Science 6: Electricity

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CONCEPT 1 Electric Charge and Electric Force

Learning Objectives

- Define electric charge.
- Describe electric forces between charged particles.

A lightning bolt is like the spark that gives you a shock when you touch a metal doorknob. Of course, the lightning bolt is on a *much* larger scale. But both the lightning bolt and spark are a sudden transfer of electric charge.

Introducing Electric Charge

Electric charge is a physical property of particles or objects that causes them to attract or repel each other without touching. All electric charge is based on the protons and electrons in atoms. A proton has a positive electric charge, and an electron has a negative electric charge. In the **Figure** 1.1, you can see that positively charged protons (+) are located in the nucleus of the atom, while negatively charged electrons (-) move around the nucleus.

Electric Force

When it comes to electric charges, opposites attract, so positive and negative particles attract each other. You can see this in the **Figure** 1.2. This attraction explains why negative electrons keep moving around the positive nucleus of the atom. Like charges, on the other hand, repel each other, so two positive or two negative charges push apart. This is also shown in the diagram. The attraction or repulsion between charged particles is called **electric force**. The strength of electric force depends on the amount of electric charge on the particles and the distance between them. Larger charges or shorter distances result in greater force.

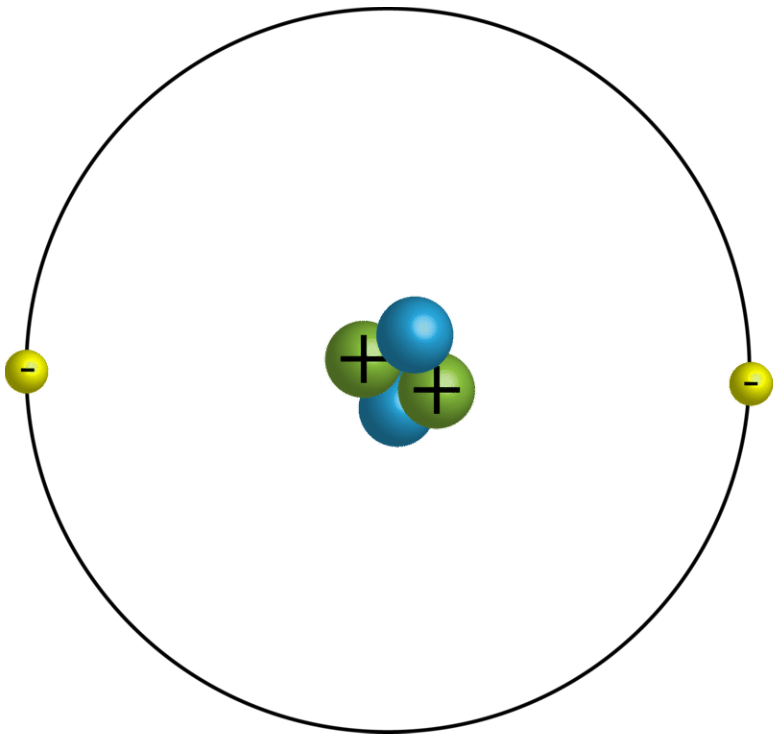


FIGURE 1.1

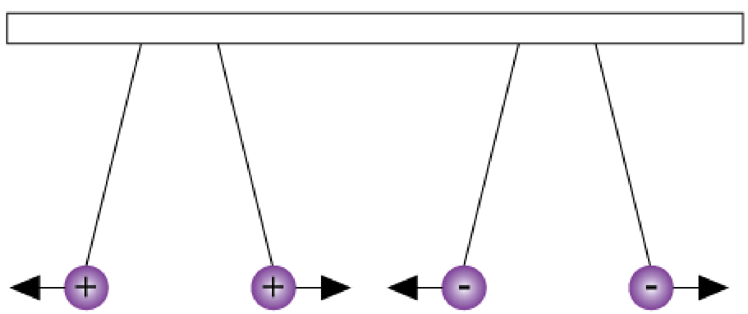


FIGURE 1.2

Q: How do positive protons stay close together inside the nucleus of the atom if like charges repel each other?

A: Other, stronger forces in the nucleus hold the protons together.

Summary

- Electric charge is a physical property of particles or objects that causes them to attract or repel each other without touching.
- Particles that have opposite charges attract each other. Particles that have like charges repel each other. The force of attraction or repulsion is called electric force.

Review

1. What is electric charge?
2. Make a simple table summarizing electric forces between charged particles.

References

1. Christopher Auyeung. Location of charges in an atom . CC BY-NC 3.0
2. Zachary Wilson. Like charges repel each other . CC BY-NC 3.0

CONCEPT 2 Transfer of Electric Charge

Learning Objectives

- Describe how the transfer of electrons changes the charge of matter.
- Relate the transfer of electrons to the law of conservation of charge.
- Compare and contrast three ways that electric charge can be transferred.

Why is this girl's hair standing straight up? She is touching a device called a van de Graaff generator. The dome on top of the device has a negative electric charge. When the girl places her hand on the dome, she becomes negatively charged as well—right down to the tip of each hair!

Q: What causes the hair to stand on end?

A: All of the hairs have all become negatively charged, and like charges repel each other. Therefore, the hairs are pushing away from each other, causing them to stand on end.

Transferring Electrons

The girl pictured above became negatively charged because electrons flowed from the van de Graaff generator to her. Whenever electrons are transferred between objects, neutral matter becomes charged. This occurs even with individual atoms. Atoms are neutral in electric charge because they have the same number of negative electrons as positive protons. However, if atoms lose or gain electrons, they become charged particles called ions. You can see how this happens in the **Figure** 2.1. When an atom loses electrons, it becomes a positively charged ion, or cation. When an atom gains electrons, it becomes a negative charged ion, or anion.

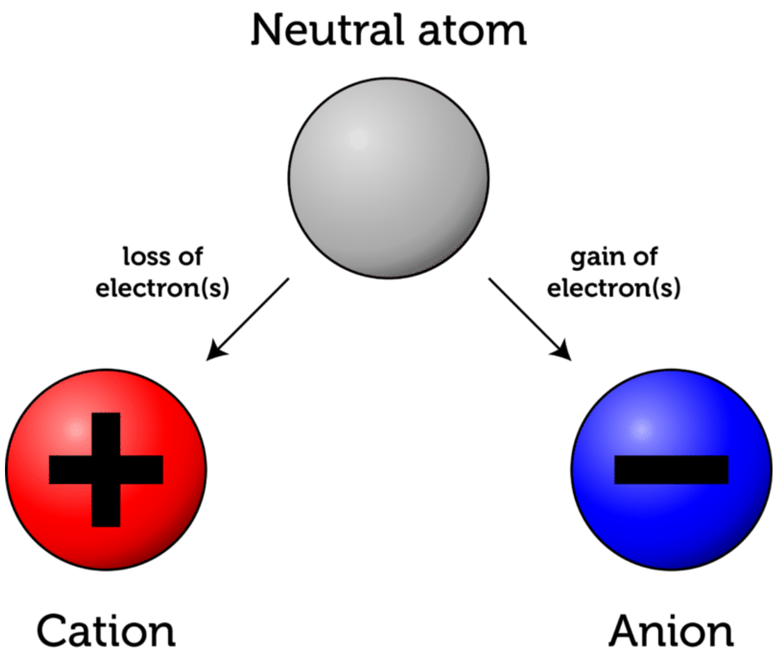


FIGURE 2.1

Conservation of Charge

Like the formation of ions, the formation of charged matter in general depends on the transfer of electrons, either between two materials or within a material. Three ways this can occur are referred to as conduction, polarization, and friction. All three ways are described below. However, regardless of how electrons are transferred, the total charge always remains the same. Electrons move, but they aren't destroyed. This is the **law of conservation of charge**.

Conduction

The transfer of electrons from the van de Graaff generator to the man is an example of conduction. Conduction occurs when there is direct contact between materials that differ in their ability to give up or accept electrons. A van de Graff generator produces a negative charge on its dome, so it tends to give up electrons. Human hands are positively charged, so they tend to accept electrons. Therefore, electrons flow from the dome to the man's hand when they are in contact.

You don't need a van de Graaff generator for conduction to take place. It may occur when you walk across a wool carpet in rubber-soled shoes. Wool tends to give up electrons and rubber tends to accept them. Therefore, the carpet transfers electrons to your shoes each time you put down your foot. The transfer of electrons results in you becoming negatively charged and the carpet becoming positively charged.

Polarization

Assume that you have walked across a wool carpet in rubber-soled shoes and become negatively charged. If you then reach out to touch a metal doorknob, electrons in the neutral metal will be repelled and move away from your hand before you even touch the knob. In this way, one end of the doorknob becomes positively charged and the other end becomes negatively charged. This is called polarization. Polarization occurs whenever electrons within a neutral object move because of the electric field of a nearby charged object. It occurs without direct contact between the two objects. The **Figure** 2.2 models how polarization occurs.

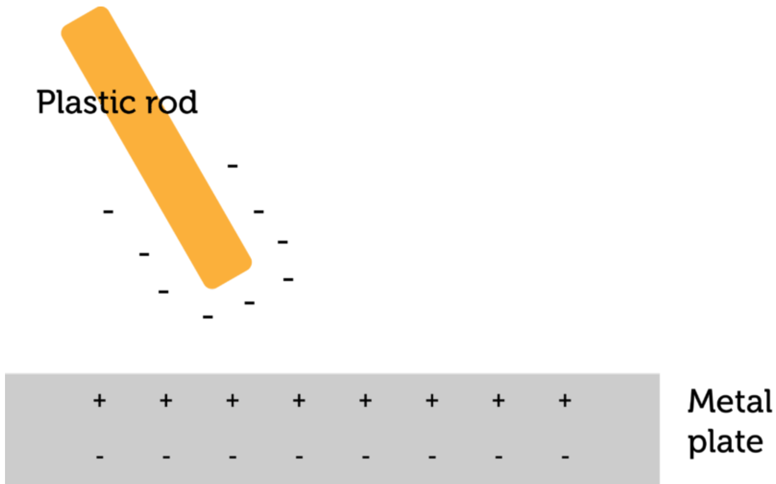


FIGURE 2.2

Q: What happens when the negatively charged plastic rod in the diagram is placed close to the neutral metal plate?

A: Electrons in the plate are repelled by the positive charges in the rod. The electrons move away from the rod, causing one side of the plate to become positively charged and the other side to become negatively charged.

Friction

Did you ever rub an inflated balloon against your hair? You can see what happens in the **Figure** 2.3. Friction between the balloon and hair cause electrons from the hair to "rub off" on the balloon. That's because a balloon attracts electrons more strongly than hair does. After the transfer of electrons, the balloon becomes negatively charged and the hair becomes positively charged. The individual hairs push away from each other and stand on end because like charges repel each other. The balloon and the hair attract each other because opposite charges attract.

FIGURE 2.3

Electrons are transferred in this way whenever there is friction between materials that differ in their ability to give up or accept electrons.

Q: If you rub a balloon against a wall, it may stick to the wall. Explain why.

A: Electrons are transferred from the wall to the balloon, making the balloon negatively charged and the wall positively charged. The balloon sticks to the wall because opposite charges attract.

Summary

- Whenever electrons are transferred between objects, neutral matter becomes charged. For example, when atoms lose or gain electrons they become charged particles called ions.
- Three ways electrons can be transferred are conduction, friction, and polarization. In each case, the total charge remains the same. This is the law of conservation of charge.
- Conduction occurs when there is direct contact between materials that differ in their ability to give up or accept electrons.
- Polarization is the movement of electrons within a neutral object due to the electric field of a nearby charged object. It occurs without direct contact between the two objects.
- Electrons are transferred whenever there is friction between materials that differ in their ability to give up or accept electrons.

Review

1. How is charge transferred by a van de Graaff generator?
2. Compare and contrast the formation of cations and anions.
3. State the law of conservation of charge.
4. Explain how conduction and polarization occur, using the example of walking across a wool carpet in rubber-soled shoes and then reaching out to touch a metal doorknob.
5. Predict what will happen to the charges of a plastic comb and a piece of tissue paper if you rub the tissue paper on the comb. (*Hint*: Plastic tends to accept electrons and tissue paper tends to give up electrons.)

Resources

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/177734

References

1. Christopher Auyeung. Ions are created by the loss or gain of electrons . CC BY-NC 3.0
2. Christopher Auyeung. Objects can get polarized when charged objects are nearby . CC BY-NC 3.0
3. Flickr:olga.palma. A positively charged balloon will attract negatively charged hair . CC BY 2.0

Concept 3 Static Electricity and Static Discharge

Learning Objectives

- Describe static electricity.
- Explain static discharge.
- Outline how lightning occurs.

You're a thoughtful visitor, so you wipe your feet on the welcome mat before you reach out to touch the brass knocker on the door. Ouch! A spark suddenly jumps between your hand and the metal, and you feel an electric shock.

Q: Why do you think an electric shock occurs?

A: An electric shock occurs when there is a sudden discharge of static electricity.

What Is Static Electricity?

Static electricity is a buildup of electric charges on objects. Charges build up when negative electrons are transferred from one object to another. The object that gives up electrons becomes positively charged, and the object that accepts the electrons becomes negatively charged. This can happen in several ways.

One way electric charges can build up is through friction between materials that differ in their ability to give up or accept electrons. When you wipe your rubber-soled shoes on the wool mat, for example, electrons rub off the mat onto your shoes. As a result of this transfer of electrons, positive charges build up on the mat and negative charges build up on you.

Once an object becomes electrically charged, it is likely to remain charged until it touches another object or at least comes very close to another object. That's because electric charges cannot travel easily through air, especially if the air is dry.

Q: You're more likely to get a shock in the winter when the air is very dry. Can you explain why?

A: When the air is very dry, electric charges are more likely to build up objects because they cannot travel easily through the dry air. This makes a shock more likely when you touch another object.

Static Discharge

What happens when you have become negatively charged and your hand approaches the metal doorknocker? Your negatively charged hand repels electrons in the metal, so the electrons move to the other side of the knocker. This makes the side of the knocker closest to your hand positively charged. As your negatively charged hand gets very close to the positively charged side of the metal, the air between your hand and the knocker also becomes electrically charged. This allows electrons to suddenly flow from your hand to the knocker. The sudden flow of electrons is **static discharge**. The discharge of electrons is the spark you see and the shock you feel.

How Lightning Occurs

Another example of static discharge, but on a much larger scale, is lightning. You can see how it occurs in the following diagram (**Figure** 3.1).

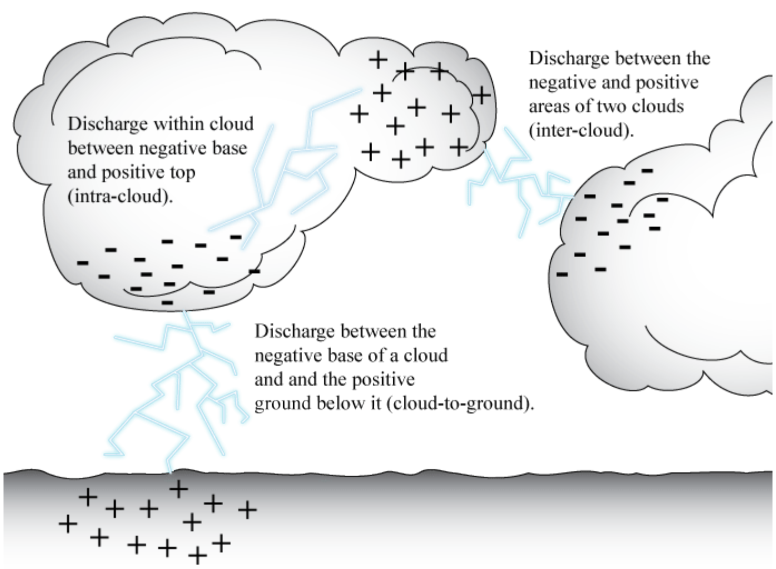


FIGURE 3.1

During a rainstorm, clouds develop regions of positive and negative charge due to the movement of air molecules, water drops, and ice particles. The negative charges are concentrated at the base of the clouds, and the positive charges are concentrated at the top. The negative charges repel electrons on the ground beneath them, so the ground below the clouds becomes positively charged. At first, the atmosphere prevents electrons from flowing away from areas of negative charge and toward areas of positive charge. As more charges build up, however, the air between the oppositely charged areas also becomes charged. When this happens, static electricity is discharged as bolts of lightning.

Summary

- Static electricity is a buildup of electric charges on objects. It occurs when electrons are transferred from one object to another.
- A sudden flow of electrons from one charged object to another is called static discharge.
- Examples of static discharge include lightning and the shock you sometimes feel when you touch another object.

Review

1. What is static electricity?
2. How does static discharge occur?
3. Explain why a bolt of lightning is like the spark you might see when you touch a metal object and get a shock.

Resources

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/177735

References

1. Zachary Wilson. Lightning is the result of the discharge of static electricity . CC BY-NC 3.0

CONCEPT 4 Electric Fields

Learning Objectives

- Describe the electric field around a charged particle.
- Explain how electric fields of two charged particles interact.

Halt! This science fiction image shows a human hand surrounded by a green force field. It's supposed to represent an electric field generated by a hand. What is an electric field? Read on to find out.

What Is an Electric Field?

An **electric field** is a space around a charged particle where the particle exerts electric force on other charged particles. Because of their force fields, charged particles can exert force on each other without actually touching. Electric fields are generally represented by arrows, as you can see in the **Figure** 4.1. The arrows show the direction of electric force around a positive particle and a negative particle.

Interacting Electric Fields

When charged particles are close enough to exert force on each other, their electric fields interact. This is illustrated in the **Figure** 4.2. The lines of force bend together when particles with different charges attract each other. The lines bend apart when particles with like charges repel each other.

Q: What would the lines of force look like around two negative particles?

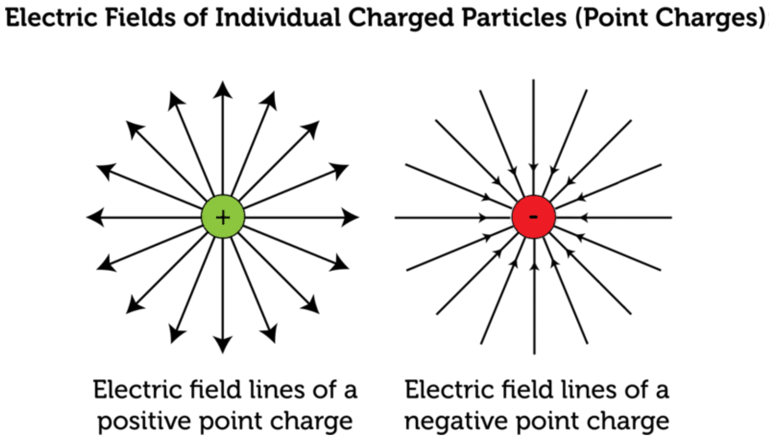


FIGURE 4.1

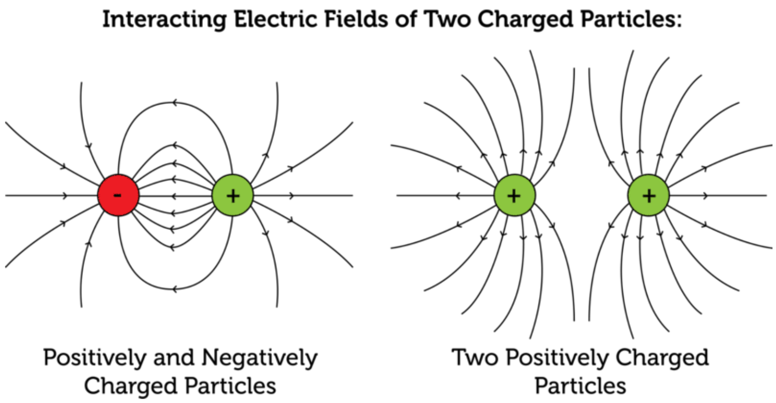


FIGURE 4.2

Note: +q = positive charge and -q = negative charge

A: They would look like the lines around two positive particles, except the arrows would point toward, rather than away from, the negative particles.

Summary

- An electric field is a space surrounding a charged particle where the particle exerts electric force.
- When charged particles are close enough to exert force on each other, their electric fields interact. Particles with opposite charges attract each other. Particles with like charges repel each other.

Review

1. What is an electric field?
2. Create a sketch showing how the electric fields of two negatively charged particles interact.

References

1. Christopher Auyeung. Point charge electric field . CC BY-NC 3.0
2. Christopher Auyeung. Field lines of two close charges . CC BY-NC 3.0

Concept 5 Electric Current

Learning Objectives

- Describe electric current.
- Explain why electric current occurs.
- Define voltage.

Emily's dad is giving his car battery a "jump" because the battery "died" overnight. He's attaching cables to the terminals of the car battery. Then he will connect the other ends of the cables to the terminals of a "live" battery. The cables will carry electric current to the dead battery, providing the energy needed for the car to start.

Flowing Charges

Electric current is a continuous flow of electric charges (electrons). Current is measured as the amount of charge that flows past a given point in a certain amount of time. The SI unit for electric current is the ampere (A), or amp. Electric current may flow in just one direction (direct current), or it may keep reversing direction (alternating current).

Q: Why do you think charges flow in an electric current?

A: Electric charges flow when they have electric potential energy. Potential energy is stored energy that an object has due to its position or shape.

Electric Potential Energy

Electric potential energy comes from the position of a charged particle in an electric field. For example, when two negative charges are close together, they have potential energy because they repel each other and have the potential to push apart. If the charges actually move apart, their potential energy decreases. Electric charges always move spontaneously from a position where they have higher potential energy to a position where they have lower potential energy. This is like water falling over a dam from an area of higher to lower potential energy due to gravity.

Voltage

For an electric charge to move from one position to another, there must be a difference in electric potential energy between the two positions. A difference in electric potential energy is called **voltage**. The SI unit for voltage is the volt (V). Look at the **Figure** 5.1. It shows a simple circuit. The source of voltage in the circuit is a 1.5-volt battery. The difference of 1.5 volts between the two battery terminals results in a spontaneous flow of charges, or electric current, between them. Notice that the current flows from the negative terminal to the positive terminal, because electric current is a flow of electrons.

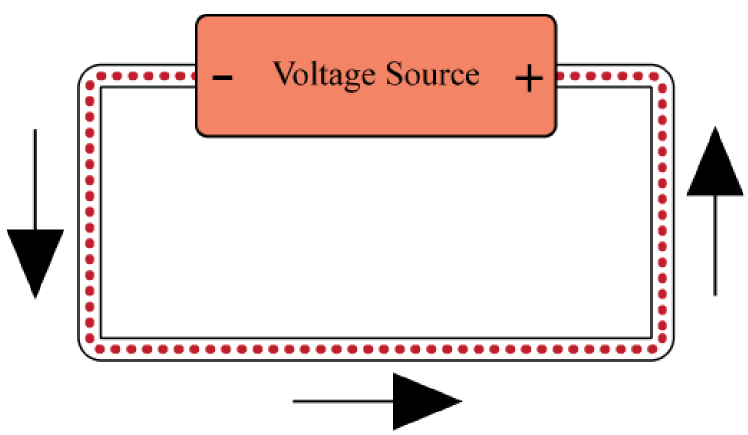


FIGURE 5.1

Q: You might put a 1.5-volt battery in a TV remote. The battery in a car is a 12-volt battery. How do you think the current of a 12-volt battery compares to the current of a 1.5-volt battery?

A: Greater voltage means a greater difference in potential energy, so the 12-volt battery can produce more current than the 1.5-volt battery.

Summary

- Electric current is a continuous flow of electric charges. The SI unit for electric current is the ampere (A).
- An electric charge flows when it has electric potential energy due to its position in an electric field. An electric charge always moves spontaneously from a position of higher to lower potential energy.
- For an electric charge to move from one position to another, there must be a difference in electric potential energy between the two positions. This difference is called voltage. The SI unit for voltage is the volt (V).

Review

1. What is electric current? Name the SI unit for electric current.
2. Explain what gives a charge electric potential energy. Describe an example.
3. How is electric potential energy related to the direction an electric charge spontaneously moves?
4. What is voltage, and why is it needed for charges to flow in an electric current?

References

1. Zachary Wilson. Flow of electrons in a circuit . CC BY-NC 3.0

Concept 6 Direct and Alternating Current

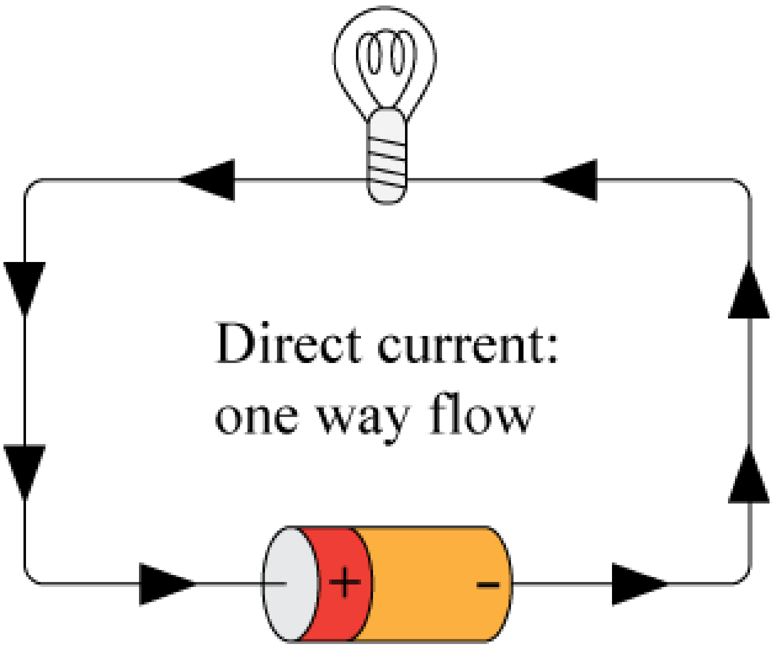
Learning Objectives

- Distinguish between direct current and alternating current.

To use an electric appliance, you have to plug it into an outlet unless it has batteries. This may be all you need to know in order to use electric current. But did you ever wonder what electric current is or how it flows through wires inside the walls of your home? Electric current is a continuous flow of electric charges. The charges may flow in just one direction, or they may keep reversing direction.

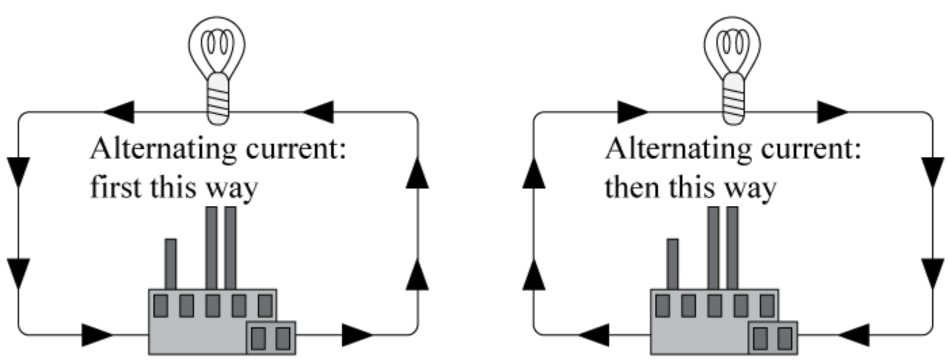
Direct Current

When current flows in just one direction, it is called **direct current (DC)**. The diagram below shows how direct current flows through a simple circuit. An example of direct current is the current that flows through a battery-powered flashlight. In addition to batteries, solar cells and fuel cells can also provide direct current.



Alternating Current

When current keeps reversing direction, it is called **alternating current (AC)**. You can see how it works in the two diagrams below. The current that comes from a power plant and supplies electricity to homes and businesses is alternating current. The current changes direction 60 times per second. It happens so quickly that the light bulb doesn't have a chance to stop glowing when the reversals occur.



Q: Which type of current flows through the wires in your home?

A: Alternating current from a power plant flows through the wires in a home.

Summary

- Direct current (DC) keeps flowing in just one direction. Batteries provide direct current.
- Alternating current (AC) keeps reversing direction. Power plants provide alternating current.

Review

1. Compare and contrast direct and alternating current.

Resources

MEDIA

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CONCEPT 7 Chemical and Solar Cells

Learning Objectives

- Explain how a chemical cell works.
- Outline how a solar cell produces electric current.

Can you identify the two objects pictured above? You've probably used objects like these many times. The photos show a TV remote (left) and a calculator (right). Both of them run on electric current. Current requires a source of voltage, which is a difference in electric potential energy.

Q: The source of voltage is different in the remote and the calculator. Do you know what source of voltage each device uses?

A: The TV remote uses chemical cells as a source of voltage. The calculator uses a solar cell.

Chemical Cells

Chemical cells are found in batteries. They produce voltage by means of chemical reactions. Chemical cells have two electrodes, which are strips of different materials, such as zinc and carbon. The electrodes are suspended in an electrolyte. This is a substance that contains free ions, which can carry electric current. The electrolyte may be either a paste, in which case the cell is called a dry cell, or a liquid, in which case the cell is called a wet cell. Flashlight batteries contain dry cells. Car batteries contain wet cells.

The **Figure** 7.1 shows how a battery works. The diagram represents the simplest type of battery, one that contains a single chemical cell. Both dry and wet cells work the same basic way. The electrodes react chemically with the electrolyte, causing one electrode to give up electrons and the other electrode to accept electrons. Electrons flow through the electrolyte from the negative to positive electrode. The electrodes extend out of the battery for the attachment of wires that carry the current. The current can be used to power a light bulb or other electric device.

Solar Cells

Solar cells convert the energy in sunlight to electrical energy. Solar cells are also called photovoltaic (PV) cells

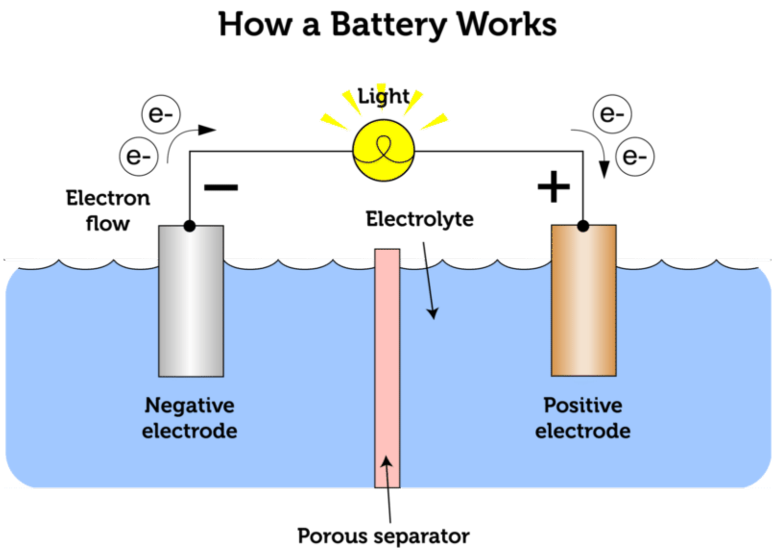


FIGURE 7.1

because they use light (*photo-*) to produce voltage (*-voltaic*). Solar cells contain a material such as silicon that absorbs light energy. The energy knocks electrons loose so they can flow freely and produce a difference in electric potential energy, or voltage. The flow of electrons creates electric current. Solar cells have positive and negative contacts, like the terminals in chemical cells. If the contacts are connected with wire, current flows from the negative to positive contact. The **Figure** 7.2 shows how a solar cell works.

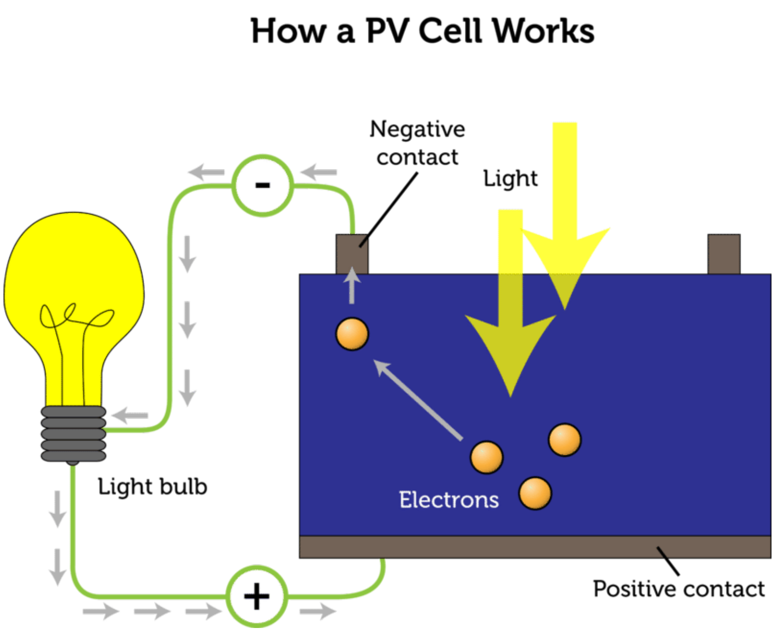


FIGURE 7.2

Summary

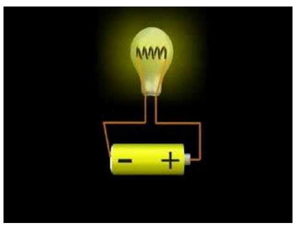
- Current requires a source of voltage, which is a difference in electric potential energy. Sources of voltage include chemical cells and solar cells.

- Chemical cells are found in batteries. They produce voltage by means of chemical reactions. They contain electrodes and an electrolyte, which may be a paste (dry cell) or a liquid (wet cell).
- Solar cells convert the energy in sunlight to electrical energy. They contain a material such as silicon that absorbs light energy and gives off electrons.

Review

1. What is voltage? How is it related to electric current?
2. How does a chemical cell produce current?
3. Explain how a solar cell works.

Resources



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References

1. Christopher Auyeung. Chemical cell . CC BY-NC 3.0
2. Christopher Auyeung. Solar power cell . CC BY-NC 3.0

Concept 8 Electric Resistance

Learning Objectives

- Define resistance and identify the SI unit for resistance.
- List factors that affect resistance.
- Explain why resistance can be a help or a hindrance.

These athletes are playing rugby, a game that is similar to American football. The players in red and blue are trying to stop the player in blue and black from running across the field with the ball. They are resisting his forward motion. This example of resistance in rugby is a little like resistance in physics.

What Is Resistance?

In physics, **resistance** is opposition to the flow of electric charges in an electric current as it travels through matter. The SI unit for resistance is the ohm. Resistance occurs because moving electrons in current bump into atoms of matter. Resistance reduces the amount of electrical energy that is transferred through matter. That's because some of the electrical energy is absorbed by the atoms and changed to other forms of energy, such as heat.

Q: In the rugby analogy to resistance in physics, what do the players on each team represent?

A: The player on the blue and black team represents a moving electron in an electric current. The players on the red and blue team represent particles of matter through which the current is flowing.

Factors That Affect Resistance

How much resistance a material has depends on several factors: the type of material, its width, its length, and its temperature.

- All materials have some resistance, but certain materials resist the flow of electric current more or less than other materials do. Materials such as plastics have high resistance to electric current. They are called electric insulators. Materials such as metals have low resistance to electric current. They are called electric conductors.
- A wide wire has less resistance than a narrow wire of the same material. Electricity flowing through a wire is like water flowing through a hose. More water can flow through a wide hose than a narrow hose. In a similar way, more current can flow through a wide wire than a narrow wire.
- A longer wire has more resistance than a shorter wire. Current must travel farther through a longer wire, so there are more chances for it to collide with particles of matter.
- A cooler wire has less resistance than a warmer wire. Cooler particles have less kinetic energy, so they move more slowly. Therefore, they are less likely to collide with moving electrons in current. Materials called superconductors have virtually no resistance when they are cooled to extremely low temperatures.

Is Resistance Good or Bad?

Resistance can be helpful or just a drain on electrical energy. If the aim is to transmit electric current through a wire from one place to another, then resistance is a drawback. It reduces the amount of electrical energy that is transmitted because some of the current is absorbed by particles of matter. On the other hand, if the aim is to use electricity to produce heat or light, then resistance is useful. When particles of matter absorb electrical energy, they change it to heat or light. For example, when electric current flows through the tungsten wire inside an incandescent light bulb like the one in the **Figure** 8.1, the tungsten resists the flow of electric charge. It absorbs electrical energy and converts some of it to light and heat.

Q: The tungsten wire inside a light bulb is extremely thin. How does this help it do its job?

A: The extremely thin wire has more resistance than a wider wire would. This helps the wire resist electric current and change it to light.

Summary

- In physics, resistance is opposition to the flow of electric charges that occurs as electric current travels through matter. The SI unit for resistance is the ohm.
- All materials have resistance. How much resistance a material has depends on the type of material, its width, its length, and its temperature.
- Resistance is a hindrance when a material is being used to transmit electric current. Resistance is helpful when a material is being used to produce heat or light.

Review

1. What is resistance? Name the SI unit for resistance.
2. Explain what causes resistance.
3. Describe properties of a metal wire that would minimize its resistance to electric current.
4. Extend the rugby analogy to explain why a longer wire has greater resistance to electric current.
5. Copper wires have about one-third the resistance of tungsten wires. Why would copper be less suitable than tungsten as a filament in an incandescent light bulb?

FIGURE 8.1
What's wrong with this picture? (Hint: How does current get to the light bulb?)

References

1. Olga Reznik. Lightbulb . CC BY 2.0

Concept 9 Electric Conductors and Insulators

Learning Objectives

- Relate electric current to matter.
- Define electric conductor, and give examples of conductors.
- Describe electric insulators, and identify materials that are insulators.

Do you see the wires and peaks on top of this old house? They are lightning rods, and their purpose is to protect the building in the event of a lightning strike. Each lightning rod is connected to a wire that goes down the side of the house and into the ground. If lightning strikes the building, it will target the rod and be conducted by the rod and wire into the ground. There the electricity can be safely absorbed. Lightning rods may differ in style, but to work they must be good at conducting electricity.

Electric Current and Matter

Electrical energy is transmitted by moving electrons in an electric current. In order to travel, electric current needs matter. It cannot pass through empty space. However, matter resists the flow of electric current. That's because flowing electrons in current collide with particles of matter, which absorb their energy. Some types of matter offer more or less resistance to electric current than others.

Electric Conductors

Materials that have low resistance to electric current are called **electric conductors**. Many metals—including copper, aluminum, and steel—are good conductors of electricity. The outer electrons of metal atoms are loosely bound and free to move, allowing electric current to flow. Water that has even a tiny amount of impurities is an electric conductor as well.

Q: What do you think lightning rods are made of?

A: Lightning rods are made of metal, usually copper or aluminum, both of which are excellent conductors of electricity.

Electric Insulators

Materials that have high resistance to electric current are called **electric insulators**. Examples include most non-metallic solids, such as wood, rubber, and plastic. Their atoms hold onto their electrons tightly, so electric current cannot flow freely through them. Dry air is also an electric insulator.

Q: You may have heard that rubber-soled shoes will protect you if you are struck by lightning. Do you think this is true? Why or why not?

A: It isn't true. Rubber is an electric insulator, but a half-inch layer on the bottom of a pair of shoes is insignificant when it comes to lightning. The average lightning bolt has 100 million volts and can burn through any insulator, even the insulators on high-voltage power lines.

The Path of Least Resistance

Look at the electric wires in the **Figure** 9.1. They are made of copper and coated with plastic. Copper is very good conductor, and plastic is a very good insulator. When more than one material is available for electric current to flow through, the current always travels through the material with the least resistance. That's why all the current passes through the copper wire and none flows through its plastic coating.

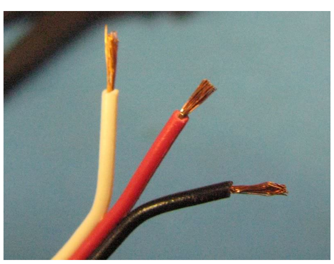

FIGURE 9.1

Summary

- Electricity must travel through matter. All matter offers some resistance to the flow of electrons in an electric current. Some materials resist current more or less than others.
- Materials that have low resistance to electric current are called electric conductors. Many metals are good electric conductors.
- Materials that have high resistance to electric current are called electric insulators. Wood, rubber, and plastic are good electric insulators.
- When more than one material is available for electric current to flow through, the current always travels through the material with the least resistance.

Review

1. What is an electric conductor? Give examples of good electric conductors.
2. Explain why electric current doesn't flow through rubber.
3. Jon can see the conductor of the power cord for an electric lamp. Should he use the lamp? Why or why not?

References

1. Flickr:solarbotics. Closeup of copper wires . CC BY 2.0

CONCEPT 10 Ohm's Law

Learning Objectives

- Explain Ohm's law.
- Use Ohm's law to calculate current from voltage and resistance.

Look at the water spraying out of this garden hose. You have to be careful using water around power tools and electric outlets because water can conduct an electric current. But in some ways, water flowing through a hose is like electric current flowing through a wire.

Introducing Ohm's Law

For electric current to flow through a wire, there must be a source of voltage. Voltage is a difference in electric potential energy. As you might have guessed, greater voltage results in more current. As electric current flows through matter, particles of matter resist the moving charges. This is called resistance, and greater resistance results in less current. These relationships between electric current, voltage, and resistance were first demonstrated in the early 1800s by a German scientist named Georg Ohm, so they are referred to as Ohm's law. **Ohm's law** can be represented by the following equation.

$$\text{Current(amps)} = \frac{\text{Voltage(volts)}}{\text{Resistance(ohms)}}$$

Understanding Ohm's Law

Ohm's law may be easier to understand with an analogy. Current flowing through a wire is like water flowing through a hose. Increasing voltage with a higher-volt battery increases the current. This is like opening the tap wider so more water flows through the hose. Increasing resistance reduces the current. This is like stepping on the hose so less water can flow through it.

Using Ohm's Law to Calculate Current

You can use the equation for current (above) to calculate the amount of current flowing through a circuit when the voltage and resistance are known. Consider an electric wire that is connected to a 12-volt battery. If the wire has a resistance of 2 ohms, how much current is flowing through the wire?

$$\text{Current} = \frac{12 \text{ volts}}{2 \text{ ohms}} = 6 \text{ amps}$$

Q: If a 120-volt voltage source is connected to a wire with 10 ohms of resistance, how much current is flowing through the wire?

A: Substitute these values into the equation for current:

$$\text{Current} = \frac{120 \text{ volts}}{10 \text{ ohms}} = 12 \text{ amps}$$

Summary

- According to Ohm's law, greater voltage results in more current and greater resistance results in less current.
- Ohm's law can be represented by the equation:

$$\text{Current (amps)} = \frac{\text{Voltage (volts)}}{\text{Resistance (ohms)}}$$

- This equation can be used to calculate current when voltage and resistance are known.

Review

1. State Ohm's law.
2. An electric appliance is connected by wires to a 240-volt source of voltage. If the combined resistance of the appliance and wires is 12 ohms, how much current is flowing through the circuit?

Resources

MEDIA

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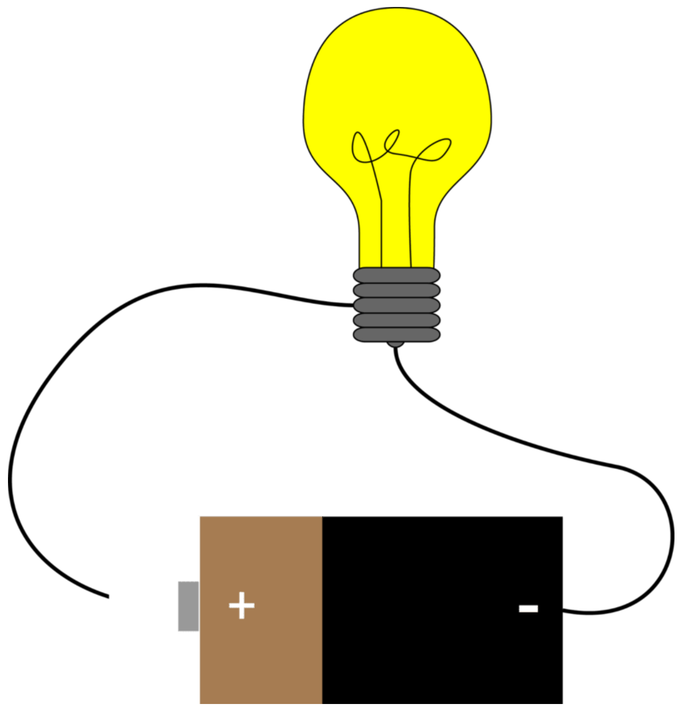
CONCEPT 11 Electric Circuits

Learning Objectives

- Define electric circuit.
- Describe the parts of an electric circuit.
- Show how to represent a simple electric circuit with a circuit diagram.



Jose made this sketch of a battery and light bulb for science class. If this were a real set up, the light bulb wouldn't work. The problem is the loose wire on the left. It must be connected to the positive terminal of the battery in order for the bulb to light up.

Q: Why does the light bulb need to be connected to both battery terminals?

A: Electric current can flow through a wire only if it forms a closed loop. Charges must have an unbroken path to follow between the positively and negatively charged parts of the voltage source, in this case, the battery.

Electric Circuit Basics

A closed loop through which current can flow is called an **electric circuit**. In homes in the U.S., most electric circuits have a voltage of 120 volts. The amount of current (amps) a circuit carries depends on the number and power of electrical devices connected to the circuit. Home circuits generally have a safe upper limit of about 20 or 30 amps.

Parts of an Electric Circuit

All electric circuits have at least two parts: a voltage source and a conductor. They may have other parts as well, such as light bulbs and switches, as in the simple circuit seen in the **Figure** 11.1.

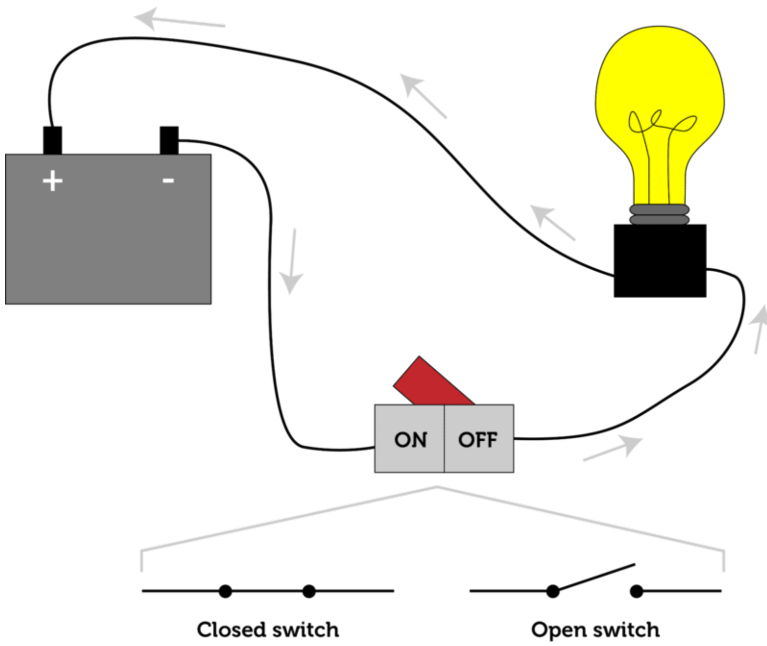


FIGURE 11.1

- The voltage source of this simple circuit is a battery. In a home circuit, the source of voltage is an electric power plant, which may supply electric current to many homes and businesses in a community or even to many communities.
- The conductor in most circuits consists of one or more wires. The conductor must form a closed loop from the source of voltage and back again. In the **Figure** 11.1, the wires are connected to both terminals of the battery, so they form a closed loop.
- Most circuits have devices such as light bulbs that convert electrical energy to other forms of energy. In the case of a light bulb, electrical energy is converted to light and thermal energy.
- Many circuits have switches to control the flow of current. When the switch is turned on, the circuit is closed and current can flow through it. When the switch is turned off, the circuit is open and current cannot flow through it.

Circuit Diagrams

When a contractor builds a new home, she uses a set of plans called blueprints that show her how to build the house. The blueprints include circuit diagrams. The diagrams show how the wiring and other electrical components are to be installed in order to supply current to appliances, lights, and other electric devices. You can see an example of a very simple circuit in the **Figure** 11.2. Different parts of the circuit are represented by standard circuit symbols. An ammeter measures the flow of current through the circuit, and a voltmeter measures the voltage. A resistor is any device that converts some of the electricity to other forms of energy. For example, a resistor might be a light bulb or doorbell.

Q: Only one of the circuit symbols in the **Figure** 11.2 must be included in every circuit. Which symbol is it?

A: The battery symbol (or a symbol for some other voltage source) must be included in every circuit. Without a source of voltage, there is no electric current.

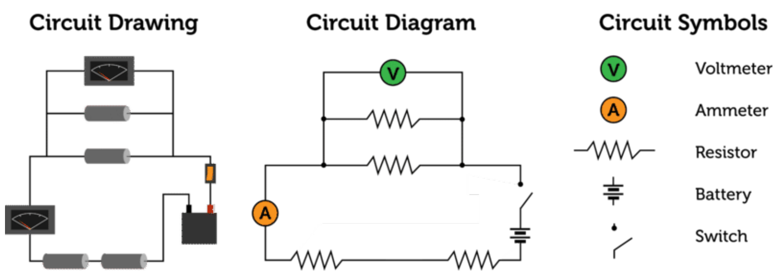


FIGURE 11.2
The circuit diagram in the middle represents the circuit drawing on the left. On the right are some of the standard symbols used in circuit diagrams.

Summary

- An electric circuit is a closed loop through which current can flow.
- All electric circuits must have a voltage source, such as a battery, and a conductor, which is usually wire. They may have one or more electric devices as well.
- An electric circuit can be represented by a circuit diagram, which uses standard symbols to represent the parts of the circuit.

Review

1. What is an electric circuit?
2. Which two parts must all electric circuits contain?
3. Sketch a simple circuit that includes a battery, switch, and light bulb. Then make a circuit diagram to represent your circuit, using standard circuit symbols.

References

1. Christopher Auyeung. A properly closed circuit . CC BY-NC 3.0
2. Christopher Auyeung. Circuit diagrams utilize a standard set of symbols to represent circuits . CC BY-NC 3.0

CONCEPT 12 Electric Safety

Learning Objectives

- Explain how a short circuit occurs.
- Identify safety features built into electric circuits and devices.
- List rules for using electricity safely.

Electricity is dangerous and contact with electric current can cause severe burns and even death. Electricity can also cause serious fires.

Q: A common cause of electric hazards and fires is a short circuit. Do you know what a short circuit is?

A: As its name suggests, a short circuit is damage that allows electric current to travel through a shorter loop than it should. To find out how this can occur and why it is dangerous, keep reading.

How a Short Circuit Occurs

Did you ever see an old appliance with a damaged cord, like the old shown in the **Figure** 12.1? A damaged electric cord can cause a severe shock if it allows current to pass from the cord to a person who touches it. A damaged cord can also cause a short circuit. A short circuit occurs when electric current follows a shorter path than the intended loop of the circuit. An electric cord contains two wires: one that carries current from the outlet to the appliance and one that carries current from the appliance back to the outlet. If the two wires in a damaged cord come into contact with each other, current flows from one wire to the other and bypasses the appliance. This may cause the wires to overheat and start a fire.

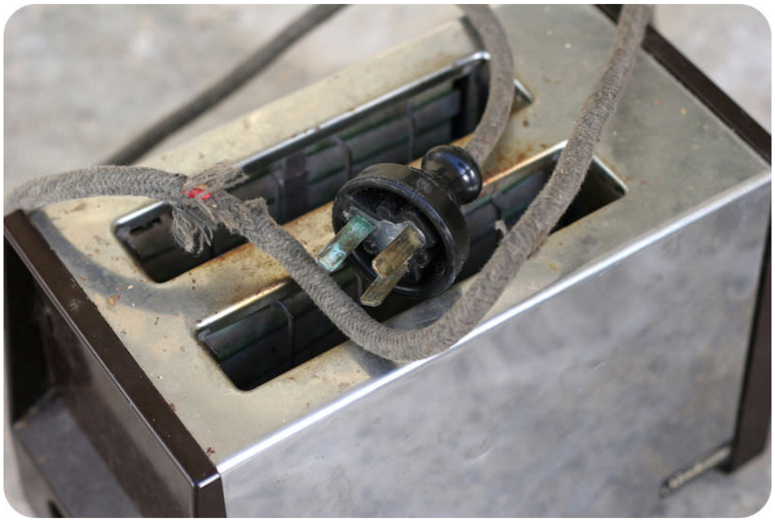


FIGURE 12.1

Electric Safety Features

Because electricity can be so dangerous, safety features are built into modern electric circuits and devices. They include three-prong plugs, circuit breakers, and GFCI outlets. You can read about these three safety features in the **Figure** 12.2.

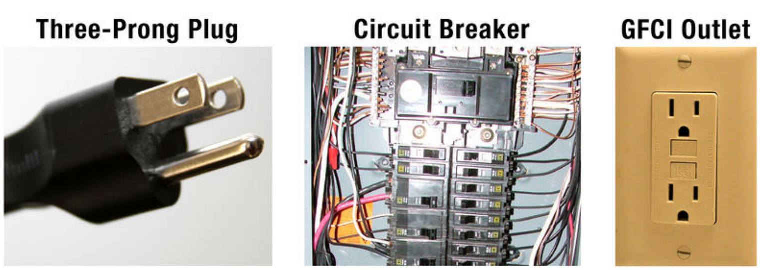


FIGURE 12.2

GFCI Outlet: GFCI stands for ground-fault circuit interrupter. GFCI outlets are typically found in bathrooms and kitchens where the use of water poses a risk of shock (because water is a good electric conductor). A GFCI outlet contains a device that monitors the amount of current leaving and returning to the outlet. If less current is returning than leaving, this means that current is escaping. When this occurs, a tiny circuit breaker in the outlet interrupts the circuit. The breaker can be reset by pushing a button on the outlet cover.

Q: Can you think of any other electric safety features?

A: One safety feature is the label on a lamp that warns the user of the maximum safe wattage for light bulbs. Another safety feature is double insulation on many electric devices. Not only are the electric wires insulated with a coating of plastic but so is the entire device. The old toaster pictured in the **Figure** 12.1 lacks this safety feature, but most modern toasters have a plastic casing. This reduces the risk of current leaving the device except through the cord.

Using Electricity Safely

Even with electric safety features, electricity is still dangerous if it is misused. Follow the safety rules below to reduce the risk of injury or fire from electricity.

- Never mix electricity and water. Don't plug in or turn on electric lights or appliances when your hands are wet, you are standing in water, or you are in the shower or bathtub. The current could flow through the water—and you—because water is a good conductor of electricity.
- Never overload circuits. Avoid plugging too many devices into one outlet or extension cord. The more devices that are plugged in, the more current the circuit carries. Too much current can overheat a circuit and start a fire.
- Never use devices with damaged cords or plugs. They can cause shocks, shorts, and fires.
- Never put anything except plugs into electric outlets. Putting any other object into an outlet is likely to cause a serious shock that could be fatal.
- Never go near fallen electric lines. They could have very high voltage. Report fallen lines to the electric company as soon as possible.

Summary

- A short circuit occurs when electric current follows a shorter path than the intended loop of the circuit. A short circuit may cause wires to overheat and start a fire.
- Several safety features are built into modern electric circuits and devices. They include three-prong plugs, circuit breakers, and GFCI outlets.
- Following safety rules can reduce the risk of injury or fire from electricity.

Review

1. What causes a short circuit? Why is a short circuit dangerous?
2. Identify an electric safety feature and explain how it works.
3. Create an illustrated poster to share electric safety rules with other people your age. Include at least three safety rules in your poster.

References

1. Image copyright Sue McDonald, 2014. Frayed cords are dangerous . Used under license from Shutterstock.com
2. Plug: Samuel M. Livingston; Circuit breaker: Flickr:davef3138; GFCI: http://www.homespothq.com/. A variety of safety features help protect users . CC BY 2.0

CONCEPT 13 Electronic Component

Learning Objectives

- Define electronic component.
- Describe semiconductors.
- Outline the structure and function of diodes, transistors, and integrated circuits.

You've probably heard of Silicon Valley. You may even know that it's a region in northern California. But do you know how the region got its name? Silicon Valley is the birthplace of modern electronics and continues to be a hub of electronic innovation. The word *silicon* in the name refers to the element silicon, which is the chief "ingredient" of electronic components.

What Are Electronic Components?

Electronic components are the parts used in electronic devices such as computers. The components change electric current so it can carry information. Types of electronic components include diodes, transistors, and integrated circuits, all of which you can read about below. However, to understand how these components work, you first need to know about semiconductors. That's because electronic components consist of semiconductors—sometimes millions of them!

Semiconductors

A **semiconductor** is a solid crystal, consisting mainly of silicon. It gets its name from the fact that it can conduct current better than an electric insulator but not as well as an electric conductor. As you can see in the **Figure** 13.1, each silicon atom has four valence electrons that it shares with other silicon atoms in the crystal. A semiconductor is formed by replacing a few silicon atoms with other atoms, such as phosphorus or boron, which have more or less valence electrons than silicon. This is called doping, and it's what allows the semiconductor to conduct electric current.

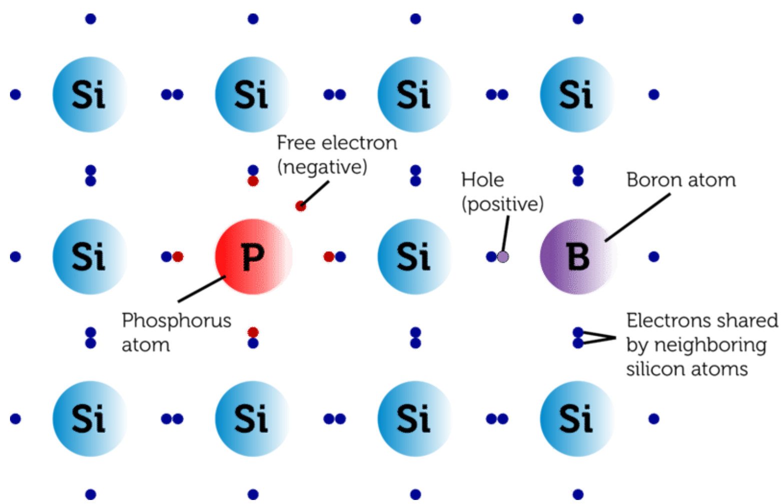


FIGURE 13.1

Q: Why wouldn't a pure silicon crystal be able to conduct electric current?

A: Electric current is a flow of electrons. All of the valence electrons of silicon atoms in a pure crystal are shared with other silicon atoms, so they are not free to move and carry current.

There are two different types of semiconductors: n-type and p-type.

- An n-type (negative-type) semiconductor consists of silicon and an element such as phosphorus that gives the silicon crystal extra electrons. You can see this in the **Figure** 13.1. An n-type semiconductor is like the negative terminal of a battery.
- A p-type (positive-type) semiconductor consists of silicon and an element such as boron that gives the silicon positively charged "holes" where electrons are missing. This is also shown in the **Figure** 13.1. A p-type semiconductor is like the positive terminal of a battery.

Diode

A diode is an electronic component that consists of a p-type and an n-type semiconductor placed side by side, as shown in the **Figure** 13.2. When a diode is connected by leads to a source of voltage, electrons flow from the n-type to the p-type semiconductor. This is the only direction that electrons can flow in a diode. This makes a diode useful for changing alternating current to direct current.

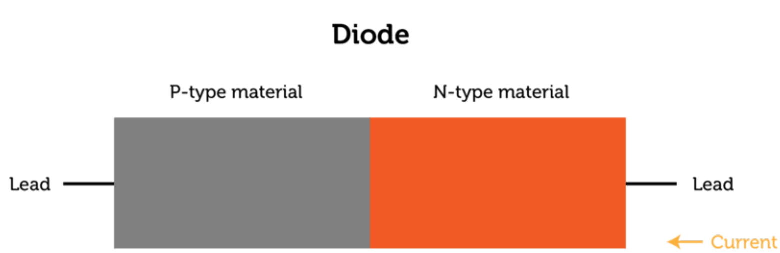


FIGURE 13.2

Transistor

A transistor consists of three semiconductors, either p-n-p or n-p-n. Both arrangements are illustrated in the **Figure** 13.3. Current can't flow through a transistor unless a small amount of current is applied to the center semiconductor (through the base). Then a much larger current can flow through the transistor from end to end (from collector to emitter). This means that a transmitter can be used as a switch, with pulses of a small current turning a larger current on and off. A transistor can also be used to increase the amount of current flowing through a circuit.

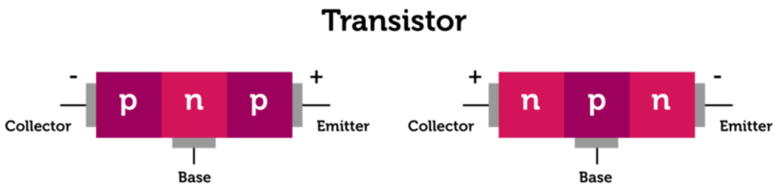


FIGURE 13.3

Integrated Circuit

An integrated circuit—also called a microchip—is a tiny, flat piece of silicon that consists of layers of many electronic components such as transistors. You can see an integrated circuit in the **Figure** 13.4. Look how small it is compared with the finger it's resting on. Although the integrated circuit is tiny, it may contain millions of smaller electronic components. Current flows extremely rapidly in an integrated circuit because it doesn't have far to travel. Integrated circuits are used in virtually all modern electronic devices to carry out specific tasks.

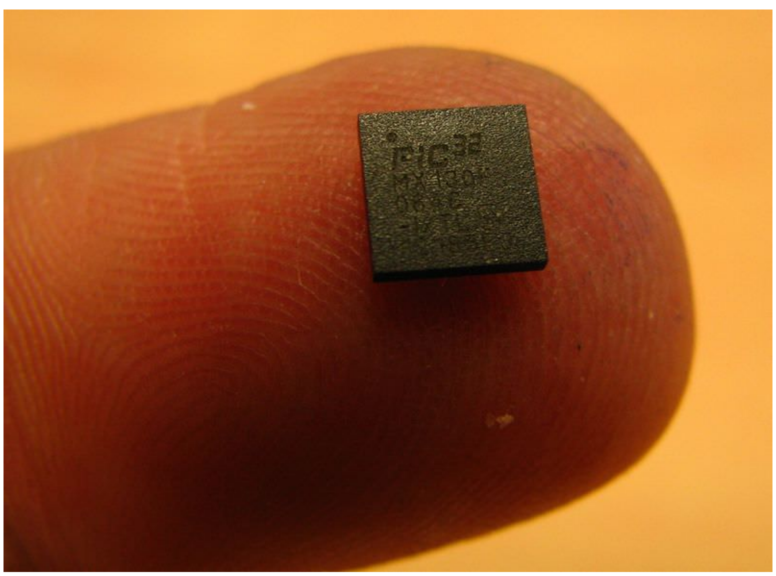


FIGURE 13.4

Summary

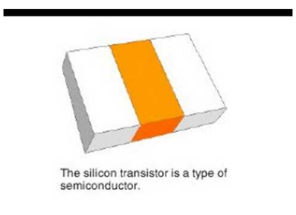
- Electronic components are the parts used in electronic devices such as computers. Types of electronic components include diodes, transistors, and integrated circuits.
- Electronic components consist of semiconductors, which are solid crystals consisting mainly of silicon. There are two types of semiconductors, called n-type and p-type.

- A diode is an electronic component consisting of two semiconductors. It is used to change alternating current to direct current.
- A transistor is an electronic component consisting of three semiconductors. It can be used to turn current on or off or to increase current.
- An integrated circuit (microchip) is an electronic component that consists of many other electronic components such as transistors. Integrated circuits are used in virtually all modern electronic devices to carry out specific tasks.

Review

1. What are electronic components?
2. Compare and contrast n-type and p-type semiconductors.
3. Describe the structure and function of a diode.
4. How does a transistor act as a switch?
5. Explain how the size of an integrated circuit helps it carry out tasks with incredible speed.

Resources



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References

1. User:Guillom/Wikimedia Commons, modified by CK-12 Foundation. Semiconductors are created by "dopin g" silicon . CC BY 2.5
2. Christopher Auyeung. Diagram of a diode . CC BY-NC 3.0
3. Christopher Auyeung. Diagram of a transistor . CC BY-NC 3.0
4. Flickr:fdecomite. Microchips are very small . CC BY 2.0

Concept 14 Electronic Device

Learning Objectives

- Identify common electronic devices.
- Outline the parts of a computer and what they do.

If you were born in the last few decades, it's probably impossible for you to imagine life without the computer. The computer is just one of many electronic devices that make modern life possible.

What Are Electronic Devices?

Many of the devices people commonly use today are electronic devices. **Electronic devices** use electric current to encode, analyze, or transmit information. In addition to computers, they include mobile phones, TV remotes, DVD and CD players, and digital cameras, to name just a few.

Q: Can you think of other electronic devices that you use?

A: Other examples include game systems and MP3 players.

Focus on the Computer

Let's take a close look at the computer as an example of an electronic device. A computer contains integrated circuits, or microchips, that consist of millions of tiny electronic components. Information is encoded in digital electronic signals. Rapid pulses of voltage switch electric current on and off, producing long strings of 1's (current on) and 0's (current off). The 1's and 0's are the "letters" of the code, and a huge number of them are needed. One digit (either 0 or 1) is called a bit, which stands for "binary digit." Each group of eight digits is called a byte, and a billion bytes is called a gigabyte. Because a computer's circuits are so tiny and close together, the computer can be very fast and capable of many complex tasks while remaining small.

The parts of a computer that transmit, process, or store digital signals are pictured and described in the **Figure** 14.1. They include the CPU, hard drive, ROM, and RAM. The motherboard ties all these parts of the computer together.

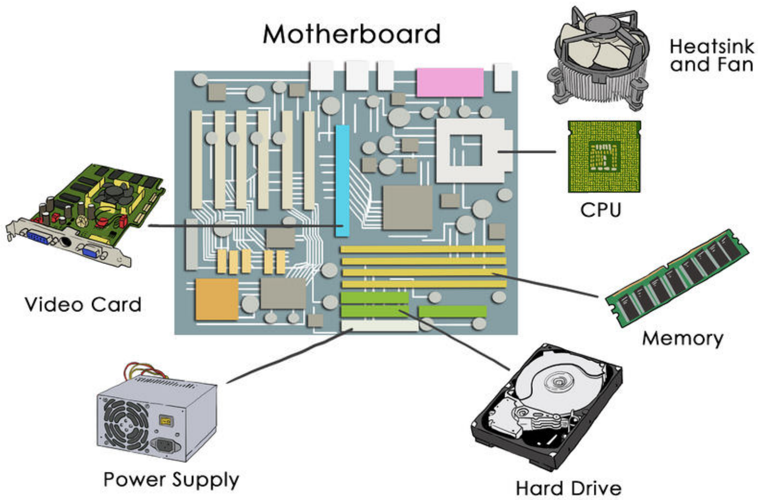


FIGURE 14.1

- The CPU, or central processing unit, carries out program instructions.
- The hard drive is a magnetic disc that provides long-term storage for programs and data.
- ROM (read-only memory) is a microchip that provides permanent storage. It stores important information such as start-up instructions. This memory remains even after the computer is turned off.
- RAM (random-access memory) is a microchip that temporarily stores programs and data that are currently being used. Anything stored in RAM is lost when the computer is turned off.
- The motherboard is connected to the CPU, hard drive, ROM, and RAM. It allows all these parts of the computer to receive power and communicate with one another.

Q: Which part(s) of a computer are you using when you type a school report?

A: You are using the RAM to store the word processing program and your document as you type it. You are using the CPU to carry out instructions in the word processing program, and you are probably using the hard drive to save your document.

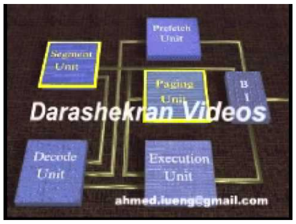
Summary

- Electronic devices—such as computers, mobile phones, remotes, and cameras—use electric current to encode, analyze, or transmit information.
- A computer contains millions of tiny electronic components. Parts of a computer that transmit, process, or store information include the CPU, hard drive, ROM, and RAM. The motherboard ties all these parts together.

Review

1. What is an electronic device?
2. Give three examples of electronic devices.
3. Which part of a computer allows the CPU and RAM to communicate?

Resources



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References

1. Laura Guerin. Parts of a computer . CC BY-NC 3.0

CONCEPT 15 Series and Parallel Circuits

Learning Objectives

- Describe a series circuit.
- Explain how a parallel circuit differs from a series circuit.

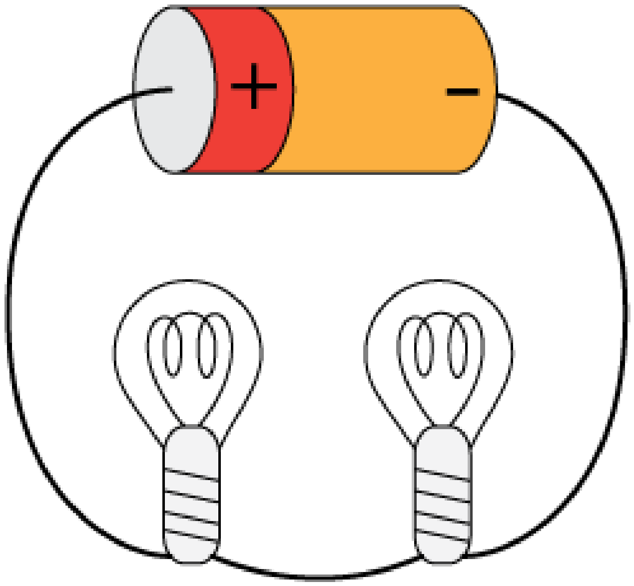
Only a licensed professional electrician like this one is qualified to install or repair the electrical system inside a home. It's a complicated system that consists of a maze of electric circuits.

One Loop or Two?

An electric circuit consists of at least one closed loop through which electric current can flow. Every circuit has a voltage source such as a battery and a conductor such as metal wire. A circuit may have other parts as well, such as lights and switches. In addition, a circuit may consist of one loop or two loops.

Series Circuit

A circuit that consists of one loop is called a **series circuit**. You can see a simple series circuit below. If a series circuit is interrupted at any point in its single loop, no current can flow through the circuit and no devices in the circuit will work. In the series circuit below, if one light bulb burns out, the other light bulb won't work because it won't receive any current. Series circuits are commonly used in flashlights.

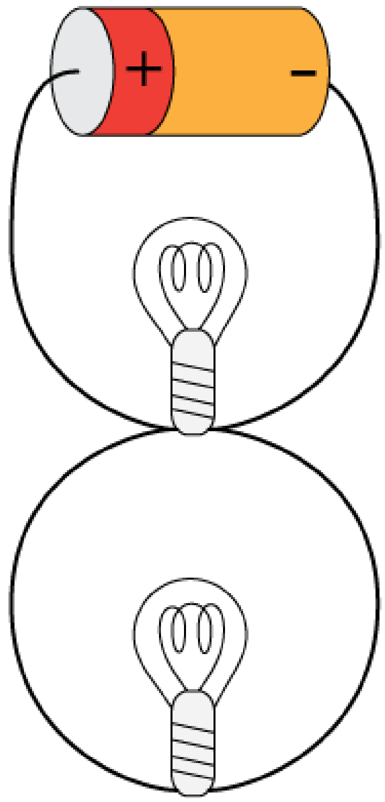


Q: If one light bulb burns out in this series circuit, how can you tell which bulb it is?

A: It may not be obvious, because neither bulb will light if one is burned out. You can tell which one it is only by replacing first one bulb and then the other to see which replacement results in both bulbs lighting up.

Parallel Circuit

A circuit that has two loops is called a **parallel circuit**. A simple parallel circuit is sketched below. If one loop of a parallel circuit is interrupted, current can still flow through the other loop. In the parallel circuit below, if one light bulb burns out, the other light bulb will still work because current can bypass the burned-out bulb. The wiring in a house consists of parallel circuits.



Summary

- An electric circuit consists of one or two closed loops through which current can flow. It has a voltage source and a conductor and may have other devices such as lights and switches.
- A circuit that consists of one loop is called a series circuit. If its single loop is interrupted at any point, no current can flow through the circuit.
- A circuit that consists of two loops is called a parallel circuit. If one loop of a parallel circuit is interrupted, current can still flow through the other loop.

Review

1. Compare and contrast series and parallel circuits.
2. Create a sketch of a parallel circuit that contains a voltage source and two light bulbs.

CONCEPT 16 Electromagnetism

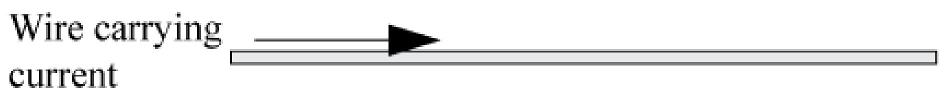
Learning Objectives

- Define electromagnetism.
- State the right hand rule.
- Explain why electromagnetism is very useful.

What a clever dog! He wants to go inside to get out of the rain, so he's ringing the doorbell. Does your home have a doorbell? Did you ever wonder how a doorbell works? The answer is electromagnetism.

What Is Electromagnetism?

Electromagnetism is magnetism produced by an electric current. When electric current flows through a wire, it creates a magnetic field that surrounds the wire in circles. You can see this in the diagram below. Note that electric current is conventionally shown moving from positive to negative electric potential, as in this diagram. However, electrons in current actually flow in the opposite direction, from negative to positive potential.

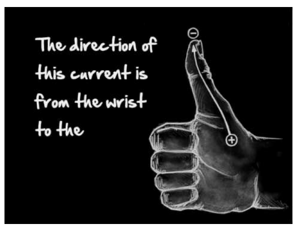


Q: If more current flows through a wire, how might this affect the magnetic field surrounding the wire?

A: With more current, the magnetic field is stronger.

Right Hand Rule

The direction of the magnetic field created when current flows through a wire depends on the direction of the current. A simple rule, called the right hand rule, makes it easy to find the direction of the magnetic field if the direction of the current is known. The rule is illustrated in the **Figure** 16.1. When the thumb of the right hand is pointing in the same direction as the current, the fingers of the right hand curl around the wire in the direction of the magnetic field.



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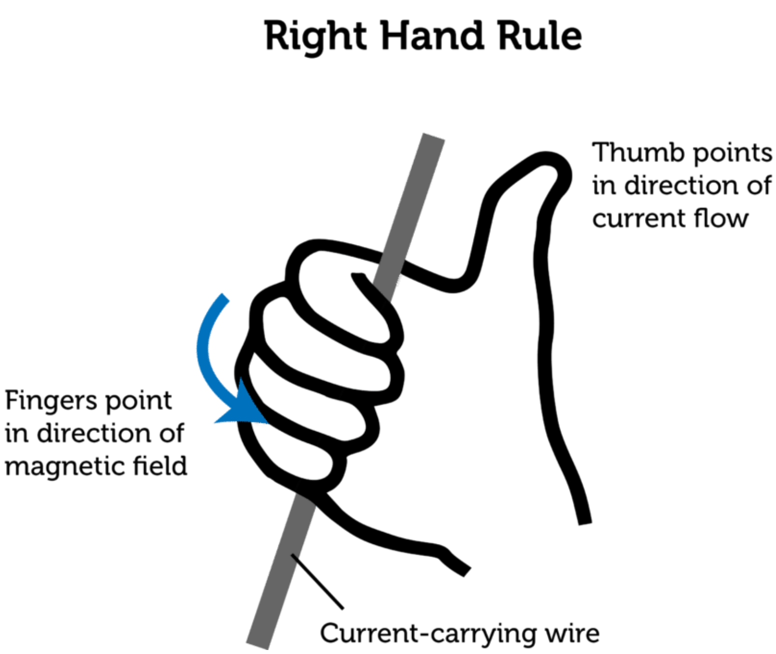


FIGURE 16.1

Uses of Electromagnetism

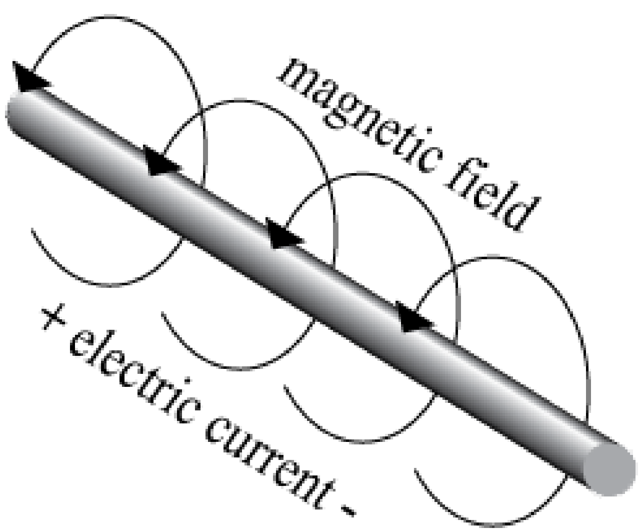
Electromagnetism is used not only in a doorbells but in many other electric devices as well, such as electric motors and loudspeakers. It is also used to store information on computer disks. An important medical use of electromagnetism is magnetic resonance imaging (MRI). This is a technique for making images of the inside of the body in order to diagnose diseases or injuries. Magnetism created with electric current is so useful because it can be turned on or off simply by turning the current on or off. The strength of the magnetic field is also easy to control by changing the amount of current. You can't do either of these things with a regular magnet.

Summary

- Electromagnetism is magnetism produced by an electric current. Current flowing through a wire creates a magnetic field that surrounds the wire in concentric circles.
- When the thumb of the right hand is pointing in the same direction as the current flowing through a wire, the fingers of the right hand curl around the wire in the direction of the magnetic field.
- Electromagnetism is very useful because it can be turned on or off by turning the current on or off, and it can be made stronger or weaker by using more or less current.

Review

1. Define electromagnetism.
2. Apply the right hand rule to determine the direction of the magnetic field around the wire shown below. The arrow inside the wire shows the direction of electric current flowing through the wire. Add more arrows to the sketch to show the direction of the magnetic field.



3. Why is electromagnetism more useful than regular magnetism?

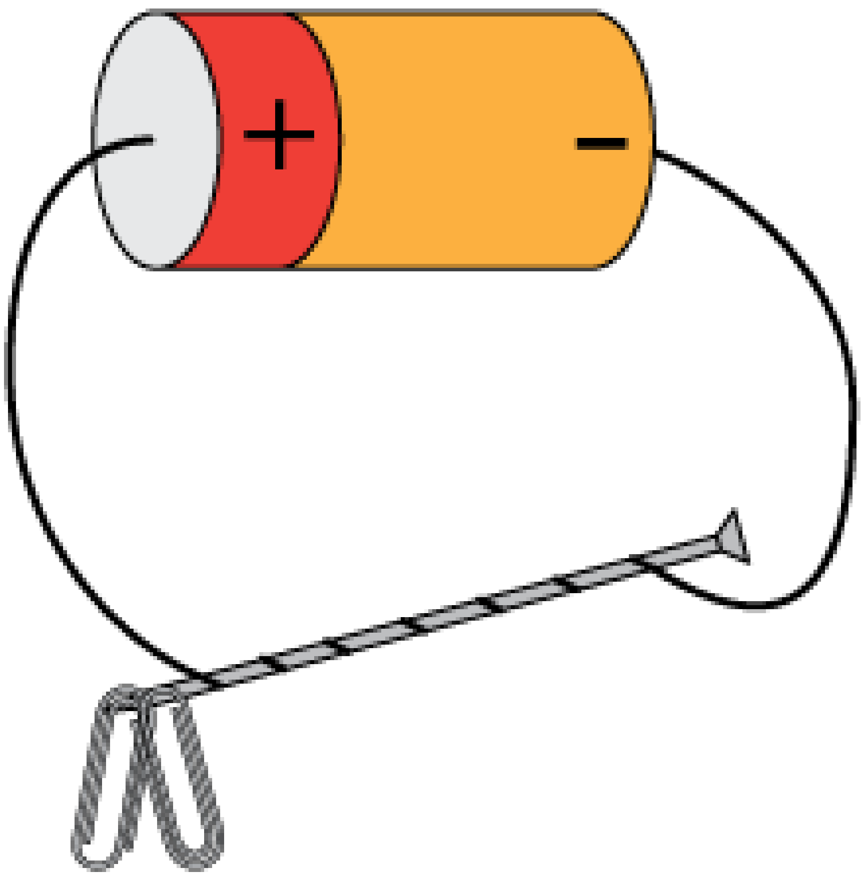
References

1. Hand by Wizard191, modified by Christopher Auyeung for CK-12 Foundation. Right hand rule applied to m agnetic fields . CC BY-NC 3.0 (hand available under public domain)

CONCEPT 17 Discovery of Electromagnetism

Learning Objectives

- Describe the accidental discovery of electromagnetism.
- Explain how Oersted found the direction of the magnetic field around a wire carrying current.
- State Faraday's law.



Tamara made the simple device in this picture for science class. She wrapped a wire around a nail and connected the ends of the wire to the terminals of a battery. The nail is attracting paper clips, so it appears to have become magnetized. The device isn't complicated, but it shows a very important relationship.

Q: What does Tamara's device show?

A: The device shows that you can use electricity to create magnetism.

Electricity and Magnetism

Magnetism produced by electricity is called **electromagnetism**. Today, electromagnetism is used in many electric devices. However, until electromagnetism was discovered, scientists thought that electricity and magnetism were unrelated. A Danish scientist named Hans Christian Oersted (pictured in the **Figure** 17.1) changed all that. He made the important discovery that electric current creates a magnetic field. But like many other important discoveries in science, Oersted's discovery was just a lucky accident.

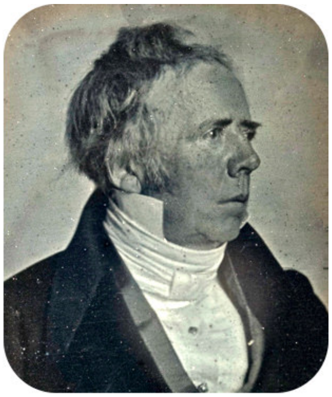


FIGURE 17.1

An Accidental Discovery

In 1820, Oersted was presenting a demonstration to some science students. Ironically, he was trying to show them that electricity and magnetism are *not* related. He placed a wire with electric current flowing through it next to a compass, which has a magnetic needle. As he expected, the needle of the compass didn't move. It just kept pointing toward Earth's north magnetic pole.

After the demonstration, a curious student held the wire near the compass again, but in a different direction. To Oersted's surprise, the needle of the compass swung toward the wire so it was no longer pointing north. Oersted was intrigued. He turned off the current in the wire to see what would happen to the compass needle. The needle swung back to its original position, pointing north once again. Oersted had discovered that an electric current creates a magnetic field. The magnetic field created by the current was strong enough to attract the needle of the nearby compass.

Oersted Learns More

Oersted wanted to learn more about the magnetic field created by a current. He placed a compass at different locations around a wire with current flowing through it. You can see what he found in the **Figure** 17.2. The lines of magnetic force circle around the wire in a counterclockwise direction.

From Magnets to Electricity

Just about a decade after Oersted discovered that electric current can produce a magnetic field, an English scientist named Michael Faraday discovered that the opposite is also true. A magnetic field can produce an electric current. This is known as Faraday's law. The process by which a magnetic field produces current is called electromagnetic induction. It occurs when a conductor, such as a wire, crosses lines of force in a magnetic field. This can happen when a wire is moving relative to a magnet or a magnet is moving relative to a wire.

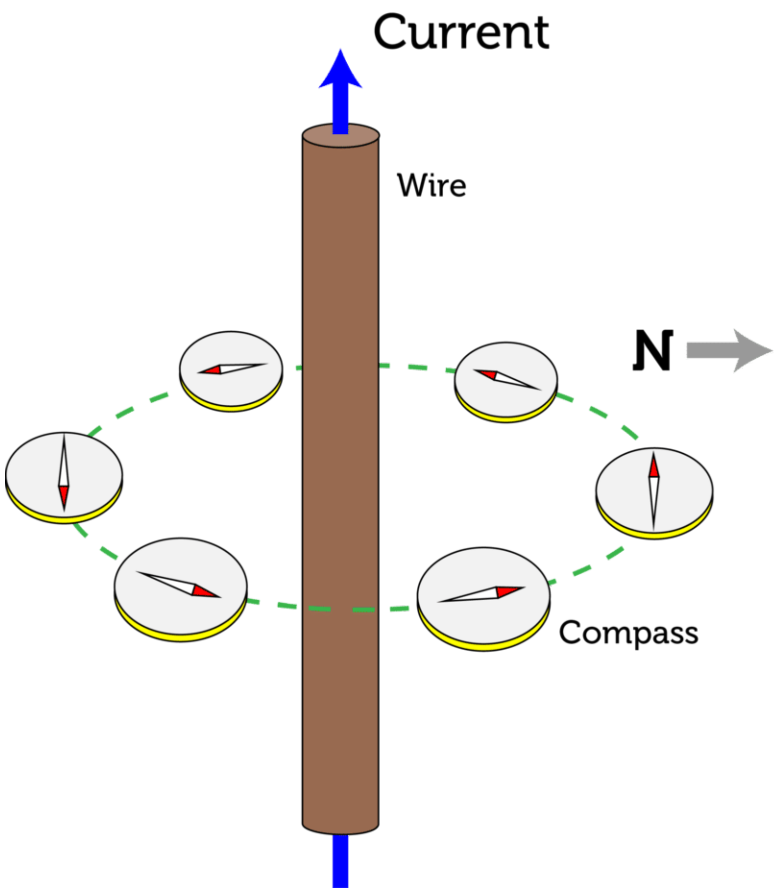


FIGURE 17.2

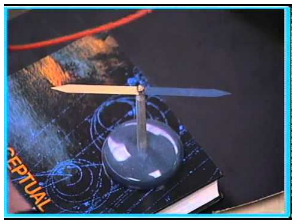
Summary

- Electricity can be used to produce a magnetic field. Magnetism produced by electricity is called electromagnetism.
- In 1820, Oersted discovered by accident that electric current creates a magnetic field. Prior to that, scientists thought that electricity and magnetism were unrelated.
- Oersted also used a compass to find the direction of the magnetic field around a wire carrying current.
- Around 1830, Michael Faraday discovered that a magnetic field can generate an electric current if a conductor crosses the lines of force in a magnetic field. This is known as Faraday's law.

Review

1. What observation led Oersted to conclude that electricity and magnetism are related?
2. How did Oersted find the direction of the magnetic field around a wire carrying current?
3. What did Faraday discover?

Resources



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URL: http://www.ck12.org/flx/render/embeddedobject/177812

References

1. . Hans Christian Oersted . Public Domain
2. Christopher Auyeung. Direction of magnetic field relative to current . CC BY-NC 3.0

CONCEPT 18 Electromagnet

Learning Objectives

- Describe an electromagnet.
- Explain why electromagnets are very strong.

This crane is dangling a big round magnet that has picked up metal car parts in a junk yard. The parts practically leap up to the magnet because it's so strong. That's because it's an electromagnet.

What Is an Electromagnet?

An **electromagnet** is a solenoid wrapped around a bar of iron or other ferromagnetic material. A solenoid is a coil of wire with electric current flowing through it. This gives the coil north and south magnetic poles and a magnetic field. The magnetic field of the solenoid magnetizes the iron bar by aligning its magnetic domains. You can see this in the **Figure** 18.1.

Strength of an Electromagnet

The combined magnetic force of the magnetized wire coil and iron bar makes an electromagnet very strong. In fact, electromagnets are the strongest magnets made. An electromagnet is stronger if there are more turns in the coil of wire or there is more current flowing through it. A bigger bar or one made of material that is easier to magnetize also increases an electromagnet's strength.

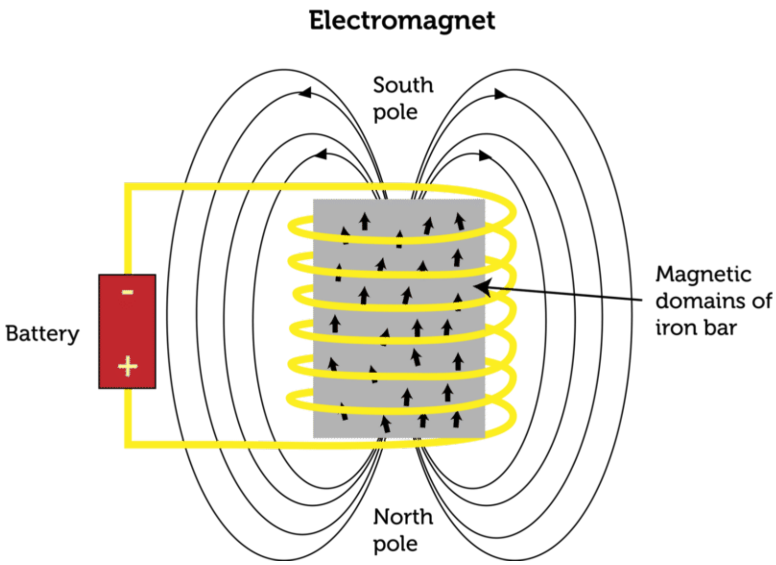

FIGURE 18.1

Easy On/Off

Besides their strength, another pro of electromagnets is the ability to control them by controlling the electric current. Turning the current on or off turns the magnetic field on or off. The amount of current flowing through the coil can also be changed to control the strength of the electromagnet.

Q: Why might it be useful to be able to turn an electromagnet on and off?

A: Look back at the electromagnet hanging from the crane in the opening photo. It is useful to turn on its magnetic field so it can pick up the metal car parts. It is also useful to turn off its magnetic field so it can drop the parts into the train car.

Summary

- An electromagnet is a solenoid wrapped around a bar of iron or other ferromagnetic material. The magnetic field of the solenoid magnetizes the iron bar.
- The combined magnetic force of the magnetized wire coil and iron bar makes an electromagnet very strong.
- Electromagnets can be turned on or off and their strength can be changed by controlling the electric current.

Review

1. What is an electromagnet?
2. How could you increase the strength of an electromagnet?
3. Why are electromagnets the strongest of all magnets?
4. How could the crane operator in the opening photo cause the electromagnet to drop the metal parts into the train car?

Resources

MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/177814

References

1. Christopher Auyeung. Schematic of an electromagnet . CC BY-NC 3.0

CONCEPT 19 Electromagnetic Devices

Learning Objectives

- Define electromagnet and identify electromagnetic devices.
- Explain how a doorbell works.
- Outline how an electric motor changes electrical energy to kinetic energy.

The little boy on the left is pressing the doorbell on his playhouse. The doorbell is connected to a battery, so it actually rings when he pushes the button. The little girl on the right is using a hand-held fan to cool off on a hot day. The fan is also battery-operated, and the blades of the fan turn in a blur of motion. What do the doorbell and fan have in common? Both of them work because they contain electromagnets.

Devices with Electromagnets

Many common electric devices contain electromagnets. An **electromagnet** is a coil of wire wrapped around a bar of iron or other ferromagnetic material. When electric current flows through the wire, it causes the coil and iron bar to become magnetized. An electromagnet has north and south magnetic poles and a magnetic field. Turning off the current turns off the electromagnet. To understand how electromagnets are used in electric devices, we'll focus on two common devices: doorbells and electric motors like the one that turns the blades of a fan.

Q: Besides doorbells and fans, what are some other devices that contain electromagnets?

A: Any device that has an electric motor contains electromagnets. Some other examples include hairdryers, CD players, power drills, electric saws, and electric mixers.

How a Doorbell Works

The **Figure** 19.1 represents a simple doorbell. Like most doorbells, it has a button located by the front door. Pressing the button causes two electric contacts to come together and complete an electric circuit. In other words, the button is a switch. The circuit is also connected to a source of current, an electromagnet, and a clapper that strikes a bell.

What happens when current flows through the doorbell circuit?

- The electromagnet turns on, and its magnetic field attracts the clapper. This causes the clapper to hit the bell, making it ring.

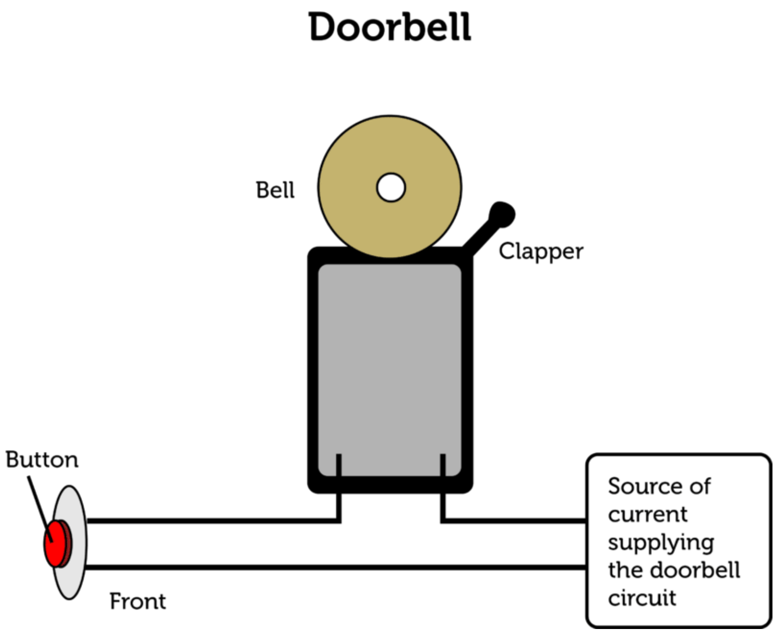

FIGURE 19.1

- Because the clapper is part of the circuit, when it moves to strike the bell, it breaks the circuit. Without current flowing through the circuit, the electromagnet turns off, and the clapper returns to its original position.
- When the clapper moves back to its original position, this closes the circuit again and turns the electromagnet back on. The electromagnet again attracts the clapper, which hits the bell once more.
- This sequence of events keeps repeating.

Q: How can you stop the sequence of events so the doorbell will stop ringing?

A: Stop pressing the button! This interrupts the circuit so no current can flow through it.

Electric Motor

An **electric motor** is a device that uses an electromagnet to change electrical energy to kinetic energy. You can see a simple diagram of an electric motor in the **Figure** 19.2. The motor contains an electromagnet that is connected to a shaft. When current flows through the motor, the electromagnet rotates, causing the shaft to rotate as well. The rotating shaft moves other parts of the device. For example, in an electric fan, the rotating shaft turns the blades of the fan.

Why does the motor's electromagnet rotate?

- The electromagnet is located between the north and south poles of two permanent magnets. When current flows through the electromagnet, it becomes magnetized, and its poles are repelled by the like poles of the permanent magnets. This causes the electromagnet to rotate toward the unlike poles of the permanent magnets.
- A device called a commutator then changes the direction of the current so the poles of the electromagnet are reversed. The reversed poles are again repelled by the poles of the permanent magnets, which have not reversed. This causes the electromagnet to continue to rotate.
- These events keep repeating, so the electromagnet rotates continuously.

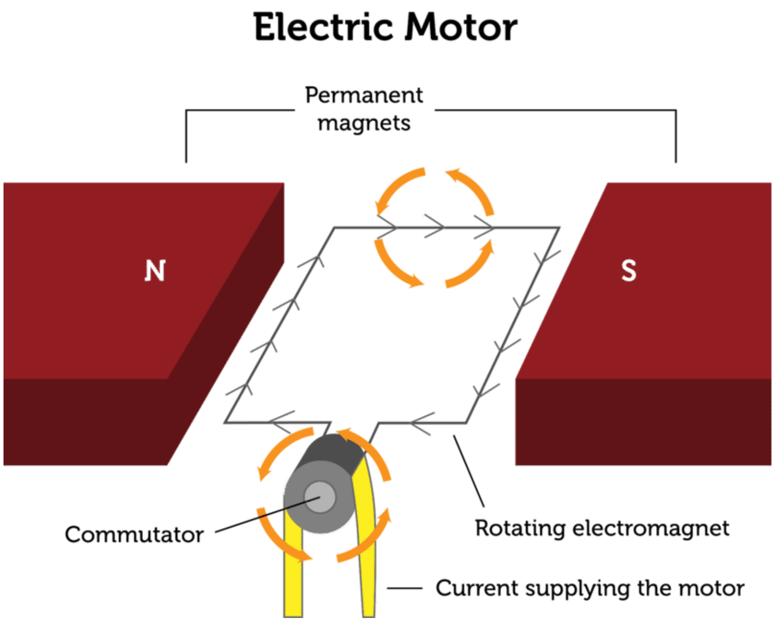

FIGURE 19.2

Summary

- Electromagnetic devices are devices that contain electromagnets. Examples of electromagnetic devices include doorbells and any devices that have electric motors, such as electric fans.
- The electromagnet in a doorbell attracts the clapper, which hits the bell and makes it ring.
- An electric motor is a device that uses an electromagnet to change electrical energy to kinetic energy. When current flows through the motor, the electromagnet rotates, causing a shaft to rotate as well. The rotating shaft moves other parts of the device.

Review

1. Describe an electromagnet.
2. What are some common devices that contain electromagnets?
3. Describe the role of the electromagnet in a doorbell.
4. What is an electric motor?
5. Explain how an electric motor turns the blades of an electric fan.

Resources

MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/177816

References

1. Christopher Auyeung. Schematic illustrating how a doorbell works . CC BY-NC 3.0
2. Christopher Auyeung. Schematic of an electromagnetic motor . CC BY-NC 3.0

CONCEPT 20 Electric Generators

Learning Objectives

- Describe an electric generator and its function.
- Explain how generators transform kinetic energy to electrical energy.

The sprawling machines in this plant aren't factory machines, but they do produce something. They are electric generators in a hydroelectric power plant, and they produce electricity.

Generating Electricity

An **electric generator** is a device that changes kinetic energy to electrical energy through electromagnetic induction. Electromagnetic induction is the process of generating electric current with a magnetic field. It occurs when a magnetic field and an electric conductor, such as a coil of wire, move relative to one another.

A simple diagram of an electric generator is shown in the **Figure** 20.1. In any electric generator, some form of energy is applied to turn a shaft. The turning shaft causes a coil of wire to rotate between the opposite poles of a magnet. Because the coil is rotating in a magnetic field, electric current is generated in the wire.

Q: What might happen to the current produced by an electric generator if the poles of the magnet kept reversing?

A: The direction of the current would also keep reversing. In other words, the electric generator would generate alternating current.

From Kinetic to Electrical Energy

Generators may be set up to produce either direct or alternating current. Generators in cars and most power plants produce alternating current. Regardless of the type of current, all generators change kinetic energy to electrical energy.

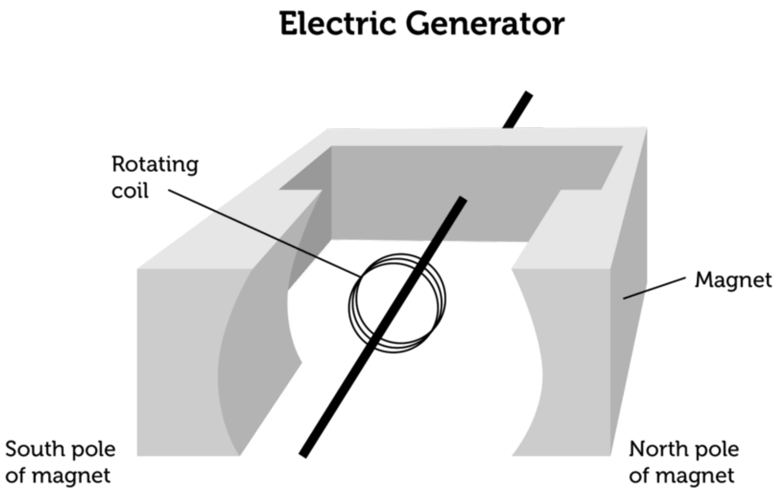

FIGURE 20.1

- A car generator produces electricity with some of the kinetic energy of the turning crankshaft. The electricity is used to run the car's lights, power windows, radio, and other electric devices. Some of the electricity is stored in the car's battery to provide electrical energy when the car isn't running.
- A power plant generator produces electricity with the kinetic energy of a turning turbine. The energy to turn the turbine may come from burning fuel, falling water, or some other energy source. You can see how falling water is used to generate electricity in a hydroelectric power plant in the **Figure** 20.2.

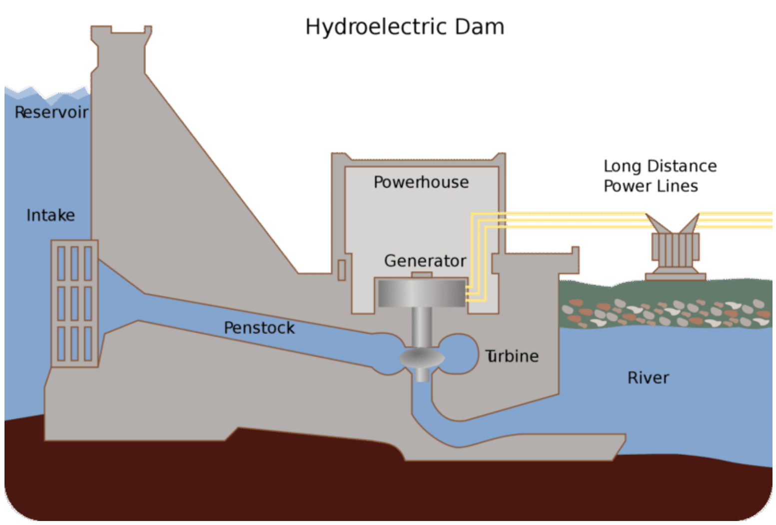

FIGURE 20.2

Q: The water flowing through the dam and over the turbine has kinetic energy because it is moving. Where does the water get the energy to move?

A: When the water is in the reservoir, it has potential energy because of gravity. Potential energy is stored in the water because of its position behind the dam. When the water flows into the intake pipe, gravity pulls it downhill to the power plant.

Summary

- An electric generator is a device that produces electricity through electromagnetic induction. Electromagnetic induction is the process of generating electric current with a magnetic field.
- Generators may produce either alternating or direct current, but they all change kinetic energy to electrical energy.

Review

1. Identify the parts of an electric generator and what they do.
2. Explain how an electric generator in a hydroelectric power plant changes kinetic energy to electrical energy.
3. An electric motor is a device that changes electrical energy to kinetic energy. How is an electric generator like an electric motor in reverse?

Resources

MEDIA

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References

1. Christopher Auyeung. Basic schematic of a generator . CC BY-NC 3.0
2. User:Tomia/Wikimedia Commons. Schematic of a dam providing hydroelectric power . CC BY 2.5

CONCEPT 21 Electric Transformers

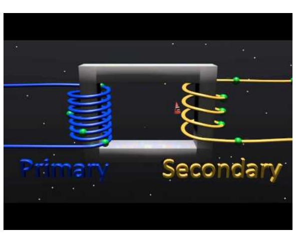
Learning Objectives

- Describe an electric transformer and how it changes electric current.
- Distinguish between step-up and step-down electric transformers.

You've probably noticed big drums like this one at the tops of electric poles. A pole close to your home is likely to have one. The drum is an electric transformer. Without it, the current entering your home would have too much voltage for your home's electric circuits to handle.

What Is an Electric Transformer?

An **electric transformer** is a device that uses electromagnetic induction to change the voltage of electric current. Electromagnetic induction is the process of generating current with a magnetic field. It occurs when a magnetic field and electric conductor, such as a coil of wire, move relative to one another. A transformer may either increase or decrease voltage. You can see the basic components of an electric transformer in the **Figure** 21.1.



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The transformer in the diagram consists of two wire coils wrapped around an iron core. Each coil is part of a different circuit. When alternating current passes through coil P, it magnetizes the iron core. Because the current is alternating, the magnetic field of the iron core keeps reversing. This is where electromagnetic induction comes in. The changing magnetic field induces alternating current in coil S of the other circuit.

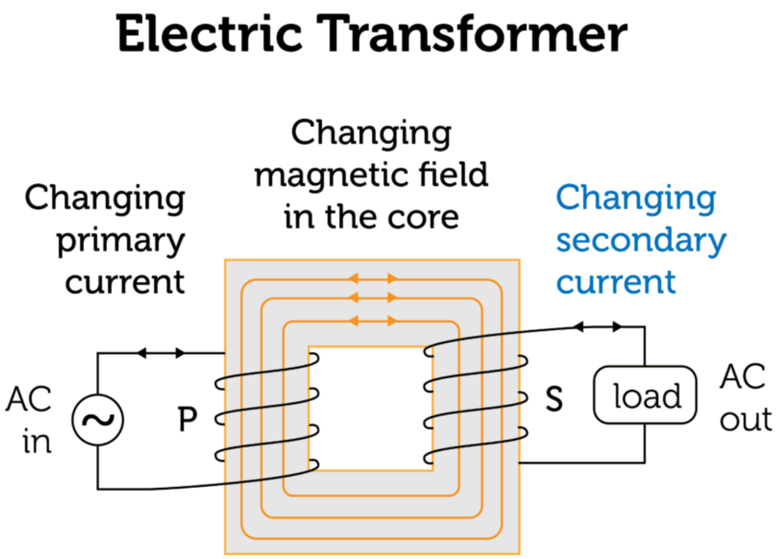

FIGURE 21.1

Stepping Up or Stepping Down

Notice that coil P and coil S in the **Figure** 21.1 have the same number of turns of wire. In this case, the voltages of the primary and secondary currents are the same. Usually, the two coils of a transformer have different numbers of turns. In that case, the voltages of the two currents are different.

- When coil S has more turns than coil P, the voltage in the secondary current is greater than the voltage in the primary current (see **Figure** 21.2). This type of transformer is called a step-up transformer. That's because it steps up, or increases, the voltage.

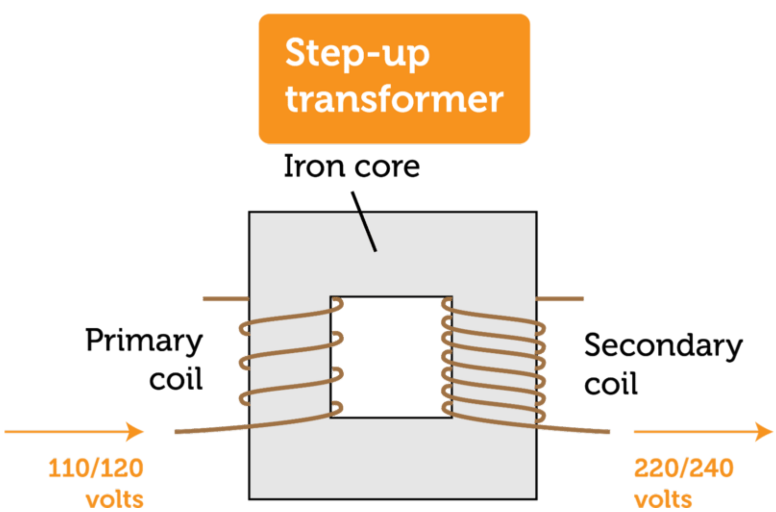

FIGURE 21.2

- When coil S has fewer turns of wire than coil P, the voltage in the secondary current is less than the voltage in the primary current (see **Figure** 21.3). This type of transformer is called a step-down transformer because it steps down, or decreases, the voltage.

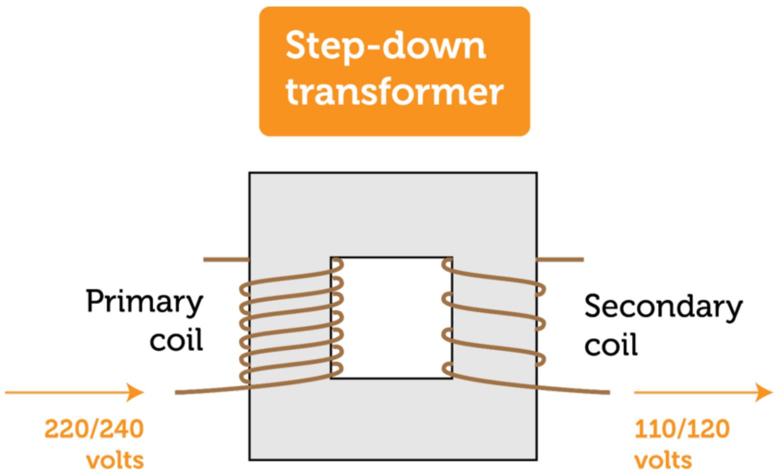

FIGURE 21.3

Q: Both step-up and step-down transformers are used in the electrical grid that carries electricity from a power plant to your home. Where in the grid do you think step-down transformers might be used?

A: One place that step-down transformers are used is on the electric poles that supply current to homes. They reduce the voltage of the electric current before it enters home circuits.

Summary

- An electric transformer is a device that uses electromagnetic induction to change the voltage of an electric current.
- A step-up transformer increases voltage. A step-down transformer decreases voltage.

Review

1. What is an electric transformer?
2. How does an electric transformer use electromagnetic induction?
3. Compare and contrast step-up and step-down transformers.

References

1. Christopher Auyeung. Schematic of a generic transformer . CC BY-NC 3.0
2. Christopher Auyeung. Schematic of a step up transformer . CC BY-NC 3.0
3. Christopher Auyeung. Schematic of a step down transformer . CC BY-NC 3.0

CONCEPT 22 Electrical Grid

Learning Objectives

- Describe an electrical grid.
- Identify the roles of power plants, transmission lines, and electric substations in an electrical grid.

These electric power towers carry high-voltage electric lines. The lines transmit electricity from power plants to homes like yours. The towers are a crucial part of the electrical grid.

What Is an Electrical Grid?

An **electrical grid** is the entire electrical system that generates, transmits, and distributes electric power throughout a region or country. A very simple electrical grid is sketched in the **Figure** 22.1. The grid includes a power plant, transmission lines, and electric substations, all of which work together to provide alternating current to customers.

Power Plants

Electricity originates in power plants. They have electric generators that produce electricity by electromagnetic induction. In this process, a changing magnetic field is used to generate electric current. The generators convert kinetic energy to electrical energy. The kinetic energy may come from flowing water, burning fuel, wind, or some other energy source.

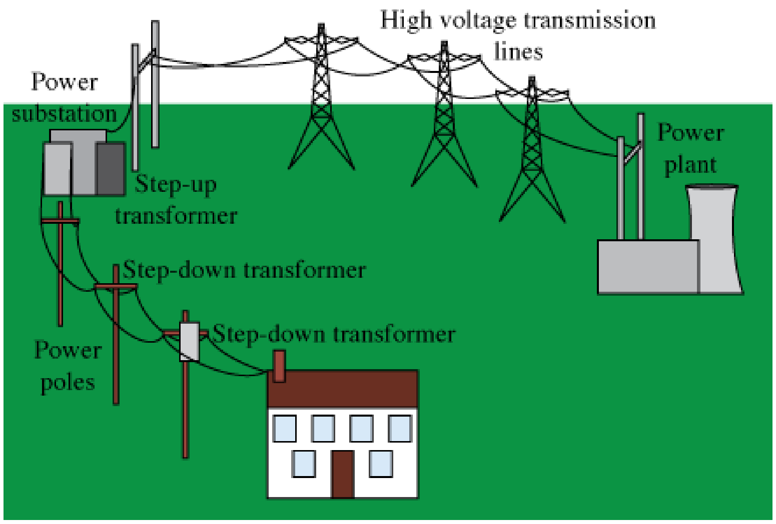

FIGURE 22.1

Transmission Lines

Transmission lines on big towers—like those in the opening photo above—carry high-voltage electric current from power plants to electric substations. Smaller towers and individual power poles carry lower-voltage current from electric substations to homes and businesses.

Electric Substations

Electric substations have several functions. Many substations distribute electricity from a few high-voltage lines to several lower-voltage lines. They have electric transformers, which use electromagnetic induction to change the voltage of the current. Some transformers increase the voltage; others decrease the voltage. In the **Figure** 22.2, you can see how both types of transformers are used in an electrical grid.

FIGURE 22.2

- A step-up transformer increases the voltage of the current as it leaves the power plant. After the voltage has been increased, less current travels through the high-voltage power lines. This reduces the amount of power that is lost due to resistance of the power lines.
- A step-down transformer decreases the voltage of the current so it can be distributed safely to businesses and homes. A high-voltage power line may have 750,000 volts, whereas most home circuits have a maximum of 240 volts. Therefore, one or more step-down transformers are needed to decrease the voltage of current before it enters homes.

Q: Assume that a home needs a 14-volt circuit for a light and a 120-volt circuit for a microwave oven. If the main power line entering home has 240 volts, what can you infer about the home's electrical system?

A: The home's electrical system must have step-down transformers that lower the voltage for some of the home's circuits.

Summary

- The electrical grid is the entire electrical system that generates, transmits, and distributes electric power throughout a region or country. It includes power plants, transmission lines, and electric substations.
- Power plants are where electric power originates. They have electric generators that generate electric current through electromagnetic induction.
- Transmission lines carry electric current from power plants to substations and from substations to homes and other places where electric power is needed.
- Electric substations have step-up or step-down transformers to increase or decrease the voltage of current as needed.

Review

1. Identify the components of an electrical grid.
2. What is the source of power in an electrical grid?
3. Explain why an electrical grid must have electric transformers.
4. If lightning strikes a transformer, it will cause power outages. Which lightning strike is likely to affect the most electric power customers: a strike to a step-down transformer on an electric pole or a strike to a step-down transformer in an electric substation?

Resources

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/177820

References

1. Zachary Wilson. Schematic of a typical power grid . CC BY-NC 3.0
2. Zachary Wilson. Linear schematic focused on transformers. . CC BY-NC 3.0