*

14. Why does a clarinet sound different from a tuning fork, even when played at the same pitch? Use these terms in your answer: *fundamental frequency, harmonics.*

15. Explain the difference between a *virtual image* and a *real image*. Give an example of each type of image.

16. Explain why a leaf may appear green in white light but black in red light. Use the following terms in your answer: *wavelength, reflection.*

17. What is the difference between a *converging lens* and a *diverging lens*?

18. Sketch the path of a white *light ray* into a water droplet that is forming a rainbow and indicate where the light is (a) *refracted,* (b) *internally reflected,* and (c) *dispersed.*

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CHAPTER 12 REVIEW

BUILDING MATH SKILLS

You may use the following for items 19–23:

- the wave speed equation from Section 11.2, $v = f \times \lambda$
- a rearranged form of the speed equation from Section 8.1, $d = vt$
- the average speed of sound in water or soft tissue, 1500 m/s
- the speed of light, 3.0×10^8 m/s

19. Sound Waves Calculate the wavelength of ultrasound used in medical imaging if the frequency is 15 MHz.

20. Sonar Calculate the distance to the bottom of a lake when a ship using sonar receives the reflection of a pulse in 0.055 s.

21. Graphing As a ship travels across a lake, a sonar device on the ship sends out pulses of ultrasound and detects the reflected pulses. The table below gives the ship's distance from the shore and the time for each pulse to return to the ship. Construct a graph of the depth of the lake as a function of distance from the shore.

Distance from shore (m)	Time to receive pulse ($\times 10^{-2}$ s)
100	1.7
120	2.0
140	2.6
150	3.1
170	3.2
200	4.1
220	3.7
250	4.4
270	5.0
300	4.6

22. Electromagnetic Waves Calculate the wavelength of radio waves from an AM radio station broadcasting at 1200 kHz.

23. Electromagnetic Waves Waves composing green light have a wavelength of about 550 nm. What is their frequency?

THINKING CRITICALLY

24. Interpreting Graphics Review the chart on page 393 that illustrates ranges of frequencies of sounds that different animals can hear. Which animal on the chart can hear sounds with the highest pitch?

25. Aquiring and Evaluating Data A guitar has six strings, each tuned to a different pitch. Research what pitches the strings are normally tuned to and what frequencies correspond to each pitch. Then calculate the wavelength of the sound waves that each string produces. Assume the speed of sound in air is 340 m/s.

26. Creative Thinking Imagine laying this page flat on a table, then standing a mirror upright at the top of the page. Using the law of reflection, draw the image of each of the following letters of the alphabet in the mirror.

A B C F W T

27. Understanding Systems The glass in greenhouses is transparent to certain wavelengths and opaque to others. Research this type of glass, and write a paragraph explaining why it is an ideal material for greenhouses.

WRITING SKILL

28. Applying Knowledge Why is white light not dispersed into a spectrum when it passes through a flat pane of glass like a window?

DEVELOPING LIFE/WORK SKILLS

29. Teaching Others Your aunt is scheduled for an ultrasound examination of her gall bladder and she is worried that it will be painful. All she knows is that the examination has something to do with sound. How would you explain the procedure to her?

30. Applying Technology Meteorologists use Doppler radar to measure the speed of approaching storms and the velocity of the swirling air in tornadoes. Research this application of radar, and write a short paragraph describing how it works.

WRITING SKILL

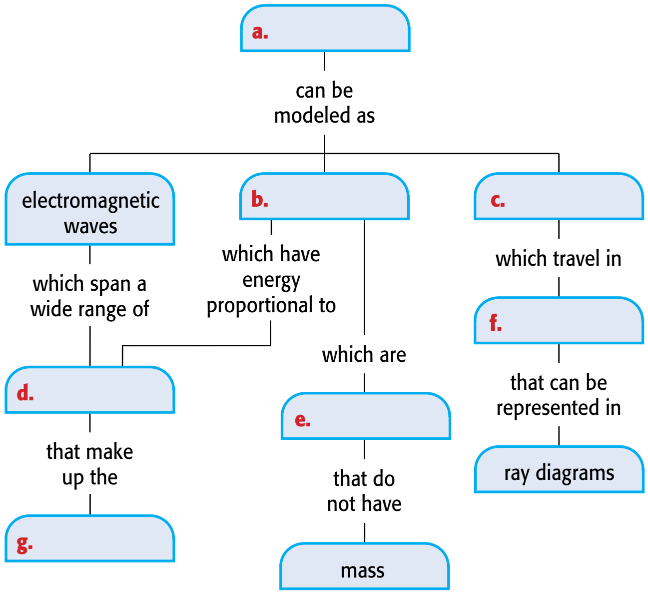
INTEGRATING CONCEPTS

31. Connection to Earth Science Landsat satellites are remote sensing satellites that can detect electromagnetic waves at a variety of wavelengths to reveal hidden features on Earth. Research the use of Landsat satellites to view Earth's surface. What kind of electromagnetic waves are detected? What features do Landsat images reveal that cannot be seen with visible light?

32. Connection to Health Research the effect of UV light on skin. Are all wavelengths of UV light harmful to your skin? What problems can too much exposure to UV light cause? Is UV light also harmful to your eyes? If so, how can you protect your eyes?

33. Connection to Biology While most people can see all the colors of the spectrum, people with *colorblindness* are unable to see at least one of the primary colors. What part of the eye do you think is malfunctioning in colorblind people?

34. Concept Mapping Copy the unfinished concept map below onto a sheet of paper. Complete the map by writing the correct word or phrase in the lettered boxes.



35. Connection to Fine Arts Describe how you can make red, green, blue, and black paint with a paint set containing only yellow, magenta, and cyan paint.

36. Connection to Space Science Telescopes can produce images in several different regions of the electromagnetic spectrum. Research photos of areas of the galaxy taken with infrared light, microwaves, and radio waves. What features are revealed by infrared light that are hidden in visible light? What kinds of objects are often studied with radio telescopes?

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TOPIC: Ultrasound
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Skill Builder Lab

Forming Images with Lenses

Introduction

How can you find the focal length of a lens and verify the value?

Objectives

- ***Observe*** images formed by a convex lens.
- ***Measure*** the distance of objects and images from the lens.
- ***Analyze*** the data to determine the focal length of the lens.

Materials

cardboard screen 10 × 20 cm
screen holder
meterstick
supports for meterstick
lens holder
convex lens, 10 cm to 15 cm focal length
light box with light bulb

Safety Needs

safety goggles

Preparing for Your Experiment

1. The shape of a lens determines the size, position, and types of images that it may form. When parallel rays of light from a distant object pass through a converging lens, they come together to form an image at a point called the focal point. The distance from this point to the lens is called the focal length. In this experiment, you will find the focal length of a lens, and then verify this value by forming images, measuring distances, and using the lens formula shown below.

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

where d_o = *object distance,*
d_i = *image distance, and*
f = *focal length.*

2. On a clean sheet of paper, make a table like the one shown at right.
3. Set up the equipment as illustrated in the figure below. Make sure the lens and screen are securely fastened to the meterstick.

Determining Focal Length

4. Stand about 1 m from a window, and point the meterstick at a tree, parked car, or similar object. Slide the screen holder along the meterstick until a clear image of the distant object forms on the screen. Measure the distance between the lens and the screen in centimeters. This distance is very close to the focal length of the lens you are using. Record this value at the top of your data table.

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Focal length of lens, f: ______ cm	Object distance, d_o (cm)	Image distance, d_i (cm)	$\frac{1}{d_o}$	$\frac{1}{d_i}$	$\frac{1}{d_o} + \frac{1}{d_i}$	$\frac{1}{f}$	Size of object (mm)	Size of image (mm)
Trial 1								
Trial 2								
Trial 3								

Forming Images

5. Set up the equipment as illustrated in the figure at right. Again, make sure that all components are securely fastened.
6. Place the lens more than twice the focal length from the light box. For example, if the lens has a focal length of 10 cm, place the lens 25 or 30 cm from the light.

7. Move the screen along the meterstick until you get a good image. Record the distance from the light to the lens, d_o, and the distance from the lens to the screen, d_i, in centimeters as Trial 1 in your data table. Also record the height of the object and of the image in millimeters. The object in this case may be either the filament of the light bulb or a cut-out shape in the light box.
8. For Trial 2, place the lens exactly twice the focal length from the object. Slide the screen along the stick until a good image is formed, as in step 7. Record the distances from the screen and the sizes of the object and image as you did in step 7.
9. For Trial 3, place the lens at a distance from the object that is greater than the focal length but less than twice the focal length. Adjust the screen, and record the measurements as you did in step 7.

Analyzing Your Results

1. Perform the calculations needed to complete your data table.
2. How does $\frac{1}{d_o} + \frac{1}{d_i}$ compare with $\frac{1}{f}$ in each of the three trials?

Defending Your Conclusions

3. If the object distance is greater than the image distance, how will the size of the image compare with the size of the object?

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viewpoints

Should the Electromagnetic Spectrum Be Auctioned?

In the late 1990s, the Federal Communications Commission (FCC) auctioned off several portions of the electromagnetic spectrum that were not being used for broadcasting or other communications. Many private companies, especially those involved in wireless communications, bought the rights to use parts of the spectrum.

Is this a good way for the government to raise money without increasing taxes? Or should the spectrum be reserved for other uses that will benefit everyone, not just a communications company and its subscribers?

If the spectrum had not been auctioned, would that have left inventors with no way to market new technologies? What will happen if new technologies are invented that require use of the spectrum, but there's not enough of it available?

Auction the Spectrum

> FROM: Derek K., Coral Springs, FL

Private companies, like those involved in wireless communications, do benefit the public even though the companies make a profit. I think we should give the government a little credit. They must know what they are doing.

> FROM: Phillip V., Chicago, IL

By selling unused parts of the spectrum to private companies, the government can earn more money that can be used to fund different programs, without increasing the tax rate. Since no one is currently using the spectrum, why not sell it to someone who will?

Don't Auction ALL of the Spectrum

> FROM: Komal V., Chicago, IL

I think that some of the spectrum should be reserved. All of it should not be auctioned off. Some of the spectrum might be needed in an emergency.

> FROM: Chris C., Lockport, IL

Many companies who bought parts of the spectrum are on the cutting edge of technology. While they advance, they will use their part of the spectrum for newer technologies. However, the spectrum never should have been sold. It should have been leased, because there might be better uses for it in the future.

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> FROM: Stacy G., Rochester, MN

I think the spectrum shouldn't be sold. It should be used in ways that will help out many people instead of helping a company become richer.

Don't Auction ANY of the Spectrum

> FROM: Maria D., Chicago, IL

The spectrum should be saved for everyone. Why does it have to be a benefit for the government? If the government collected the $3 trillion that haven't been paid in taxes, along with all the money given to foreign countries, the government could focus on things that would be more beneficial.

Your Turn

1. **Critiquing Viewpoints** Select one of the statements on this page that you *agree* with. Identify and explain at least one weak point in the statement. What would you say to respond to someone who brought up this weak point as a reason you were wrong?
2. **Critiquing Viewpoints** Select one of the statements on this page that you *disagree* with. Identify and explain at least one strong point in the statement. What would you say to respond to someone who brought up this point as a reason they were right?
3. **Creative Thinking** If the spectrum were leased instead of sold, what should the terms be? For how long and for how much money? Develop a plan and an argument in favor of it, either as a written report, or as a poster or other form of presentation.
4. **Allocating Resources** Suppose you could decide what should be done with eight available frequencies in the electromagnetic spectrum. How would you distribute them among the following categories: emergency use, military use, National Weather Service, radio, television, wireless communication, and remote-control devices? How many frequencies would you leave open for future inventions? Write a paragraph to justify your decisions.

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TOPIC: Spectrum auction
GO TO: go.hrw.com
KEYWORD: HK1Spectrum

Should the spectrum be auctioned? Why or why not? Share your views on this issue and find out what others think about it at the HRW Web site.