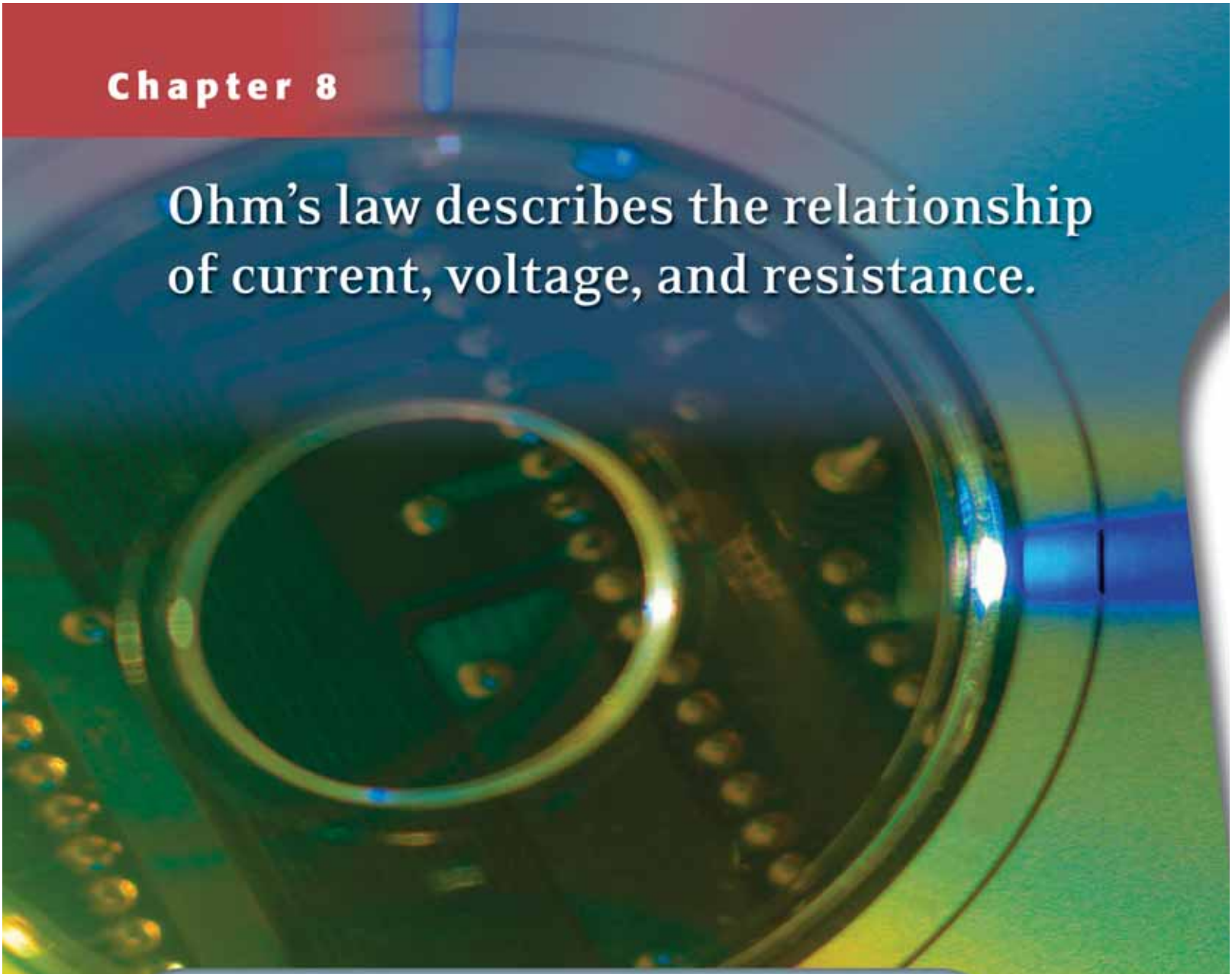
Chapter 8

Ohm's law describes the relationship of current, voltage, and resistance.



Two small batteries can be put into a CD player to bring you the thundering bass and screaming guitar of your favourite band. Batteries can also provide power for digital cameras, wristwatches, and flashlights.

How is the electrical energy that is stored in a battery transformed into so many other forms of energy? The energy in the battery is carried through hundreds of pathways inside an electrical device. Some of the pathways may produce sound, while pathways in other devices may produce motion, heat, or light. When you press "play" on a CD player like the one shown here, the pathways transform the silent chemical energy stored in the batteries into sound energy.

Electricity is not a modern discovery. However, today's technological society depends on being able to control and use electricity in many ways in many different devices. In this chapter, you will learn how electrical energy is transferred and transformed.

What You Will Learn

In this chapter, you will

- **explain** how electric current results from separation of charge and the movement of electrons
- **apply** the laws of static charge to electron flow in a circuit
- **define** voltage, current, and resistance
- **draw** circuit diagrams using appropriate symbols
- **distinguish** between potential and kinetic energy; static electricity and current electricity; and conventional current and electron flow

Why It Is Important

Every time you turn on a television, computer, or flashlight or turn the key to start a car engine, you complete an electric circuit. You use electric circuits to control how electrical energy is transferred.

Skills You Will Use

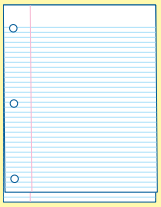
In this chapter, you will

- **measure** voltage and current using appropriate equipment
- **calculate** resistance using current and voltage data
- **model** electric circuits using circuit diagrams

FOLDABLES™
Reading & Study Skills

Make the following Foldable and use it to take notes on what you learn in Chapter 8.

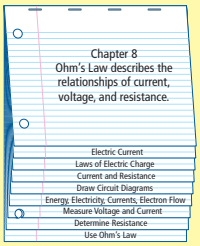
STEP 1 **Use** nine sheets of lined paper. Leave one sheet whole. Cut two lines off the bottom of the second sheet.



STEP 2 **Cut** 4 lines off the third sheet, 6 lines off the fourth sheet, 8 lines off the fifth sheet, 10 lines off the sixth sheet, 12 lines off the seventh sheet, 14 lines off the eighth sheet, and 16 lines off the ninth sheet.

STEP 3 **Align** the sheets along the top edge from shortest to longest and **staple** along the top.

STEP 4 **Label** the top section with the chapter title, and label each of the following tabs with the eight points listed under the "What You Will Learn" and "Skills You Will Use."



Summarize As you read the chapter, summarize what you learn under the appropriate tabs.

8.1 Electric Potential Energy and Voltage

When unlike charges are moved farther apart, they gain electric potential energy. Electric potential difference is the change in potential energy per coulomb of charge. Voltage is the common name for electric potential difference and is measured in volts (V). Electrical energy depends on the amount of charge and the voltage. Electrochemical cells, or batteries, are a common source of voltage. We use voltmeters to measure potential difference.

Words to Know

electric potential energy
electrochemical cells
electrodes
electrolyte
energy
potential difference
volt
voltage

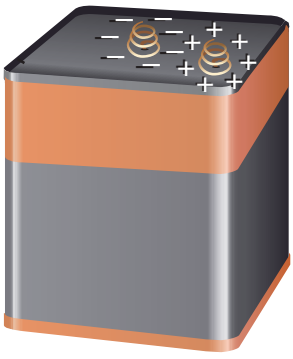


Figure 8.1 The purpose of an electrochemical cell or battery is to give electrons stored electrical energy.

What do a charged storm cloud and batteries have in common? They both separate positive and negative charges. Lightning is an uncontrolled burst of electrical energy and can cause power outages, injuries, loss of life, and fires. A battery can provide a steady, controlled flow of electricity. Which would you choose as a source of energy for a CD player?

A **battery** is a combination of electrochemical cells connected together (or a single electrochemical cell). **Electrochemical cells** convert chemical energy into electrical energy stored in charges. Electrochemical cells are commonly called cells or batteries. In a battery, chemical energy separates the positive and negative charges. Examine Figure 8.1. The battery **terminals** are the end points where we make a connection. Extra electrons accumulate on one of the battery terminals, making it negatively charged. The other terminal has lost these electrons and is therefore positively charged. When the battery is connected to a CD player, electrons can travel through the wires and into the player. The electrons' stored electrical energy is transformed into sound energy.

8-1A A Penny for a Battery

Find Out ACTIVITY

In this activity, you will build an electrochemical cell from common household materials.

Using the voltmeter

Materials

- aluminum foil
- paper towel
- penny
- voltmeter
- vinegar

Science Skills

Go to Science Skill 11 to learn more about how to use a voltmeter.

What to Do

1. Place a small piece of aluminum foil (5 cm × 5 cm) on the desk.
2. Place a piece of paper towel (2.5 cm × 2.5 cm) on the aluminum foil.
3. Place a clean copper penny on the dry paper towel.
4. Using a digital voltmeter, touch the aluminum foil with one lead and touch the penny with the other lead. Observe and record the reading on the voltmeter.
5. Remove the paper towel and soak it in vinegar. Place it back between the aluminum foil and the penny. Repeat step 4.
6. Clean up and put away the equipment you have used.

What Did You Find Out?

1. (a) How did the voltmeter reading in step 5 differ from the reading in step 4?
   (b) What do you think caused the difference?
2. (a) Vinegar is a weak acid. If you did not have vinegar, what other similar liquid do you think would have had the same result?
   (b) Explain why you chose this liquid.
3. Suppose you were to cover your penny with a paper towel soaked in vinegar and then added an identical stack of aluminum, paper towel soaked in vinegar, and penny. If you touched one lead on the bottom piece of aluminum foil and one lead on the top penny, what reading would you expect on the voltmeter? Explain.
4. What is another question about electrochemical cells that you could investigate using these materials?

Electric Potential Energy

Energy is the ability to do work. **Kinetic energy** is energy a moving object has because of its motion. **Potential energy** is the energy stored in an object. The electrical energy stored in a battery is called **electric potential energy** because the electrons have a stored energy and the ability to do work after they leave the battery.

If you stretch a spring and hold it, the energy in the spring is stored. This is an example of potential energy. The energy stored in the spring will not be released until you let go. Likewise, in order for the electrons to lose their stored electrical energy, the battery must be connected to a device. When you connect a battery to a light bulb, the electric potential energy is "released" as the electrons move through the wire inside the bulb and the electrons' energy is converted into heat and light energy.

Did You Know?

You may be familiar with AA, AAA, C, and D batteries. Have you ever seen a B battery? B batteries were used in portable radios more than 80 years ago. They are no longer used in today's technology and therefore are not common.

Did You Know?

Nearly 20 years before Volta invented the battery, the Italian scientist Luigi Galvani noticed that a frog's muscle would twitch when touched by two different metals. Galvani believed that the muscle tissue contained "animal electricity." Volta later proved that the source of the potential difference was produced by the two different metals, not by the frog's muscles.

Electric Potential Difference

You may recall from section 7.1 that charge is measured in coulombs. The amount of electric potential energy per one coulomb of charge is called the **potential difference** or **voltage**. The unit for measuring potential difference is the **volt** (V). This unit was named in honour of Alessandro Volta (Figure 8.2), an Italian physicist who invented the battery (Figure 8.3).

Figure 8.2 Alessandro Volta (1745–1827)

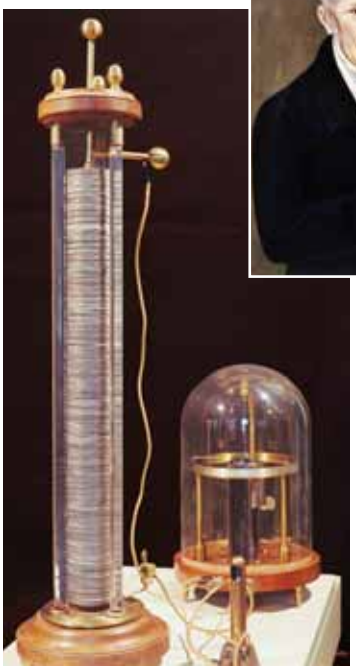


Figure 8.3 In 1799, Volta invented a "voltaic pile" battery, alternating zinc and copper disks separated by pieces of fabric soaked in salt water.

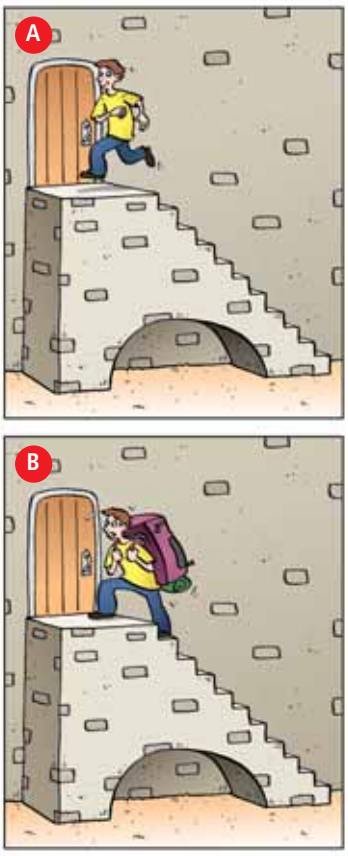


Figure 8.4 Even though the stairs are the same height in A and B, more work is done in B. Therefore, there is more potential energy in B.

Comparing Potential Energy and Potential Difference

You might compare potential energy and potential difference with climbing a staircase. When you climb a flight of stairs, your body has done work (Figure 8.4). The work you have done is now *potential energy*. If you had climbed the same set of stairs with a heavy backpack, you would have done more work. As a result, you and the backpack would have more potential energy. The potential energy thus depends on the height of the stairs and the amount of mass moved to the top.

You can think of the potential difference in a battery as being like the height of the stairs. The amount of charge separated in a battery is like the mass moved up the stairs. The potential energy in the battery is due to both the potential difference (volts) and the amount of charge that has been separated (coulombs).

The amount of potential energy a battery can output depends not only on how much voltage the battery has but also on how much charge that battery can separate. Even though C, D, AA, and AAA batteries all have a potential difference of 1.5 V, the battery that can separate the most charge would have the greatest potential energy. The energy that charge possesses is dependent on the amount of charge and the voltage.

A **voltmeter** is a device that measures the amount of potential difference between two locations of charge separation. When you place the connecting wires of a voltmeter across the + and – terminals of a battery, the voltmeter displays the battery's voltage.

Producing Voltage

We can classify batteries into two groups: dry cells and wet cells (Figure 8.5). Dry cells are the batteries in devices like flashlights, portable CD players, and watches. Wet cells are commonly used in cars, motorcycles, and electric wheelchairs. Both types of batteries produce voltage in a similar way.

Did You Know?

The voltage across a muscle cell in your body is about 70 millivolts. A millivolt (mV) is one thousandth of a volt.

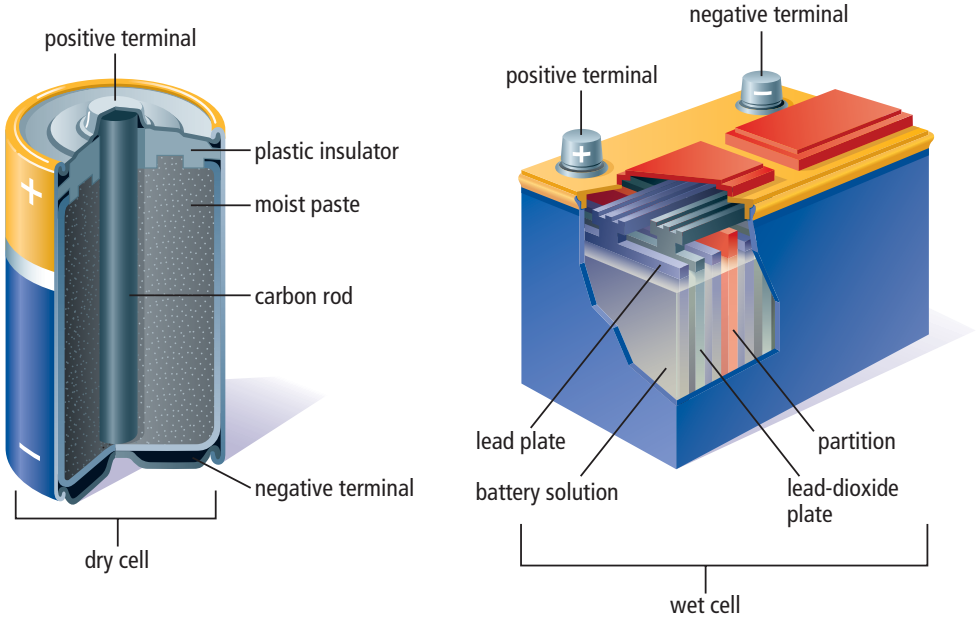


Figure 8.5 Chemical reactions in batteries produce a voltage across the positive and negative terminals.

Suggested Activities

Find Out Activity 8-1B on page 275
Conduct an Investigation 8-1C on page 276

A battery has two terminals called **electrodes**. The electrodes are usually made of two different metals but can be a metal and another material. The electrodes are in an **electrolyte**, which is a substance that conducts electricity. In a dry cell, the electrolyte is a moist paste; in a wet cell, the electrolyte is a fluid. Figure 8.6 shows an electrochemical cell that uses a zinc and a copper electrode. The acidic electrolyte attacks the zinc electrode and pulls atoms off the zinc. But the zinc atoms leave electrons behind on the electrode, and the electrode becomes negatively charged. At the same time, chemical reactions pull electrons off the copper electrode. Therefore, the copper electrode has a positive charge. Because there is an opposite charge on each electrode, there is a potential difference (voltage) between the two electrodes.

The amount of voltage that is produced in an electrochemical cell depends on the types of metal and the electrolyte used. Most modern electrochemical cells can produce 1.5 V or 2.0 V. For example, a 12 V car battery could consist of six 2.0 V cells or eight 1.5 V cells connected together.

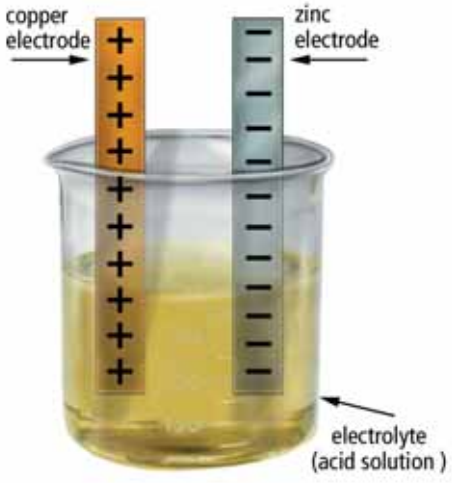


Figure 8.6 An electrochemical cell requires two different electrodes (usually metals) and an electrolyte.

Many Sources of Electrical Energy

An electrochemical cell or battery changes chemical energy into electrical energy by separating charge. Other forms of energy can also be used to separate charge and provide electrical energy.

Table 8.1 Examples of Electrical Energy Sources

Friction

Rubbing two materials together, such as acetate and paper, or rubber and wool, can separate charge. These separated charges now have electrical energy. Some of the work done by rubbing is converted into the electrical energy stored in the separated charge.

Piezoelectric crystals

A barbecue lighter has no battery inside to produce the electric spark. The electricity comes from a tiny crystal. When certain types of crystals, such as quartz, are squeezed, positive and negative charges are separated on either side of the crystal. A small hammer in the lighter hits the piezoelectric crystal, generating a burst of thousands of volts of electricity. The prefix "piezo-" means pressure or push.

Photo-electrochemical cells

Solar panels and many calculators use photo-electrochemical cells or solar cells as a source of power. Photo-electrochemical cells are made of semi-conducting material such as silicon. When light hits the cell, some of the light energy breaks electrons off the surface of the cell. These separated electrons now have the electrical energy needed to operate a calculator, a phone booth, or the International Space Station.

Thermocouples

A thermocouple is a device used to transform heat energy into electrical energy. A thermocouple consists of a loop of two wires of different metals joined at both ends. If one end of the loop is heated or cooled, charge is separated and a voltage is created across the thermocouple. Individual thermocouples can produce only a small amount of electrical energy. If a larger amount of electricity is needed, several thermocouples must be joined together. We use a thermocouple in a kitchen oven to control the temperature.

Generators

The electricity that enters most of our homes is produced by a generator. Generators work on the principle that when a wire moves close to a magnet or a magnet moves close to a wire, a voltage is created across the wire. All that is needed is an energy source to provide the wire or the magnet with the necessary motion. In British Columbia, we use hydroelectric energy, the energy of water to generate electrical energy.

Reading Check

1. What device uses chemical energy to give charges electric potential energy?
2. What is the definition of energy?
3. How is kinetic energy different from potential energy?
4. What is another name for electric potential difference?
5. What two factors determine the energy the charge possesses?
6. What is the purpose of a voltmeter?
7. What are two groups of batteries?
8. How is an electrode different from an electrolyte?
9. What are five energy sources that produce electrical energy?

Explore More

Are electric cars new or old? Electric cars powered by batteries were more popular than gas-powered cars in the early 1900s. Environmental concerns and the cost of oil have helped promote the development of new electric and hybrid vehicles. To find out more about battery technology in electric and hybrid vehicles, go to **www.bcscience9.ca.**

8-1B Using the Voltmeter

Find Out ACTIVITY

In this activity, you will use a voltmeter to measure the potential difference of different batteries.

Safety

- Be sure the positive lead is connected to the positive terminal of the battery and the negative lead is connected to the negative terminal.

Materials

- voltmeter
- various batteries: AA, AAA, lantern battery, watch battery, 9.0 V battery

What to Do

1. Make a table to record your observations. Give your table a title.
2. Attach the leads of the voltmeter to one of the batteries. Be sure that the positive (+) lead of your voltmeter is connected to the positive (+) terminal of the battery and the negative (−), or common, lead of the voltmeter is connected to the negative (−) terminal of the battery. Record the voltage in your data table.
3. Repeat step 2 with the remaining batteries.

Science Skills

Go to Science Skill 11 for information on using a voltmeter.

What Did You Find Out?

1. Why is it important to connect the positive lead of the voltmeter to the positive terminal of the battery?
2. When measuring an unknown voltage, we start with the meter set to a high voltage scale and then decrease the scale. Explain the purpose of starting with a higher setting.
3. Does the physical size of the battery indicate how much voltage it has? (That is, do larger batteries have higher voltages than smaller batteries?) Explain.

8-1C Fruit Battery

SkillCheck

- Measuring
- Classifying
- Communicating
- Evaluating information

In this investigation, you will determine the factors that produce potential difference in an electrochemical cell.

Question

What materials are needed to make a voltage-producing electrochemical cell?

Safety

- Be careful of sharp edges when inserting the metal strips into the fruit.

Materials

- various fruits
- 2 aluminum strips
- voltmeter
- 2 zinc strips
- 2 iron strips
- 2 copper strips
- steel wool
- 250 mL beaker
- water

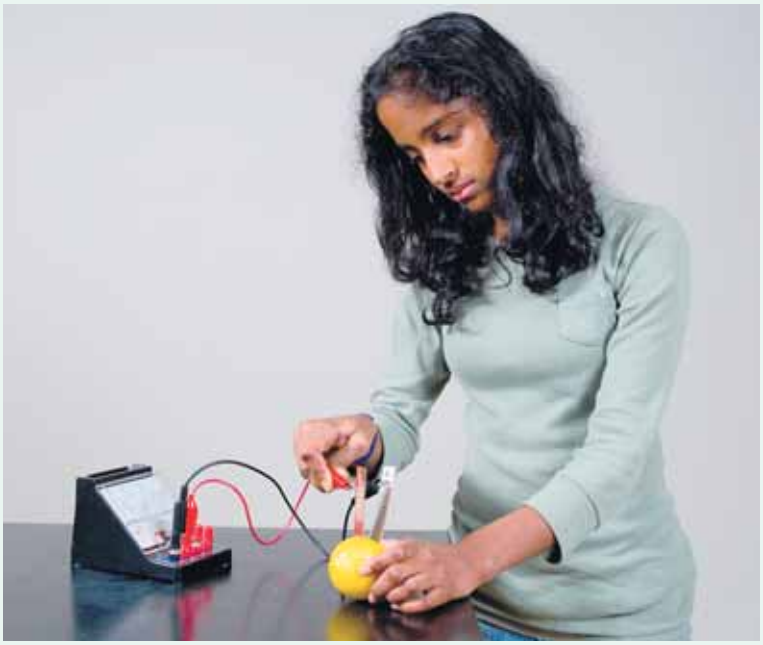
Procedure

Part 1

1. Copy the following table into your notebook. Give your table a title.

Metal 1		Metal 2			
		Aluminum	Zinc	Iron	Copper
	Aluminum				
	Zinc				
	Iron				
	Copper				

2. Select one piece of fruit. Carefully insert two aluminum strips into the fruit. The two metal strips should be about 2 cm apart and parallel to each other.



Step 3 Touch the leads from the voltmeter to the two strips.

Science Skills

Go to Science Skill 11 to learn more about how to use a voltmeter.

3. Touch the leads from the voltmeter to the two strips. You may find that the voltage fluctuates. Count 5 s from when you first started measuring the voltage. Record the voltage at 5 s in your data table.
4. Remove one of the aluminum strips from the fruit and insert the zinc strip. Be sure to use the same slit that the original strip was in. Repeat step 3.
5. Continue steps 3 and 4 until you have done all the combinations of metal strips and the data table contains all the measured voltages.

Part 2

6. Identify the combination of metals that produced the highest voltage. Wash the two strips so that there is no fruit juice on them. Use the steel wool to clean the strips. Fill a 250 mL beaker with 100 mL of clean water.
7. Place the metals identified in step 6 in the beaker of water. Place them so they are parallel and about 2 cm apart.
8. Connect the voltmeter to the two strips just as you did in step 3. Observe the reading on the voltmeter.
9. Clean up and put away the equipment you have used.

Analyze

1. In Part 1, what combination of metals produced the highest voltage?
2. In Part 1, what combination of metals produced the lowest voltage?
3. In general, how did the voltage produced by two similar metals in Part 1 compare to the voltage produced when the two metals were different types?
4. Why was it important to use the same openings in the fruit each time?
5. In Part 2, how did the voltage produced by the two metals in water compare to when the metals were in the fruit? Give a possible explanation for this result.

Conclude and Apply

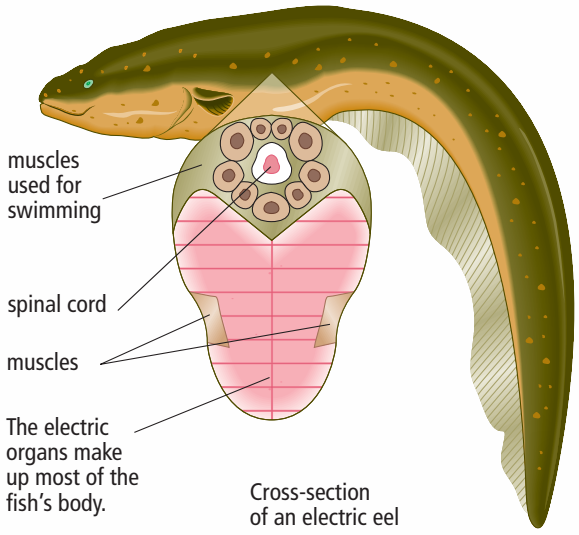
1. What materials are needed to produce a high voltage in an electrochemical cell?
2. Suppose that you needed to produce a higher voltage from a fruit battery. Suggest two ways that you could do this.
3. Batteries purchased from stores are used for devices like MP3 players and cellphones. List several reasons why fruit batteries would not be a good replacement for these store-bought batteries.
4. List at least 10 different uses for a battery.

Wild, Weird, Wonderful

www Science

Electric Fish: The Shocking Truth

Various species of fish have specialized organs that can produce small amounts of voltage. Most of these fish use the voltage to sense their environment and for navigation and communication. The Pacific electric ray (*Torpedo californica*) shown below is found in the coastal waters of British Columbia. These fish produce voltages of about 50 V, which is enough voltage to stun their prey and protect themselves from large animals.



Cross-section of an electric eel

The most famous of the strongly electric fish is the electric eel, found in the waters of South America. The electric eel (*Electrophorus electricus*) shown below is not an eel at all. Rather, it belongs to a species of fish known as knifefish. Electric eels can grow up to 2.5 m long and have a mass of 25 kg. Electric eels can produce almost 10 times more voltage than the Pacific electric ray. How do electric eels generate these large voltages?

Almost 80 percent of an eel's length is its electricity-producing tail. The eel's tail consists of an organ containing thousands of electricity-producing cells called electrogenic cells. Each cell acts like a small battery with one side of the cell containing a positive charge and the opposite side a negative charge. These cells can produce only a small voltage of approximately 100 mV (0.1 V). But because the cells are positioned one after the other, like batteries in a flashlight, the voltage of each cell is added to the next. The result is the ability for the electric eel to produce a 500 V shock. This electrical discharge only lasts approximately 2 ms (0.002 s) but is sufficient to kill small fish nearby. A single discharge from an electric eel's tail would stun a human or large animal but is usually not enough to kill.

Water is a good conductor of electricity. How is the electric eel able to shock nearby fish yet not shock itself? When the electric eel produces a 500 V shock, the electric current spreads in all directions through the water. Since a large portion of the current dissipates into the water through the eel's skin, very little current actually flows through the eel's internal organs. Therefore, creatures near the eel get shocked rather than the eel itself.

Check Your Understanding

Checking Concepts

1. What is the amount of energy per unit of charge called?
2. Explain how potential difference in a battery is similar to a staircase.
3. What is another word for potential difference?
4. What two factors determine the output energy of a battery?
5. What device could you use to measure potential difference?
6. A battery is a common source of electrical energy. Describe two other methods of producing electrical energy.

Understanding Key Ideas

7. Explain how an electrochemical cell produces a potential difference across its terminals.
8. A student conducts an experiment of building an electrochemical cell. She places two strips of silver in a beaker of lemon juice. She then connects a voltmeter to the two strips. Predict what voltage the voltmeter will measure. Explain your prediction.

Pause and Reflect

A 9.0 V battery that you might use in a television remote control is very small compared to the 12 V battery in a car. Could you use two 9.0 V batteries connected together (18 V) to start a car? Explain why or why not.