NAVES, ELECTRICITY, AND MAGNETISM

For electricity and magnetism, this section focuses on the concepts that the motion of electric charges s caused by the presence of an electric force, that there is a fundamental connection between a moving charged particle and the presence of electric and magnetic fields, and that in a closed circuit the movement of electrically charged particles (current) is modified by the amount of resistance in the circuit and the amount of energy (electrical potential energy) that is available for the charged particles to move. In addition, the section builds an understanding of the implications of different simple circuit configurations (series and parallel circuits), in the movement of electrically charged particles through them, and the circuits' uses in real life situations.

By studying this section you will develop the understanding that electric and magnetic forces are different aspects of a single electromagnetic interaction. These forces are both repulsive and attractive, depending on the sign of the electric charges involved or the orientation of the magnets. Charged particles are sources of electric fields and can be affected by the electric fields generated by other charged particles. Magnets and charged particles in motion are sources of magnetic fields and can also be affected by magnetic fields generated by other sources. The magnitude of electric forces depends on the size of the charges and the distance between them. The magnitude of magnetic forces depends on the magnitude of the electric current or magnetic strength and the distance between the objects.

In an electric circuit, electric charges continually flow through a complete loop, returning to their origin and cycling through the loop again. In order for an electrically charged particle to move, energy must be provided to increase the electric potential energy of the charged particle.

The section also covers the behavior of waves. Energy can travel over great distances in the form of waves. The two significant types of waves for this course are mechanical waves and electromagnetic waves. The most familiar type of electromagnetic wave is visible light. However, electromagnetic waves also include radio, microwaves, infrared, ultraviolet, X rays, and gamma radiation that can travel through air; liquids, such as water; or solid objects.

CORE IDEAS

- An electric current requires a complete circuit and a voltage source. (SPS10a, b)
- The amount of current that flows in a circuit depends on both the resistance of the circuit and the voltage of the source. (SPS10a)
- In a series circuit, the same amount of current flows through all the components. (SPS10b)
- In a parallel circuit, the voltage drop across each branch of the circuit is equal and is also equal to the voltage of the power source. (SPS10b)
- In a direct-current circuit, the electrons flow in only one direction. (SPS10b)
- In an alternating current, the motion of the electrons alternates back and forth, due to the changing polarity of the voltage source. (SPS10b)
- Charges in motion generate magnetic fields. (SPS10c)
- Variable magnetic fields induce currents in a circuit. (SPS10c)
- A moving electrical charge, or current, in a magnetic field experiences a force. (SPS10c)
- Waves carry energy that can be transferred or transformed in interactions with matter or other waves. (SPS9a)
- The pitch of a sound is a measure of its frequency. (SPS9d)
- Although electromagnetic and mechanical waves share some characteristics, they are different in the way they are generated and transfer energy. (SPS9b)
- The speed at which sound travels is dependent upon the material in which it travels. (SPS9d)

- As a wave encounters another medium, it may be reflected and/or refracted. (SPS9c, d)
- As a wave encounters an obstacle or an opening, it may be reflected, refracted, and/or diffracted. (SPS9c)
- Two waves that meet will create a pattern of interference. (SPS9c)
- The energy of a wave can be determined from the wave's physical characteristics. (SPS9a)

KEY CONCEPTS

The word **electricity** sounds very much like *electron*. The similarity between the words is no accident. Recall that electrons are negatively charged particles, while protons are positively charged particles. When like charges come near each other, the charges repel each other. When opposite charges come near each other, the charges attract each other.

- In **conduction**, electrons flow through one object into another by direct contact. Silver, copper, aluminum, and magnesium are examples of good conductors. These materials allow electrons to flow freely.
- **Induction** involves electrons being rearranged. No contact needs to occur between two objects for induction to take place. A neutral object only needs to approach a charged object. For example, a negatively charged rubber rod picks up tiny slips of paper by induction. The electrons on the parts of the paper nearest to the rod are pushed away, leaving positive charges. Because the positive charges are closer to the negatively charged rod, the slips of paper are attracted to the rod.

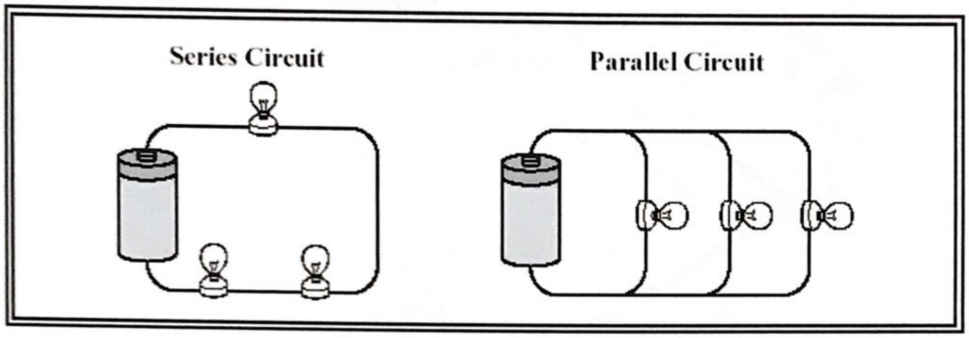
Electric charges leave a charged object during an **electric discharge**. Lightning is probably the most dramatic example of an electric discharge. The repulsion and attraction of particles can be described in terms of **electric fields.** The electric field is an alteration of space caused by the presence of an electric charge. The manifestation of the presence of an electric field results in other charges experiencing an electric force.

The strength of the electric field depends on the magnitude of the electric charge generating the field and decreases inversely proportionally to the square of the distance from the charge.

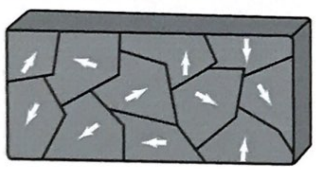
Electric current results from the movement of electric charges. A **circuit** is a complete, closed path for electron flow. A simple circuit consists of a source of electrons (such as a battery), a resistance or load, conducting wires, and a switch. In a battery, electrical energy is produced by a chemical reaction. When charged particles flow through the wire in a circuit, an electric current, represented by the letter **I**, results. The current is measured in amperes whose symbol is A. The electron is the charged particle that most likely moves through the circuit. To get electrons flowing through a circuit, a voltage, represented by the letter V, is applied. **Voltage**, which is measured in volts (symbol V), is the potential difference in electrical potential energy between two places in a circuit. In other words, voltage is the energy per unit of charge that causes charges to move. The opposition to current is called **resistance**, represented by the letter R, which is measured in ohms, represented by the Greek letter capital Omega (Ω). Light bulbs and resistors are examples of objects with resistance. Materials like copper that are good conductors of electricity have low resistance. The resistance of a wire depends on the thickness, length, and temperature of the wire. As a wire is made longer, its resistance increases, while thicker wires have lower resistance. Increasing a wire's temperature will also increase its resistance. Insulators keep electrons from flowing easily. Although electrons move one way through a wire, the current, by convention, is the relative movement of a positive charge. Electrons flow opposite the direction of the current.

Charges can move through a circuit continuously in the same direction, producing a **direct current**, or **DC**. Electrons can also change direction, moving back and forth in cycles. This kind of current is known as **alternating current**, or **AC**. Batteries, such as those found in cars, produce DC, while a gasoline-driven generator usually produces AC.

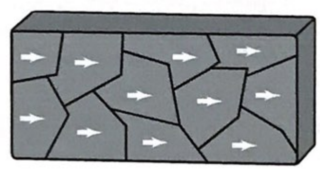
When the electric charges in a circuit have only one path in which to flow, the circuit is called a **series circuit.** If the circuit has different branches in which the electric charges can flow, the circuit is called a **parallel circuit.** Parallel circuits are used in houses. The following box shows examples of these circuits:



An electric current will also produce a magnetic field. A **magnetic field** is a region around a magnet or current-carrying wire where magnetic forces can be measured. **Magnetism** is the force of attraction or repulsion that is caused by the motion of electric charges. Magnets have two poles: a north pole and a south pole. *Unlike* magnetic poles attract each other, while *like* magnetic poles repel each other. Groups of atoms with magnetic poles aligned are called **magnetic domains.** Materials with most of these domains lined up are considered magnetized. When a metal bar or another object is composed of stable magnetic domains, a **permanent magnet** results.



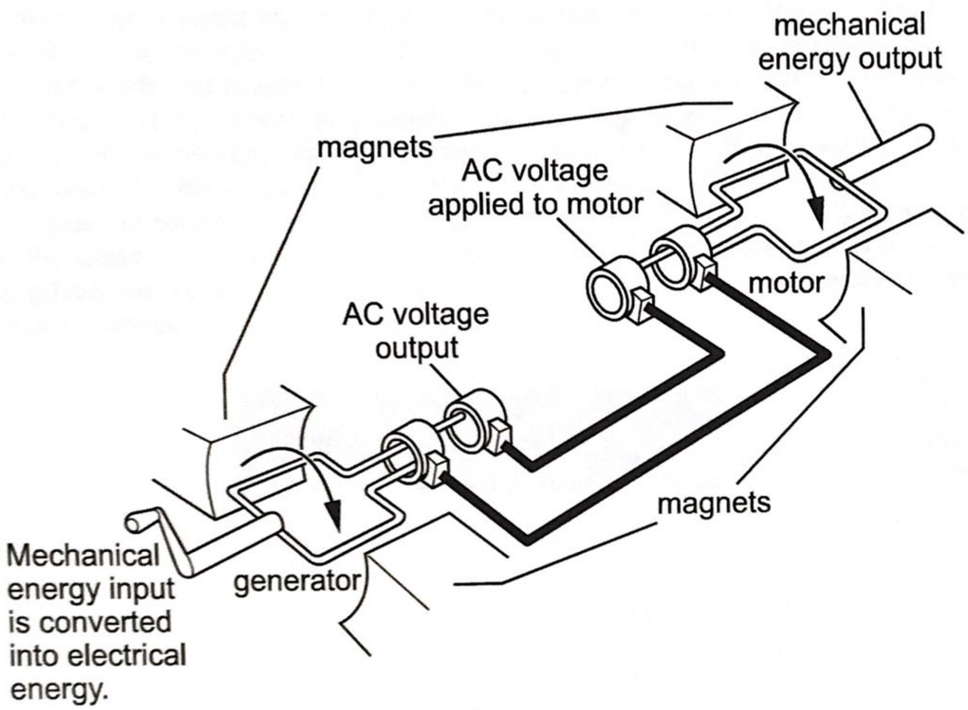
Not Magnetized



Magnetized

When an electric current is used to produce a magnetic field in a coil of wire, the coil becomes an electromagnet. An electromagnet using just a simple wire coil is comparatively weak. Electromagnets can be made stronger by wrapping the coils around a core made of a material that responds to a magnetic field, particularly iron; by using more coils; and by using a stronger electrical current.

When a magnet is moved near a wire, an electric current is generated. This process, called **electromagnetic induction**, is used to operate a **generator.** A generator is a device that converts mechanical energy to electrical energy. In a commercial generator, an electric current is produced when a large coil of wire is rotated in a strong magnetic field.



Waves are phenomena that occur, seen and unseen, all around us. Suppose that a student drops a stone into a pond; the surface of the water becomes disturbed. Some of the kinetic energy of the stone as it falls into the water is transferred to surrounding water molecules. This causes the surface of the water to be disturbed as water molecules move up and down while transferring energy through the water. This energy transfer can be seen moving in all directions through waves moving outward in concentric circles. Particles of matter do not move along with the waves. Only the energy that creates the waves moves with them. Waves by definition are disturbances that repeat the same cycle of motion and transfer energy through matter or empty space.

Mechanical waves (such as sound waves) are similar to electromagnetic waves (such as light waves) in that both types of waves transmit energy over a distance. However, there are some major differences:

- Sound waves require a medium for traveling. Light waves may travel either through a transparent medium or through empty space.
- Sound waves travel through all substances, but light waves are absorbed and reflected by opaque materials so that no light travels through them.
- A sound wave travels slowly through air at a speed of about 340 meters per second at 15°C. Electromagnetic waves, on the other hand, travel through air or the vacuum of space at extremely high speeds of about 300,000,000 meters per second.

Sound waves travel by compressing and stretching the separation of the particles of the medium in which they travel. Because of this, the nature of a medium has a significant effect on the speed of sound. Sound travels faster through solids and liquids than it does through gases because particles are closer together in solids or liquids than in gases. Sound also travels fastest through elastic materials. Elasticity refers to the characteristic of the material allowing it to maintain its shape and not deform when a force is applied to it. For example, sound travels at about 1,500 meters per second in water, but in aluminum, which is more elastic, the speed of sound is about 5,000 meters per second. In materials of the same phase, or state of matter, the speed of sound tends to decrease as the density increases. The molecules of a denser substance have greater inertia and do not move as quickly as molecules of a less dense substance. The table below shows the speed of sound in various substances.

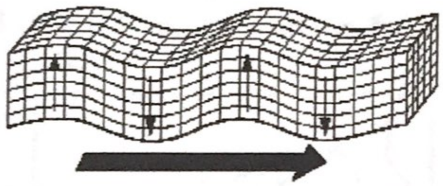
Speed of Sound (at 25°C)		
Substance	State	Speed (m/s)
Air	Gas	346
Helium	Gas	1,016
Ethanol	Liquid	1,144
Water	Liquid	1,494
Steel	Solid	5,000
Lead	Solid	1,320

Because waves involve the transfer of energy, the properties of a wave will change when a wave encounters another wave or an object. Waves undergo four basic interactions. **Reflection** occurs when a wave hits an object that it cannot pass through or when it reaches the boundary of the medium of transmission. Both situations involve the return of the wave as it bounces off the object or medium boundary. **Refraction** takes place when a wave passes from one medium into another at an angle and bends (changes direction) due to a change in speed. **Diffraction** results when a wave passes through a hole or moves past a barrier and spreads out in the region beyond the hole or barrier. Finally, **interference** occurs when two or more waves arrive at the same point at the same time. As a result, they combine to produce a single wave. This new wave will have different properties from the two waves that composed it. For example, when similar parts such as the peaks of the waves line up, the combined wave's amplitude will be larger. When the low part of one wave lines up with the peak of another, the combined amplitude will be smaller.

Sample Questions for Content Domain IV

This section has some sample questions for you to try. After you have answered all the questions, check your answers in the "Answers to the Content Domain IV Sample Questions" section that follows. That section will give you the correct answer to each question and will explain why the other answer choices are incorrect.

1 The following diagram shows a type of earthquake wave called an s-wave.



Besides the wave, what else is moving to the right?

A rocks in the wave
B the wavelength
C energy of the wave
D electromagnetic waves

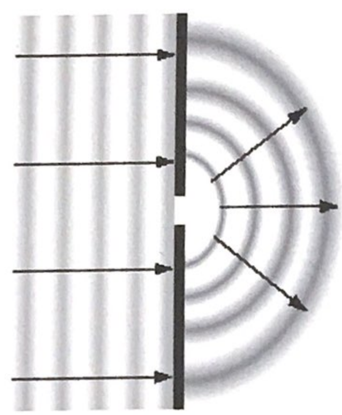
2 A system of filters gradually turns a beam of orange light ($f = 5.0 \times 10^{14}$ Hz) into green light ($f = 6.0 \times 10^{14}$ Hz). Which of the following experiences an increase during the color change?

A wavelength of the wave
B speed of the wave
C average number of photons
D average energy of the photons

3 Sound waves and ultraviolet light waves both share the property of being able to

A move through space
B travel at 300,000 $\frac{m}{s}$
C carry energy
D propagate through rock

4 The following diagram shows what happens to some water waves.



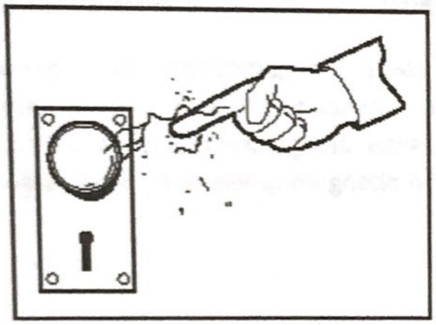
What process are the waves undergoing?

A refraction
B diffraction
C reflection
D interference

5 A truck is blowing its horn as it approaches a bystander at an intersection. According to the Doppler Effect, the bystander will notice that the sound

A decreases in frequency
B increases in wavelength
C increases in pitch
D decreases in speed

6 Use the diagram to answer the question.



A person received an electrical shock when reaching for the metal doorknob. The shock was caused by the

A high number of electrons on the doorknob
B discharge of an imbalance of electrons
C highly conductive surface of the doorknob
D low resistance of the person's skin

7 What is the resistance of an electrical device that allows a current of 10 amperes with 120 volts?

A 12Ω
B 110Ω
C 130Ω
D 1200Ω

8 When a loop of wire is turned at a right angle to Earth's magnetic field, the wire and magnetic field will create a weak

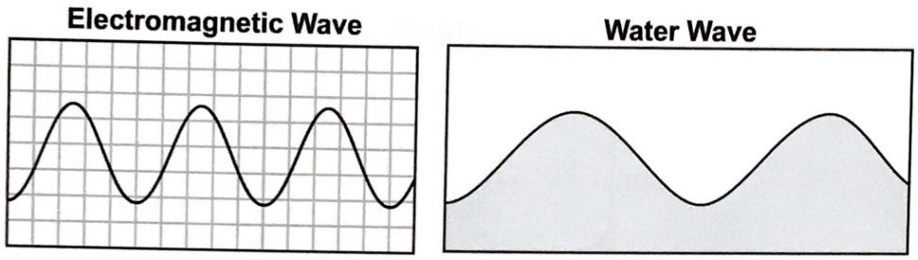
A electric transformer
B electromagnet
C electric motor
D electric generator

SAMPLE ITEMS

Item 15

Selected-Response

A student drew models of an electromagnetic wave and a water wave.



Which scientific question did the student MOST LIKELY ask to know how to draw these models?

A. Are water waves and electromagnetic waves examples of transverse waves?
B. Do water waves travel at a slower speed than electromagnetic waves?
C. Can water waves and electromagnetic waves travel through different media?
D. How do water waves and electromagnetic waves increase their amplitude?

Item 16

Selected-Response

The table compares data for two different light-emitting diodes (LEDs).

LED Type	Emission Wavelength (nanometers)	Current through LED (milliamps)
green diffused	565	40
gallium arsenide	930	120

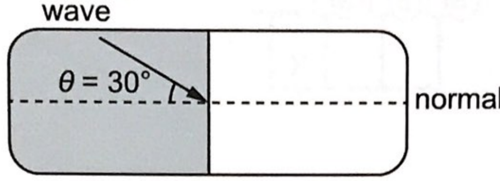
Based on the data, what can be identified about the energy of the waves emitted by the LEDs?

A. The wave energy of the green diffused LED is 1.65 times that of the gallium arsenide LED.
B. The wave energy of the green diffused LED is 0.333 times that of the gallium arsenide LED.
C. The wave energy of the green diffused LED is 0.608 times that of the gallium arsenide LED.
D. The wave energy of the green diffused LED is 3.00 times that of the gallium arsenide LED.

Item 17

Multi-Select Technology-Enhanced

A student is investigating the differences between light waves and sound waves. The student does this by using a capsule filled with solid glass at one end and a vacuum at the other end. The student will transmit waves into the capsule at a 30° angle to the (normal) centerline.



Which TWO questions should the student ask, and which predictions are MOST LIKELY correct based on this investigation?

A. **question:** How are electromagnetic waves and mechanical waves affected when traveling from a solid glass medium to a vacuum?
prediction: The electromagnetic waves and mechanical waves will continue through the vacuum at a lower speed.

B. **question:** How is the speed of electromagnetic waves affected when traveling from a solid glass medium to a vacuum at a 30° angle?
prediction: The electromagnetic waves will travel in a straight line, showing that they have maintained a constant speed.

C. **question:** How are electromagnetic waves and mechanical waves affected when traveling from a solid glass medium to a vacuum?
prediction: The electromagnetic waves will continue through the vacuum, while the mechanical waves will go no farther.

D. **question:** Can electromagnetic waves and mechanical waves travel from a solid glass medium into a liquid medium?
prediction: Both electromagnetic waves and mechanical waves will bend, showing that they have passed through each medium.

E. **question:** How is the speed of electromagnetic waves affected when traveling from a solid glass medium to a vacuum at a 30° angle?
prediction: The electromagnetic waves will bend downward, showing that they have sped up slightly.

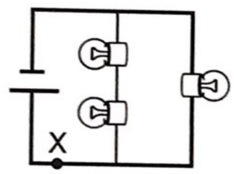
F. **question:** Can electromagnetic waves and mechanical waves travel from a solid glass medium into a liquid medium?
prediction: The electromagnetic waves will continue through the liquid medium, while the mechanical waves will go no farther.

Item 18

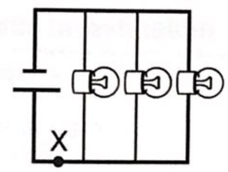
Selected-Response

A student is modeling an electric circuit containing three light bulbs and a battery. Which model shows a circuit where the current flowing through each bulb will be the same as the current at point X?

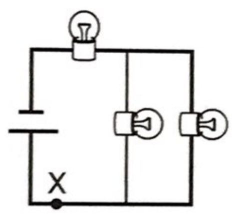
A.



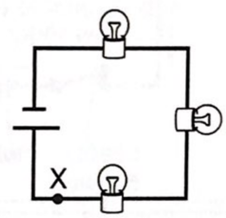
B.



C.



D.

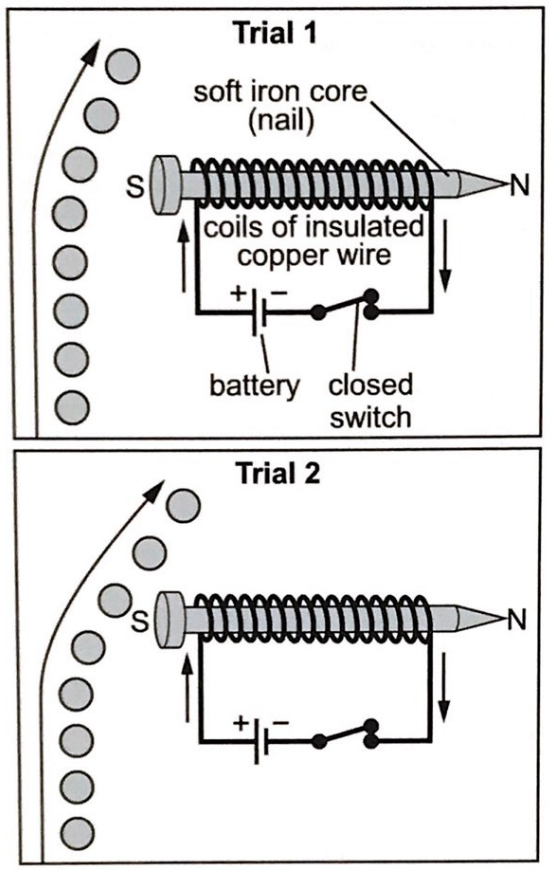


Item 19

Selected-Response

A student did an investigation to determine the effect of a magnetic field on a moving steel sphere. The student recorded the motion of the steel sphere in trial 1 and then drew the desired motion of the steel sphere for trial 2 as shown in the diagram.

Electromagnetic Investigation



If the steel sphere has the same initial velocity in both trials, which action would BEST help to achieve the motion of the steel sphere shown in trial 2?

A. putting a resistor between the battery and switch
B. replacing the nail with one made out of aluminum
C. reversing the direction of the poles of the iron core
D. increasing the number of coils of insulated copper wire

Item 20

Selected-Response

A parallel circuit contains a battery with a voltage of 9 V. The total resistance in the circuit is 18 ohms. Which claim about the current in the circuit can be supported mathematically from the relationships between voltage, current, and resistance?

A. **claim 1:** the current flowing through the circuit is 0.5 amps because current is related to voltage and resistance by the formula $I = V/R$

B. **claim 2:** the current flowing through the circuit is 2 amps because current is related to voltage and resistance by the formula $I = R/V$

C. **claim 3:** the current flowing through the circuit is 27 amps because current is related to voltage and resistance by the formula $I = R + V$

D. **claim 4:** the current flowing through the circuit is 162 amps because current is related to voltage and resistance by the formula $I = VR$