chapter 11

Electromagnetic Waves

section 1 What are electromagnetic waves?

What You'll Learn

- how electromagnetic waves are formed
- how electric charges produce electromagnetic waves
- properties of electromagnetic waves

Before You Read

Light is transmitted by electromagnetic waves. Without light, you would not be able to see. On the lines below, write three things you could not do without light.

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Study Coach

Summarize As you read, summarize the key information under each heading in one or two sentences.

Read to Learn

Electromagnetic Waves

No matter where you are, you are surrounded by electromagnetic waves. You can't see them or feel them. But some of these waves are passing through your body right now. Electromagnetic waves make it possible for you to see. They make your skin feel warm. You use electromagnetic waves when you watch TV, talk on a cordless phone, or make popcorn in a microwave oven.

How do sound and water waves move?

Waves are produced when something vibrates. They carry energy from one place to another. Both sound waves and water waves move through matter. Sound waves move through matter that is solid, liquid, or gas. Water waves move through water, a liquid. Sound waves and water waves travel because energy is transferred from one particle to another particle.

Reading Check

1. **Apply** What vibrates when electromagnetic waves transfer energy?

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How are electromagnetic waves made?

Electromagnetic waves do not need matter to transfer energy. **Electromagnetic waves** are made by vibrating electric charges and can travel through space where there is no matter. Electromagnetic waves do not transfer energy from particle to particle. Instead, they travel by transferring energy between vibrating electric and magnetic fields.

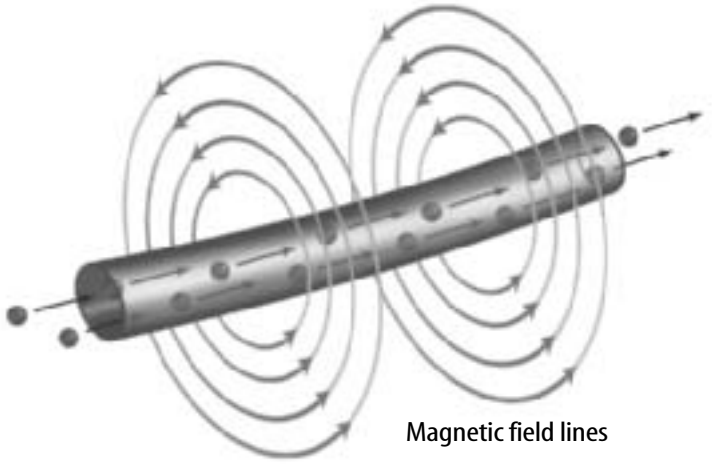
Electric and Magnetic Fields

What happens if you move a magnet close to a metal paper clip? The paper clip moves toward the magnet and sticks to it. The magnet moves the paper clip without touching it because every magnet is surrounded by a magnetic field. There is a magnetic field around magnets even if the space around the magnets contains no matter.

Electric charges are surrounded by electric fields in the same way. An electric field surrounds an electric charge even if the space around the charge has no matter. An electric field allows electric charges to exert forces on each other even when they are far apart.

How do moving charges create magnetic fields?

An electric charge is surrounded by an electric field. Electric charges also can be surrounded by magnetic fields. An electric current in a wire is the flow of electrons in one direction. The movement of these electrons creates a magnetic field around the wire as shown in the figure. So, any moving electric charge is surrounded by an electric field and a magnetic field.



Magnetic field lines

What happens when electric and magnetic fields change?

A changing magnetic field creates a changing electric field. One example of this relationship can be seen in a transformer. A transformer transfers electric energy from one circuit to another circuit. In the main coil of a transformer, changing electric current produces a changing magnetic field. This changing magnetic field then creates a changing electric field in another coil. This electric field produces an electric current in the coil. The reverse is also true. A changing electric field creates a changing magnetic field.

Think it Over

2. Draw Conclusions How could you test an object to see if it has a magnetic field?

Picture This

3. Label the electrons moving through the wire. What is the flow of electrons in one direction in a wire called?

Reading Check

4. **Identify** What is produced when an electric charge vibrates?

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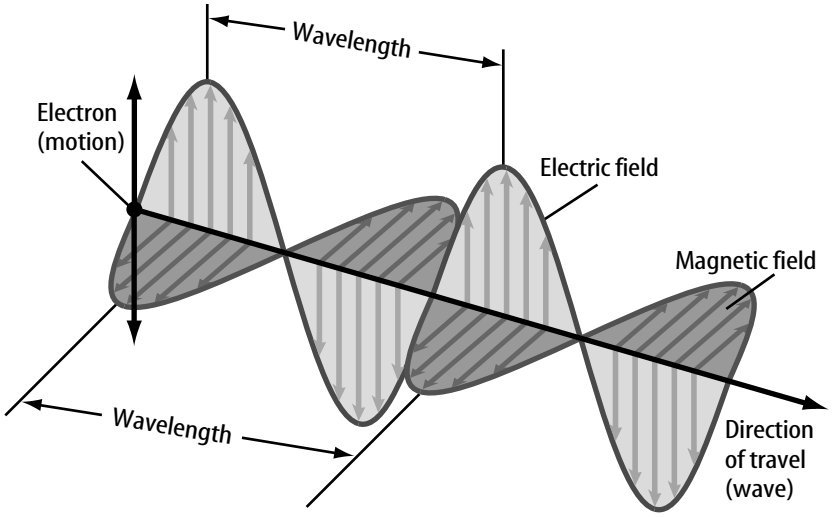
Picture This

5. **Trace** Use a highlighter to trace the magnetic field. Use a pencil to trace the electric field.

Making Electromagnetic Waves

Waves are made when something vibrates. **Electromagnetic waves** are made when an electric charge vibrates. When an electric charge vibrates, the electric field around it changes. Remember, a changing electric field creates a changing magnetic field. Then the changing magnetic field creates a changing electric field. How do the changing fields become a wave? Look at the figure below. This process of changing electric and magnetic fields continues. The magnetic and electric fields create each other again and again.



Electromagnetic Wave

Properties of Electromagnetic Waves

An electromagnetic wave travels in all directions. The figure shows a wave traveling in only one direction. The electric and magnetic fields vibrate at right angles to the direction the wave travels. Remember, in a transverse wave, the matter in the medium moves at a right angle to the direction the wave travels. So, an electromagnetic wave is a transverse wave.

All matter contains charged particles that are always moving. Therefore, all objects emit electromagnetic waves. The wavelengths of the waves become shorter as the temperature of the material increases. As an electromagnetic wave moves, its electric and magnetic fields meet objects. These vibrating fields can exert forces on charged particles and magnetic materials. The forces make the charged particles and magnetic materials move. For example, electromagnetic waves from the Sun cause the electrons in your skin to vibrate and gain energy. The energy carried by an electromagnetic wave is radiant energy. Radiant energy makes a fire feel warm. Radiant energy also allows you to see.

What is the speed of electromagnetic waves?

All electromagnetic waves travel at 300,000 km/s in a vacuum. Light is an electromagnetic wave. So, the speed of electromagnetic waves in a vacuum is usually called the speed of light. The speed of light is nature's speed limit. Nothing in the universe can travel faster than the speed of light. The speed of electromagnetic waves through matter depends on what material the waves travel through. Electromagnetic waves usually travel slowest in solids and fastest in gases. The table shows the speed of visible light in some materials.

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

Applying Math

6. **Calculate** Use the table at left. The average distance from the Sun to Earth is about 150,000,000 km. About how long does it take light from the Sun to reach Earth? Round your answer to the nearest minute.

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What are the wavelength and frequency of an electromagnetic wave?

Electromagnetic waves can be described by their wavelengths and frequencies. Look at the figure on the previous page. The wavelength is the distance from the top of one wave to the top of the next wave.

The frequency of any wave is the number of wavelengths that pass a point in 1 s. The frequency of an electromagnetic wave is the same as the frequency of the vibrating charge that makes the wave. This frequency is the number of vibrations of the charge in one second. As the frequency of an electromagnetic wave increases, the wavelength becomes smaller.

Picture This

7. **Draw and Label** On your own paper, draw two electromagnetic waves. The wavelength of the second wave should be half the wavelength of the first wave. Label the wavelength of each wave.

Waves and Particles

The difference between a wave and a particle might seem obvious. A wave is a disturbance that carries energy. A particle is a piece of matter. But the difference is really not so clear.

FOLDABLES™

A Find Main Ideas Make two quarter-sheets of paper into note cards to organize information about waves and particles.

Picture This

8. Describe Look at the second part of the figure showing electrons being sprayed at two slits. Describe the pattern that they form.

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Can a wave be a particle?

In 1887, a scientist named Heinrich Hertz discovered that when light is shined on a metal, electrons are ejected from the metal. Hertz found that whether or not electrons were ejected depended on the frequency of the light and not the amplitude. This result seemed mysterious because the energy carried by a sound wave depends on its amplitude and not on its frequency. Years later, Albert Einstein explained Hertz's discovery. Electromagnetic waves can behave as a particle, called a **photon**, whose energy depends on the frequency of the waves.

Can a particle be a wave?

The discovery that electromagnetic waves could behave as a particle led to other questions. Scientists wondered whether matter could behave as a wave.

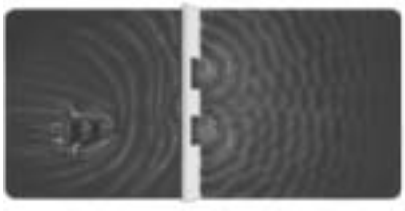
Look at the figure below. The first part shows paint particles being sprayed at two narrow openings, or slits. The paint particles cover only the area behind the slits.

The second part shows a beam of electrons being sprayed at two slits. You might expect the electrons to strike only the area behind the slits. But scientists found that electrons form an interference pattern.

Paint particles sprayed at two slits coat only the area behind the slits.

Electrons fired at two slits form an interference pattern, similar to patterns made by waves.

An interference pattern is formed by waves when they pass through two slits and interfere with each other. The pattern is like the one made by water waves in the diagram below. The experiment with two slits shows that electrons can behave like waves. In fact, all particles, not only electrons, can behave like waves.



Water waves make an interference pattern after they pass through two slits.

After You Read

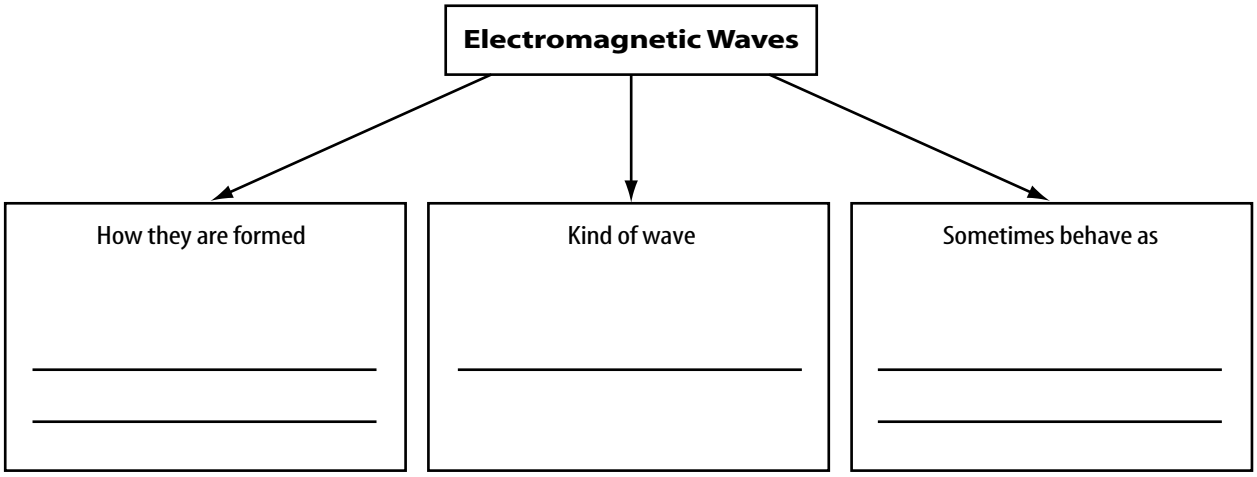
Mini Glossary

electromagnetic waves: waves made by vibrating electric charges that can travel through space where there is no matter

photon: an electromagnetic wave that behaves like a particle and whose energy depends on the frequency of the waves

1. Review the terms and their definitions in the Mini Glossary. Choose one term and use it in a sentence that shows your understanding of the term.

2. Write a fact about electromagnetic waves on the lines under each heading.



3. Study Coach As you read this section, you summarized the important information under each heading. How did that strategy help you learn the material in this section?

End of Section