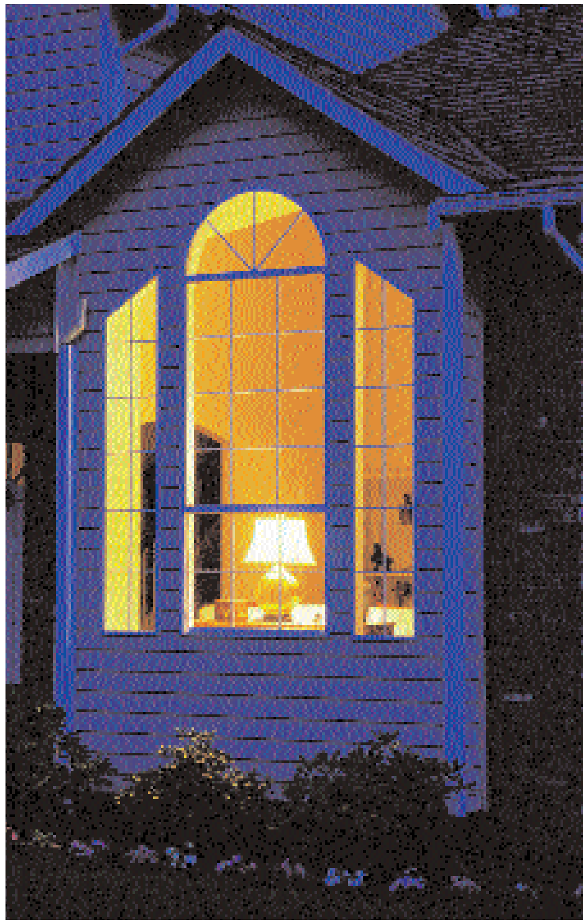
CHAPTER

10 The Control of Electricity in Circuits

Getting Started



1 We use lights for so many different purposes that we tend to take them for granted. Walk through each room in the house and count the number of light sources in each room. Don't forget to include lights that might not actually be glowing or flashing at the time you look at them. There will be a number of them in the basement, garage, outside and inside the car, and outside the house.

How many different kinds of light sources that are operated with electrical energy are there in your home and in the car? To summarize your results, draw up a table that lists the type of light source (bulb), the number of each type, the operating voltage, the size, and the colour.

What proportion of the total electrical energy used in your home do you think is used up by operating light bulbs?

2 Has this ever happened to you? The big day arrives, and you finally get a gift you have been hoping for. You eagerly tear open the package, take out your gift, turn it on and—nothing happens! You look at the box and there is the answer. It reads "Batteries not included. Requires 2 AA alkaline cells."

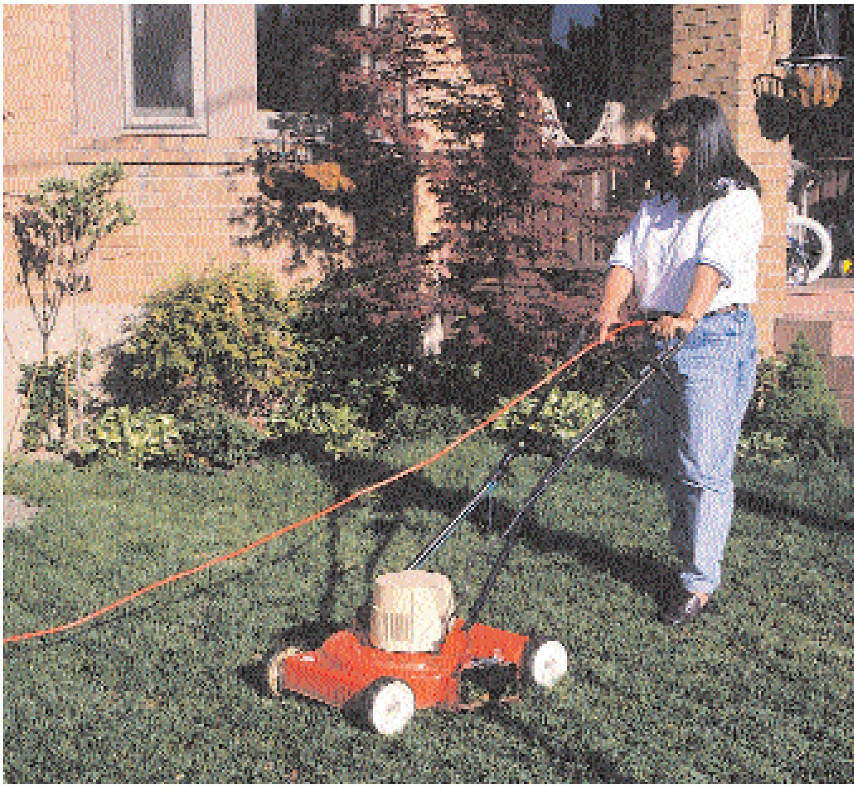
Every day we use electrical and electronic devices that we can carry around with us. They require a portable source of electricity that comes in the form of a battery or dry cell. Look in and around your home and find devices that require batteries. Make a table in which you record the following: Device, Type of Battery, Number Required, Voltage, Rechargeable or Disposable.

Why are there so many different kinds and sizes of cells and batteries? Although we often use the terms "cells" and "batteries" interchangeably, they are not the same thing. What is the difference between them?

3 It is not by accident that electrical energy is the energy of choice for modern society. It has many advantages over the other forms of energy we could use to operate all the different appliances found in our homes. Just imagine what it would be like to have appliances in the kitchen and laundry room operated by little gasoline engines, similar to the ones used on lawnmowers.

However, from our very earliest days when we are first able to understand our parents' warnings, we are constantly made aware of just how dangerous electricity can be. There are many situations in our daily lives where there is the potential for electricity to harm us. Electrical outlets have the potential to be dangerous, depending on the room they are in. Extension cords, which can be dangerous, are continually being used to operate appliances and devices, both inside and outside the house or apartment.

What are some of the ways in which a careless person could receive an electric shock? Look around your home and list some of the safety features that have been designed into the electrical equipment you use.



Reflecting

Think about the questions in 1, 2, 3. What ideas do you already have? What other questions do you have about electric circuits? Think about your answers and questions as you read this chapter.

Try This: Make a Cell

In earlier grades you may have made a cell using pieces of metal and an orange or lemon. These kinds of cells can be made with common materials available in your home. You can use such things as aluminum foil, the copper tubing used for plumbing, and the zinc on galvanized nails for the metal plates of a wet cell. You will need some wire to connect the pieces of metal together.

Try making a 3-V flashlight bulb glow with just one cell. What happens? Look at the number of dry cells in one of the larger flashlights. Try to do something similar with one or more oranges, potatoes, or some other fruit or vegetable. What arrangement did you need to light the bulb? Explain why.

10.1 Investigation

SKILLS MENU
- ○ Questioning
- ○ Hypothesizing
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Communicating

The Electric Circuit

Use a flashlight, plug in an electric fan, or turn on the defroster on the back window of the car. In each case you are changing electrical energy into another form of energy. In this activity you will construct a simple electric circuit that operates safely and can be controlled. You will also determine the function of each of its parts.

Question

What are the components of a complete electric circuit?

Hypothesis

A source of electrical energy, connecting wires, a switch, and a device operated by electricity can be connected to create an electric circuit.

Materials

- dry cell or battery (with holder)
- switch
- light bulb (with holder)
- connecting wires (conductors)
- small electric motor

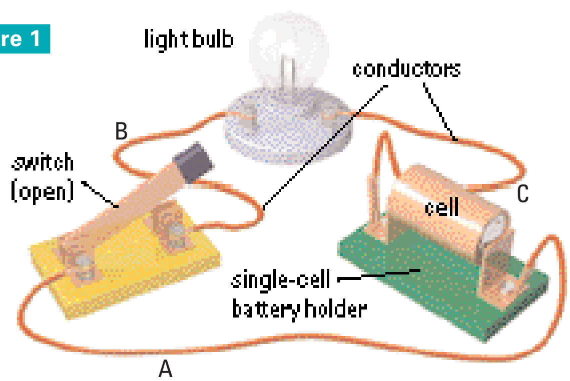
Procedure

1 Study the electric circuit shown in **Figure 1**.

(a) Draw the diagram. Do not draw the (5D) wires connecting the parts of the circuit together.

Ensure that the switch is "open," as shown in **Figure 1**, before connecting the wires in the electric circuit. When the arm on the switch is up, it is "open," and when it is pushed down, the switch is said to be "closed."

Figure 1



2 Place the dry cell, the (open) switch, and the light bulb on your desk, in the positions shown in **Figure 1**.

3 Identify the negative terminal of the dry cell and connect a wire from it to one side of the switch.

(a) Draw a line on the circuit diagram to show which wire has been connected.

4 Connect a wire from the other side of the switch to the bulb.

(a) Draw the appropriate line on your circuit diagram.

5 Connect a wire from the other side of the bulb to the positive terminal of the cell.

(a) Draw the appropriate line on your circuit diagram.

Do not operate the circuit until it has been checked by the teacher.

6 Close and open the switch several times. Touch the light bulb.

(a) Record your observations.

7 Close the switch. Disconnect and then reconnect each end of all three wires in turn. Open the switch.

(a) Record your observations.

8 Close the switch. Remove the bulb from its socket, and then replace it again. Open the switch.

(a) Record your observations.

9 Disconnect the wires attached to the light bulb holder, and reconnect them on the opposite sides of the holder. Close and open the switch.

(a) Record your observations.

10 Disconnect the light bulb holder from the circuit and connect the electric motor in its place. Repeat steps 6 to 9 with the motor instead of the light bulb.

(a) Record your observations.

Analysis and Communication

11 Analyze your observations by answering the following questions:

(a) What happens to the stored chemical energy in the dry cell when the switch is closed?

(b) What energy changes occur (i) in the light bulb and (ii) in the motor?

(c) What is the function of (i) the dry cell, (ii) the switch, (iii) the light bulb and the motor, and (iv) the wires?

(d) Which one of the four parts of the circuit can be omitted while allowing the circuit to continue to function? Why is it usually included in a circuit?

(e) List three different ways of turning the light bulb on and off.

(f) List the ways you can start and stop the motor.

(g) Would the circuit operate differently if (i) the connections on the switch were reversed and (ii) the switch were connected on the other side of the light bulb? If you aren't sure, try making the changes. Explain your answers.

(h) What happened when wire C was disconnected? Why does wire C have to be there?

(i) What effect did reversing the connecting leads have on (i) the light bulb and (ii) the motor? Explain your answer.

12 Write a summary paragraph in response to the question posed for this investigation.

Making Connections

1. Identify and describe three kinds of switches (a) in your home, (b) on electrical devices you use every day, and (c) in a car. Suggest reasons why different switches are used in different situations.

2. Identify three different kinds of electrical connecting wires used on electrical devices and appliances in your home and a car. Suggest reasons why different wires are used in different situations.

3. Think about toys with electric circuits in them that you used when you were younger or that children use now.

(a) What problems did you have with the electrical parts of the toys?

(b) How did you know how to replace the cells or batteries in the correct position or order? What did the toy manufacturer do to try to make sure you didn't put the cells in incorrectly?

(c) How has the electrical operation of toys improved in the past few years?

Exploring

4. (a) Predict what would happen if you connected the light bulb directly to the motor in the same circuit at the same time and closed the switch. Try it and comment on your prediction.

(b) How many different ways can you connect the light bulb and the motor directly to each other? What happens in each case? Explain why.

Challenge

What components will you need for your electric circuit board?

SKILLS HANDBOOK: 5D Drawing and Constructing Circuits

10.2

Electricity and Electric Circuits

Static electric charge may build up to the point that it causes a discharge in the form of lightning strikes or a spark jumping from your hand to a doorknob. Whatever way it happens, electrical energy is transferred by the movement of electric charge. The movement, or flow, of electric charges from one place to another is called an **electric current**. A more detailed discussion of electric current, how it is measured, and the units it is measured in occurs on page 314.

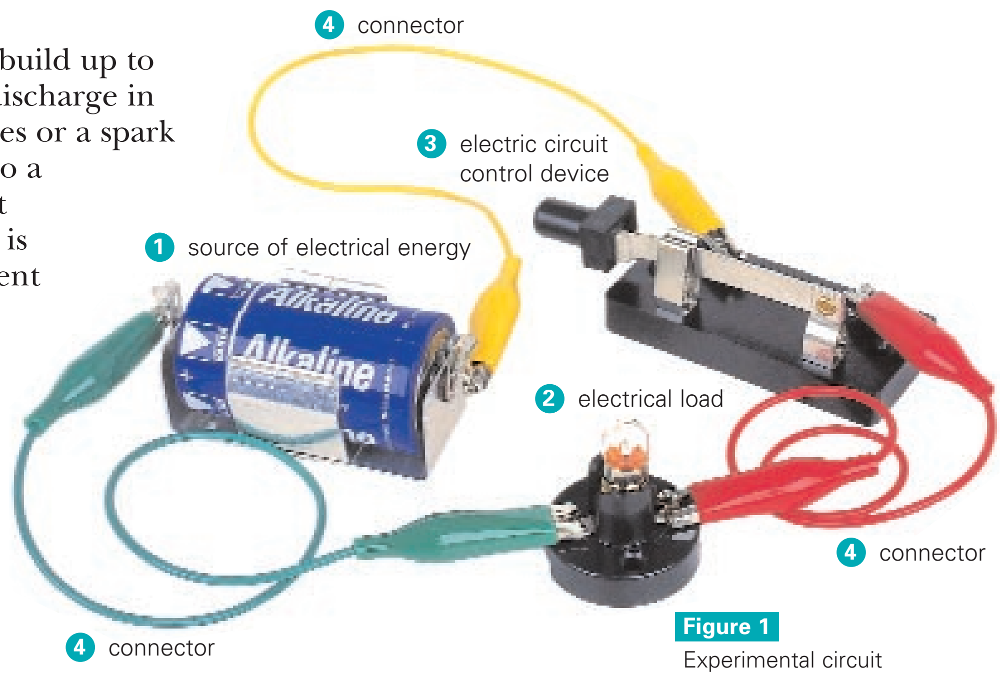


Figure 1
Experimental circuit

There is one very important difference between the electric current flowing during a lightning strike and that flowing through a light bulb in a flashlight. The current passing through the bulb is flowing in a controlled path called an **electric circuit**. Electric circuits are used to convert electrical energy into the other forms of energy we need.

The Parts of an Electric Circuit

A study lamp, a flashlight, and the experimental circuit shown in **Figure 1** look quite different. However, the electric circuits that operate all three of them are essentially the same. They all have the same four basic parts found in the simple electric circuit shown in **Figure 1**. These four parts are:

Did You Know

We often use the term "battery" instead of "cell." A battery is actually a combination of two or more cells.

1. Source of Electrical Energy

Almost daily scientific and technological developments provide new ways of producing electrical energy. They range from the minute amounts of electrical energy generated for obtaining information from a computer hard drive to the large amounts produced at nuclear power stations. In between these two extremes are such sources as the photoelectric cells used in calculators, cells and batteries, portable generators, and of course wall outlets. Electrical energy is discussed in more detail in Chapter 11.

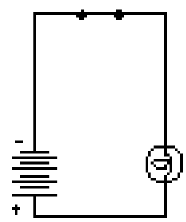


Figure 2
Schematic diagram of a closed circuit shown in Figure 1

2. Electrical Load

Although the word "load" normally tends to imply something heavy, an **electrical load** is simply the name given to anything that converts electrical energy into whatever form of energy we need. The electrical load is actually the reason the electric circuit exists in the first place. The toaster you use at breakfast is an electrical load. What electrical loads have you used so far today?

3. Electric Circuit Control Device

The most obvious devices for controlling electric circuits are the simple switches we use in our homes, cars, and many kinds of portable electronic equipment. However, there are many more that we never see. They are often hidden inside the appliances, like the clock timer that controls the microwave oven. Many operate automatically, like the thermostat that controls the temperature of the house.

4. Connectors

One of the most amazing electric circuits is the microchip. The conducting wires, or **connectors**, used in these circuits are now so small that they are sometimes only a few atoms wide. However, whether they are the size of the wires on transmission lines or microscopic strands of wire 10 000 times thinner than a human hair, they all have the same purpose: to provide a controlled path for electric current to flow to each part of the circuit.

The words used to describe whether an electric circuit is operating often cause confusion. When a circuit is operating, and current is flowing, there is said to be a **closed circuit**. In the closed circuit shown in the photograph (**Figure 1**), the arm on the switch is connected to the other part of the switch, and the switch is said to be "on." When the arm of the switch is not connected to the other part of the switch, the switch is said to be "open" or "off" and there is said to be an **open circuit**. The electric current flows in a continuous loop from the negative terminal of the cell, through the wires, the switch, and the light bulb, and returns to the cell's positive terminal.

Electric Circuit Diagrams and Symbols

To simplify the drawing of electric circuits, a special set of symbols is used. This is much more convenient because we need to draw only one symbol for a switch, instead of different symbols for each kind of switch that exists or will be invented. Drawings of circuits using these symbols are called **schematic circuit diagrams** (**Figure 2**). 5D

In these diagrams, the connecting wires are usually drawn as straight lines, with right-angled corners. This makes it easier to understand complicated circuits.

Understanding Concepts

1. Describe the difference between static electricity and current electricity.
2. Make a chart listing the parts of an electric circuit. State a function for each part and provide two examples.
3. In which direction does the electric charge flow around the circuit in **Figure 1**? What causes it to happen?

Making Connections

4. List four examples of electrical loads in the kitchen that convert electrical energy to (a) light energy and (b) mechanical energy. Predict which load uses the most, and the least, amount of energy.
5. List four different examples of electric control devices
   - **(a)** in the kitchen;
   - **(b)** the basement or laundry room;
   - **(c)** in a car.

   Choose two devices from your list and suggest reasons for their design.

Exploring

6. What process is used to create the complex, multilayer circuit diagrams that make up the microchips used in computers? Visit the Internet sites of some of the major computer microchip manufacturers and find out how this is done. Create a flow chart describing the process.

Reflecting

7. Why are schematic circuit diagrams used rather than pictorial circuit diagrams?

Challenge

What should be included in the schematic circuit diagram for your challenge?

Electric Potential (Voltage)

Why is it safe to touch some sources of electrical energy and very unsafe to touch others? Most people know that if you touch both ends of a 1.5-V dry cell, whether it is a small AAA cell or a large D cell, you will not get an electric shock. However, everyone knows how dangerous it is to touch the terminals of a wall outlet.

The difference between the dry cell and the wall outlet is in the amount of energy that each electron receives from the energy source before moving into the electric circuit. The energy given to each electron leaving the terminal of a 120-V wall outlet is about 80 times greater than the energy given to each electron leaving the terminal of a 1.5-V dry cell. In fact, the energy of the electrons leaving the terminals of a wall outlet is great enough to cause a dangerous amount of electric current to flow through your body, giving you a severe electric shock.

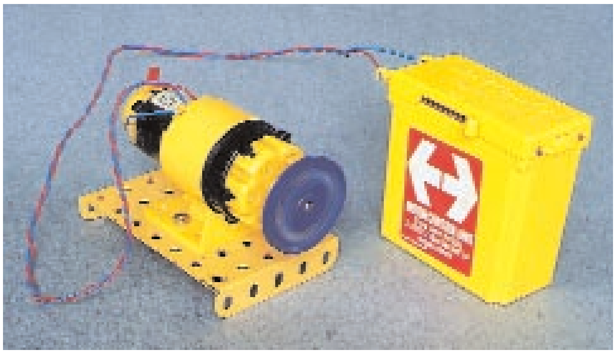


Figure 1
A dry cell connected to a motor

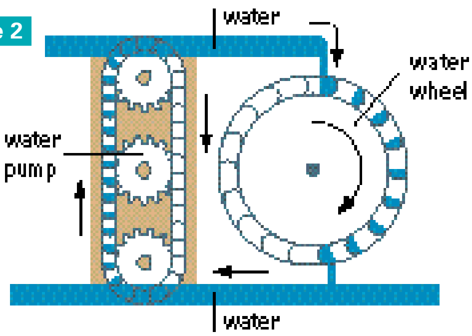
A Model of Electric Potential

When you connect a simple electric circuit using a dry cell and an electric motor, the dry cell supplies electrical energy to the motor and causes the motor shaft to turn (**Figure 1**). However, you cannot actually see what is happening inside the circuit. To understand what is happening in a circuit, we can use an analogy to help us visualize it.

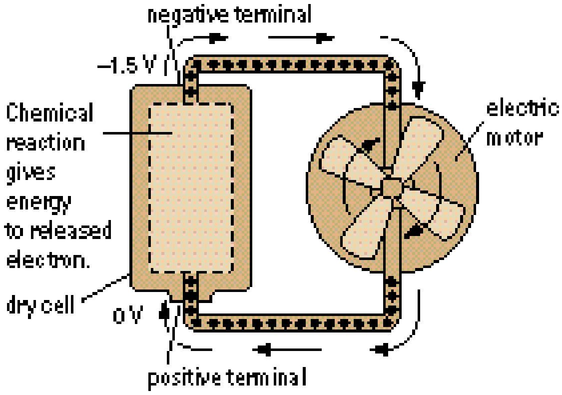
The energy in falling water has been used for thousands of years to turn water wheels. The way falling water gives up its gravitational potential energy to turn a water wheel can be compared with the way the electric charges released from a dry cell give up their energy to turn the electric motor.

In **Figure 2a**, a pump has lifted a large amount of water to the top of the building. Once the pump has lifted the water to the top, we say that the water has some stored or potential energy. If the water is now allowed to pour out on to a water wheel, the energy of the falling water can be used to turn the wheel. As long as the pump inside the building gives the water at the bottom potential energy by pumping it back up to the top, it will again be available to fall from the top of the building to keep the wheel turning.

Figure 2



a The gravitational potential energy given to the water by the pump is released to turn the water wheel.



b The electric potential energy released by the chemical reaction in the cell is used to turn the electric motor.

In the same way that many molecules of water gain energy by being lifted up to the top of the building, a dry cell gives a huge number of electric charges (electrons) a certain amount of electric potential energy (**Figure 2b**). The energy each electron gains is released to it by the chemical reactions that occur. Just as the water molecules have gravitational potential energy at the top of the building, the electrons have electrical potential energy at the negative terminal of the dry cell.

Electricity from Chemical Reactions

Even if the dry cell is not connected to a circuit, the stationary electrons at the negative terminal have electric potential energy. At the instant the dry cell is made, a chemical reaction occurs, and the stored energy released by the reaction exerts a force on the electric charges and pushes a certain number of them on to the terminals of the dry cell. An excess of electrons accumulates on the negative terminal, thus giving it a negative charge, and a matching number of positive charges remain on the positive terminal.

Electrons can be released with their electric potential energy in a circuit only when the switch is closed and electrons can flow completely around the circuit. Any further chemical action that occurs in the dry cell will happen only if, for every electron that leaves the negative terminal to move into the circuit, another electron at the other end of the circuit enters the positive terminal to replace the one that left. These electrons are required to complete the chemical reaction. Whenever a current flows in an electric circuit, there is a continuous, unbroken chain of moving electrons in the circuit. As the electrons move through the circuit, they release the energy to the electrical load in the circuit.

In **Figure 2b**, the electrical energy is carried through the circuit by the electrons and is used to turn the electric motor. The energy each electron has is called the **electric potential** of the electron. Electric potential is commonly referred to as **voltage**. The SI unit used to measure electric potential is the **volt**, and the symbol for this unit is V. **Table 1** lists some sources of electric potential, with typical voltage values.

Table 1

Source of Electric Potential	Voltage (volts)
tape playback head	0.015
human cell	0.08
microphone	0.1
photocell	0.8
electrochemical cell	1.1 to 2.9
electric eel	650
portable generators	24, 120, 240
wall outlets in house	120, 240
generators in power stations	550

Understanding Concepts

1. (a) Why is it necessary for the electrons to move continuously around the circuit?
   (b) From which terminal do the electric charges flow into the circuit? Explain why.
2. (a) Define the term "electric potential."
   (b) State the SI unit and name the symbol used for electric potential.
3. Why is it possible to measure an electric potential across the terminals of a dry cell, even if electrons are not flowing into the circuit?
4. Explain, in terms of the energy of the electrons, why someone would receive a severe electric shock from a 120-V source, yet hardly notice the electric shock from a 6-V battery.

Exploring

5. (3A) Research the typical voltages generated by computer hard drives, VCRs, and tape cassette players. Record your findings as an information fact sheet for electrical equipment.

Reflecting

6. Make your own analogy using marbles to help you visualize how electrons can move continuously through a circuit.

Career Profile

Master Electrician

When Shelley Harding-Smith was a little girl, she was fascinated by the debris that came home from her father's various jobs as a master electrician. When she was ten, she went to work with her father. Although she didn't see any women on the job, the work appealed to her.

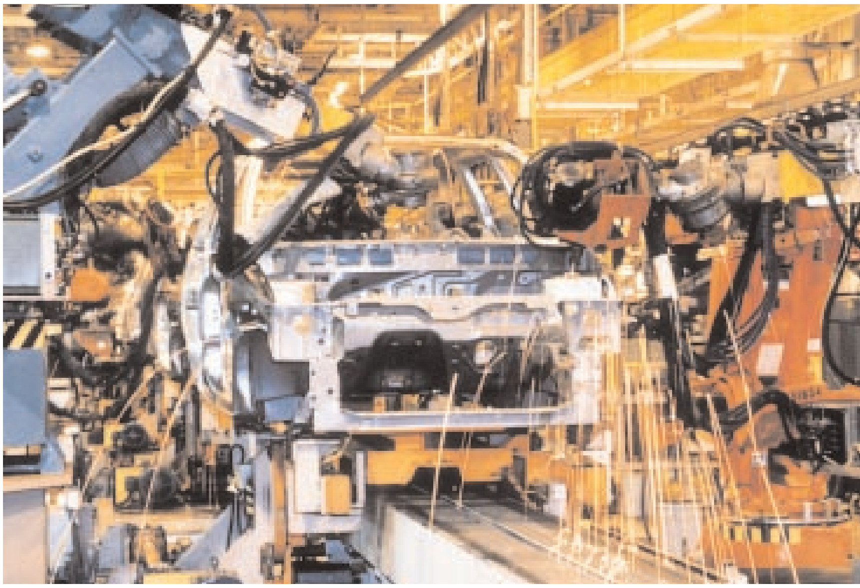
> Recognize the great opportunities for a career where you constantly progress, constantly grow, and are well rewarded.

After a "typical high school program of language, social sciences, mathematics, and science," Harding-Smith enrolled in a three-year electrical apprenticeship program at St. Clair College, involving on-the-job training as an indentured apprentice and three months a year of classes on the college campus. She was the only woman in a class of 34 men.

After graduation, Harding-Smith first worked with a small firm doing residential, commercial, and industrial work. Attracted by the challenge of the new field of robotics, however, she returned to St. Clair to complete two years of training as a robotic electronics technician. She subsequently worked at a firm that used robots to weld automobile bumpers, then as a maintenance electrician at an amusement park, meanwhile obtaining her master electrician's certificate.

Harding-Smith started her own electrical contracting business, hired her son as an apprentice, and proudly watched him become a third-generation licenced electrician.

But the robotics field still intrigued Harding-Smith. She went to work at Chrysler Canada, at first with only two welding robots; now servicing and trouble-shooting the many robots occupies approximately 75 electricians per shift. Harding-Smith calls her work "challenging, rapid-paced, and exciting," and she enjoys the interaction with the other workers.



Exploring

1. Check community colleges and technical schools in your area for courses in trades related to electricity. What high school qualifications are needed for admission into these courses?
2. Research and compare the advantages of working for a large company and being self-employed.

10.4 Activity

Building a Simple Wet Cell

When you began this chapter you made a table describing the many types of cells or batteries that you found around your home. No matter how many different kinds of dry cells exist, they all operate using the same principle—a chemical reaction that releases electric potential energy to the electrons. In this activity you will make your own wet cell.

Materials

- zinc plate
- copper plate
- steel wool
- 150-mL beaker
- light bulb
- light bulb holder
- voltmeter
- connecting wires
- dilute sulfuric acid
- small piece of insulating material
- small brush
- safety goggles

Sulfuric acid is corrosive. If it touches your skin, wash with cold water and inform your teacher.

Procedure

1. Put your safety goggles on. Polish the zinc and copper plates using steel wool.
2. Place the zinc and copper plates in the beaker. Place a small piece of insulating material between the two metal plates.
3. Connect the light bulb and the voltmeter to the two metal plates as shown in the schematic circuit diagram in **Figure 1**.

(a) Record your observations. Record the 5E voltmeter reading.

4. Pour about 50 mL of dilute sulfuric acid into the beaker.

(b) Record your observations (i) immediately and (ii) after 4 min. Record the voltmeter readings.

5. Using the brush, sweep the bubbles off the plates.

(c) Record your observations. Record the voltmeter reading.

6. If plates of different metals are available, try different combinations of two plates.

(d) Record the voltmeter readings. Design 6D a suitable table to display the data.

7. Return used solutions to containers designated by your teacher. Rinse, clean, and dry all equipment. Wash your hands.

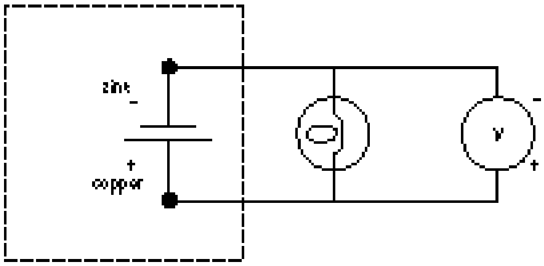


Figure 1

Understanding Concepts

1. List the energy changes that take place (a) in the wet cell and (b) in the bulb.
2. Draw the schematic circuit diagram shown in **Figure 1**; draw an arrow on your circuit diagram to indicate the direction of current flow in the circuit.
3. **(a)** Why does the brightness of the light from the bulb change in step 4?
   (b) How can this be overcome?
4. Explain the changes in voltage readings observed in steps 3 to 5.
5. **(a)** Why is it necessary to consider the positive and negative terminals of the wet cell when you connect the leads from the voltmeter to the circuit?
   (b) What would happen if the voltmeter were connected incorrectly?

Reflecting

6. Compare the similarities and differences of the physical process of charging different materials by rubbing them together and the chemical process of producing electricity, using different metals in wet cells.

Electrochemical Cells

Primary Cells

There are two basic types of **primary cells**: the primary wet cell (voltaic cell) and the primary dry cell. In a primary cell, chemical reactions use up some of the materials in the cell as electrons flow from it. When these materials have been used up, the cell is said to be discharged and cannot be recharged.

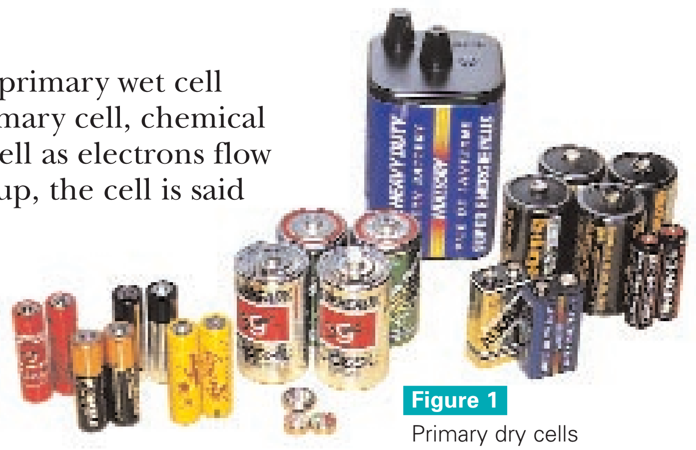


Figure 1
Primary dry cells

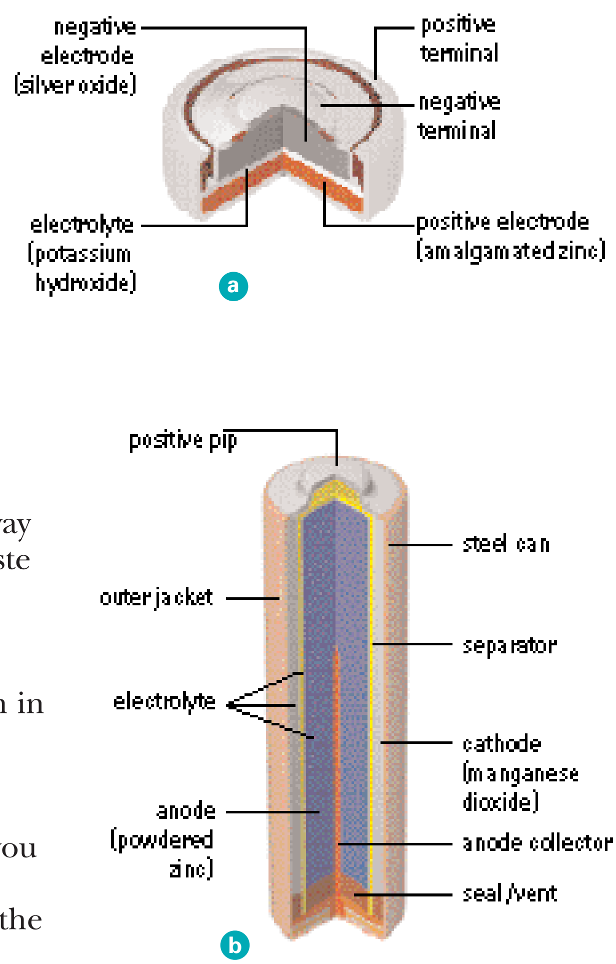
The Primary Wet Cell

The primary wet cell, or **voltaic cell**, was developed in 1800 by an Italian scientist, Alessandro Volta. It is called a **wet cell** because it is made of two pieces of metal that are placed in a liquid. The metal plates, usually zinc and copper, are called **electrodes**. The liquid in the cell is called the **electrolyte**. An electrolyte is any liquid that conducts an electric current.

The zinc electrode reacts chemically with the sulfuric acid. The chemical energy released separates electrons from the zinc atoms. These electrons collect on the zinc plate, which is called the **negative terminal** of the cell. At the same time, positive charges collect on the copper plate, which is called the **positive terminal** of the cell. These electric charges remain static on each electrode. Cells discharge only when connected to a closed electric circuit.

Two major disadvantages of the wet cell are the danger of spilling the electrolyte, and the continual need to replace the zinc plate and the electrolyte.

Figure 2
A cross section of two kinds of primary cells: (a) a silver oxide cell and (b) an alkaline cell.



The Primary Dry Cell

The familiar primary **dry cell** functions in the same way as a primary wet cell, but the electrolyte is a moist paste rather than a liquid (**Figure 1**). When most of the negative electrode has been used up by the chemical reaction, the electrons stop flowing, and the cell is discharged. Two common types of dry cells are shown in **Figure 2**.

The printed warnings on battery blister packs (**Figure 3**) are there for your safety. It is unsafe to recharge disposable (primary) cells and batteries. If you tried to recharge the cell, the energy supplied by the charging device would cause the cell to heat up, and the cell casing could break open, or the cell could even explode. Also, because the outer casing of the cell is very tightly sealed, it is dangerous to throw a discharged cell into a fire. The gases formed inside may cause an explosion. If the cell's outer casing is punctured, corrosive liquids can leak out.

Over long periods of time, even new dry cells or batteries will gradually discharge. An expiry date is printed directly onto many dry cells. Dry cells and batteries in flashlights and lanterns, especially those used for emergencies, should be checked regularly to ensure they will operate when needed.

Secondary Cells

Unlike the single-use, disposable primary cell, a **secondary cell** can be discharged and recharged many hundreds of times. It is called a secondary cell because there are two chemical processes involved, one to discharge the cell, and another to recharge it to its original state. The secondary cell was initially developed to provide larger amounts of electrical energy economically, especially for cars, but now many different kinds of rechargeable cells are available. A car battery consists of a group of connected secondary cells.

Try This: Batteries on the Internet (3A)

Visit the web sites of some well-known battery manufacturers. Explore each of the sites to investigate different kinds of cells.

1. How many different types of primary and secondary cells can you find that are available commercially?
2. List the advantages and disadvantages of at least four types of secondary cells.

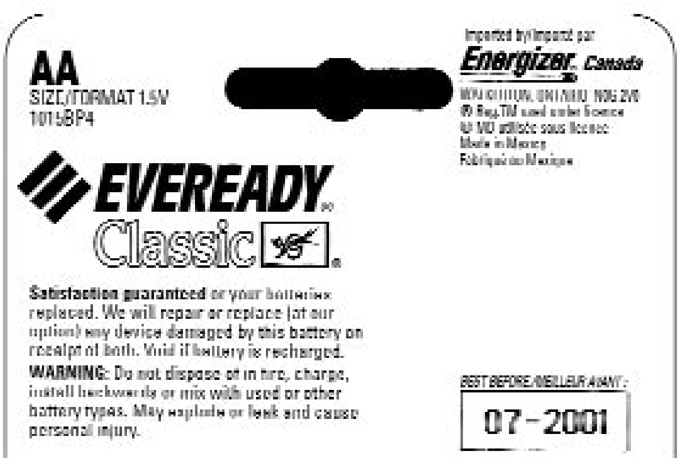


Figure 3
This standard warning found on battery blister packs reminds us that a battery is an electrochemical device that needs to be used and disposed of with care.

Understanding Concepts

1. **(a)** What energy changes occur in an electrochemical cell when electric current flows from it?
   (b) Describe the conditions necessary in a voltaic cell to produce a steady supply of electrons.
2. **(a)** Explain why primary dry cells were developed.
   (b) Explain the difference between a primary cell and a secondary cell.
3. Why is it necessary for one electron to leave the circuit at the positive terminal of the cell every time an electron enters the circuit from the negative terminal?

Making Connections

4. How do manufacturers of devices that use batteries make sure you do not install the batteries incorrectly? Check some devices and describe the different solutions.
5. (1A) Make a safety chart on using batteries. List four safety precautions to be observed when using dry cells or batteries. Indicate what could result if each safety precaution is not observed. Use WHMIS symbols where appropriate.

Exploring

6. Which would be best for making a simple voltaic cell—a lemon or a potato? Why? Is size important?
7. Volta and Galvani were two scientists who had very different ideas about the effects caused by electricity. Carry out some research, and describe what they disagreed about, who was eventually proved to be correct, and why.

SKILLS MENU
- ● Questioning
- ● Hypothesizing
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Communicating

Batteries—Combinations of Cells

When you are on a camping trip and have only a small, single-cell flashlight to read with, how long will it last? Compare this with the amount of time for which a large lantern battery can produce light. The large battery can store much more energy than the small cell.

Dry cells can be connected together to increase the amount of energy available to operate the electrical load in the circuit. In this investigation, you will study the characteristics of each of the two basic kinds of electric circuits used to form batteries.

Question

1 Formulate a question about connecting cells in series and parallel and identifying the relationships among the variables. (4A)

Hypothesis

2 Restate the question in a testable form.

Materials

- 4 dry cells
- 4 dry-cell holders
- voltmeter
- connecting wires
- switch
- light bulb
- light-bulb holder

Be careful not to connect a wire from the positive terminal to the negative terminal on the same cell. When there is no light bulb to act as an electrical load, a connecting wire provides a "short" circuit for the electric current. When a short circuit occurs, very large currents flow from the cell that will cause it to heat up, and it may explode.

Procedure

Part 1: Connecting Cells in Series (5D)

3 Connect the positive terminal of a dry cell to the positive terminal of the voltmeter.

4 Connect the negative terminal of the cell to the negative terminal of the voltmeter. (5E)

(a) Draw the schematic diagram and record the voltmeter reading.

5 Disconnect the wire attached to the negative terminal of the cell. Connect the negative terminal of the first cell to the positive terminal of a second cell. Cells connected in this way are said to be connected in "series" (**Figure 1**).

6 Predict the voltage that will be produced by the two cells when connected in series. Reconnect the wire from the negative terminal of the voltmeter to the negative terminal of the second cell.

(a) Draw the schematic diagram, record your prediction, and then connect the voltmeter and record the reading.

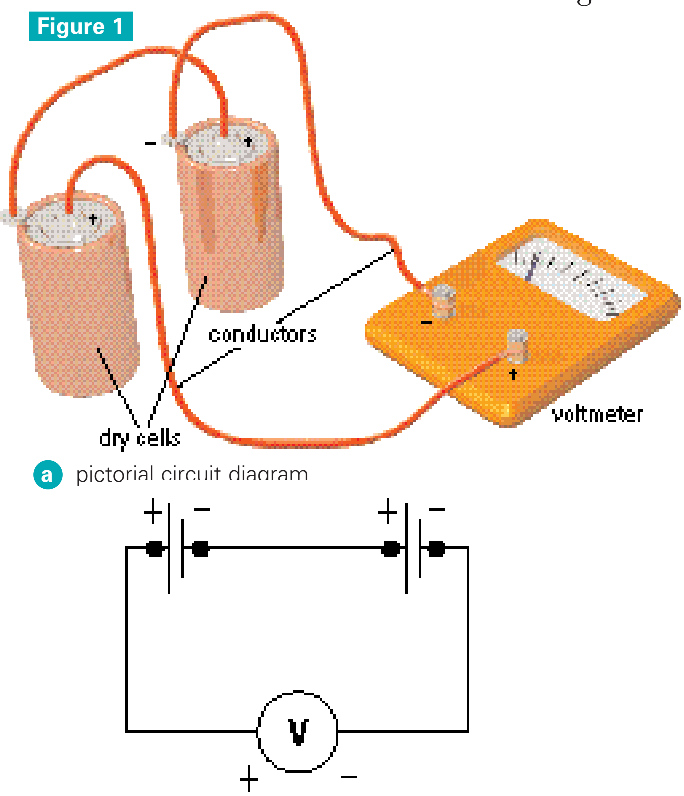
7 Repeat steps 5 and 6, this time connecting a third cell to the second one.

(a) Draw the schematic diagram, record your prediction, and then connect the voltmeter and record the reading.

8 Repeat steps 5 and 6, this time connecting a fourth cell to the third one.

(a) Draw the schematic diagram, record your prediction, and then connect the voltmeter and record the reading.

Figure 1



(a) pictorial circuit diagram

(b) schematic circuit diagram

Part 2: Connecting Cells in Parallel

9 Connect the circuit as shown in **Figure 2**.

10 Close the switch, measure the voltage across the cell, and note the brightness of the bulb. Then open the switch.

(a) Draw the schematic diagram and record the voltmeter reading and your observations.

11 Connect the negative terminal of the first cell to the negative terminal of the second cell, and the positive terminal of the first cell to the positive terminal of the second cell. The second cell is now connected in "parallel" with the first cell.

(a) Draw the schematic diagram.

12 Predict the voltage that will be produced by the two cells when connected in parallel, and what will happen to the brightness of the light from the bulb.

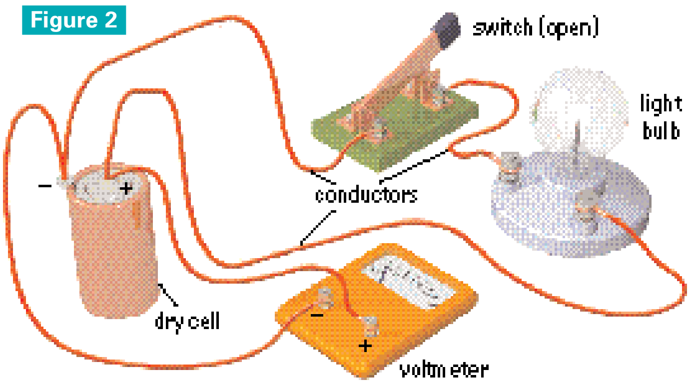
(a) Record your prediction, then record the voltmeter reading and your observations.

13 Repeat steps 11 and 12, connecting a third cell in parallel with the first two cells.

(a) Draw the schematic diagram, record your prediction, then record the voltmeter reading and your observations.

14 Review the observations you have made in both parts of the investigation, and organize and display them in a suitable format.

Figure 2



Analysis and Communication

15 Analyze your observations by answering the following questions:

(a) Comment on the validity of the predictions you made throughout the investigation.

(b) (i) What happens to the total voltage of a battery when its cells are connected in series?

(ii) What can be inferred about the electric potential of the electrons leaving the negative terminal of the battery as each new cell is added?

(c) (i) What happens to the total voltage of a battery when its cells are connected in parallel with one another?

(ii) What can be inferred about the electric potential of the electrons leaving the negative terminal of the battery as each new cell is added?

(d) What happens to the brightness of the bulb as more cells are added in parallel? Explain why.

Making Connections:

1. What changes have occurred and what features have been added in the way cells and batteries have been manufactured over the past few years? Which changes have been most useful to you? Why?

Exploring

2. How are cells connected together in car batteries? How many cells are there in most modern car batteries?

3. On a single piece of graph paper, plot a graph (7B) of Total Voltage versus Number of Cells for the combinations of cells used in the investigation

   (a) for cells connected in series;

   (b) for cells connected in parallel.

   From the graph determine how many cells would need to be connected in series to produce 15 V. How did you obtain your answer? Why was it possible to use this method?

Cells in Series and Parallel

Look at the collection of batteries in **Figure 1**. The little 9-V battery has six miniature dry cells in it. The big 6-V lantern battery has eight much larger dry cells. The flashlight requires three D size dry cells. All three combinations of dry cells produce different voltages. Dry cells can be connected together as a battery using two basic kinds of circuits: **series circuits** and **parallel circuits**. Which battery in the photo is connected using both kinds of circuits?

Figure 1
A 9-V battery, a 6-V battery, and three 1.5-V cells

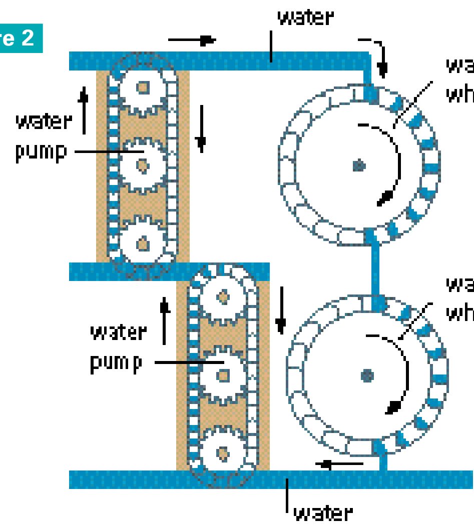
Cells in Series

The electric potential given to a single electron by a dry cell has an absolute maximum value of slightly under 2 V. The value depends on the two materials used for the two electrodes of the cell. However, by connecting cells together in a series circuit, it is possible to obtain much higher voltages.

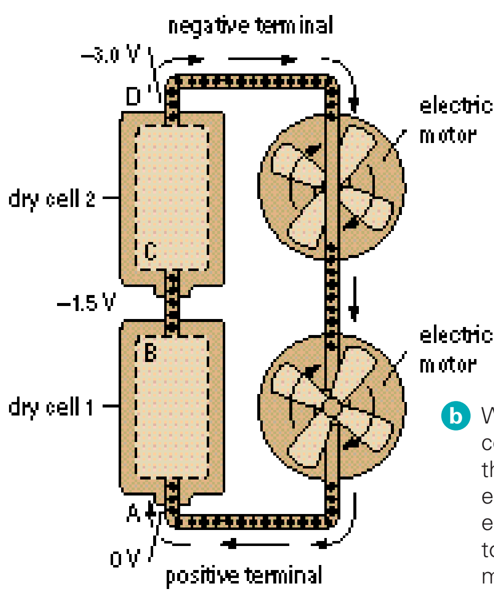
We can use the water analogy again. If we wanted to get twice as much energy from the same amount of water, we could simply lift the water twice as high as we did before (**Figure 2a**). In that way, it would gain twice the amount of gravitational potential energy, and then give up that energy turning the water wheel, as it fell to the bottom again.

We can achieve the same result with two dry cells by connecting them as shown in **Figure 2b**. When the switch is closed, and electrons flow around the complete circuit loop, the electrons get two boosts of energy instead of just one. Each time an electron leaves the negative terminal of cell 2 at D, another electron enters the positive terminal of cell 1 at A. When this occurs, two chemical reactions occur, one in each cell. The first reaction releases an electron at B with 1.5 V of electric potential. This means that all the electrons that go into cell 2 at C have the 1.5-V boost from cell 1. When each electron enters cell 2, a second chemical reaction takes place and a second boost occurs. The net result is that each electron leaving cell 2 to go into the circuit has a gain in electric

Figure 2



a Using two pumps connected in series the water gains twice the amount of gravitational energy and can turn two water wheels as it falls.



b When two cells are connected in series the increase in electric potential energy is sufficient to turn two electric motors.

potential of 3.0 V. Every time we connect a cell such that the negative terminal of one cell is connected to the positive terminal of the next one, the voltage of the combination of cells will increase by 1.5 V. Cells can be added in series indefinitely to increase the voltage of the battery.

Cells in Parallel

The cells used in many watches and calculators all have the same voltage value—1.5 V. These cells come in several different shapes and sizes. In each case, the size of the cell is based on the amount of electrical energy the device needs to operate for a reasonable amount of time (from the consumers' point of view).

There is, however, a practical limit for the size of a cell. How do you obtain more energy than can be given by just one cell? You connect the cells in parallel. Once again we can use the water analogy to explain what is happening to the electric charge from the cells (**Figure 3a**). If we have two pumping devices, each with its own supply of water, placed side by side instead of on top of one another, we can lift twice the amount of water to the top of the building and make it available to operate the water wheel. The water wheel would be able to operate for twice as long as it could with just one pump lifting the water. However, all the water would only have the gravitational potential energy from being lifted just one level.

Similarly, if we connect two cells side by side, or in parallel, with the positive terminals connected together and the two negative terminals connected together, there will be twice as many electrons available as there would be with only one cell (**Figure 3b**). Notice, however, that each electron released from the negative terminal will still only have the electrical potential energy gained from just one cell.

Understanding Concepts

1. Explain the difference between a cell and a battery.
2. (a) Why are cells connected in series?
   (b) Draw a schematic circuit diagram, showing five cells connected to produce the highest electric potential.
3. (a) Why are cells connected in parallel?
   (b) Draw a schematic circuit diagram showing four cells connected in parallel.

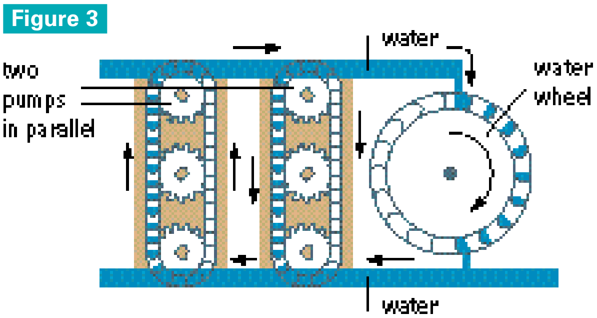
Exploring

4. Human and other animal cells typically produce a voltage of about 0.08 V. What is different about the way cells in humans are connected together compared with the cells in an electric eel? What are the maximum voltages and currents that can be produced by electric eels? Research these two questions and present your findings. (3A)

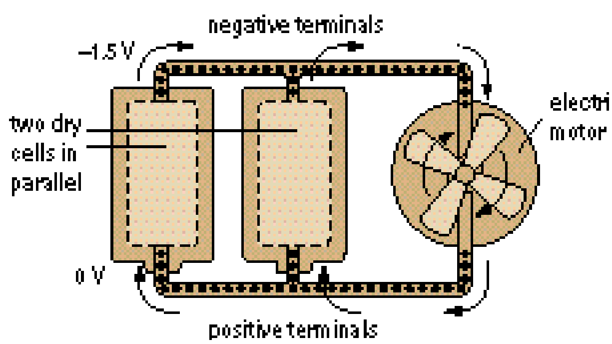
Challenge

Which combination of cells (if any) is appropriate for your electric circuit board?

Figure 3



(a) When two pumps are connected in parallel, the water only gains the same amount of gravitational potential energy as with a single pump, but twice as much water is lifted. The pump can only turn one water wheel, but for twice as long.



(b) When two cells are connected in parallel, the electric potential energy remains the same as that of a single cell, but with twice as much electric charge, the electric motor will operate for twice as long.

10.8 Explore an Issue

Cells and Batteries: Costs and Benefits

Cells are a convenient, portable way of supplying electricity. They convert chemical energy directly into electrical energy. In voltaic cells the electrodes themselves are involved in the chemical reactions, so they can only supply a certain amount of energy before they are used up.

As scientists and engineers continue to design and develop new kinds of cells and batteries, they are using a variety of different substances for the electrodes and the electrolytes. Some of the substances being used in both types of commercially available electrochemical cells and batteries are listed in **Table 1**. Many other different combinations of substances are currently being investigated in research programs around the world.

A quick glance at the list of substances used in the different kinds of cells reveals that there are several areas that we should be concerned about if we wish to produce increasing numbers of cells and batteries in the future. These concerns include availability, cost, toxicity, and disposal.

Availability and Cost of Resources

Many of the substances used are quite rare and are found in specific deposits on the planet. The extraction of the elements from their minerals is an expensive process. In fact, some of the substances are so rare that it may not be practical to continue to use them, except in exceptional circumstances.

The issue of availability would be less of a problem if each cell or battery had a longer lifetime: if it were rechargeable. Rechargeable cells are now both available and suitable for most uses. The small rechargeable cells we recharge in our homes usually range from AAA to D size cells. Larger rechargeable batteries are used in cars and trucks, where they are automatically recharged by the vehicle itself. It is much more economical to use rechargeable cells than the single-use cells. However, rechargeable cells and batteries are much more expensive to manufacture and to purchase and may not be cost effective for some low-use devices such as smoke detectors.

Toxicity

Many of the substances used in cells and batteries are poisonous: lead and mercury are heavy metals, which can cause long-term health effects in a wide range of organisms; chlorine is a poisonous gas; lithium and sodium are highly reactive elements that require very careful handling. The more cells we use, the more of these substances we have around us.

Disposal

Both single-use and rechargeable cells eventually have to be replaced. Most of these cells and batteries are routinely tossed into the garbage container and dumped in the local landfill site. It has been estimated that about 50% of the mercury in our landfill sites comes from discarded cells and batteries. The uncontrolled disposal of millions of these cells, even though they are quite small, may lead to significant increases in pollution in areas around the landfill sites.

Recycling facilities are available (**Figure 1**), where used cells and batteries can be safely dismantled and their valuable components processed into a form that can be reused. However, this requires some effort on the part of the general public. Because of this, only a fairly small percentage of used cells are actually recycled. To make recycling a little more convenient, we could set up recycling boxes in stores that sell batteries.

Table 1

Electrochemical Cells

Single Use	Rechargeable
alkaline	nickel/metal hydride
lithium/ion	nickel/cadmium
zinc/manganese	lead/acid
zinc/mercury	zinc/air

Figure 1

Issue: Should battery recycling be mandated by law? (8B)

Point

Opinion of an environmental scientist
The continued uncontrolled dumping of these toxic substances into the landfill sites over many years may lead to severe and long-term damage to the environment. If we provide a safe and convenient way to collect, process, and reuse these discarded cells and batteries we will be able to avoid significant pollution problems. We know the problem exists—we should do something about it now.

Opinion of a research scientist
If we know we will be able to recycle some of the rarer or more toxic substances, we may be encouraged to develop cells that do not use up these materials in the chemical reactions while the cell is being used.

Counterpoint

Opinion of a citizen
It will be inconvenient to have to take all the cells to the recycling centres. Besides, not all of the substances are harmful to the environment. I would have to take the cells out of some of the things I throw away, and I might not be able to take them apart.

Opinion of a store owner
The handling and storage of these discarded cells sounds dangerous, and I would have to train my staff to do this. In addition, I may have to provide a special storage area to keep them until they are collected. How am I going to be paid for providing these extra services?

What Do You Think?

Decide how you feel about this issue, and write your thoughts and reasons in the form of a position statement. Present your opinions in a letter to your local member of parliament or prepare a short speech to present at a local council meeting.

Electric Current

We have all experienced irritating electric shocks from static electricity, especially in dry, cold weather. But shocks from electric circuits are quite another matter. Every year people are injured and sometimes die from electrocution. Surprisingly small amounts of electric current can be lethal.

As you learned earlier, an electric current is made up of moving electric charges. In solids it is only the negative electric charges on electrons that move through the circuit. The positive charges on protons remain in their fixed positions in the atoms. Electric current is a measure of the rate at which electric charges move past a given point in a circuit. The metric SI unit used to measure electric current is the **ampere**. The symbol for the ampere is A. Slightly less than one ampere (1 A) of current flows through a 100-W light bulb in a lamp connected to a 120-V circuit. (**Table 1** lists the electric current required to operate some electrical loads.) Current is measured using an ammeter connected to the circuit in series.

Table 1

The Electric Current Ratings of Some Common Electrical Loads

Electrical Device	Electric Current (amperes)
electronic wrist watch	0.000 13
electronic calculator	0.002
electric clock	0.16
light bulb (100 W)	0.833
television (colour)	4.1
electric drill	4.5
vacuum cleaner	6.5
stove element	6.8
oven element	11.4
toaster	13.6
water heater element	27.3
car starter motor (V-8)	500.0

Comparing Static and Moving Electric Charges

Static electricity is electric charge that remains in a fixed position on an insulator and distributes itself over the entire surface of a conductor. Static electric charges can be transferred by friction, contact, and induction.

Current electricity is electric charge that moves from a source of electrical energy in a controlled path through an electric circuit. The electrical energy of the moving electric charge can be converted into other desired forms of energy using a wide variety of electrical loads.

Human Response to Electric Shock

One of the most common misconceptions about electric shock concerns how much current is required to kill a person. A surprisingly small amount of current is lethal. That is one reason why it is important to read the safety precautions in the operating manuals of any kind of electrical device or equipment.

The electric potentials that cause muscle movement in the human body are produced by nerve cells and are typically about 0.08 V. When muscles are stimulated by electrochemical

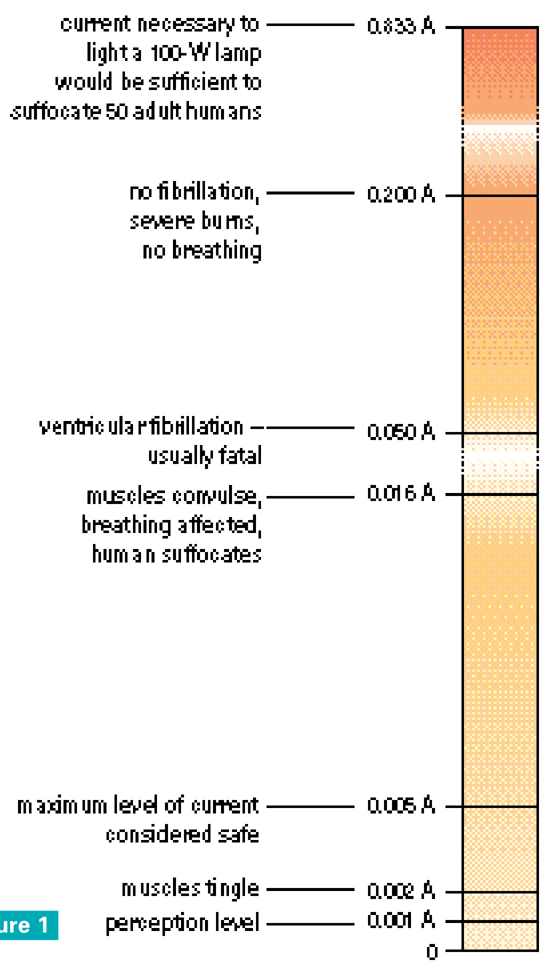


Figure 1

impulses from the nerve cells, the fibres in the muscle cells contract. The larger the electric current, the more strongly the muscles contract.

When a part of someone's body touches a source of electricity, and there is a complete circuit, an electric current flows through the body. If the current is large enough, the muscles in the part of the body in which the electric current is flowing automatically contract and remain contracted until the electric current ceases. The chart in **Figure 1** shows the effects produced by varying amounts of electric current. The amounts of electric current listed are average values.

Most people do not feel anything if the current is below 0.001 A, but there is a tingling sensation if the current is about 0.002 A. When the electric current is about 0.016 A, the muscles contract or convulse. This level of electric current is sometimes referred to as the "let-go threshold," because if the current is above that value, the person cannot let go of the object giving the electric shock. If the electric current is flowing from one hand to the other through the chest, the breathing muscles may become paralyzed, and the victim will suffocate unless the current is stopped.

If a current of 0.050 A or more passes through the chest, the heart muscles stop their regular pumping action and merely flutter. This fluttering of the heart muscles is called ventricular fibrillation. After a few seconds, the victim will become unconscious. The only way to stop ventricular fibrillation is to restart the pumping of the heart muscles by means of another controlled electric shock, such as you have probably seen on television or in the movies when a doctor uses defibrillator paddles on someone whose heart has stopped. This treatment must be administered as soon as possible. Electric currents above 0.200 A usually cause severe burns.

Before helping a victim of electric shock, ensure that you cannot receive a shock yourself. The electric current must be turned off, or the victim must be pulled from the danger zone with a nonconducting object, such as a piece of wood.

Understanding Concepts

1. **(a)** Define the term "electric current."
   (b) State the SI unit and name the symbol used for electric current.
2. **(a)** What kind of electric charges move through solids to form an electric current?
   (b) Why is it that only this kind of charge moves in solids?
3. **(a)** 5E Why is it necessary to consider the positive and negative terminals of the ammeter when you connect leads from it to the circuit?
   (b) What happens if the ammeter is connected incorrectly?
4. Compare static and current electricity, and describe how you would use a measuring device to demonstrate at least one characteristic of each.

Making Connections

5. Why is it dangerous to try to help someone who is experiencing an electric shock? Explain what you should do if you wish to help the person.
6. **(a)** Why is it necessary to help a person who is suffering from ventricular fibrillation as soon as possible?
   (b) What treatment is necessary, and why do the medical personnel use the equipment for only a short period of time on the patient?

Exploring

7. 3A A number of organisms stun or kill prey using electric shocks. Others sense danger by responding to electric fields given off by other organisms. Research these topics, using the library or the Internet, and prepare an oral report for the class.

Reflecting

8. Design a poster to inform others about why and how working with or using electrical devices can be dangerous to the human body.

SKILLS HANDBOOK: 5E Using the Voltmeter and the Ammeter 3A Research Skills

10.10

Electrical Resistance and Ohm's Law

Why do we use electric circuits at all? Think about all the ways you use electricity in a typical day. Every time you use electricity, electrical energy is changed into heat, sound, light, or mechanical energy by many different kinds of electrical loads. Each electrical load actually performs a useful task for us.

There are thousands of different kinds of loads, and each has been designed to operate with a specific source of electrical energy (**Figure 1**). A digital watch or portable CD player is a load that uses a particular size and type of dry cell. An electric kettle has been designed so that the heating element (coil) inside the kettle is the correct size to heat water quickly and safely when plugged into a 120-V outlet.

Figure 1
The photographs show how electricity can be transformed into heat, light, motion, or sound.

Electrons are able to move easily through the atoms of a conductor. In a good electrical conductor, such as copper, the electrons lose very little energy when they collide with the copper atoms as they move through. In other materials, such as the tungsten filament in a light bulb, the electrons lose much more of their energy. As a result of the collisions with the tungsten atoms, the electric potential energy of the electrons is converted to thermal energy, and the filament becomes so hot that it glows brightly.

Electrical Resistance

The molecules of all types of conductors impede, or resist, the flow of electrons to some extent. This ability to impede the flow of electrons in conductors is called electrical **resistance**. Some kinds of electrical devices used in circuits are designed for this purpose and are called **resistors**. The symbol for electrical resistance is R, and the SI unit is the ohm (Ω). The resistance of a 100-W light bulb is about 144 Ω.

When electrons flow through a conductor, the electrical resistance causes a loss of electric potential (voltage). There is a "difference" in the amount of electric potential after the electrons have flowed through the conductor. Physicists refer to this loss as electric potential difference, or more simply, **potential difference**.

In 1827, the German scientist Georg Ohm (1789–1854) discovered a special relationship, now called Ohm's law, that exists between the potential difference across a conductor, such as copper wire, and the electric current that flows through it. Ohm's law states that *the potential difference between two points on a conductor is proportional (directly related) to the electric current flowing through the conductor.* The factor that relates the potential difference to the current is the resistance of the conductor or load. This very simple law is used to calculate the resistance of the load when designing many different electrical devices. Although potential difference is the correct term, the term **voltage drop** is commonly used instead. Voltage is lost or is "dropped" across the conductor.

Potential Difference = Electric Current × Electrical Resistance
(Voltage Drop)

$$V = I \times R$$

Where potential difference (voltage drop) (V) is measured in volts (V), electric current (I) is measured in amperes (A), and resistance (R) is measured in **ohms** (Ω).

Table 1 lists the resistance of some electrical loads and the electric currents and voltages required to operate them. Ohm's law only applies to types of electrical loads called **ohmic resistors** that do not change electrical resistance with temperature.

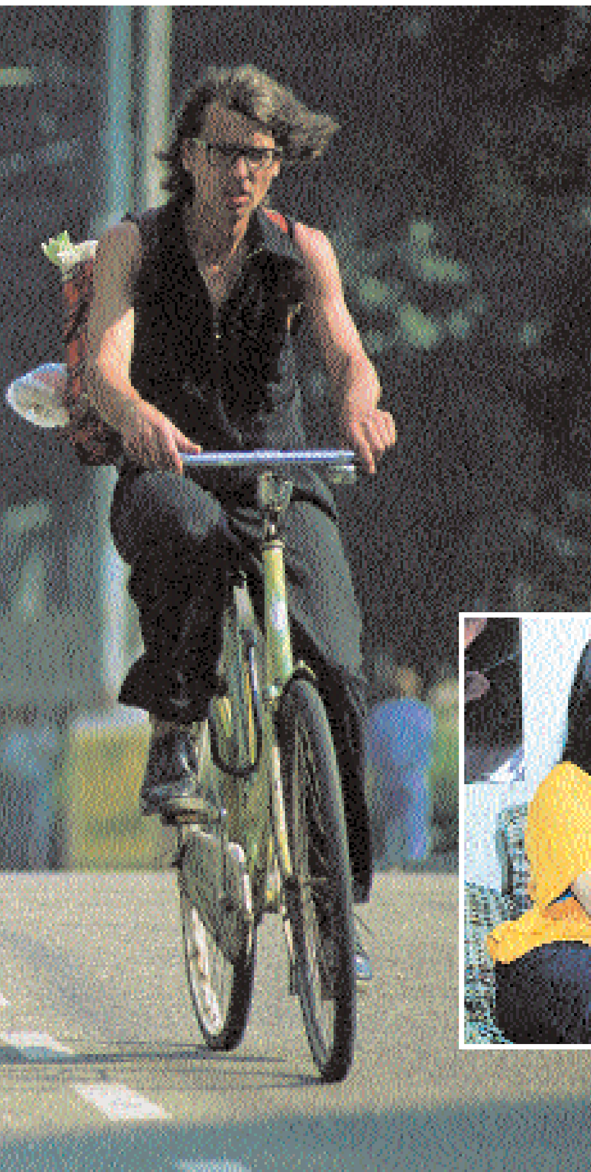


Table 1 **Resistance of Some Electrical Loads**

Voltage Drop = Current x Resistance
V = I x R

Electrical Load	Voltage Drop (V) (volts)	Current (I) (amperes)	Resistance (R) (ohms)
flashlight bulb	6.0	0.25	24
light bulb (60 W)	120	0.50	240
coffee grinder	120	1.20	100
food dehydrator	120	4.60	26
toaster oven	120	14.0	8.6
water heater	240	18.75	12.8

A Short Circuit

One of the warnings printed on battery blister packs states "Do not carry batteries loose in your pockets or purse." This warning is to prevent a dangerous condition known as a "short circuit." Let's suppose some dry cells get mixed up with a set of keys in a tote bag. Sometimes the positive and negative terminals of a dry cell become accidentally connected by the metal keys. There is now a complete, but very "short" circuit, with no electrical load to use up the energy from the dry cell as the current flows through the keys. In the confined space, both the keys and the dry cell may actually become hot enough to start a fire.

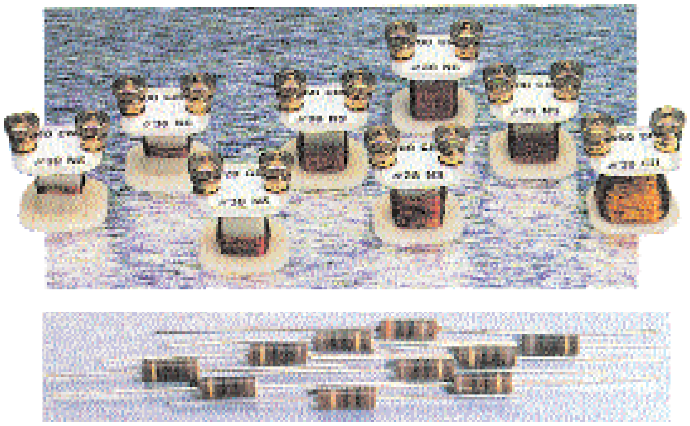


Figure 2

Many household appliances use resistors, as **Figure 2** shows. The equation for Ohm's law can be used to design electric circuits so that the resistance of the electrical load is properly matched to its energy source. For example, the tiny coil of tungsten wire (the glowing filament) inside a 100-W light bulb is just the right length so that it will glow very brightly as it uses up the electrical energy supplied by the wall outlet. Let's use Ohm's law to calculate the voltage drop across the light bulb.

Solving Science Problems Involving Formulas

The procedure below provides a standard method for solving problems.

Sample problem 1: What is the voltage drop across the tungsten filament in a 100-W light bulb? The resistance of the filament is 144 Ω and a current of 0.833 A is flowing through it.

1. **Data:** Read the problem carefully and record all given quantities, using correct symbols and units. Also, record symbols and units for the unknown quantities. (Note: Most difficulties can be traced to omissions or errors made in recording given and unknown quantities.)

   $I = 0.833$ A
   $R = 144$ Ω
   $V = ?$ V

2. **Equation:** Write the formula(s) related to the problem. Compare the data with the formula(s). Determine how the unknown quantities can be found using the formula(s).

   $V = I \times R$

3. **Substitute:** Ensure that units for given quantities are the same as those needed for the formula. Substitute given quantities into the formula.

   $V = (0.833\ \text{A})(144\ \Omega)$

4. **Compute:** Compute the numerical answer. Record it with the correct units.

   $V = 120$ V

5. **Answer:** Write an answer statement in sentence form.

   The voltage drop across a 100-W light bulb is 120 V.

Sample problem 2: An electric toaster is connected to a 120-V outlet in the kitchen. If the heating element in the toaster has a resistance of 14 Ω, calculate the current flowing through it.

Data:
$V = 120\ V$
$I = ?\ A$
$R = 14\ \Omega$

Formula:
$V = I \times R$

Substitute:
$120\ V = I \times 14\ \Omega$

Compute:
$$\frac{120\ V}{14\ \Omega} = I$$

$I = 8.6\ A$

Answer: The current flowing through the toaster is 8.6 A.

Sample problem 3: The current required to operate an electric can opener is 1.5 A. What is its resistance if the supply voltage is 120 V?

Data:
$V = 120\ V$
$I = 1.5\ A$
$R = ?\ \Omega$

Formula:
$V = I \times R$

Substitute:
$120\ V = 1.5\ A \times R$

Compute:
$$\frac{120\ V}{1.5\ A} = R$$

$R = 80\ \Omega$

Answer: The resistance of the can opener is 80 Ω.

Try This: Are You Resistant?

Most multirange meters can measure electrical resistance as well as voltage and current. Set the multirange meter to its resistance scale, and hold one of the tips of the meter leads in each hand. First, record the resistance of your body with your hands dry, and then repeat the measurement after wetting your hands. Comment on the safety aspects identified by this activity.

Understanding Concepts

1. **(a)** Define the term "electrical resistance."
   (b) State the SI unit and name the symbol used for resistance.
2. **(a)** State Ohm's law.
   (b) What does the term "potential difference" mean when applied to an electric circuit?
   (c) Explain why it is reasonable to consider the terms "voltage drop" and "potential difference" to be equivalent to one another.
3. For a given voltage drop, what would happen to the electric current through the resistance if the value of the resistance was (a) doubled, (b) halved, and (c) five times as large?
4. What is a "short circuit" and why is it considered to be a safety hazard?
5. Calculate the voltage drop across the following electrical loads:
   (a) a resistance of 500 Ω that has a current of 1.4 A flowing through it;
   (b) a resistance of 39 Ω that has a current of 0.58 A flowing through it;
   (c) a resistance of 15 000 Ω that has a current of 0.08 A flowing through it.
6. Does the wire in the electrical cord of an electric kettle have a higher or lower resistance than the heating element inside the kettle? Explain your answer.
7. A 3-V battery sends a current of 0.10 A through a light bulb. What is the resistance of the filament of the bulb?

Making Connections

8. Compared with copper, is tungsten wire a high-resistance or low-resistance metal? How does this account for how these metals are used?

Challenge

Eliminating short circuits is an important consideration when designing electric circuits. How will you avoid short circuits in your design?

10.11 Investigation

SKILLS MENU
- ○ Questioning
- ○ Hypothesizing
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Communicating

Ohm's Law

Ohm's law is one of the most useful relationships in the study of electric circuits. It is used in the design of circuits that range in complexity from toasters to those used in advanced computer systems.

In Part 1 of this investigation, you will study the relationship between voltage drop and electric current for special electrical loads known as "ohmic" resistors. In Part 2 you will study the relationship between voltage drop and electric current when an incandescent light bulb is used as an electrical load.

Question

How can the relationship between the voltage drop (potential difference) across an ohmic resistance and the electric current flowing through it be determined?

Hypothesis

If we measure the changes in voltage drop across an ohmic resistor for a series of values of electric current, we can plot the experimental data on a graph and determine the relationship between the two quantities.

Materials

- low-voltage power supply (variable from 0 V–6 V)

OR

- 4 D dry cells
- holder for 4 D dry cells
- 2 different resistors (39 Ω–100 Ω) – 1-W rating minimum
- ammeter
- voltmeter
- 6 connecting wires
- switch
- bulb (6-V rating minimum)
- bulb holder

Procedure

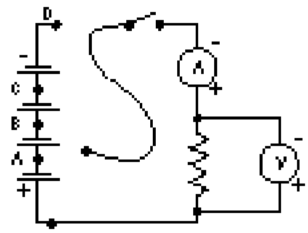
1 Before you begin, read the procedure and analysis.

(a) Design and draw a table to record your observations in Parts 1 and 2.

Part 1: Ohmic Resistors as Electrical Loads

2 Refer to the diagram below. (Note that the connecting lead from the switch is not attached and will be moved along the set of dry cells in sequence to obtain the required voltages.)

(a) Draw the schematic diagram for the circuit.



Ensure terminals are connected correctly to avoid short-circuiting the dry cells.

3 Construct the circuit you have drawn using the larger of the two resistor values (resistor 1). Do not close the switch. Ask your teacher to inspect your circuit before continuing.

4 Attach the connecting lead from the switch to the negative terminal of the battery holder at A. Close the switch and record the ammeter and voltmeter readings in the table. Open the switch.

(a) Record your observations in the table.

5 Repeat step 4 three more times by connecting the lead from the switch:
(i) first to point B on the battery case;
(ii) next to point C on the battery case;
(iii) and finally to point D on the battery case.

(a) Record your observations in the table for each step.

6 With the switch open, remove resistor 1 from the circuit and replace it with resistor 2. Do not close the switch. Ask your teacher to inspect your circuit before continuing.

7 Attach the connecting lead from the switch to the negative terminal of the battery holder at A. Close the switch and record the ammeter and voltmeter readings in the table. Open the switch.

(a) Record your observations in the table.

8 Analyze the observations in the table for both resistors, then predict the values of voltage drop and current you expect to observe when you repeat step 5 for resistor 2.

(a) Record your predicted values for voltage drop and current in the table.

9 Repeat step 5 for resistor 2.

(a) Record your observations in the table in each step.

Part 2: An Incandescent Light Bulb as an Electrical Load

10 With the switch open remove resistor 2 from the circuit and replace it with the light bulb. Do not close the switch. Ask your teacher to inspect your circuit before continuing.

11 Repeat steps 4 and 5 for the light bulb.

(a) Record your observations in the table in each step.

Analysis and Communication

12 Analyze your observations by answering the following questions:

(a) For each pair of values of V and I in the table, calculate the ratio of V/I and record it in the table.

(b) What quantity is represented by the V/I ratio for each resistor?

(c) In what way are the V/I values for the incandescent light bulb different from those of the resistors? Suggest reasons for these differences.

(d) On a single sheet of graph paper, plot (7B) three separate graphs of V versus I for the two resistors and the light bulb. Plot I on the horizontal axis and label each of the three graph lines.

(i) From the graph line of resistor 1, record in the table the values of current for voltages of 1.0 V, 2.0 V, and 4.0 V. Then calculate the V/I ratio for these three values. What did you notice about the three V/I ratios? This ratio is known as the "slope" of the graph line.

(ii) Repeat step (i) for resistor 2. What was different about the "slope" of the graph line of resistor 2 compared with that of resistor 1?

(iii) Review your answers for (i) and (ii). Write a statement that links the concepts of slope for the V/I graph and the value of the resistors used in the investigation.

(iv) Compare the graph lines for the two resistors with that of the light bulb. What can you infer about the resistance of the light bulb as the current through it increased?

Making Connections

1. (a) What is the voltage rating of the bulb you used in this investigation?

(b) Why was it this value?

(c) What would have happened in this investigation if the voltage rating was i) 3.0 V, ii) 12 V? Explain your answers.

2. Suppose you had to replace a burned-out light bulb in a flashlight. Describe at least two ways that you could determine the correct voltage rating for the bulb.

Reflecting

3. Explain why an ammeter should be connected in series with a load, while a voltmeter should be connected in parallel with a battery or a load.

SKILLS MENU
- ○ Questioning
- ○ Hypothesizing
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Communicating

Parallel and Series Circuits

There are many more examples of electrical loads connected in parallel than connected in series. Why is this so? When control devices such as switches are included as part of the circuit, together with the loads, you will find that most of the circuits we use are a combination of both series and parallel circuits.

Question

How can the characteristics of parallel and series circuits, including the relationships between voltage drop and current for each kind of circuit, be determined?

Hypothesis

If we measure the current flowing in and the voltage drops across the electrical loads in each kind of circuit, we can determine the relationships between current and voltage drop, and describe the characteristics of parallel and series circuits.

Materials

- 3 bulbs
- 3 bulb holders
- 4 D dry cells
- holder for 4 D dry cells

OR

- 1 6-V lantern battery
- voltmeter
- ammeter
- switch
- 12 connecting wires

Ensure terminals are connected correctly to avoid short-circuiting the dry cells.

Procedure

Part 1: Electrical Loads in a Parallel Circuit

1 Construct the circuit shown in **Figure 1a**. The ammeter will remain in the same position for the complete investigation. Ask your teacher to inspect your circuit before continuing. (5D) (5E)

(a) Draw the schematic circuit diagrams. Draw a table for your observations in Part 1 (**Table 1**).

Table 1

Supply Voltage V_{supply}	Voltage Drop across bulb V_{bulb}		Current I_{supply}		V_{supply}/I_{supply} ratio
	Predicted	Actual	Predicted	Actual	
?	?	?	?	?	?
?	?	?	?	?	?

2 Close the switch and note the brightness of the bulb. Connect the voltmeter first across the bulb and then across the battery. Open the switch.

(a) Record the voltmeter readings in each case. Record the ammeter reading.

3 Connect the second bulb to the circuit, as shown in **Figure 1b**. Predict the voltmeter and ammeter readings. Repeat step 2.

(a) Record your predictions and observations in the table.

4 Connect the third bulb to the circuit, as shown in **Figure 1c**. Predict the voltmeter and ammeter readings. Repeat step 2.

(a) Record your predictions and observations in the table.

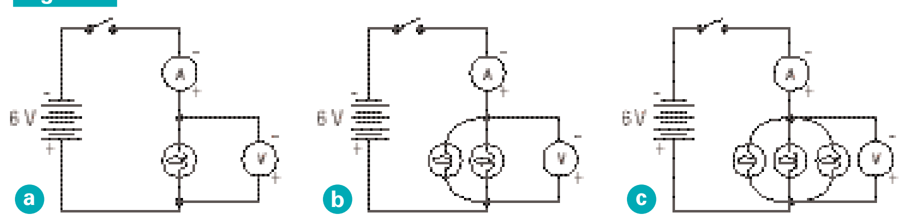
5 Remove one bulb from its socket, then close the switch.

(a) Record your observations.

6 Open the switch, and replace the bulb in the socket.

7 Repeat steps 5 and 6 for each of the other two bulbs in turn.

Figure 1



SKILLS HANDBOOK: (5D) Drawing and Constructing Circuits (5E) Using the Voltmeter and the Ammeter

Part 2: Electrical Loads in a Series Circuit

8 Construct the circuit shown in **Figure 2a**. Ask your teacher to inspect your circuit before continuing.

(a) Draw the schematic circuit diagrams shown in **Figure 2**. Draw a table for your observations in Part 2.

9 Close the switch, and note the brightness of the bulb. Connect the voltmeter first across the battery and then across the bulb. Open the switch.

(a) Record the voltmeter readings in each case. Record the ammeter reading.

10 Leaving the voltmeter connected across the first bulb, connect a second bulb in series with the first bulb, as shown in **Figure 2b**. Predict the voltmeter and ammeter readings. Close the switch.

(a) Record your predictions and meter readings in the table.

11 Open the switch and connect a third light bulb in series with the other two bulbs, as shown in **Figure 2c**. Predict the voltmeter and ammeter readings. Close the switch.

(a) Record your predictions and meter readings in the table.

12 With the switch closed, remove the first light bulb from its socket, then replace it in the socket. Open the switch.

(a) Record your observations.

13 Close the switch and repeat step 12 for each of the other two bulbs. Open the switch.

Analysis and Communication

14 Analyze your observations by answering the following questions for both Part 1 and Part 2:

(a) How does the voltage measured across the dry cell compare with the voltage drop measured across each of the three bulbs? Explain your answers.

(b) What happens to the brightness of the light from each bulb as each new bulb is added?

(c) What can you infer about the amount of electric current flowing through each bulb as each bulb is added? Explain your answers.

(d) What can you infer about the total current flowing from the cell each time compared with the current flowing through each of the bulbs?

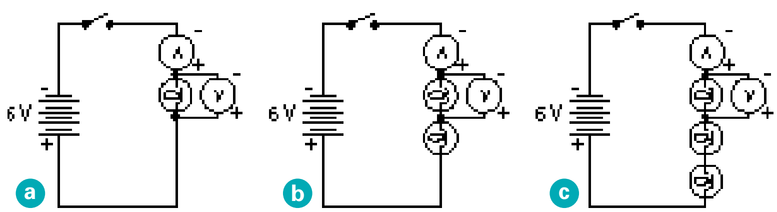
(e) Explain what happens when one of the bulbs is unscrewed.

(f) How many paths for current flow are there in each circuit?

(g) Calculate the V_{supply}/I_{supply} ratio.

(h) Explain why the V_{supply}/I_{supply} ratio changes as it does.

Figure 2



Making Connections

1. (a) Suppose 15 light bulbs were connected in series, and one bulb burned out. How could you find the defective bulb?
   (b) How could you identify one defective bulb if the 15 bulbs are connected in parallel? Explain.
2. Are the electrical wall outlets in your home wired in series or in parallel? Explain.
3. (a) Why are power bars used so commonly for connecting computer systems?
   (b) Are power bars examples of series or parallel circuit connections? Explain.

10.13

Electric Circuits with Multiple Loads

The cells and batteries in some electrical devices, such as calculators, simple cameras, and flashlights, operate only one electrical load at a time. However, when strings of decorative lights or the lights on a car are turned on, several electrical loads operate simultaneously (**Figure 1**). Two basic kinds of electric circuits are used to connect these loads: the series circuit and the parallel circuit.

The Series Circuit

The term "series" applies to any electric circuit in which the parts of the circuit are wired to one another in a single path. Have you ever had a set of minibulb lights that wouldn't light up when you plugged it in? These lights are connected in series and contain many bulbs in each circuit. If one bulb burns out, all the bulbs have to be checked to find the burned-out bulb. **Figure 2c** shows how the wires are connected to three bulbs in a series circuit.

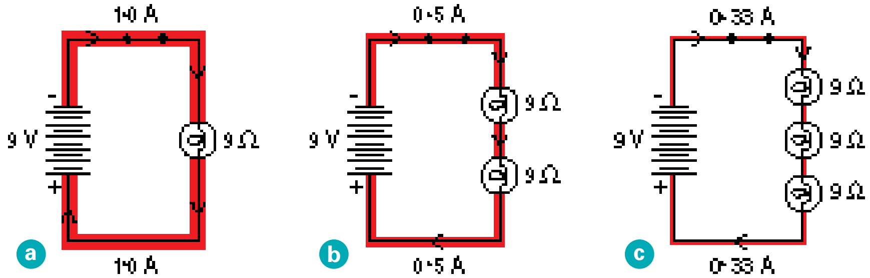
We will use Ohm's law to analyze what is happening in the three-bulb series circuit. The circuit consists of a 9-V battery and light bulbs that each have a resistance of 9 Ω. In the simple circuit shown in **Figure 2a**, only one bulb is connected to a switch and a 9-V battery. When the switch is closed, the bulb lights up. A current of 1 A flows through the bulb and it glows brightly.

Figure 1
Which kind of circuit (series or parallel) would be most suitable to connect all the light bulbs on each of these trees?

Series Circuit with Multiple Loads

In **Figure 2b** a second bulb is connected directly after, or in series with, the first bulb. Notice that there is still only one single path for the current to flow through in the circuit. The current flowing through the circuit is now only 0.5 A, exactly half the current flowing with just one bulb in the circuit. The voltage drop across the two-bulb circuit is still the same 9 V, but the amount of resistance in the circuit is now doubled. This is because the two 9-Ω bulbs are in line with one another, and the resistances add together,

Figure 2



making the total resistance 18 Ω. Using Ohm's law, if the resistance in the circuit is doubled, then, for the same voltage drop across the circuit, the current will be halved.

Predict what will happen when we connect three bulbs in series, as shown in **Figure 2c**. There is still only one path through which the current can flow. The total resistance of the three-bulb circuit will now be tripled to 27 Ω. Because there is still the same 9-V battery connected to the three-bulb circuit, the current will now be only one-third of its original value—one-third of an ampere (0.33 A). Predict what the current would be if four of these bulbs were connected in series.

Characteristics of a Series Circuit

Look at the diagrams of the two-bulb and three-bulb circuits. For the two-bulb circuit, the effect on the battery is the same as if the two bulbs were replaced by just one load (resistor) with twice the resistance (18 Ω). For the three-bulb circuit, it is as though the bulbs were replaced by a single 27-Ω resistor load. As each load is added to a series circuit, the total resistance of the circuit increases as well. If the voltage remains the same, and the resistance increases, the current flowing in the circuit decreases.

The three light bulbs in **Figure 2c** are connected in a series circuit. When the switch is closed, all three bulbs produce light. When the switch is open, the three bulbs stop producing light. Notice that the three bulbs and the switch are all wired together, one after the other, to provide a single path for the electric current. The same electric current flows through the cell, the bulbs, and the switch. Another characteristic of a series circuit is that the electric current is the same in all parts of the circuit.

A burned-out bulb prevents current from flowing, just as if a switch were open. Removing a bulb from its socket has the same effect. Because there is only one path for the current to flow through, the other two bulbs will also stop glowing. If the path of the current in a series circuit is broken at any point, the current stops flowing. This is another characteristic of a series circuit.

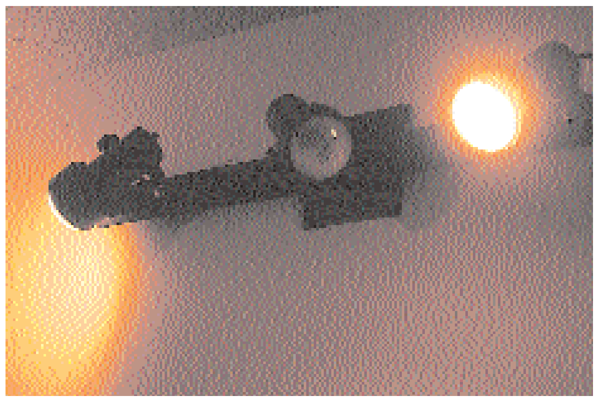


Figure 3

The Parallel Circuit

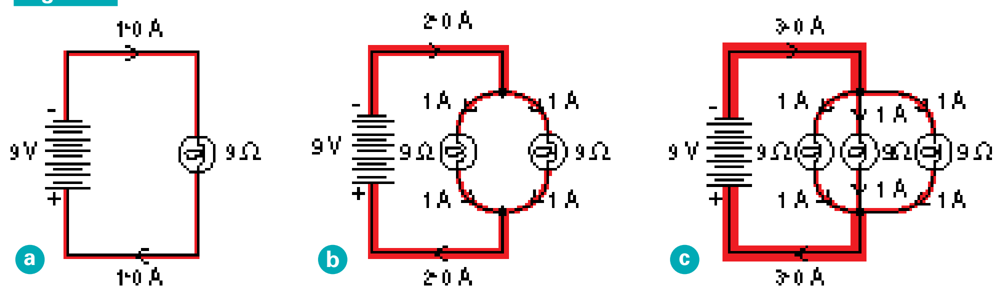
Figure 3 shows three lights in a track-light fixture. Two of the bulbs are glowing, even though the other one remains unlit. The bulbs are connected in a parallel circuit, in which the current passes through a separate circuit to each bulb. Each separate circuit is called a **branch circuit**. Because each bulb is connected to its own branch circuit, it does not affect the other bulbs. If any one of the bulbs is removed from its socket, or the filament in the bulb breaks, all the other bulbs remain lit. **Figure 4** shows how the wires are connected to three bulbs in a parallel circuit.

Figure 4

Again, we will use Ohm's law to analyze what is happening in the three-bulb parallel circuit. We will use a 9-V battery and 9-Ω light bulbs. In the first circuit shown in **Figure 5a**, only one bulb is connected to a switch and a 9-V battery. When the switch is closed, the bulb lights up. A current of 1 A flows through the bulb and it glows brightly.

Parallel Circuit with Multiple Loads

Figure 5



In **Figure 5b**, a second bulb is connected beside, or in parallel with, the first bulb. Notice that the current can now flow through two separate paths or branch circuits. The two bulbs are identical, and because the voltage drop is the same in each case, the same current of 1 A will flow through each bulb. The current flowing from the negative terminal of the battery will now be 2 A, twice the amount it was with only one bulb. After passing through the bulbs, the two currents combine again and return to the battery. If either bulb is removed from its socket, the other one stays lit because each bulb has a separate branch circuit connected to the battery.

In **Figure 5c**, a third bulb is connected in parallel. The current can now flow in three separate paths around the circuit, so the current flowing from the battery will be 3 A, three times what it was when only one bulb was connected. One-third of the total current flowing from the battery passes through each bulb. In this circuit as well, each bulb can be switched on and off or removed from its socket without affecting the other bulbs.

Did You Know

All the electric circuits in a car are wired in parallel. There is only one 12-V battery, but you can operate any electrical device in the car without affecting any of the others.

Characteristics of a Parallel Circuit

Note that each time another bulb is added in parallel to the circuit, the current from the battery increases. In any parallel circuit, the total current flowing from the source of electrical energy equals the sum of all the separate branch currents in the circuit. The voltage drop across each branch circuit is 9 V, the same as that produced by the source of electrical energy.

An interesting effect of connecting loads in parallel is that the total current always increases when you add another load. Look at the diagrams for the two-bulb and three-bulb circuits. For the two-bulb circuit, the effect on the battery is the same as if the two bulbs were replaced by just one load (resistor) with half the resistance (4.5 Ω). In the case of the three-bulb circuit, the effect is the same as if the three bulbs were replaced by one load with one-third of the resistance (3 Ω). In each case the current will increase, because adding another bulb in parallel has the same effect as decreasing the effective (total) resistance connected to the battery. If the voltage drop remains the same, and the resistance decreases, the current will always increase.

Large appliances in your home such as the clothes dryer, stove, and electric water heater are each connected to a separate branch circuit. On other branch circuits, as many as ten different lighting fixtures and wall outlets may be connected together in parallel. Because all the circuits are wired in parallel, any appliance, light, or wall outlet can be used without affecting the others. Almost all the electric circuits in your home are connected in parallel.

Combinations of Series and Parallel Circuits

Electric circuits often contain both series and parallel circuits that are combined together. Each parallel circuit in your home is connected to the main control panel and is controlled by a safety switch connected in series with the circuit. Every time you turn on the set of three bulbs in the bathroom fixture, you are actually using two switches in series with the three light bulbs that are connected in parallel. The first switch is the safety switch in the main control panel, and the second is the switch on the wall.

Try This — Make a Circuit (5D)

Design a parallel electric circuit such that one bulb is controlled by a switch while two other bulbs are not and glow continuously. Draw the schematic circuit diagram. Construct the circuit to test your circuit design. Explain the operation of the circuit.

Understanding Concepts

1. (a) State two characteristics of (i) a series circuit and (ii) a parallel circuit.
   (b) What is meant by the term "branch" circuit?
2. What happens to the total current that flows in a
   (a) series circuit if another load is connected in series with the existing loads?
   (b) parallel circuit if another load is connected in parallel with the existing loads?
3. What effect does the change in current have on the effective resistance of the total circuit in 2 (a) and (b)?
4. (5D) Draw a schematic circuit diagram for each of the following:
   (a) Three cells are connected in series, which in turn are connected to two light bulbs, a motor, and a switch, also connected in series. A voltmeter is connected to the battery to measure its voltage.
   (b) Two cells are connected in parallel, which in turn are connected to three light bulbs connected in parallel. A switch is connected in series with just one of the light bulbs.
5. Design an electric circuit so that an electric motor is controlled by a switch. In addition, one bulb is to remain lit all the time, and another is to be lit only when the motor is operating. Draw the schematic circuit diagram. Construct the circuit to test your circuit design.
6. Try to design a light bulb that could be used in a series circuit so that, if the filament burned out, all the other lights would continue to glow.

Making Connections

7. (a) Why are the electric circuits in a house wired in parallel with one another?
   (b) The more expensive strings of coloured lights are connected in parallel. Explain why. Why are they more expensive?

Challenge

Consider which type of circuit you will need to build your electric circuit board.

SKILLS HANDBOOK: (5D) Drawing and Constructing Circuits

Chapter 10 Review

Key Expectations

Throughout the chapter, you have had opportunities to do the following things:

- Compare static and current electricity. (10.3, 10.9)
- Explain the function of each part of an electric circuit. (10.1, 10.2, 10.4, 10.5)
- Describe the concepts of electric current, potential difference, and resistance, and their relationship to one another. (10.3, 10.9, 10.10)
- Determine resistance using Ohm's Law. (10.10, 10.11)
- Describe and compare the characteristics of series and parallel circuits. (10.7, 10.12, 10.13)
- Design, draw, and construct series and parallel circuits, and measure electric potentials and current related to the circuits. (10.4, 10.6, 10.12)
- Use safety procedures when conducting investigations. (10.1, 10.4, 10.11, 10.12)
- Investigate circuits, and organize, record, analyze, and communicate results. (10.1, 10.4, 10.11, 10.12)
- Formulate and research questions related to electric circuits and communicate results. (10.2, 10.5, 10.7, 10.8, 10.9)
- Describe practical applications of current electricity. (10.10, 10.13)
- Explore careers requiring an understanding of electricity. (Career Profile)

KEY TERMS

ampere
branch circuit
closed circuit
connector
dry cell
electric circuit
electric current
electric potential
electrical load
electrodes
electrolyte
negative terminal
ohm
ohmic resistor
open circuit
parallel circuit
positive terminal
potential difference
primary cell
resistance
resistor
schematic circuit diagram
secondary cell
series circuit
volt
voltage
voltage drop
voltaic cell
wet cell

Reflecting

- "The electric circuits in our homes and in many electrical appliances consist of combinations of two simple electric circuits: the series circuit and the parallel circuit." Reflect on this idea. How does it connect with what you've done in this chapter? (To review, check the sections indicated above.)
- Revise your answers to the questions raised in Getting Started. How has your thinking changed?
- What new questions do you have? How will you answer them?

Understanding Concepts

1. Make a concept map to summarize the material that you studied in this chapter. Start with the words "electric circuit."
2. (a) What is a voltaic cell?
   (b) What is an electrolyte? Explain its purpose.
3. What is the major advantage of a secondary cell compared with a primary cell?
4. (a) What is an "ohmic" resistor?
   (b) Why are light bulbs not considered to be ohmic resistors?
5. State the characteristics of (a) a series circuit, and (b) a parallel circuit in terms of the electric current and voltage drops across electrical loads in each circuit.
6. (a) In what part of the circuit do the electric charges release most of their energy?
   (b) In what other parts of the circuit are very small amounts of energy released? Explain why.
7. (a) What happens when a short circuit occurs in an electric circuit?

(b) Why can a short circuit be dangerous?

8. Explain what happens when one bulb burns out in a circuit made up of six bulbs connected in series with one another?

9. Why are series circuits with more than three or four loads not very common?

10. Describe and explain what would happen in the circuit diagram shown in **Figure 1** below if
    (a) the switch is closed;
    (b) the switch is closed and light bulb 1 is unscrewed;
    (c) the switch is closed and light bulb 3 is unscrewed;
    (d) the switch is closed, and light bulb 6 is removed and replaced by a copper wire.

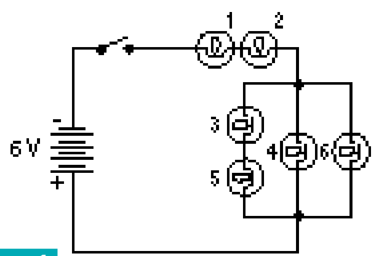


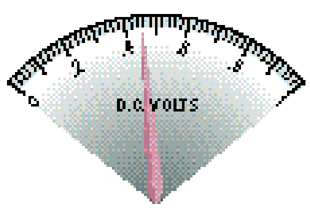
Figure 1

Applying Skills

11. Calculate the voltage drop across the following electrical loads:
    (a) A bulb that has 2.4 A flowing through it. The resistance of the bulb is 16 Ω.
    (b) A coffee grinder that has a resistance of 85.0 Ω and a current of 1.41 A flowing through it.
    (c) A current of 0.024 A flowing through a resistance of 750 Ω.

12. Determine the value of voltage indicated by the meter needle position in **Figure 2**.

Figure 2



13. (a) What voltage is produced when five 1.8-V cells are connected in series? Draw a circuit diagram of this battery.
    (b) What is the lowest voltage that can be obtained by connecting the five cells together? Draw a circuit diagram to show how to obtain this value.

14. What voltage is produced when three 1.3-V cells are connected in parallel? Explain why. Draw a schematic diagram.

15. (a) To measure the electric current flowing through a bulb, should an ammeter be connected in series or in parallel with the bulb? Explain your answer.
    (b) To measure the voltage of a battery, how should a voltmeter be connected with the battery? Explain your answer.

16. Draw a schematic circuit diagram showing a 120-V source of electrical energy and two light bulbs connected in series, which in turn are connected to two light bulbs and a motor, all connected in parallel with each other. The complete circuit is controlled by a switch and protected by a fuse. An ammeter is connected to measure the current through the motor and a voltmeter measures the 120-V supply.

17. Design three different circuits that are combinations of series and parallel circuits, using light bulbs and switches to demonstrate your understanding of the characteristics of each kind of circuit. With your teacher's permission, construct them, have them checked, and test their operation.

Making Connections

18. List four household electrical loads and state the forms of energy each load produces.

19. List three electrical loads that use batteries with cells connected in series.

20. Make a list of devices that use batteries in your home, and identify how many cells are used in each case. Indicate whether the cells are connected in series or parallel. Display the information in a table.

21. Explain why electrical insulators are used to cover the conducting wires in electrical cords attached to appliances.

22. (a) What effect does an electric current have on human muscles?
    (b) Explain what is meant by the term "let-go threshold"?

23. Are series or parallel circuits used to provide electrical energy to wall outlets? Explain why.