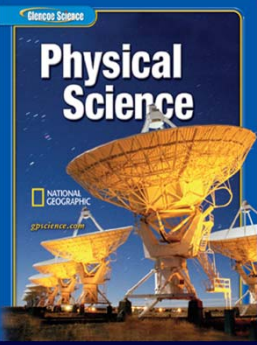


12



Physical Science

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CHAPTER RESOURCES

END

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Chapter 12: Electromagnetic Waves

12.1: What are electromagnetic waves?

12.2: The Electromagnetic Spectrum

12.3: Radio Communication


CHAPTER RESOURCES

END

What are electromagnetic waves?

12.1 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.
- Both waves are moving through matter.




CHAPTER RESOURCES

END

What are electromagnetic waves?

12.1 Sound and Water Waves

- The sound wave is moving through air and the water wave through water.
- Without matter to transfer the energy, they cannot move.



CHAPTER RESOURCES

END

What are electromagnetic waves?

12.1 Electromagnetic Waves

- 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.

CHAPTER RESOURCES

END

What are electromagnetic waves?

12.1 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.

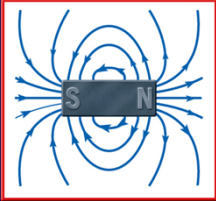
CHAPTER RESOURCES

END

What are electromagnetic waves?

12.1 Electric and Magnetic Fields

- The magnet exerts a force without touching the paper clip because all magnets are surrounded by a magnetic field.
- Magnetic fields exist around magnets even if the space around the magnet contains no matter.




CHAPTER RESOURCES

END

What are electromagnetic waves?

12.1 Electric and Magnetic Fields

- Just as magnets are surrounded by magnetic fields, electric charges are surrounded by electric fields.
- An electric field enables charges to exert forces on each other even when they are far apart.
- An electric field exists around an electric charge even if the space around it contains no matter.



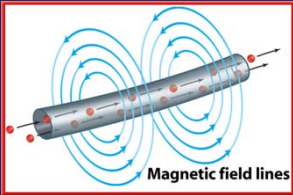
CHAPTER RESOURCES

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What are electromagnetic waves?

12.1 Magnetic Fields and Moving Charges

- Electric charges also can be surrounded by magnetic fields.
- An electric current flowing through a wire is surrounded by a magnetic field, as shown.



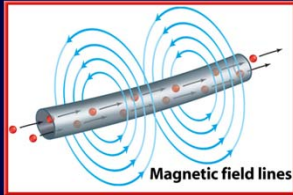
CHAPTER RESOURCES

END

What are electromagnetic waves?

12.1 Magnetic Fields and Moving Charges

- An electric current in a wire is the flow of electrons in a single direction.
- It is the motion of these electrons that creates the magnetic field around the wire.



CHAPTER RESOURCES

END

What are electromagnetic waves?

12.1 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.

CHAPTER RESOURCES

END

What are electromagnetic waves?

12.1 Making Electromagnetic Waves

- Electromagnetic waves are produced when something vibrates—an electric charge that moves back and forth.
- When an electric charge vibrates, the electric field around it changes.
- Because the electric charge is in motion, it also has a magnetic field around it.

CHAPTER RESOURCES

END

What are electromagnetic waves?

12.1

Making Electromagnetic Waves

- This magnetic field also changes as the charge vibrates.
- As a result, the vibrating electric charge is surrounded by changing electric and magnetic fields.



CHAPTER RESOURCES



END

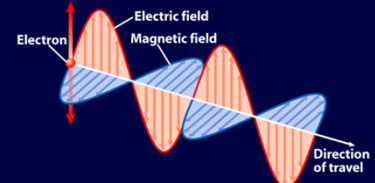
What are electromagnetic waves?

12.1

Making Electromagnetic Waves

- A vibrating electric charge creates an electromagnetic wave that travels outward in all directions from the charge.

- The wave in only one direction is shown here.



CHAPTER RESOURCES



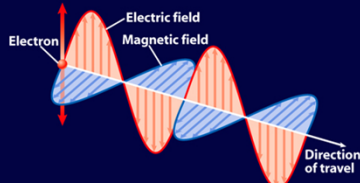
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What are electromagnetic waves?

12.1

Making Electromagnetic Waves

- Because the electric and magnetic fields vibrate at right angles to the direction the wave travels, an electromagnetic wave is a transverse wave.



CHAPTER RESOURCES



END

What are electromagnetic waves?

12.1

Properties of Electromagnetic Waves

- All objects emit electromagnetic waves.
- The wavelengths of the emitted waves become shorter as the temperature of the material increases.



CHAPTER RESOURCES



END

What are electromagnetic waves?

12.1

Properties of Electromagnetic Waves

- 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.



CHAPTER RESOURCES



END

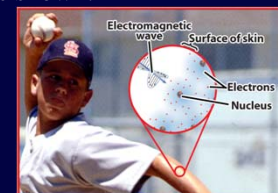
What are electromagnetic waves?

12.1

Properties of Electromagnetic Waves

- For example, electromagnetic waves from the Sun cause electrons in your skin to vibrate and gain energy, as shown.

- The energy carried by an electromagnetic wave is called radiant energy.



CHAPTER RESOURCES



END

What are electromagnetic waves?

12.1

Wave Speed

- All electromagnetic waves travel at 300,000 km/s in the vacuum of space.
- The speed of electromagnetic waves in space is usually called the “speed of light.”



CHAPTER RESOURCES



END

What are electromagnetic waves?

12.1

Wave Speed

- Nothing travels faster than the speed of light.
- In matter, the speed of electromagnetic waves depends on the material they travel through.

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



CHAPTER RESOURCES



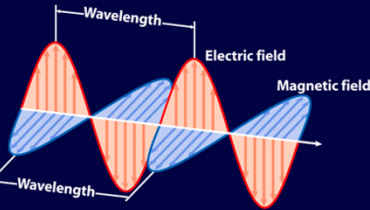
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What are electromagnetic waves?

12.1

Wavelength and Frequency

- The wavelength of an electromagnetic wave is the distance from one crest to another.
- The frequency of any wave is the number of wavelengths that pass a point in 1 s.



CHAPTER RESOURCES



END

What are electromagnetic waves?

12.1

Wavelength and Frequency

- The frequency of an electromagnetic wave also equals the frequency of the vibrating charge that produces the wave.
- This frequency is the number of vibrations, or back and forth movements, of the charge in one second.
- As the frequency increases, the wavelength becomes smaller.



CHAPTER RESOURCES



END

What are electromagnetic waves?

12.1

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.



CHAPTER RESOURCES



END

What are electromagnetic waves?

12.1

Waves and 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.



CHAPTER RESOURCES



END

What are electromagnetic waves?

12.1

Waves and Particles

- 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—electromagnetic waves can behave as a particle, called a **photon**, whose energy depends on the frequency of the waves.



CHAPTER RESOURCES



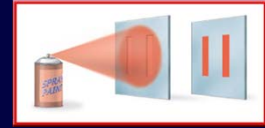
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What are electromagnetic waves?

12.1

Particles as Waves

- Because electromagnetic waves 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.



CHAPTER RESOURCES



END

What are electromagnetic waves?

12.1

Particles as Waves

- Instead, it was found that the electrons formed an interference pattern.
- This type of pattern is produced by waves when they pass through two slits and interfere with each other.



CHAPTER RESOURCES



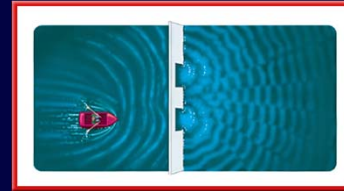
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What are electromagnetic waves?

12.1

Particles as Waves

- Water waves produce an interference pattern after passing through two openings.



- It is now known that all particles, not only electrons, can behave like waves.



CHAPTER RESOURCES



END

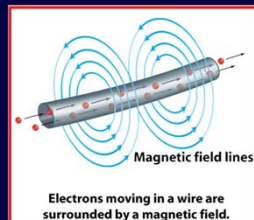
Section Check

12.1

Question 1

What is represented by the blue lines in this figure?

- an electric charge
- an electric field
- a magnetic field
- electromagnetic waves



CHAPTER RESOURCES



END

Section Check

12.1

Answer

The answer is C. Electrons moving in a wire are surrounded by a magnetic field.



CHAPTER RESOURCES



END

Section Check

12.1

Question 2

Describe the major difference between electromagnetic waves and sound waves.

Answer

Sound waves require matter in order to travel; electromagnetic waves can travel where matter is not present.

CHAPTER RESOURCES

END

Section Check

12.1

Question 3

An electromagnetic wave is a(n) _____ wave.

A. longitudinal
B. opaque
C. pitch
D. transverse

CHAPTER RESOURCES

END

Section Check

12.1

Answer

The answer is D. Electromagnetic waves travel in directions that are perpendicular to their electric and magnetic fields.

CHAPTER RESOURCES

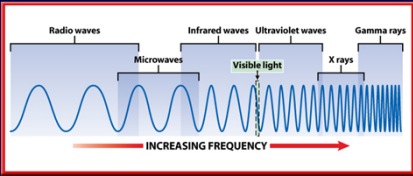
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The Electromagnetic Spectrum

12.2

A Range of Frequencies

- Electromagnetic waves can have a wide variety of frequencies.
- The entire range of electromagnetic wave frequencies is known as the electromagnetic spectrum.



CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2

Radio Waves

- Even though radio waves carry information that a radio uses to create sound, you can't hear radio waves.
- You hear a sound wave when the compressions and rarefactions the sound wave produces reach your ears.
- A radio wave does not produce compressions and rarefactions as it travels through air.

CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2

Microwaves

- Radio waves** are low-frequency electromagnetic waves with wavelengths longer than about 1 mm.
- Radio waves with wavelengths of less than 1 mm are called **microwaves**.

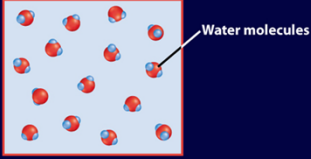
CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **Microwaves**

- You are probably most familiar with microwaves because of their use in microwave ovens.
- Microwave ovens heat food when microwaves interact with water molecules in food, as shown.



Water molecules

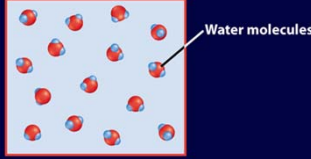
CHAPTER RESOURCES

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The Electromagnetic Spectrum

12.2 **Microwaves**

- Each water molecule is positively charged on one side and negatively charged on the other side.



Water molecules

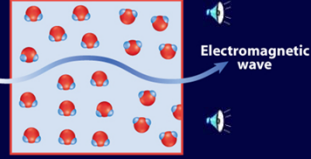
CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **Microwaves**

- The vibrating electric field inside a microwave oven causes water molecules in food to rotate back and forth billions of times each second.
- This rotation causes a type of friction between water molecules that generates thermal energy.



Electromagnetic wave

CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **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.


CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **Magnetic Resonance Imaging (MRI)**

- Magnetic Resonance Imaging uses radio waves to help diagnose illness.
- The patient lies inside a large cylinder.
- Housed in the cylinder is a powerful magnet, a radio wave emitter, and a radio wave detector.



CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **Magnetic Resonance Imaging (MRI)**

- 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.

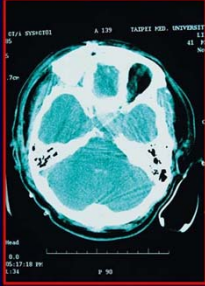
CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **Magnetic Resonance Imaging (MRI)**

- A radio receiver detects this released energy.
- The released energy detected by the radio receiver is used to create a map of the different tissues.



CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **Infrared Waves**

- When you stand in front of a fireplace, you feel the warmth of the blazing fire.
- 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.


CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **Infrared Waves**

- You use infrared waves every day. A remote control emits infrared waves to control your television.
- Every object emits infrared waves.



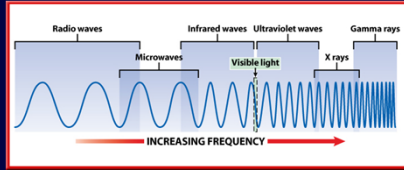
CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **Visible Light**

- Visible light** is the range of electromagnetic waves that you can detect with your eyes.
- Visible light has wavelengths around 750 billionths to 400 billionths of a meter.



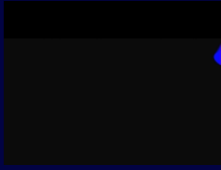
CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **Visible Light**

- 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.



Click image to view movie

CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **Ultraviolet Waves**

- Ultraviolet waves** are electromagnetic waves with wavelengths from about 400 billionths to 10 billionths of a meter.
- Overexposure to ultraviolet rays can cause skin damage and cancer.

CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **Ultraviolet Waves**

- 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.

CHAPTER RESOURCES

The Electromagnetic Spectrum

12.2 **Useful UVs**

- 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.

CHAPTER RESOURCES

The Electromagnetic Spectrum

12.2 **Useful UVs**

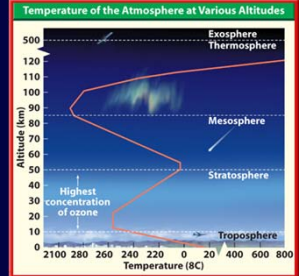
- Ultraviolet waves are also useful because they make some materials fluoresce (floor ES).
- Fluorescent materials absorb ultraviolet waves and reemit the energy as visible light.
- Police detectives sometimes use fluorescent powder to show fingerprints when solving crimes.

CHAPTER RESOURCES

The Electromagnetic Spectrum

12.2 **The Ozone Layer**

- About 20 to 50 km above Earth's surface in the stratosphere is a region called the ozone layer.

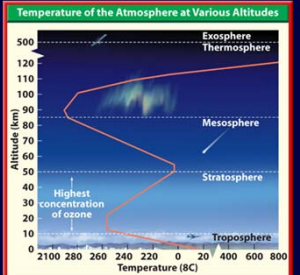


CHAPTER RESOURCES

The Electromagnetic Spectrum

12.2 **The Ozone Layer**

- Ozone is a molecule composed of three oxygen atoms. It is continually being formed and destroyed by ultraviolet waves high in the atmosphere.




CHAPTER RESOURCES

The Electromagnetic Spectrum

12.2 **The Ozone Layer**

- The decrease in ozone is caused by the presence of certain chemicals, such as CFCs, high in Earth's atmosphere.
- CFCs are chemicals called chlorofluorocarbons that have been widely used in air conditioners, refrigerators, and cleaning fluids.

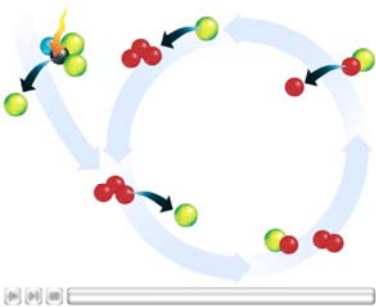


CHAPTER RESOURCES

The Electromagnetic Spectrum

12.2 **The Ozone Layer**

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



MAC OSX users click here to view.

CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **X Rays and Gamma Rays**

- The electromagnetic waves with the shortest wavelengths and highest frequencies are X rays and gamma rays.
- Both X rays and gamma rays are high energy electromagnetic waves.


CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **X Rays and Gamma Rays**

- X rays have wavelengths between about ten billionths of a meter and ten trillionths of a meter.
- Doctors use low doses of X rays to form images of internal organs.



CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **X Rays and Gamma Rays**

- Electromagnetic waves with wavelengths shorter than about 10 trillionths of a meter are gamma rays.
- These are the highest-energy electromagnetic waves and can penetrate through several centimeters of lead.

CHAPTER RESOURCES

END

The Electromagnetic Spectrum

12.2 **X Rays and Gamma Rays**

- Gamma rays are produced by processes that occur in atomic nuclei.
- Both X rays and gamma rays are used in a technique called radiation therapy to kill diseased cells in the human body.

CHAPTER RESOURCES

END

Section Check

12.2

Question 1

Which has the highest frequency?

- infrared waves
- microwaves
- radio waves
- visible light

CHAPTER RESOURCES

END

Section Check

12.2

Answer

The answer is D. Visible light has wavelengths from 400 to 750 nm.

CHAPTER RESOURCES

END

Section Check

12.2

Question 2

What is the range of wavelengths of X-rays?

A. $10^2 - 10^4$ m
 B. 1 - 2 m
 C. $10^{-2} - 10^{-4}$ m
 D. $10^{-8} - 10^{-12}$ m

CHAPTER RESOURCES

END

Section Check

12.2

Answer

The answer is D. X-rays are high-energy electromagnetic waves.

CHAPTER RESOURCES

END

Section Check

12.2

Question 3

What range of electromagnetic waves can you detect with your eyes?

Answer

Visible light is the range of electromagnetic waves that you can detect with your eyes and has wavelengths from 750 billionths to 400 billionths of a meter.

CHAPTER RESOURCES

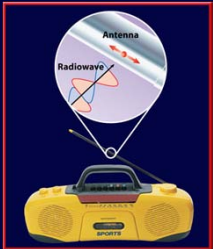
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Radio Communication

12.3

Radio Transmission

- Music and words are sent to your radio by radio waves. The metal antenna of your radio detects radio waves.
- As the electromagnetic waves pass by your radio's antenna, the electrons in the metal vibrate.



CHAPTER RESOURCES

END

Radio Communication

12.3

Radio Transmission

- These vibrating electrons produce a changing electric current that contains the information about the music and words.
- An amplifier boosts the current and sends it to speakers, causing them to vibrate.
- The vibrating speakers create sound waves that travel to your ears.

CHAPTER RESOURCES

END

Radio Communication

12.3 Dividing the Radio Spectrum

- 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.

? CHAPTER RESOURCES < > END

Radio Communication

12.3 AM Radio

- An AM radio station broadcasts information by varying the amplitude of the carrier wave, as shown.
- Your radio detects the variations in amplitude of the carrier wave and produces a changing electric current from these variations.

? CHAPTER RESOURCES < > END

Radio Communication

12.3 AM Radio

- The changing electric current makes the speaker vibrate.
- AM carrier wave frequencies range from 540,000 to 1,600,000 Hz.

? CHAPTER RESOURCES < > END

Radio Communication

12.3 FM Radio

- Electronic signals are transmitted by FM radio stations by varying the frequency of the carrier wave.
- Your radio detects the changes in frequency of the carrier wave.

? CHAPTER RESOURCES < > END

Radio Communication

12.3 FM Radio

- Because the strength of the FM waves is kept fixed, FM signals tend to be more clear than AM signals.
- The graph shows how radio signals are broadcast.

Service	Frequency Range (Hz)
Cell phone	1 billion
TV	100 million - 1 billion
FM TV	10 million - 100 million
AM	1 million - 10 million

? CHAPTER RESOURCES < > END

Radio Communication

12.3 Television

- 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.

? CHAPTER RESOURCES < > END

Radio Communication

12.3 **Cathode-Ray Tubes**

- 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.

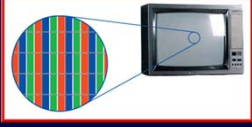
CHAPTER RESOURCES

END

Radio Communication

12.3 **Cathode-Ray Tubes**

- 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.



- An image is created when the three electron beams of the CRT sweep back and forth across the screen.

CHAPTER RESOURCES

END

Radio Communication

12.3 **Telephones**

- 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.



CHAPTER RESOURCES

END

Radio Communication

12.3 **Telephones**

- 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.

CHAPTER RESOURCES

END

Radio Communication

12.3 **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. 🗣️
- Cordless telephones work much like cell phones. With a cordless telephone, however, you must be close to the base unit.


CHAPTER RESOURCES

END

Radio Communication

12.3 **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 callback number through a telephone keypad or by entering a text message from a computer.



CHAPTER RESOURCES

END

Radio Communication

12.3 **Pagers**

- At the terminal, the message is changed into an electronic signal and transmitted by radio waves.
- 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.

CHAPTER RESOURCES

Radio Communication

12.3 **Communications Satellites**

- Since satellites were first developed, thousands have been launched into Earth's orbit. Communications satellites use solar panels to provide the electrical energy they need to communicate with receivers on Earth.

CHAPTER RESOURCES

Radio Communication

12.3 **Communications Satellites**

- A station broadcasts a high-frequency microwave signal to the satellite.
- To avoid interference, the frequency broadcast by the satellite is different than the frequency broadcast from Earth.

CHAPTER RESOURCES

Radio Communication

12.3 **Satellite Telephone Systems**


- 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.

CHAPTER RESOURCES

Radio Communication

12.3 **Television Satellites**

- 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.



CHAPTER RESOURCES

Radio Communication

12.3 **Television Satellites**

- Short-wavelength microwaves travel more easily through the atmosphere.
- The ground receiver dishes are rounded to help focus the microwaves onto an antenna.

CHAPTER RESOURCES

Radio Communication

12.3 **The Global Positioning System**

- The **Global Positioning System (GPS)** is a system of satellites, ground monitoring stations, and receivers that determine your exact location at or above Earth's surface.
- 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.

? CHAPTER RESOURCES < > END

Radio Communication

12.3 **The Global Positioning System**

- Signals from four satellites are needed to determine the location of an object using a GPS receiver.



? CHAPTER RESOURCES < > END

Section Check

12.3

Question 1

What is a carrier wave?

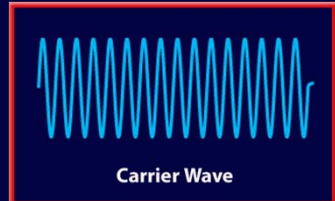
? CHAPTER RESOURCES < > END

Section Check

12.3

Answer

A carrier wave is the specific frequency of the electromagnetic wave that a radio station is assigned.



? CHAPTER RESOURCES < > END

Section Check

12.3

Question 2

Why do FM radio signals tend to be clearer than AM signals?

Answer

The strength of FM waves is kept fixed, but AM signals are amplitude modulated signals and vary in strength.

? CHAPTER RESOURCES < > END

Section Check

12.3

Question 3

What is the system of satellites, ground monitoring stations, and receivers that can determine your exact location at Earth's surface?

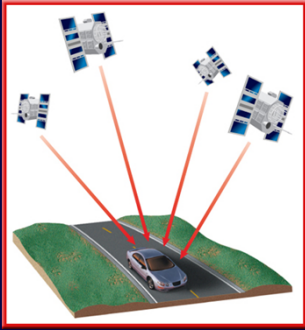
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Section Check

12.3

Answer

A Global Positioning System uses signals from orbiting satellites to determine the receiver's location.






The diagram shows four GPS satellites in orbit above a green landscape with a road. Red lines represent signals being transmitted from the satellites to a silver car on the road, which is the receiver.

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Help

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