

Electromagnetic Waves

What do cordless phones and microwave ovens have in common with the stars? Each emits electromagnetic waves. These waves also help your computer read a CD-ROM and they enable quick communication across the globe. The data and information explosion is made possible by manipulating electromagnetic waves. In this chapter, you will learn about the usefulness of the entire spectrum of electromagnetic waves.

What do you think?

Science Journal Look at the picture below with a classmate. Discuss what you think this is. Here's a hint: *Cell phones would be useless without them.* Write your answer or best guess in your Science Journal.



EXPLORE ACTIVITY

You often hear about the danger of too much exposure to the Sun's ultraviolet rays, which can damage the cells of your skin. When the exposure isn't too great, your cells can repair themselves, but too much exposure at one time can cause a painful sunburn.

Repeated overexposure to the Sun over many years can damage cells and cause skin cancer. In the activity below, observe how energy carried by ultraviolet waves can cause changes in other materials.

Observe damage by ultraviolet waves

1. Cut a sheet of red construction paper in half.
2. Place one piece outside in direct sunlight. Place the other in a shaded location or behind a window.
3. Keep the construction paper in full sunlight for at least 45 min. If possible, allow it to stay there for 3 h or more before taking it down.



Observe

In your Science Journal, describe any differences you notice in the two pieces of construction paper. Comment on your results.

FOLDABLES Reading & Study Skills



Before You Read

Making a Question Study Fold Asking yourself questions helps you stay focused and better understand electromagnetic waves when you are reading the chapter.

1. Place a sheet of paper in front of you so the long side is at the top. Fold the paper in half from the left side to the right side. Fold top to bottom and crease. Then unfold.
2. Through the top thickness of paper, cut along the middle fold line to form two tabs, as shown.
3. Write these questions on the tabs: *How do electromagnetic waves travel through space? How do electromagnetic waves transfer energy to matter?*
4. As you read the chapter, write answers to the questions under the tabs.

*How do
electromagnetic
waves travel
through space?*

*How do
electromagnetic
waves transfer
energy to matter?*

What are electromagnetic waves?

As You Read

What You'll Learn

- **Explain** how vibrating charges produce electromagnetic waves.
- **Describe** properties of electromagnetic waves.

Vocabulary

electromagnetic wave
radiant energy
frequency
photon

Why It's Important

Knowledge of electromagnetic waves helps you understand much of the technology around you.

Waves in Space

Stay calm. Do not panic. As you are reading this sentence, no matter where you are, you are surrounded by electromagnetic waves. Even though you can't feel them, some of these waves are traveling right through your body. They enable you to see. They make your skin feel warm. You use electromagnetic waves when you watch television, talk on a cordless phone, or prepare popcorn in a microwave oven.

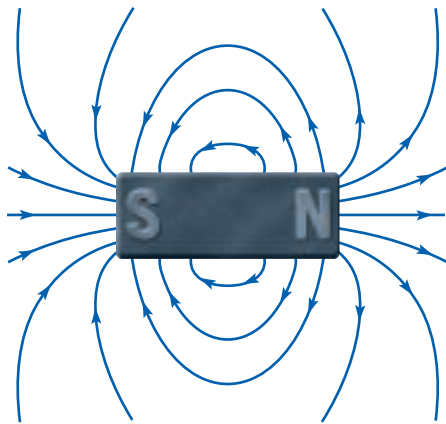
Sound and Water Waves Waves are produced by something that vibrates, and they carry energy from one place to another. Look at the sound wave and the water wave in **Figure 1**. Both waves are moving through matter. The sound wave is moving through air and the water wave through water. These waves travel because energy is transferred from particle to particle. Without matter to transfer the energy, they cannot move.

Electromagnetic Waves However, electromagnetic waves do not require matter to transfer energy. **Electromagnetic waves** are made by vibrating electric charges and can travel through space where matter is not present. Instead of transferring energy from particle to particle, electromagnetic waves travel by transferring energy between vibrating electric and magnetic fields.

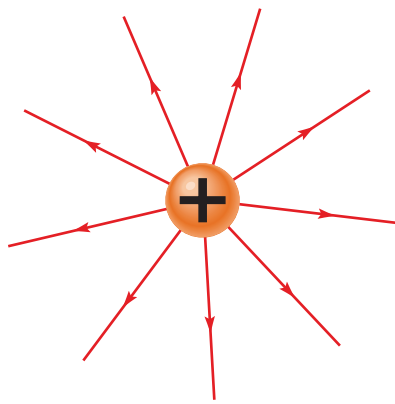
Figure 1

Water waves and sound waves require matter to move through. Energy is transferred from one particle to the next as the wave travels through the matter.





A A magnetic field surrounds all magnets.



B An electric field surrounds all charges.

Figure 2
Fields enable magnets and charges to exert forces at a distance. These fields extend throughout space. How can you detect a magnetic field?

Electric and Magnetic Fields

When you bring a magnet near a metal paper clip, the paper clip moves toward the magnet and sticks to it. The paper clip moved because the magnet exerted a force on it. The magnet exerted this force without having to touch the paper clip. The magnet exerts a force without touching the paper clip because all magnets are surrounded by a magnetic field, as shown in **Figure 2A**. Magnetic fields exist around magnets even if the space around the magnet contains no matter.

Just as magnets are surrounded by magnetic fields, electric charges are surrounded by electric fields, as shown in **Figure 2B**. An electric field enables charges to exert forces on each other even when they are far apart. Just as a magnetic field around a magnet can exist in empty space, an electric field exists around an electric charge even if the space around it contains no matter.

Magnetic Fields and Moving Charges

Electricity and magnetism are related. An electric current flowing through a wire is surrounded by a magnetic field, as shown in **Figure 3**. An electric current is created by the movement of electrons in a wire. It is the motion of these electrons that creates the magnetic field around the wire. In fact, any moving electric charge is surrounded by a magnetic field, as well as an electric field.

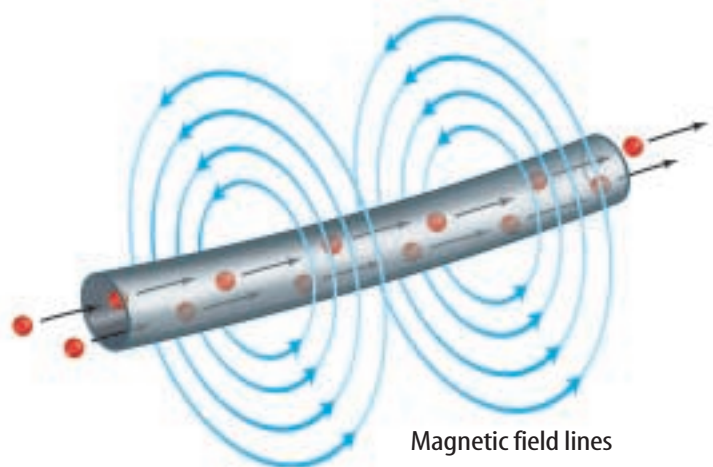


Figure 3
Electrons moving in a wire are surrounded by a magnetic field. How would you confirm that a magnetic field exists around a current-carrying wire?

Investigating Electromagnetic Waves

Procedure

1. Point your **television remote control** in different directions and observe whether it will still control the **television**.
2. Place various materials in front of the infrared receiver on the television and observe whether the remote still will control the television. Some materials you might try are **glass, a book, your hand, paper, and a metal pan**.

Analysis

1. Was it necessary for the remote to be pointing exactly toward the receiver to control the television? Explain.
2. Did the remote continue to work when the various materials were placed between it and the receiver? Explain why or why not.

Changing Electric and Magnetic Fields The relationship between electricity and magnetism can explain the behavior of electric motors, generators, and transformers. This behavior is the result of the relationship between changing electric and magnetic fields. A changing magnetic field creates a changing electric field. The reverse is also true—a changing electric field creates a changing magnetic field.

Making Electromagnetic Waves

Waves such as sound waves are produced when something vibrates. Electromagnetic waves also are produced when something vibrates—an electric charge that moves back and forth.

 **Reading Check** *What produces an electromagnetic wave?*

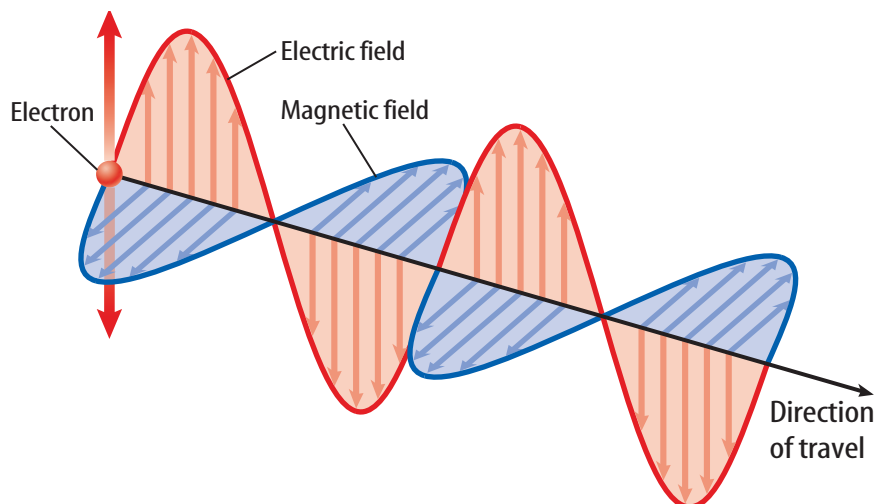
Vibrating Fields When an electric charge vibrates, the electric field around it vibrates. Because the electric charge is in motion, it also has a magnetic field around it. This magnetic field is changing as the charge moves back and forth. As a result, the vibrating electric charge is surrounded by vibrating electric and magnetic fields.

How do the vibrating electric and magnetic fields around the charge become a wave that travels through space? The changing electric field around the charge creates a changing magnetic field. This changing magnetic field then creates a changing electric field. This process continues, with the magnetic and electric fields continually creating each other. These vibrating electric and magnetic fields are perpendicular to each other and travel outward from the moving charge, as shown in

Figure 4.

Figure 4

A vibrating electric charge creates an electromagnetic wave that travels outward in all directions from the charge. Only one direction is shown here.



Properties of Electromagnetic Waves

Electromagnetic waves travel outward from a vibrating charge in all directions. Recall that a wave transfers energy without transporting matter. How does an electromagnetic wave transfer energy? As an electromagnetic wave moves, its electric and magnetic fields encounter objects. These vibrating fields can exert forces on charged particles and magnetic materials, causing them to move. For example, electromagnetic waves from the Sun cause electrons in your skin to vibrate and gain energy, as shown in **Figure 5**. The energy carried by an electromagnetic wave is called **radiant energy**. Radiant energy makes a fire feel warm and enables you to see.

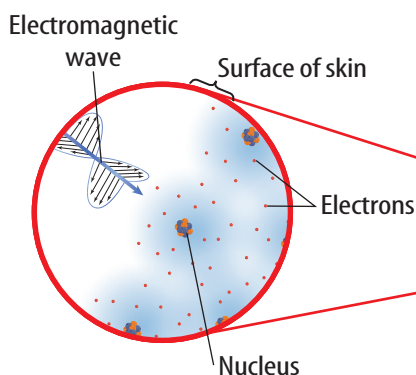


Figure 5

As an electromagnetic wave strikes your skin, electric charges in your skin gain energy from the vibrating electric and magnetic fields.



Problem-Solving Activity

What is scientific notation?

In science, numbers such as the speed of light (300,000,000 m/s) and the size of a gold atom (0.000 000 000 288 m) are either too large or too small to use easily. By using scientific notation, numbers that are very large or very small can be written in a more compact way. For example, in scientific notation the speed of light is 3.00×10^8 m/s and the size of a gold atom is 2.88×10^{-10} m. Scientific notation follows the form $M \times 10^n$. M is a number with only one number to the left of the decimal point. The number of places the decimal point was moved is represented by n . If the original number is greater than 1, n is positive. If the original number is less than 1, n is negative.

Example Problem

Put the numbers 2,000 and 0.003 into scientific notation.

Solution

- 1 For the number 2000, move the decimal point 3 places to the left.
- 2 Because you moved the decimal point 3 places and the number is greater than 1, n equals 3. In scientific notation the number is 2×10^3 .
- 3 For the number 0.003, move the decimal point 3 places to the right.
- 4 Because you moved the decimal point 3 places and the number is less than 1, n equals -3 . In scientific notation the number is 3×10^{-3} .

Practice Problems

1. Put the following numbers into scientific notation:
40; 7,000; 100,000.
2. Put the following numbers into scientific notation:
0.09; 0.000,6; 0.000,005.

Table 1 Speed of Visible Light

Material	Speed (km/s)
Vacuum	300,000
Air	slightly less than 300,000
Water	226,000
Glass	200,000
Diamond	124,000

Wave Speed Electromagnetic waves travel through space, which is empty, as well as through various materials—and they travel fast. In the time it takes you to blink your eyes, an electromagnetic wave can travel around the entire Earth. All electromagnetic waves travel at 300,000 km/s in the vacuum of space. Because light is an electromagnetic wave, the speed of electromagnetic waves in space is usually called the “speed of light.” However, when electromagnetic waves travel through matter, they slow down. The speed of the wave depends upon the material they travel through. Electromagnetic waves usually travel the slowest in solids and the fastest in gases. **Table 1** lists the speed of visible light in various materials.

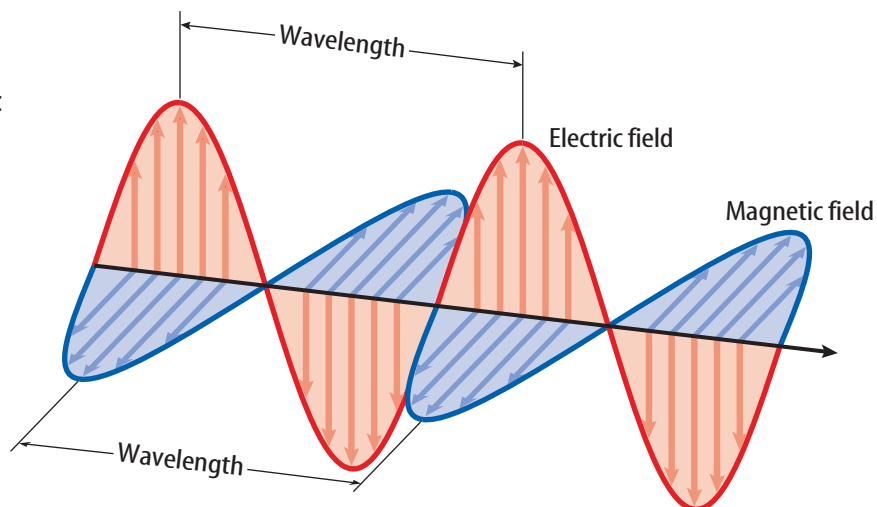
Frequency and Wavelength Like all waves, electromagnetic waves can be described by their frequency and their wavelength. A vibrating charge produces an electromagnetic wave. A charge can vibrate at different speeds, or frequencies. **Frequency** is the number of vibrations that occur in 1 s. Frequency is measured in hertz. One Hz is one vibration each second. For example, if you clap your hands four times each second, then you are clapping at a frequency of 4 Hz.

The wavelength of an electromagnetic wave is the distance from one crest to another, as shown in **Figure 6**. Wavelength is measured in meters. The frequency and wavelength of electromagnetic waves are related. As the frequency of the wave increases, the wavelength becomes smaller.

 **Reading Check** *How are the wavelength and frequency of electromagnetic waves related?*

Figure 6

The wavelength of an electromagnetic wave is the distance from one crest to the next one. *What happens to the wavelength as the frequency decreases?*



Waves and Particles

The difference between a wave and a particle might seem obvious—a wave is a disturbance that carries energy, and a particle is a piece of matter. However, in reality the difference is not so clear.

Waves as Particles In 1887, Heinrich Hertz found that by shining light on a metal, electrons were ejected from the metal. Hertz found that whether or not electrons were ejected depended on the frequency of the light and not the amplitude. Because the energy carried by a wave depends on its amplitude and not its frequency, this result was mysterious. Years later, Albert Einstein provided an explanation—light can behave as a particle, called a **photon**, whose energy depends on the frequency of the light.

Particles as Waves Because light could behave as a particle, others wondered whether matter could behave as a wave. If a beam of electrons were sprayed at two tiny slits, you might expect that the electrons would strike only the area behind the slits, like the spray paint in **Figure 7A**. Instead, it was found that the electrons formed an interference pattern, as shown in **Figure 7B**. This type of pattern is produced by waves when they pass through two slits and interfere with each other, as the water waves do in **Figure 7C**. This experiment showed that electrons can behave like waves. It is now known that all particles, not only electrons, can behave like waves.

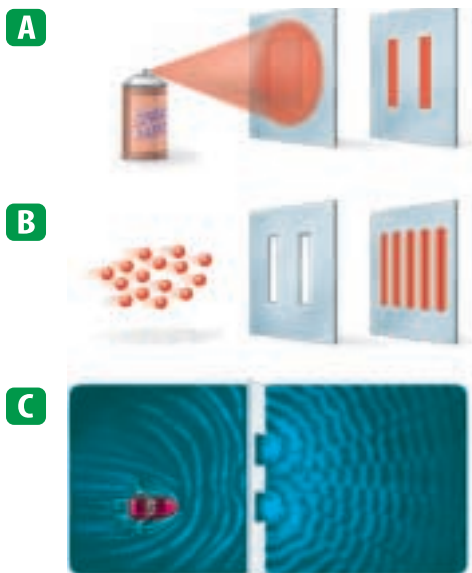


Figure 7

When electrons are sent through two narrow slits, they behave as a wave. **A** Particles of paint sprayed through two slits coat only the area behind the slits.

B Electrons fired at two closely spaced openings don't strike only the area behind the slits. Instead they form a wave-like interference pattern. **C** Water waves produce an interference pattern after passing through two openings.

Section 1 Assessment

1. What produces electromagnetic waves?
2. How is an electromagnetic wave similar to the wave created when a pebble is dropped into a pond?
3. What is the relationship between the frequency and wavelength of electromagnetic waves?
4. **Think Critically** Is it possible to have just an electric-field wave or just a magnetic-field wave? Explain.

Skill Builder Activities

5. **Testing a Hypothesis** Hypothesize that light behaves like water waves. Design an experiment to test your hypothesis. For more help, refer to the **Science Skill Handbook**.
6. **Solving One-Step Equations** When light travels in ethyl alcohol, its speed is about three-fourths its speed in air. What is the speed of light in ethyl alcohol? For more help, refer to the **Math Skill Handbook**.

The Electromagnetic Spectrum

As You Read

What You'll Learn

- **Compare** the various types of electromagnetic waves.
- **Identify** some useful and some harmful properties of electromagnetic waves.

Vocabulary

radio wave	ultraviolet wave
microwave	X ray
infrared wave	gamma ray
visible light	

Why It's Important

Different types of electromagnetic waves can be used in different ways.

Figure 8

Electromagnetic waves are described by different names depending on their frequency and wavelength.

A Range of Frequencies

Electromagnetic waves can have a wide variety of frequencies. They might vibrate once each second or trillions of times each second. The entire range of electromagnetic wave frequencies is known as the electromagnetic spectrum (SPEK trum), shown in **Figure 8**. Various portions of the electromagnetic spectrum interact with matter differently. As a result, they are given different names. The electromagnetic waves that humans can detect with their eyes, called visible light, are a small portion of the entire electromagnetic spectrum. However, devices have been built to detect the other frequencies. For example, the antenna of your radio detects radio waves.

Radio Waves

Stop reading for a moment and look around you. Everywhere you look, radio waves are traveling. You can't see or hear them, but they are there. Radio waves carry the signal from a radio station to your radio. It might seem that radio waves should be the same as sound waves. However, sound waves are compressions and expansions of groups of molecules, while radio waves shake electrons, not molecules of air. Therefore, you can't hear radio waves. You can hear sound waves because molecules bump against your eardrums.

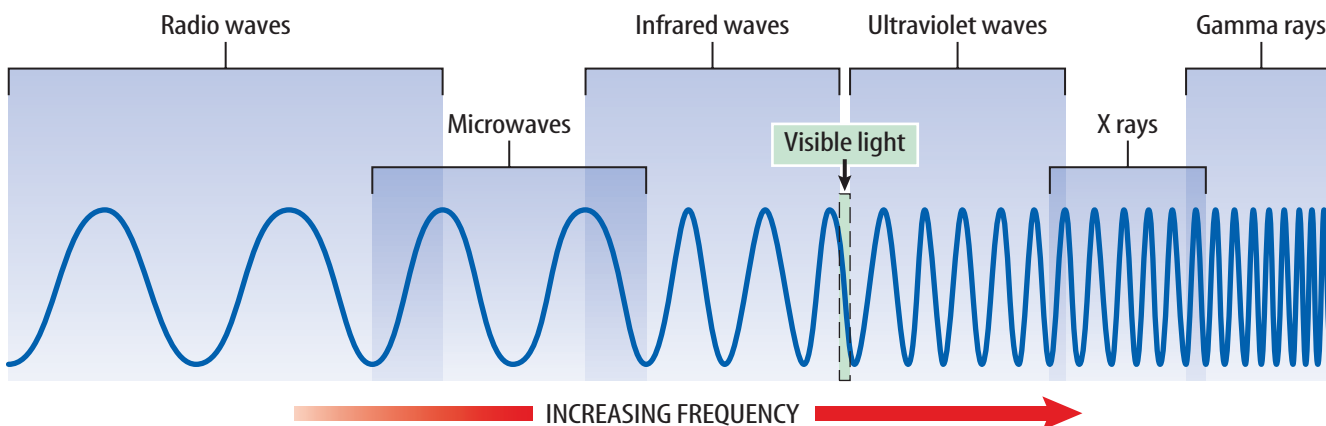
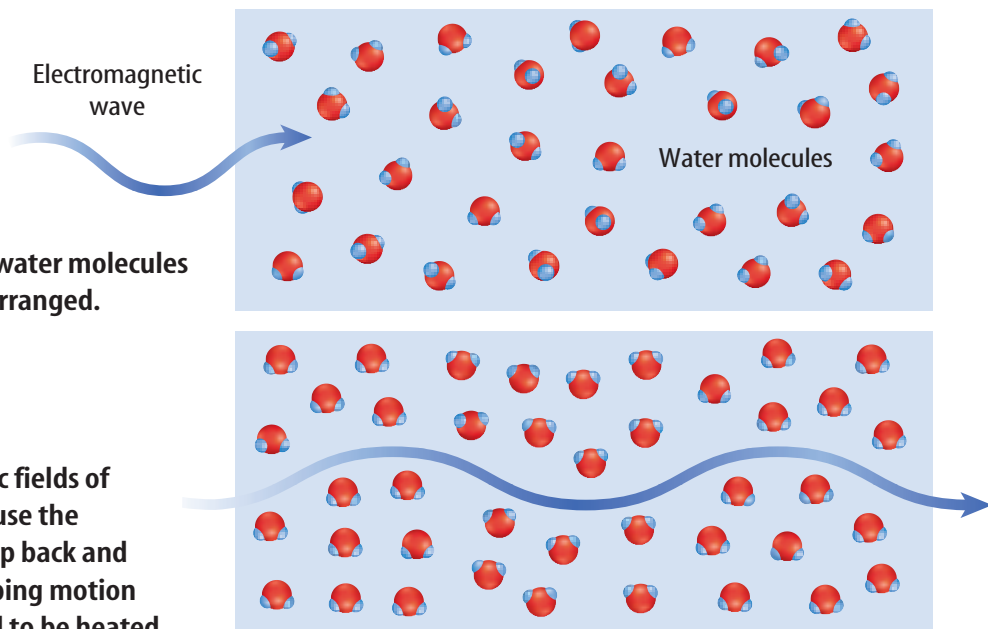


Figure 9
Microwave ovens use electromagnetic waves to heat food.

A Normally water molecules are randomly arranged.

B The electric fields of microwaves cause the molecules to flip back and forth. This flipping motion causes the food to be heated.



Microwaves Radio waves are low-frequency electromagnetic waves with wavelengths greater than about 1 mm. Radio waves with wavelengths of less than 1 m are called **microwaves**. Microwaves with wavelengths of about 1 cm to 10 cm are widely used for communication, such as for cellular telephones and satellite signals. You are probably most familiar with microwaves because of their use in microwave ovens.

✓ Reading Check *What is the difference between a microwave and a radio wave?*

Microwave ovens heat food when microwaves interact with water molecules in food, as shown in **Figure 9**. Each water molecule is positively charged on one side and negatively charged on the other side. The vibrating electric field in microwaves causes water molecules in food to flip direction billions of times each second. This motion causes the molecules to bump one another. Bumping causes friction between the molecules, changing the microwave's radiant energy into thermal energy. It is the thermal energy that cooks your food.

Radar Another use for radio waves is to find the position and movement of objects by a method called radar. Radar stands for **R**adio **D**etecting **A**nd **R**anging. With radar, radio waves are transmitted toward an object. By measuring the time required for the waves to bounce off the object and return to a receiving antenna, the location of the object can be found. Law enforcement officers use radar to measure how fast a vehicle is moving. Radar also is used for tracking the movement of aircraft, watercraft, and spacecraft.

Mini LAB

Heating Food with Microwaves

Procedure

1. Obtain two small **beakers** or **baby food jars**. Place 50 mL of **dry sand** into each. In one of the jars, add 20 mL of **room-temperature water** and stir well.
2. Record the temperature of the sand in each jar.
3. Together, **microwave** both jars of sand for 10 s and immediately record the temperature again.

Analysis

1. Compare the initial and final temperatures of the wet and dry sand.
2. Infer why there was a difference.



Figure 10
Magnetic resonance imaging technology uses radio waves as an alternative to X-ray imaging.

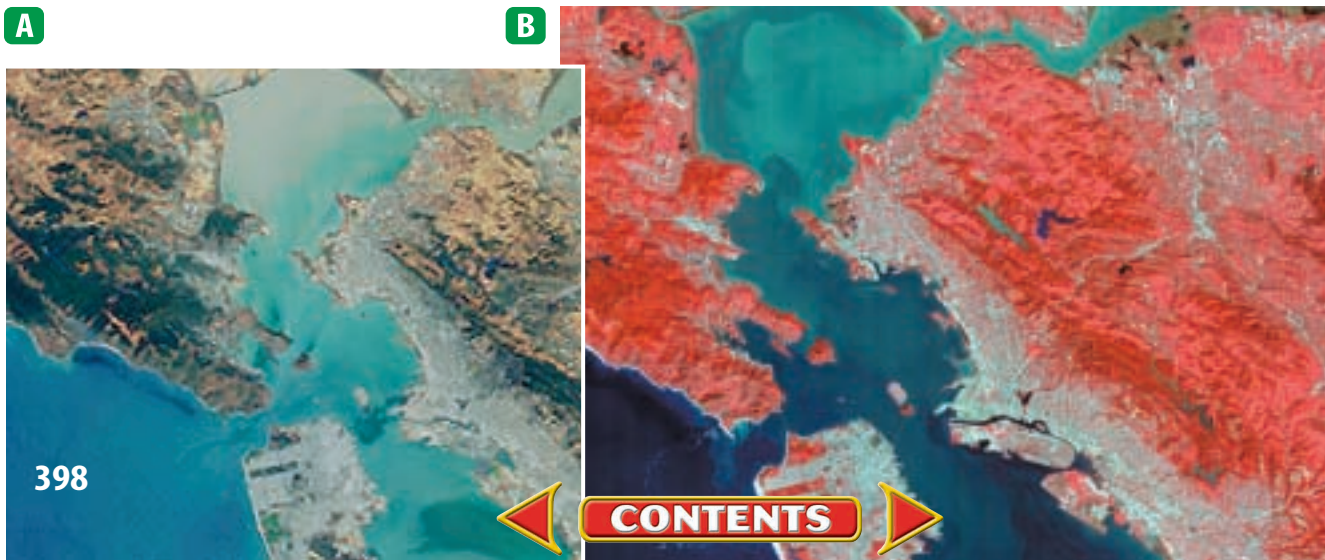
Magnetic Resonance Imaging (MRI) In the early 1980s, medical researchers developed a technique called Magnetic Resonance Imaging, which uses radio waves to help diagnose illness. The patient lies inside a large cylinder, like the one shown in **Figure 10**. Housed in the cylinder is a powerful magnet, a radio wave emitter, and a radio wave detector. Protons in hydrogen atoms in bones and soft tissue behave like magnets and align with the strong magnetic field. Energy from radio waves causes some of the protons to flip their alignment. As the protons flip, they release radiant energy. A radio receiver detects this released energy. The amount of energy a proton releases depends on the type of tissue it is part of. The released energy detected by the radio receiver is used to create a map of the different tissues. A picture of the inside of the patient's body is produced without pain or risk.

Infrared Waves

Most of the warm air in a fireplace moves up the chimney, yet when you stand in front of a fireplace, you feel the warmth of the blazing fire. Why do you feel the heat? The warmth you feel is thermal energy transmitted to you by **infrared waves**, which are a type of electromagnetic wave with wavelengths between about 1 mm and about 750 billionths of a meter.

You use infrared waves every day. A remote control emits infrared waves to communicate with your television. A computer uses infrared waves to read CD-ROMs. In fact, every object emits infrared waves. Hotter objects emit more than cooler objects do. Your world would look strange if you could see infrared waves. It is possible to take photographs called thermograms with a special film that is sensitive to infrared waves. These photographs show cool and warm areas in different colors. Infrared photography is used in many ways. **Figure 11** shows how cities appear different from surrounding vegetation in infrared imagery.

Figure 11
A This visible-light image of the region around San Francisco Bay in California was taken from an aircraft at an altitude of 20,000 m. **B** This infrared image of the same area was taken from a satellite. In this image, vegetation is red and buildings are gray.



Visible Light

Visible light is the range of electromagnetic waves that you can detect with your eyes. Light differs from radio waves and infrared waves only by its frequency and wavelength. Visible light has wavelengths around 400 billionths to 750 billionths of a meter. Your eyes contain substances that react differently to various wavelengths of visible light, so you see different colors. These colors range from short-wavelength blue to long-wavelength red. If all the colors are present, you see the light as white.

Ultraviolet Waves

Ultraviolet waves are electromagnetic waves with wavelengths from about 400 billionths to 10 billionths of a meter. Ultraviolet waves are energetic enough to enter skin cells. Overexposure to ultraviolet rays can cause skin damage and cancer. Most of the ultraviolet radiation that reaches Earth's surface are longer-wavelength UVA rays. The shorter-wavelength UVB rays cause sunburn, and both UVA and UVB rays can cause skin cancers and skin damage such as wrinkling. Although too much exposure to the Sun's ultraviolet waves is damaging, some exposure is healthy. Ultraviolet light striking the skin enables your body to make vitamin D, which is needed for healthy bones and teeth.

Useful UVs A useful property of ultraviolet waves is their ability to kill bacteria on objects such as food or medical supplies. When ultraviolet light enters a cell, it damages protein and DNA molecules. For some single-celled organisms, damage can mean death, which can be a benefit to health. Ultraviolet waves are also useful because they make some materials fluoresce (fluorescence). Fluorescent materials absorb ultraviolet waves and reemit the energy as visible light. As shown in **Figure 12**, police detectives sometimes use fluorescent powder to show fingerprints when solving crimes.

Figure 12
The police detective in this picture is shining ultraviolet light on a fingerprint dusted with fluorescent powder.



Health

INTEGRATION

In certain situations, doctors will perform a CT scan on a patient instead of a traditional X ray. Research to find out more about CT scans. Compare and contrast the CT scan to X rays. What are the advantages and disadvantages of a CT scan? Write a paragraph about your findings in your Science Journal.

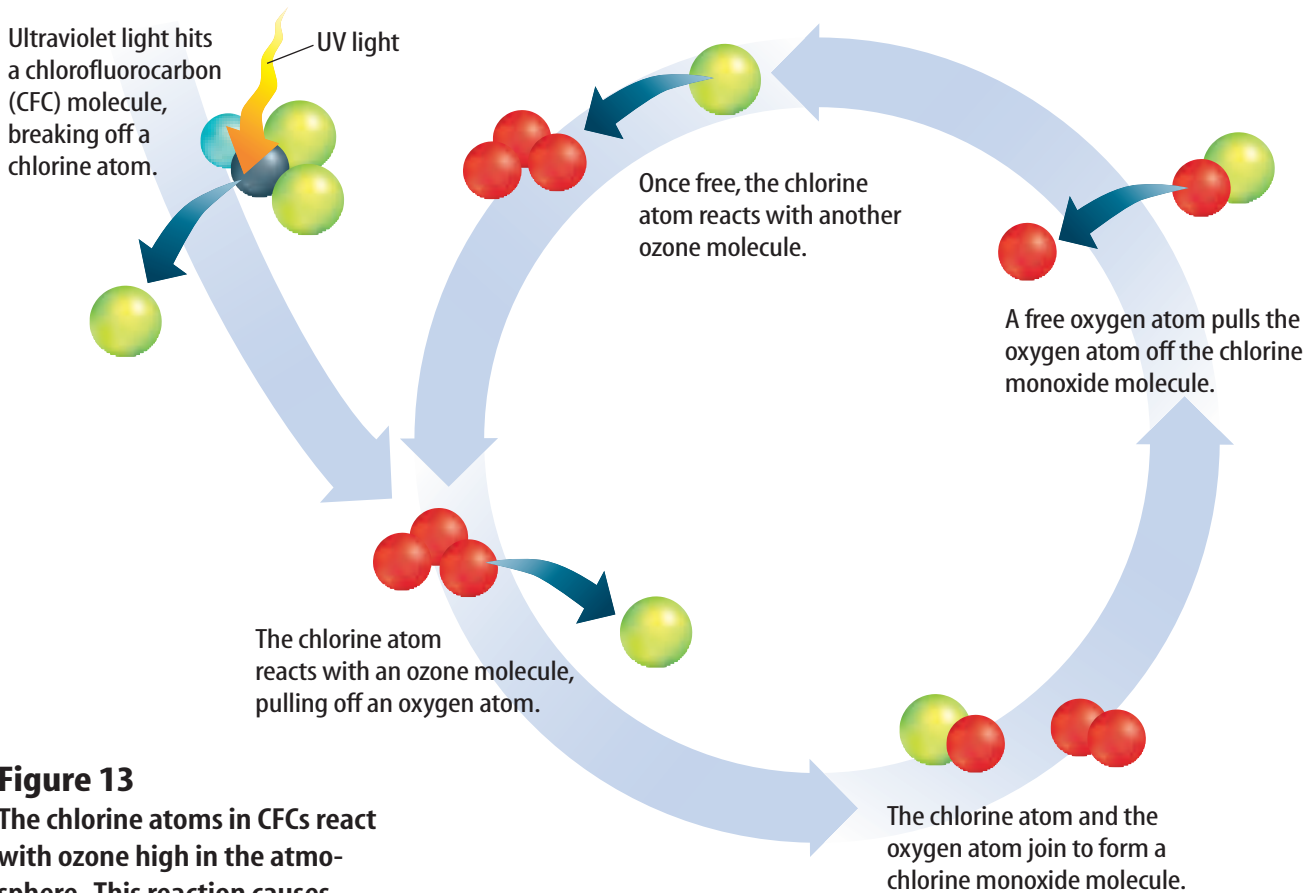


Figure 13
The chlorine atoms in CFCs react with ozone high in the atmosphere. This reaction causes ozone molecules to break apart.

The Ozone Layer About 20 to 50 km above Earth's surface is a region called the ozone layer. Ozone is a molecule composed of three oxygen atoms. It is continually being formed and destroyed high in the atmosphere. The ozone layer is vital to life on Earth because it absorbs most of the Sun's harmful ultraviolet waves. You might have heard of an ozone hole that forms over Antarctica. In fact, thinning of the ozone layer has occurred over areas of Earth but is greatest over Antarctica.



Environmental Science

INTEGRATION

The greatest threat to the ozone layer is from ozone-depleting chemicals, such as nitric oxides and CFCs. CFCs, which stands for chlorofluorocarbons, are used in air conditioners, refrigerators, and as cleaning fluids. When these substances reach the ozone layer, they react chemically with ozone, breaking the ozone molecule apart, as shown in **Figure 13**. One chlorine atom of a CFC molecule will break apart many ozone molecules. To reduce the damage to the ozone layer, many countries in the world are reducing their use of ozone-depleting chemicals.



Reading Check

What chemicals can reduce the amount of ozone in the ozone layer?

X Rays and Gamma Rays

At the far end of the electromagnetic spectrum are **X rays** and **gamma rays**. These ultra-high-frequency electromagnetic waves are so energetic that they can travel through matter, breaking molecular bonds as they go. Doctors and dentists often send low doses of X rays through a patient's body onto photographic film. Dense parts of the body such as bones or teeth absorb more X rays than soft parts do. **Figure 14** shows the shadow image of bones produced by X rays. New techniques are being developed to use gamma rays for more precise medical imaging. X rays are used at airports to inspect luggage without opening it. X rays and gamma rays are used at low doses in industry to check metal objects for cracks and defects.

Radiation therapy is a technique used in medicine for exposing part of a patient's body to X rays or gamma rays to kill diseased cells. X rays and gamma rays have short wavelengths and are highly energetic. When X rays or gamma rays pass through matter, part of the energy damages molecules. This eventually kills cells. However, nearby healthy cells also are damaged by the radiation. By carefully controlling the amount of radiation, the damage to healthy cells is reduced.



Figure 14
Bones are more dense than surrounding tissues and absorb more X rays. The image of a bone on an X ray is the shadow cast by the bone as X rays pass through the soft tissue.

Section 2 Assessment

1. Explain how a microwave oven heats food. Draw a diagram to help your explanation.
2. Describe how light you see with your eyes differs from other forms of electromagnetic waves, such as X rays and radio waves.
3. Name some ways that ultraviolet waves are useful and some ways in which they are dangerous.
4. Describe the ozone layer and why damage to the ozone layer could be harmful.
5. **Think Critically** Why are ultraviolet waves, X rays, and gamma rays far more dangerous to humans than other forms of electromagnetic waves?

Skill Builder Activities

6. **Researching Information** Many scientists around the world are studying ozone depletion and how we can solve the problem. Learn about one of these scientists and write a paragraph about the work he or she is doing. **For more help, refer to the Science Skill Handbook.**
7. **Using Graphics Software** Use graphics software to create your own version of the electromagnetic spectrum. Be sure to include all of the forms of electromagnetic waves mentioned in this section. Use clip art to represent how each part of the spectrum is used. **For more help, refer to the Technology Skill Handbook.**

Activity

The Shape of Satellite Dishes

Communications satellites transmit signals with a narrow beam pointed toward a particular area of Earth. To detect this signal, receivers are typically large, parabolic dishes. Why is the shape of the dish important?

What You'll Investigate

How does the shape of a satellite dish improve reception?

Materials

flashlight
several books
aluminum foil
small, parabolically shaped bowl
(such as a mortar bowl)

**large, metal spoon*

**Alternate materials*

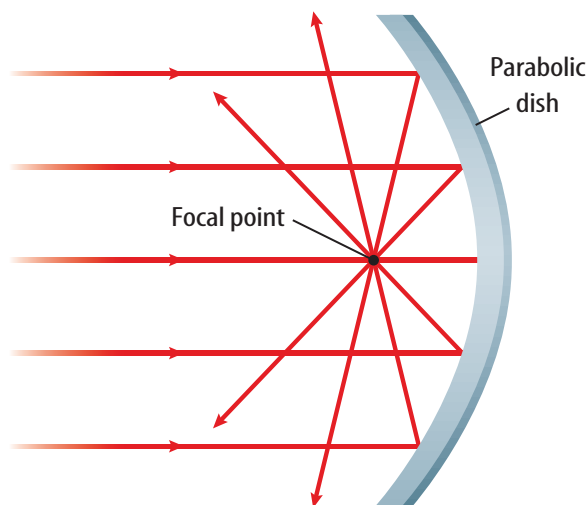
Goals

- **Make** a model of a satellite reflecting dish.
- **Observe** how the shape of the dish affects reception.

Safety Precautions

Procedure

1. Cover one side of a book with aluminum foil. Be careful not to wrinkle the foil.
2. Line the inside of the bowl with foil, also keeping it as smooth as possible.
3. Place some of the books on a table. Put the flashlight on top of the books so that its beam of light will shine several centimeters above and across the table.
4. Hold the foil-covered book on its side at a right angle to the top of the table. The foil-covered side should face the beam of light.
5. **Observe** the intensity of the light on the foil.



6. Repeat these procedures, replacing the foil-covered book with the bowl, keeping it at the same distance from the flashlight.
7. **Observe** how the intensity of light differs when the flat surface is used rather than the curved surface.

Conclude and Apply

1. **Compare** the difference in intensity of light when the two surfaces were used.
2. **Infer** what caused this difference.
3. **Explain** how these results relate to why parabolic dishes are used for satellite signal receivers.

Communicating Your Data

Compare your conclusions with those observed by other students in your class. For more help, refer to the **Science Skill Handbook**.

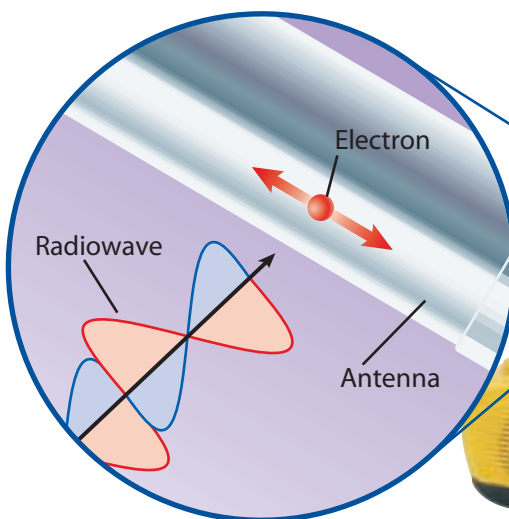
Radio Communication

Radio Transmission

When you listen to the radio, you hear music and words that are produced at a distant location. The music and words are sent to your radio by radio waves. You can't actually hear the radio waves, because they are electromagnetic waves. Ears only detect sound waves. It is the metal antenna of your radio that detects radio waves. As the electromagnetic waves pass by your radio's antenna, the electrons in the metal vibrate, as shown in **Figure 15**. These vibrating electrons produce an electric signal that contains the information about the music and words. An amplifier boosts the signal and sends it to speakers, causing them to vibrate. The vibrating speakers create sound waves that travel to your ears.

Dividing the Radio Spectrum Many radio stations broadcast programs for you to listen to. What is it that allows you to listen to only one station at a time? Each station is assigned to broadcast at one particular radio frequency. Turning the tuning knob on your radio allows you to select a particular frequency to listen to. The specific frequency of the electromagnetic wave that a radio station is assigned is called the **carrier wave**.

The radio station must do more than simply transmit a carrier wave. The station has to send information about the sounds that you are to receive. This information is sent by modifying the carrier wave. The carrier wave is modified to carry information in one of two ways, as shown in **Figure 16**. One way is to vary the amplitude of the carrier wave. This method is called amplitude modulation, or AM. The other way is to vary the frequency of the carrier wave. This method is called frequency modulation, or FM.



As You Read

What You'll Learn

- **Explain** how modulating carrier waves make radio transmissions.
- **Distinguish** between AM and FM radio.
- **Identify** various ways of communicating using radio waves.

Vocabulary

carrier wave
cathode-ray tube
transceiver

Why It's Important

Every day you use radio waves to communicate.

Figure 15

Radio waves exert a force on the electrons in an antenna, causing the electrons to vibrate. *Why does lengthening the antenna often help a radio's reception?*



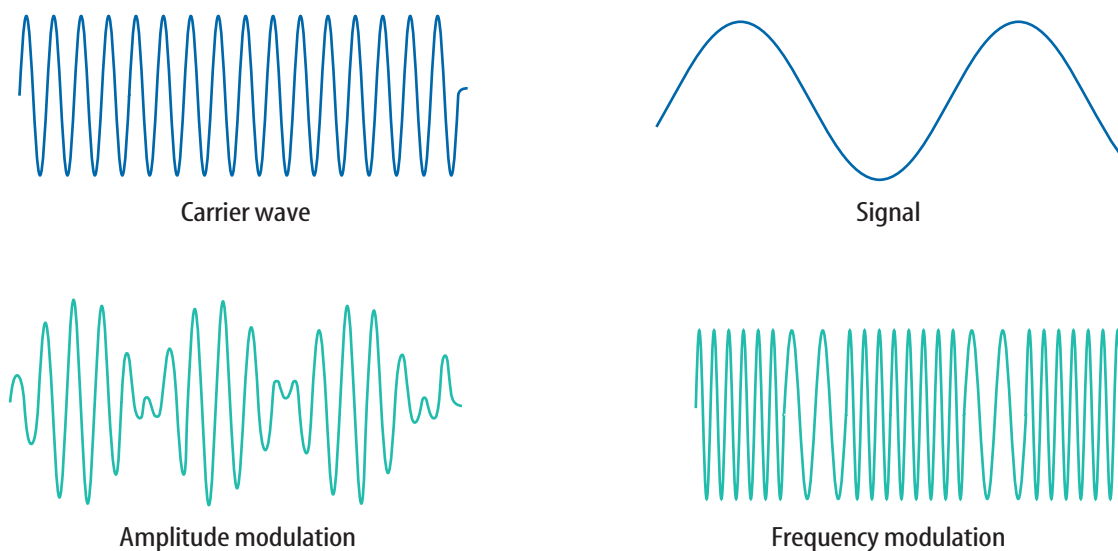


Figure 16
A carrier wave broadcast by a radio station can be altered in one of two ways to transmit a signal: amplitude modulation (AM), or frequency modulation (FM).

AM Radio An AM radio station broadcasts information by varying the amplitude of the carrier wave, as shown in **Figure 16**. Your radio detects the variations in amplitude of the carrier wave and makes an electronic signal from these slight variations. The electronic signal is then used to make the speaker vibrate. AM carrier wave frequencies range from 540,000 to 1,600,000 vibrations each second.

FM Radio Electronic signals are transmitted by FM radio stations by varying the frequency of the carrier wave, as in **Figure 16**. Your radio detects the changes in frequency of the carrier wave. Because the strength of the FM waves is kept fixed, FM signals tend to be more clear than AM signals. FM carrier frequencies range from 88 million to 108 million vibrations each second. This is much higher than AM frequencies, as shown in **Figure 17**. **Figure 18** shows how radio signals are broadcast.

Figure 17
Cellphones, TVs, and radios broadcast at frequencies that range from more than 500,000 Hz to almost 1 billion Hz.

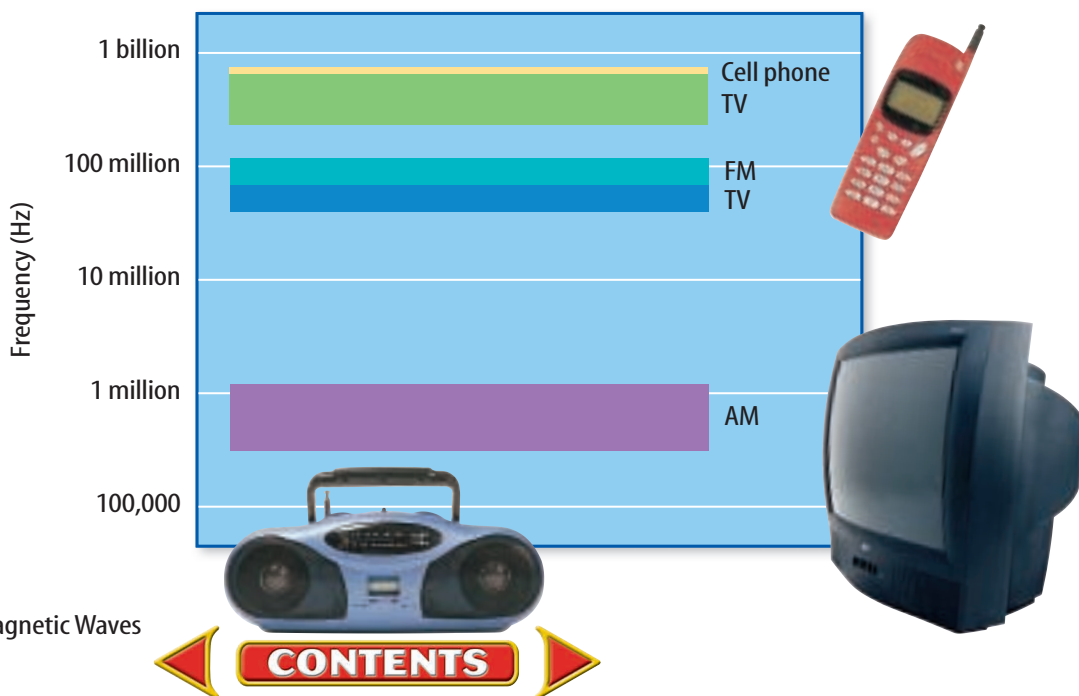


Figure 18

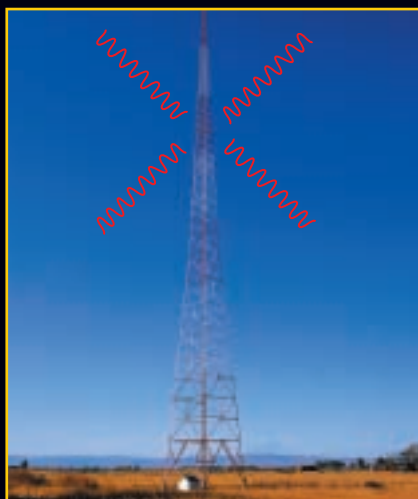
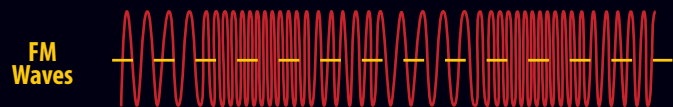
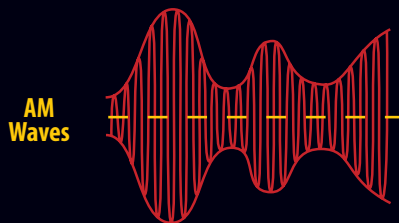
You flick a switch, turn the dial, and music from your favorite radio station fills the room. Although it seems like magic, sounds are transmitted over great distances by converting sound waves to electromagnetic waves and back again, as shown here.



A At the radio station, musical instruments and voices create sound waves by causing air molecules to vibrate. Microphones convert these sound waves to a varying electric current, or electronic signal.



B This signal then is added to the station's carrier wave. If the station is an AM station, the electronic signal modifies the amplitude of the carrier wave. If the station is a FM station, the electronic signal modifies the frequency of the carrier wave.



C The modified carrier wave is used to vibrate electrons in the station's antenna. These vibrating electrons create a radio wave that travels out in all directions at the speed of light.



D The radio wave from the station makes electrons in your radio's antenna vibrate. This creates an electric current. If your radio is tuned to the station's frequency, the carrier wave is removed from the original electronic signal. This signal then makes the radio's speaker vibrate, creating sound waves that you hear as music.



Astronomy INTEGRATION

Do you ever look up at the stars at night and wonder how they were formed? With so many stars and so many galaxies, life might be possible on other planets. Research ways that astronomers use electromagnetic waves to investigate the universe. Choose one project astronomers currently are working on, and write about it in your Science Journal.

Television

What would people hundreds of years ago have thought if they had seen a television? It might seem like magic, but it's not if you know how they work. Television and radio transmissions are similar. At the television station, sound and images are changed into electronic signals. These signals are broadcast by carrier waves. The audio part of television is sent by FM radio waves. Information about the color and brightness is sent at the same time by AM signals.

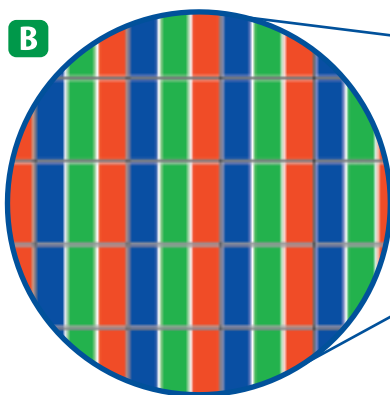
Cathode-Ray Tubes In many television sets, images are displayed on a cathode-ray tube (CRT), as shown in **Figure 19**. A **cathode-ray tube** is a sealed vacuum tube in which one or more beams of electrons are produced. The CRT in a color TV produces three electron beams that are focused by a magnetic field and strike a coated screen. The screen is speckled with more than 100,000 rectangular spots that are of three types. One type glows red, another glows green, and the third type glows blue when electrons strike it. The spots are grouped together with a red, green, and blue spot in each group.

An image is created when the three electron beams of the CRT sweep back and forth across the screen. Each electron beam controls the brightness of each type of spot, according to the information in the video signal from the TV station. By varying the brightness of each spot in a group, the three spots together can form any color so that you see a full-color image.

 **Reading Check** *What is a cathode-ray tube?*

Figure 19

- A** Cathode-ray tubes produce the images you see on television.
- B** The inside surface of a television screen is covered by groups of spots that glow red, green, or blue when struck by an electron beam.



Telephones

Until about 1950, human operators were needed to connect many calls between people. Just 20 years ago you never would have seen someone walking down the street talking on a telephone. Today, cell phones are seen everywhere. When you speak into a telephone, a microphone converts sound waves into an electrical signal. In cell phones, this current is used to create radio waves that are transmitted to and from a microwave tower, as shown in **Figure 20**. A cell phone uses one radio signal for sending information to a tower at a base station. It uses another signal for receiving information from the base station. The base stations are several kilometers apart. The area each one covers is called a cell. If you move from one cell to another while using a cell phone, an automated control station transfers your signal to the new cell.



Figure 20
The antenna at the top of a microwave tower receives signals from nearby cell phones. Are any microwave towers located near your school or home? Where?

Cordless Telephones Like a cellular telephone, a cordless telephone is a transceiver. A **transceiver** transmits one radio signal and receives another radio signal from a base unit. Having two signals at different frequencies allows you to talk and listen at the same time. Cordless telephones work much like cell phones. With a cordless telephone, however, you must be close to the base unit. Another drawback is that when someone nearby is using a cordless telephone, you could hear that conversation on your phone if the frequencies match. For this reason, many cordless phones have a channel button. This allows you to switch your call to another frequency.

Pagers Another method of transmitting signals is a pager, which allows messages to be sent to a small radio receiver. A caller leaves a message at a central terminal by entering a call-back number through a telephone keypad or by entering a text message from a computer. At the terminal, the message is changed into an electronic signal and transmitted by radio waves. Each pager is given a unique number for identification. This identification number is sent along with the message. Your pager receives all messages that are transmitted in the area at its assigned frequency. However, your pager responds only to messages with its particular identification number. Newer pagers can send data as well as receive them.

 **Reading Check** How does a pager know when to beep you?

SCIENCE 
Online

Research Visit the Glencoe Science Web site at **science.glencoe.com** for recent news or magazine articles about advances in radio wave technology. Communicate to your class what you learn.


CLICK HERE

Figure 21

Currently, more than 2,000 satellites orbit Earth. Other than communications, what might the satellites be used for?



Communications Satellites

Since satellites were first developed, thousands have been launched into Earth's orbit. Many of these, like the one shown in **Figure 21**, are used for communication. A station broadcasts a high-frequency microwave signal to the satellite. The satellite receives the signal, amplifies it, and transmits it to a particular region on Earth. To avoid interference, the frequency broadcast by the satellite is different than the frequency broadcast from Earth.

Satellite Telephone Systems If you have a mobile telephone, you can make a phone call when sailing across the ocean. To call on a mobile telephone, the telephone transmits radio waves directly to a satellite. The satellite relays the signal to a ground station, and the call is passed on to the telephone network. Satellite links work well for one-way transmissions, but two-way communications can have an annoying delay caused by the large distance the signals travel to and from the satellite.

Television Satellites The satellite-reception dishes that you sometimes see in yards or attached to houses are receivers for television satellite signals. Satellite television is used as an alternative to ground-based transmission. Communications satellites use microwaves rather than the longer-wavelength radio waves used for normal television broadcasts. Short-wavelength microwaves travel more easily through the atmosphere. The ground receiver dishes are rounded to help focus the microwaves onto an antenna.

SCIENCE
Online



Research Visit the Glencoe Science Web site at science.glencoe.com for more information about ways satellites are used for communication. Report to your class what you learn.



The Global Positioning System

Getting lost while hiking is not uncommon, but if you are carrying a **Global Positioning System** (GPS) receiver, it is much less likely to happen. The GPS is a system of satellites, ground monitoring stations, and receivers that provide details about your exact location at or above Earth's surface. The 24 satellites necessary for 24-hour, around-the-world coverage became fully operational in 1995. GPS satellites are owned and operated by the United States Department of Defense, but the microwave signals they send out can be used by anyone. As shown in **Figure 22**, signals from four satellites are needed to determine the location of an object using a GPS receiver.

GPS receivers are used in airplanes, ships, cars, and even by hikers. Many police cars, fire trucks, and ambulances have GPS receivers. This allows the closest help to be sent in an emergency. Many automobile GPS receivers come with a high-resolution, color display screen that can show you a map of the area, display mileage to various locations, and provide information on the services provided at the next interstate exit. Can you think of other uses for the Global Positioning System?

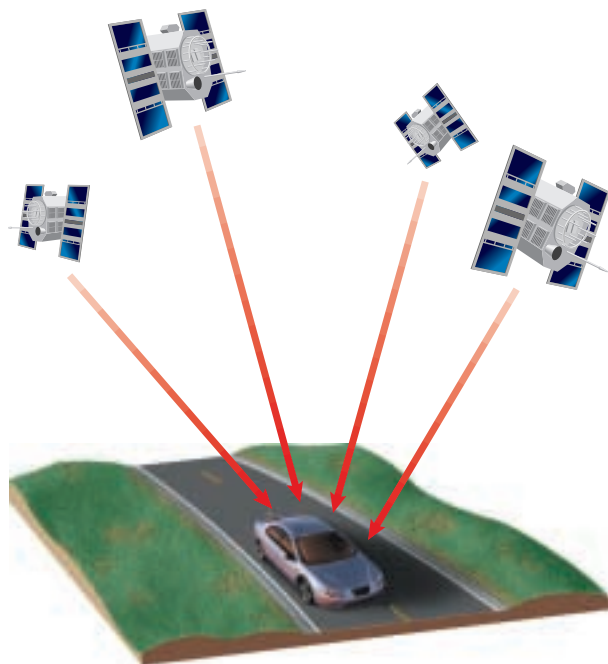


Figure 22

A GPS receiver uses signals from orbiting satellites to determine the user's location. How would having a GPS receiver in an automobile be useful?

Section 3 Assessment

1. Explain the difference between AM and FM radio. Make a sketch of how a carrier wave is modulated in AM and FM radio.
2. What is a cathode-ray tube and how is it used in a television?
3. What happens if you are talking on a cell phone while riding in a car and you travel from one cell to another cell?
4. Explain some of the uses of a Global Positioning System. Why might emergency vehicles all be equipped with GPS receivers?
5. **Think Critically** Why do cordless telephones stop working if you move too far from the base unit?

Skill Builder Activities

6. **Researching Information** For a cellular phone system to work, microwave antennas must be spaced every few kilometers throughout the area. Look around your community to see where microwave antennas are located. Draw a map of the area and note where they are. **For more help, refer to the Science Skill Handbook.**
7. **Communicating** Technology using radio waves for communication is changing rapidly. In your Science Journal, write some ways that communication with radio waves might be different in the future. **For more help, refer to the Science Skill Handbook.**

Activity

Use the Internet



Radio Frequencies

The signals from many radio stations broadcasting at different frequencies are hitting your radio's antenna at the same time. When you tune to your favorite station, the electronics inside your radio amplify the signal at the frequency broadcast by the station. The signal from your favorite station is broadcast from a transmission site that may be several miles away.

You may have noticed that if you're listening to a radio station while driving in a car, sometimes the station gets fuzzy and you'll hear another station at the same time. Sometimes you lose the station completely. How far can you drive before that happens? Does the distance vary depending on the station you listen to?

Recognize the Problem

What are the ranges of radio stations?

Form a Hypothesis

How far can a radio station transmit? Which type of signal, AM or FM, has a greater range? Form a hypothesis about the range of your favorite radio station.

Goals

- **Research** which frequencies are used by different radio stations.
- **Observe** the reception of your favorite radio station.
- **Make** a chart of your findings and communicate them to other students.

Data Source

SCIENCE Online Go to the Glencoe Science Web site at science.glencoe.com for more information on radio frequencies, different frequencies of radio stations around the country, and the ranges of AM and FM broadcasts.



Test Your Hypothesis

Plan

- 1. Research** what frequencies are used by AM and FM radio stations in your areas and other areas around the country.
- 2. Determine** these stations' broadcast locations.
- 3. Determine** the broadcast range of radio stations in your area.
- 4. Observe** how frequencies differ. What is the maximum difference between frequencies for FM stations in your area? AM stations?

Do

- 1.** Make sure your teacher approves your plan before you start.
- 2.** Visit the Glencoe Science Web site for links to different radio stations.
- 3. Compare** the different frequencies of the stations and the locations of the broadcasts.
- 4. Determine** the range of radio stations in your area and the power of their broadcast signal in watts.
- 5. Record** your data in your Science Journal.



Analyze Your Data

- 1. Make** a map of the radio stations in your area. Do the ranges of AM stations differ from FM stations?
- 2. Make** a map of different radio stations around the country. Do you see any patterns in the frequencies for stations that are located near each other?
- 3. Write** a description that compares how close the frequencies of AM stations are and how close the frequencies of FM stations are. Also compare the power of their broadcast signals and their ranges.
- 4. Share** your data by posting it on the Glencoe Science Web site.

Draw Conclusions

- 1.** Compare your findings to those of your classmates and other data that was posted on the Glencoe Science Web site. Do all AM stations and FM stations have different ranges?
- 2.** Look at your map of the country. How close can stations with similar frequencies be? Do AM and FM stations appear to be different in this respect?
- 3.** The power of the broadcast signal also determines its range. How does the power (wattage) of the signals affect your analysis of your data?

Communicating Your Data

CLICK HERE

Find this *Use the Internet* activity on the Glencoe Science Web site at science.glencoe.com. Post your data in the table provided. Compare your data to that of other students. Then combine your data with theirs and make a map for your class that shows all of the data.



Can phoning
and driving go
together safely?

Cell Phones

If you use a cell phone, you're not alone. More than 92 million Americans have them, and 30,000 more new cell phone users sign up each day. Although it seems that you can't eat in a restaurant or ride a train without hearing someone else's cell phone conversation, one of the most popular places for cell phone use is the car. And many people think that's a problem.

Danger, Danger

According to the National Highway Transportation Safety Board, driver inattention is a factor in half of all accidents. Many people believe that cell phone use distracts drivers, causing accidents. Drivers can get so excited or involved in a phone conversation that they forget they are behind the wheel. Drivers who hold phones (rather than use speaker phones) don't have complete control of the car. Dialing a phone number can make drivers take their eyes off the road.

One study found that people who talk on cell phones while driving are four times more likely to get into a car accident than people who do not. In Oklahoma, accident reports suggest that drivers with cell phones are more likely to speed and swerve between lanes. They are also involved in more fatal accidents. Because of findings such as these, many people think laws should restrict cell phone use by drivers.

This is already the case in countries such as Brazil, Sweden, and Australia. Several communities in the United States have restricted cell phone use as well. In Suffolk County, New York, for example, lawmakers have passed a bill making it illegal to use a hand-held cellular phone while driving.

Cellulars Aren't All Bad

Regardless of this evidence, some people feel that singling out cell phones as the cause of accidents is unfair. They say that drivers are inattentive for many reasons. Changing CDs, eating, or looking at maps while driving, can take attention from the road. A driver looking at a digital map display takes his or her eyes off the road about 20 times in a short period, according to one study. This can spell danger in a car speeding down the road at 100 km/h. Yet there are no laws against looking at maps while driving.

Supporters of cell phone use in cars also point out that cellular phones are useful during emergencies. Many drivers have used these phones to report accidents or roadside injuries. These reports have helped people in trouble and have saved lives.

The best course may be to just learn to use car phones more carefully. For example, drivers should pull off the road to make calls. Drivers shouldn't use a hand-held cell phone but should use a speaker phone in order to keep both hands on the steering wheel. But even if people followed those two suggestions, the debate won't end. As cars become more loaded with gadgets that enable drivers to send faxes or even microwave snacks on the road, the question of whether drivers should do anything in the car other than drive will become more important.

CONNECTIONS Survey With a partner, write a questionnaire on car cell phone use for classmates to answer. Include questions on what they think of cell phone use by drivers, and whether adults in their families use a cell phone while driving. Tabulate the results and post them.

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SCIENCE
Online

For more information, visit
science.glencoe.com

CONTENTS

Reviewing Main Ideas

Section 1 What are electromagnetic waves?

1. A vibrating charge creates electromagnetic waves. *In what ways are electromagnetic waves similar to and different from the waves in this picture?*



2. Electromagnetic waves have radiant energy and travel through a vacuum or through matter.
3. Electromagnetic waves sometimes can behave like particles. The particles are called photons.

Section 2 The Electromagnetic Spectrum

1. Electromagnetic waves with the lowest frequency are called radio waves. Infrared



waves have frequencies between radio waves and visible light. *Why would being able to detect infrared waves help this pit viper catch its prey?*

2. Human eyes can see electromagnetic waves that span a wavelength range of 390 billionths to 770 billionths of a meter.

3. Ultraviolet waves have frequencies slightly higher than visible light. They have useful and harmful properties.
4. X rays and gamma rays are two types of ultrahigh-frequency electromagnetic waves that are energetic enough to travel through many materials and destroy living cells.

Section 3 Radio Communication

1. Modulated radio waves are used often for communication. AM and FM are two forms of carrier wave modulation. *What is the purpose of AM and FM modulation of carrier waves?*



2. Television signals are transmitted as a combination of AM and FM waves.
3. Cellular telephones, cordless telephones, and pagers all rely on radio waves for signal transmission. Communications satellites are used for telephone and television transmissions.
4. The Global Positioning System uses satellites to help people determine their exact location.

After You Read

FOLDABLES Reading & Study Skills



Make a list of different types of electromagnetic waves

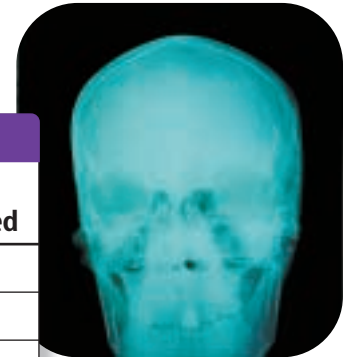
arranged in order of increasing frequency on the back of the tabs of your Foldable.

Visualizing Main Ideas

Complete the following table about the electromagnetic spectrum.



Uses of Electromagnetic Waves	
Type of Electromagnetic Waves	Examples of How Electromagnetic Waves Are Used
	radio, TV transmission
infrared waves	
visible light	vision
X rays	destroying harmful cells



Vocabulary Review

Vocabulary Words

- a. carrier wave
- b. cathode-ray tube
- c. electromagnetic wave
- d. frequency
- e. gamma ray
- f. infrared wave
- g. microwave
- h. photon
- i. radiant energy
- j. radio wave
- k. transceiver
- l. ultraviolet wave
- m. visible light
- n. X ray

Using Vocabulary

Replace the underlined words with the correct vocabulary word.

- Gamma rays are a type of electromagnetic wave often used for communication.
- Visible light and radio waves are used often for medical imaging.
- A remote control is able to communicate with a television by sending X rays.
- Electromagnetic waves are composed of massless particles called carrier waves.
- If you stay outdoors too long, your skin might be burned by exposure to radio waves from the Sun.
- Microwaves are waves of unique frequencies used by radio stations to broadcast information.



Study Tip

Keep all your homework assignments and reread them from time to time. Make sure you understand any problems you answered incorrectly.

Chapter 13 Assessment

Checking Concepts

Choose the word or phrase that best answers the question.

- Which type of electromagnetic wave is the most energetic?
A) gamma rays C) infrared waves
B) ultraviolet waves D) microwaves
- Electromagnetic waves can behave like what type of particle?
A) electrons C) photons
B) molecules D) atoms
- Which type of electromagnetic wave enables skin cells to produce vitamin D?
A) visible light C) infrared waves
B) ultraviolet waves D) X rays
- Which of the following describes X rays?
A) short wavelength, high frequency
B) short wavelength, low frequency
C) long wavelength, high frequency
D) long wavelength, low frequency
- Which of the following is changing in an AM radio wave?
A) speed C) amplitude
B) frequency D) wavelength
- Which type of electromagnetic wave is used to produce a thermogram?
A) X rays C) infrared waves
B) ultraviolet waves D) gamma rays
- Which type of electromagnetic wave has wavelengths greater than about 1 mm?
A) X rays C) gamma rays
B) radio waves D) ultraviolet waves
- What is the name of the ability of some materials to absorb ultraviolet light and re-emit it as visible light?
A) modulation C) transmission
B) handoff D) fluorescence

- Which of these colors of visible light has the shortest wavelength?
A) blue C) red
B) green D) white
- Which type of electromagnetic wave has wavelengths slightly longer than humans can see?
A) X rays C) infrared waves
B) ultraviolet waves D) gamma rays

Thinking Critically

- When you heat food in a microwave oven, the ceramic, glass, or plastic containers usually remain cool, even though the food can become hot. Why is this?
- Doctors and dentists often use X rays for medical imaging. Why are X rays useful for this purpose?
- Give one reason why communications satellites don't use ultraviolet waves to transmit and receive information.
- Could an electromagnetic wave travel through space if its electric and magnetic fields were not changing with time? Explain.
- Electromagnetic waves consist of vibrating electric and magnetic fields. Even though a magnetic field can make a compass needle move, a compass needle doesn't move when light strikes it. Explain.



Developing Skills

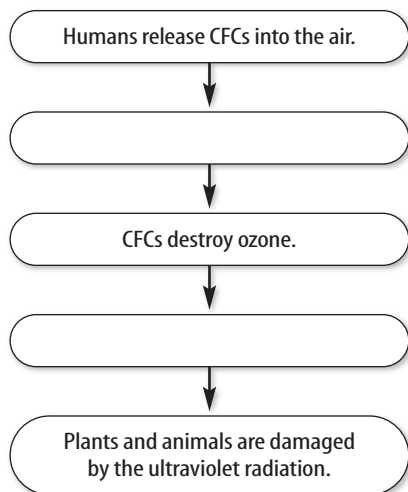
16. Developing Multimedia Presentations

Create a multimedia presentation on how radio waves are used for communication.

17. Classifying Look around your home, school, and community. Make a list of the many types of technology that use electromagnetic waves. Beside each item, write the type of electromagnetic wave it uses.

18. Writing a Paper Some people warn that microwaves from cell phones can be harmful. Research this problem and write a paper describing your opinion.

19. Concept Mapping Copy the diagram and fill in the missing events about ozone destruction.



Performance Assessment

20. Observe and Infer Tune a radio to various AM and FM frequencies. Notice how strong or weak the signals are at various times of the day and night. Record your observations in your Science Journal.

TECHNOLOGY

Go to the Glencoe Science Web site at science.glencoe.com or use the Glencoe Science CD-ROM for additional chapter assessment.



Test Practice

Because radio waves can reflect off objects, they are used to detect an object's location. The two rescue ships below are using radio waves to search for a lifeboat.



Study the picture and answer the following questions.

- What do the rescuers need to know to help find the lifeboat?
 - the strength of the carrier wave
 - the amplitude and frequency of the radio waves that were sent out
 - the frequency of the reflected radio waves
 - the direction from which the reflected radio waves came
- Why will the rescuers detect the reflected radio waves at different times?
 - The speed of the radio waves leaving each ship is different.
 - The life boat is a different distance from each ship.
 - Only one ship is sending radio waves.
 - The lifeboat is avoiding detection.