Topic 4.4

How can people control and use the movement of charges?

Key Concepts

- A constant source of electrical energy can drive a steady current (flow of charges).
- An electric current carries energy from the source to an electrical device (a load) that converts it to a useful form.
- A source, load, and connecting wires can form a simple circuit.
- Meters can measure potential difference and current.
- Potential difference and resistance affect current.

Key Skills

Inquiry
Literacy

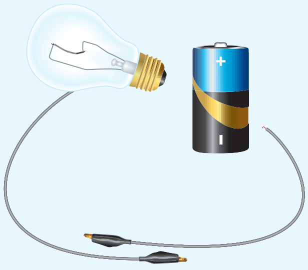
Key Terms

source
potential difference
current
ampere
load
resistance
ohm
electrical circuit
voltmeter
ammeter

Western societies such as Canada depend greatly on electrical energy to run our homes, our communities, and the whole country. In three hours, you and the other 33 million Canadians use the same amount of electrical energy that is released in just one major electrical storm. That's a lot of energy. Unfortunately, there is no way to control the energy of a thunderstorm so that it can be used in lights and other common electrical devices. The electrical energy that you depend on to run a lamp, stove, or any other electrical device must be controlled and distributed to the device continuously. This is true whether you "plug into" electrical energy from a wall socket or "snap into" electrical energy from batteries.

Starting Point Activity

1. Obtain a 1.5 V battery, a flashlight bulb, and two insulated wires with alligator clips on the ends.
2. Decide how to connect the battery and light bulb in a way that will make the light bulb light up. (**Caution**: If the wires begin to get hot, disconnect them right away.)
3. Sketch the connection arrangement that made the light bulb light up.
4. Compare your sketch with those of other students. Describe how the successful arrangements are similar.



A constant source of electrical energy can drive a steady current (flow of charges).

source: device that supplies electrical energy

potential difference: change in the energy of a unit of charge after passing through a source or a load

The device that supplies electrical energy to operate any electrical equipment is called the **source**. Your source might be an electrical outlet or a battery. You would describe your source by a quantity called its **potential difference**. The symbol for potential difference is ***V***.

Charges gain energy when they pass through a source. Potential difference describes how much their energy changes as they pass through a source. The potential difference across a source is the difference in the energy of a unit of charge entering one end of the source and the energy of a unit of charge leaving the other end of the source. **Figure 4.13** shows the potential difference across two common sources of electrical energy.

Some people also use the word “voltage” to mean potential difference. In fact, the SI unit of potential difference is the volt, and the symbol for the volt is V. This can get confusing, so be careful when you are reading and working with potential difference. Notice that the symbol for the quantity, potential difference, is in italics (*V*) and the symbol for the unit, the volt, is not in italics (V). They look similar, but they are not the same thing. The quantity of potential difference is measured in units of volts. In other words, *V* is measured in V.

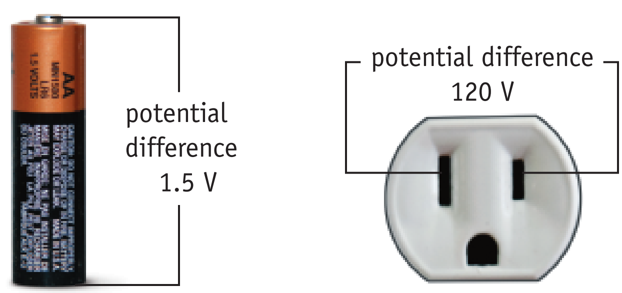
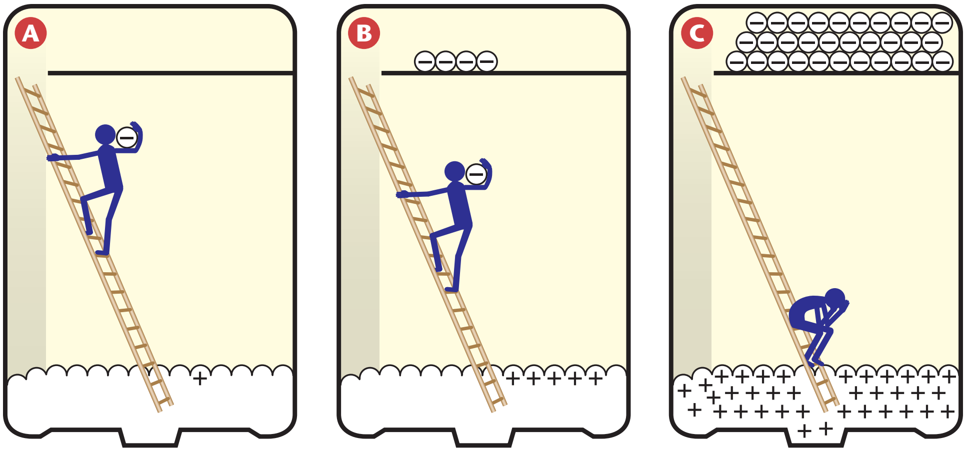


Figure 4.13 A normal electrical outlet in your home or classroom has a potential difference of 120 V. A typical battery such as an AA battery or AAA battery provides a potential difference of 1.5 V.

How Potential Difference across a Battery Works

Whenever charges are separated, there is a potential difference between the positive and negative charges. For example, when you rubbed different materials together and separated positive and negative charges, you generated a potential difference between the charged materials. Instead of rubbing, a battery uses energy from chemical changes to separate charges. **Figure 4.14** shows a model to help you understand the way this works. In the model, a miniature worker is carrying negative charges up a ladder and placing them on a shelf, leaving positive charges on the bottom. By separating charges in this way, the worker is generating a potential difference between the ends of the battery.



◀ **Figure 4.14** This model shows how charges are separated in a battery.

A The first charge is easy to carry up the ladder because only one pair of charges is being separated.

B After a few charges have been separated, all of the positive charges at the bottom are attracting the negative charge that the worker is carrying. Therefore, it takes more energy to carry each additional charge up the ladder.

C Eventually, the attraction between the positive and negative charges gets so strong that the worker cannot carry any more negative charges up the ladder. The potential difference across the battery represents the amount of energy it took to carry the last unit of charge up the ladder. For example, if this is a 1.5 V battery, it took 1.5 units of energy to carry that last unit of charge up the ladder.

Inquiry Focus

Activity 4.10

BATTERY SIZE

Five of these batteries have a potential difference of 1.5 V. One is a 3 V battery, one is a 6 V battery, and one is a 9 V battery. Can you match the voltages to the batteries?

What To Do

1. With a partner, choose a potential difference for each battery from the following possibilities: 1.5 V, 1.5 V, 1.5 V, 1.5 V, 1.5 V, 3 V, 6 V, 9 V.
2. Your teacher will give you a list of the correct values for the potential difference of each battery, so you can check your choices.
   a) Is the size of a battery related to its potential difference? Explain.
   b) What property do you think is affected by the size of a battery?

LEARNING CHECK

1. Describe what an electrical source is, and give two examples.
2. Define the terms "potential difference (V)" and "volt (V)."
3. What kind of energy does a battery use to separate charges?
4. Explain how the model in **Figure 4.14** describes the way that charges are separated in a battery.

An electric current carries energy from the source to an electrical device (a load) that converts it to a useful form.

When you want to use the energy from a source to make a device work, you must connect the source to the device. The connection is usually made with metal wire conductors that are covered by an insulator.

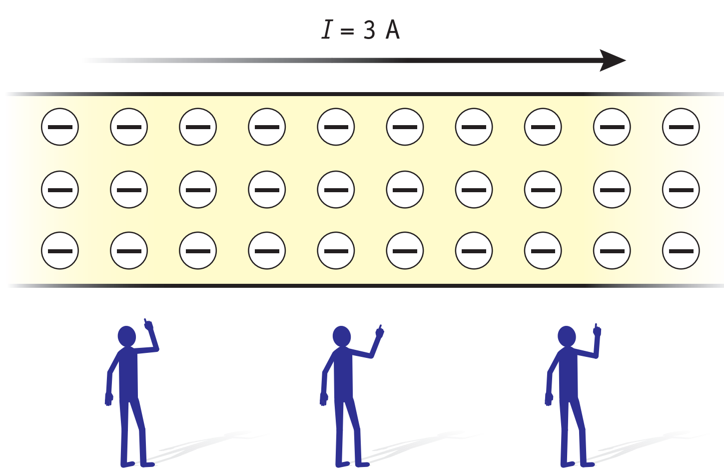
Current: The Flow of Charges

current: moving charges

The energy from the source causes charges to move through the wires, carrying energy to the device. The moving charges are called an electric **current**. The symbol for current is ***I***.

Charges cannot build up in a conductor. The amount of current flowing into one end of the wire is the same as the amount of current flowing out the other end. In fact, the amount of current flowing past every point in the wire is the same. This idea is shown in **Figure 4.15**. You describe the amount of current flowing through a wire in units called **amperes**. The symbol for amperes is **A**.

ampere: unit of current



▶ **Figure 4.15** If it was possible to count charges as they flowed past any point in a wire, you would find that the count is the same at every point in the wire. The equation $I = 3$ A means that the current (I) is three amperes (3 A). In other words, three units of charge are passing each point in the wire each second.

The Load: An Energy Converter

load: device that converts electrical energy into another form of energy

Any device that converts electrical energy into a different form of energy is called a **load**. For example, a light bulb is a load. A light bulb converts electrical energy into light energy. A radio is also a load. A radio converts electrical energy into sound energy. A printer is also a load. A printer converts electrical energy into motion energy (mechanical energy). A load always converts electrical energy into another useful form of energy.

The Load and Resistance

A load resists the flow of current. This means that a load hinders the flow of the charges passing through it. **Figure 4.16** shows how resistance makes a filament-type light bulb light up.

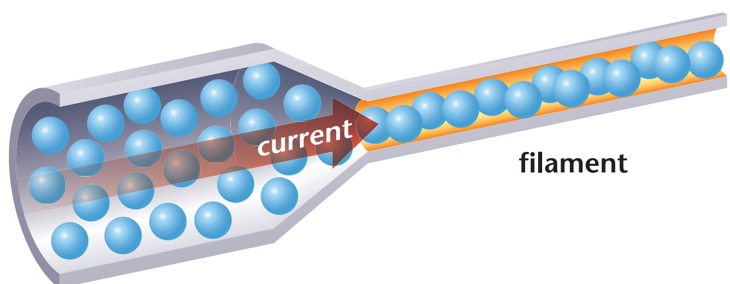
The quantity that describes this hindering is called **resistance**. The symbol for resistance is ***R***. And the unit used to measure resistance is the **ohm**. The symbol for an ohm is the Greek letter omega, **Ω**.

The filament in a light bulb is a good example of the resistance to the flow of charges. Use **Figure 4.16** to help you understand the role of resistance in making a filament-type light bulb light up.

As charges pass through a load, they lose energy. This happens because the electrical energy has been converted into another form of energy such as heat or light. Recall that the increase in the energy of a unit of charge passing through a source is the potential difference. You can also use potential difference to describe the amount of electrical energy that is lost by each unit of charge as it passes through a load. Both the increase and the decrease of the energy of a unit charge are described as a potential difference.

resistance: describes the amount that current is hindered by load

ohm: unit of resistance



▼ **Figure 4.16** A filament in a light bulb is a very thin wire. Many charges are trying to move from a much larger wire into it. As the charges move into the small wire, they collide with each other so hard that the filament gets very hot. This heat makes the filament glow.

LEARNING CHECK

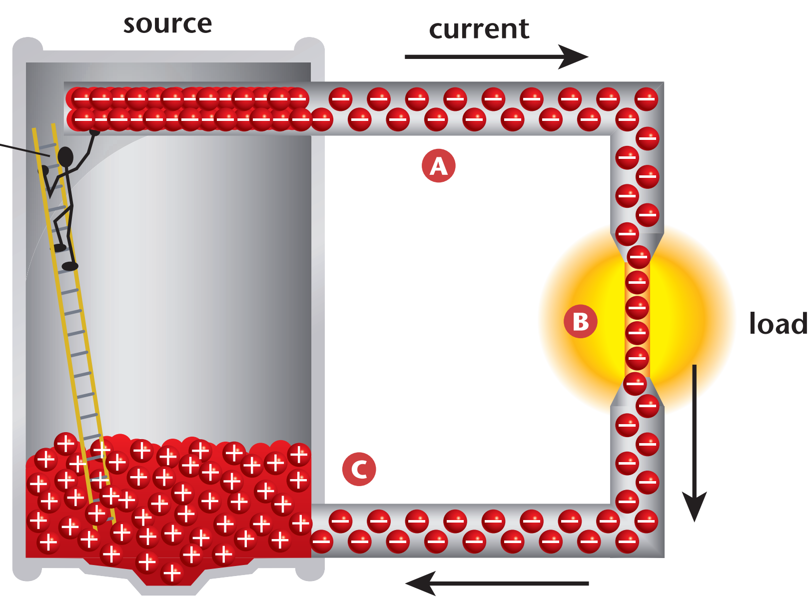
1. Identify what is required to connect a source of electricity to a load.
2. Use a main idea web or a spider map to show the relationships among the following terms: current, ampere, load, resistance, ohm. Add other terms if they help make your graphic organizer easier to understand.
3. Use the terms "source," "current," and "load" to describe how the heating element on an electric stove probably works. Refer to **Figure 4.16** to help you.

A source, load, and connecting wires form a simple circuit.

electrical circuit: at least a source, a load, and wires that allow current to flow

Now that you have learned about sources and loads, you can connect them and let the current flow. When a source, load, and conductor are connected in a way that can allow current to flow, it is called an **electrical circuit**. As you read on page 278, charges cannot build up in a conductor. All charges that leave the source must return to the source. Therefore, a circuit must form a closed loop. Examine the circuit picture in **Figure 4.17**. It uses a diagram like the ones on pages 278 and 279. **Figure 4.18** shows you how the circuit might look if you assembled it.

Remember, the "worker" represents a model of the energy that is provided by chemical changes in the battery.

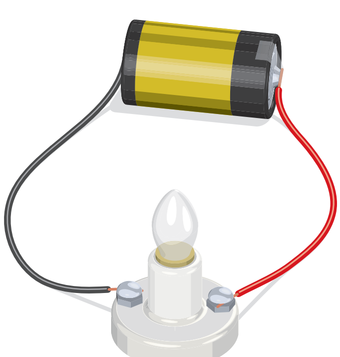


▲ **Figure 4.17** How charges move from a source and through a load in a working circuit

A The wires that are attached to the ends of the battery (source) already have charges in them that can move. The negatively charged end of the battery repels the negative charges in the wires. The positively charged end of the battery attracts the negative charges in the wire. As a result, the negative charges move along the conducting wires. Some negative charges that were inside the battery also start to move into the wire.

B As the negative charges pass through the load, they transfer some of their energy to the load. They then leave the load and return to the battery.

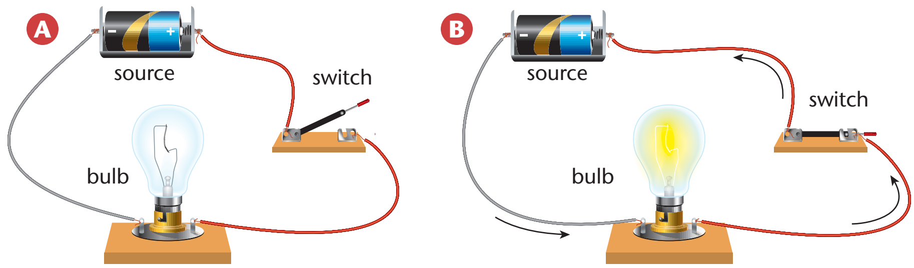
C When negative charges enter the battery, they combine with positive charges and make them neutral (no charge). The process results in a smaller number of negative charges at the negative end and a smaller number positive charges at the positive end of the battery. Now the "worker" inside the battery can carry more negative charges up the ladder and keep the number of separated positive and negative charges the same at all times.



▲ **Figure 4.18** This picture shows how the circuit in Figure 4.17 would look if you built it. When you look at a circuit like this one, try to imagine the negative charges moving in the battery, wires, and load.

A Switch: Controlling the Flow of Current

The circuit on page 280 is like the circuit in a flashlight. However, in a circuit connected this way, the light bulb would always be on. In a typical flashlight, you have a switch to turn the light on and off. To see how a switch works in a circuit, study **Figure 4.19**.



◀ **Figure 4.19** How a switch controls current in a circuit

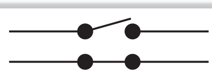
A This circuit includes an open switch. With the switch open, the circuit is not a closed loop. Because negative charges cannot build up at any point in a circuit, the current cannot flow while the switch is open.

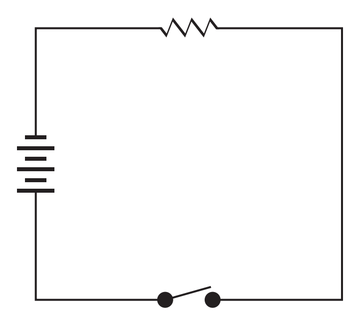
B When you close the switch, you complete the circuit. Current can flow, and the light bulb goes on.

Using Circuit Diagrams To Represent the Parts of a Circuit

Simple symbols are used to make it easier to draw circuits. **Table 1** lists the symbols for the basic parts of a circuit. The quantities used to describe the components and their units of measurement are also included. **Figure 4.20** shows how the symbols are used to draw a circuit with a battery, wires, a light bulb, and a switch.

Table 4.1 Symbols for Circuit Diagrams

Component of Circuit	Component Symbol	Quantity	Unit of Measurement
Source (battery)		Potential difference (V)	Volt (V)
Conducting wire	——	Current (I)	Ampere (A)
Load (resistance)			Ohm (Ω)
Switch: open closed			



▲ **Figure 4.20** A circuit diagram uses the symbols for circuit components to make it simpler to communicate the parts of a circuit.

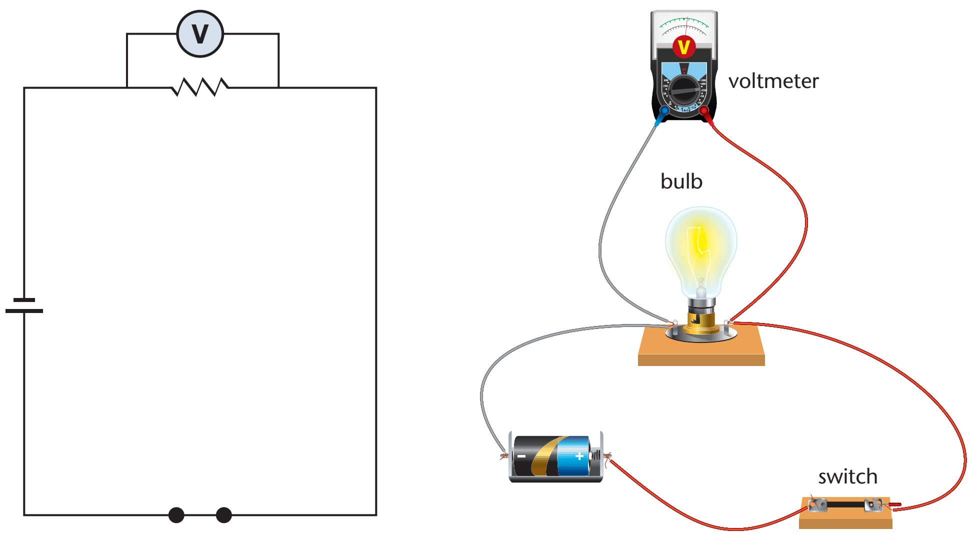
LEARNING CHECK

1. Use a flowchart to show charges moving from a source through a load in a working circuit.
2. Describe the role of a switch in an electrical circuit.
3. Refer to **Table 4.1**. Draw a circuit diagram for the circuit that you made in the Starting Point Activity for Topic 4.4.

Meters can measure potential difference and current.

voltmeter: instrument that measures the potential difference between two points in a circuit

The instrument you use to measure the potential difference across a battery or across a load is called a **voltmeter**. Because you always measure the difference in energy between two points in the circuit, the voltmeter must be connected to these two points. Figure 4.21 shows you how to connect a voltmeter to a circuit to measure the potential difference across a load.



▶ **Figure 4.21** One side of the voltmeter is connected to one side of the load. The other side of the voltmeter is connected to the other side of the load. The readout tells you the value of the potential difference across the load. The potential difference across the load is the amount of energy that a unit of charge will lose while passing through the load.

ammeter: instrument that measures current in a circuit

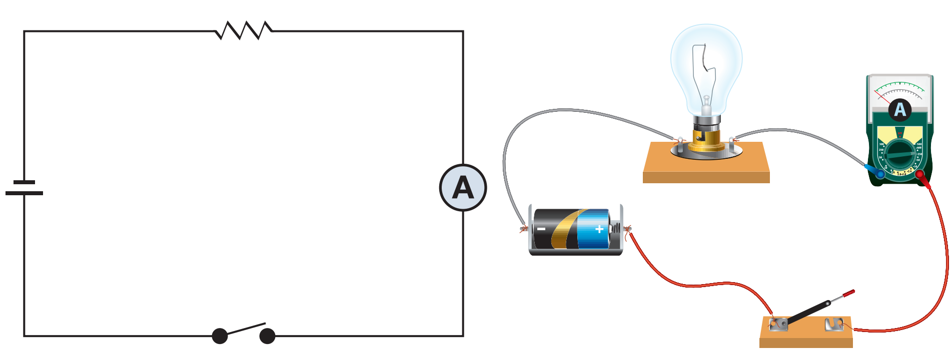
The instrument that you use to measure the current passing through a circuit is called an **ammeter**. Current flows through every point in a circuit, so you must connect the ammeter into the circuit so the current flows through it. Study Figure 4.22 to see how to connect the ammeter. Notice that the symbol for an ammeter is a circle with the letter "A" in the centre.

ACTIVITY LINK

Activity 4.11, on page 285

INVESTIGATION LINK

Investigation 4D, on page 286.



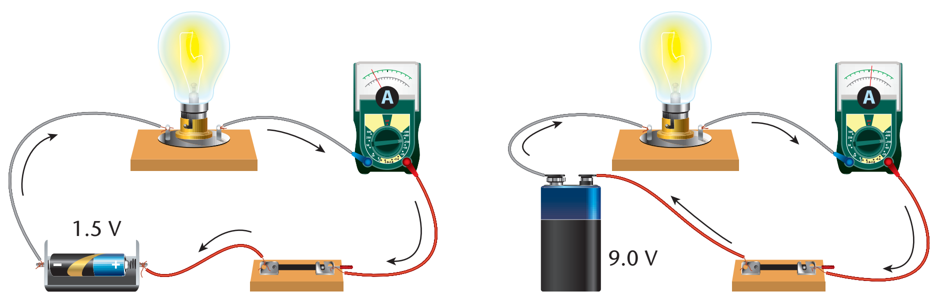
▲ **Figure 4.22** An ammeter is connected into the circuit so all of the current flows through the ammeter. In the picture, the switch is open, so no current is flowing. If you close the switch, the reading on the dial will tell you how much current is flowing through the circuit.

Potential difference and resistance affect current.

What would happen to the current in a circuit if you increased the potential difference of the source but kept the same resistance of the load? For example, in **Figure 4.23**, the first circuit has a 1.5 V battery and the second circuit has a 9.0 V battery. The resistance of the load stays the same. The higher potential difference of the source in the second diagram would give the charges more energy as they passed through it. If the charges have more energy and if the resistance to the flow of charges has not changed, the charges will flow more easily. The current will be larger.

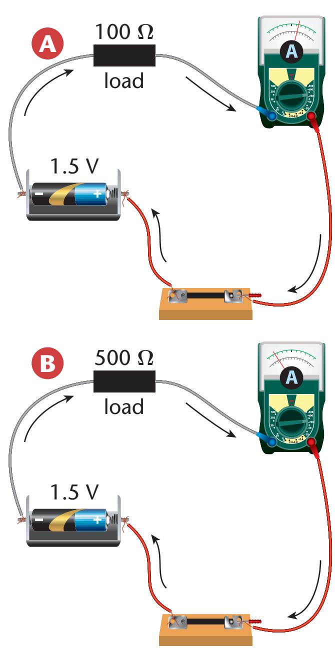
INVESTIGATION LINK

Investigation 4E, on page 288
Investigation 4F, on page 290



◀ **Figure 4.23** If you increase the potential difference of the source in a circuit but keep the resistance the same, the current will increase.

Now consider the opposite situation. What happen if you keep the potential difference of the source the same but increase the resistance in a circuit? You could just add another load or replace the load with another one that had a larger resistance. In **Figure 4.24**, the potential difference of each source is 1.5 V. In Circuit A, the resistance of the load is 100 Ω. In Circuit B, the resistance of the load is 500 Ω. Because the potential difference of the sources is the same, charges leaving the sources in the two circuits have the same amount of energy. But the resistance to the flow of charges in the second circuit is greater. So the current in the second circuit is smaller than the current in the first circuit.



▲ **Figure 4.24** If you increase the resistance in a circuit and keep the potential difference the same, the current will decrease.

LEARNING CHECK

1. Compare a voltmeter with an ammeter in terms of what each measures and how each should be connected in a circuit.
2. Describe what happens to current if you increase the potential difference of the source but keep resistance the same.
3. Describe what happens to current if you increase resistance but keep the potential difference of the source the same.

Making a DIFFERENCE

When Vishvek Babbar was 13 years old, he was walking with an elderly relative during a visit to India when there was a power outage. He noticed that some people around him were having trouble walking safely in the dark. The incident motivated Vishvek to design an inexpensive electric cane to help elderly and disabled people walk in dark and crowded places.

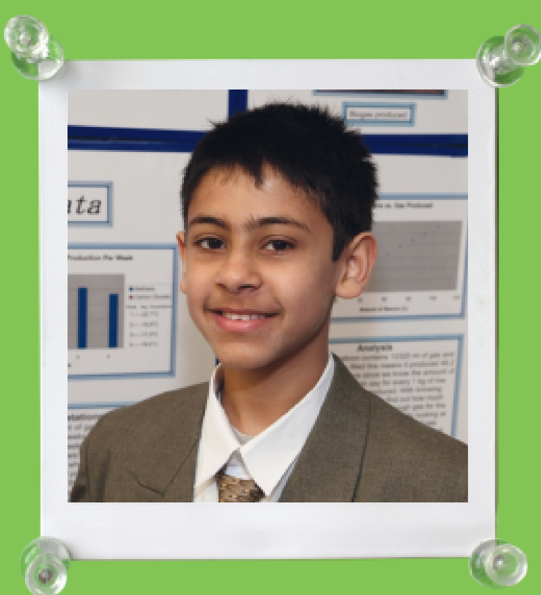
The cane cost about $20.00 to build. It includes a light, an alarm that sounds when the cane hits an obstacle, and a light and sound system that activates if the user and the cane fall down. It runs on a battery. Vishvek thinks science students should always keep their eyes open for new ideas. “Good ideas never strike when you want them to,” he says.

Have you ever witnessed a problem that could be solved with the help of a simple electrical device?

In Grade 9, Ghufran Siddiqui wanted to do a science project that could reduce waste and produce renewable energy. The Sarnia student chose to study biogas, a clean, renewable source of energy.

Ghufran built a working model of a biodigester to produce biogas. A biodigester uses bacteria to extract methane gas from plant waste. The chemical energy stored in methane can be converted into electrical energy. Meanwhile, the plant waste is changed to a rich soil to grow new plants. Ghufran used his model to calculate how large a full-scale biodigester would need to be to provide power to an average Canadian household during the summer months.

Since science projects can take time to work out and complete, Ghufran advises students who want to do projects to choose topics they are interested in. “The key is to do something you’re curious about,” he says.



What ideas about electrical applications could make a difference in your life and in the world around you?

Inquiry Focus

Activity 4.11

VOLTMETERS AND AMMETERS IN CIRCUITS

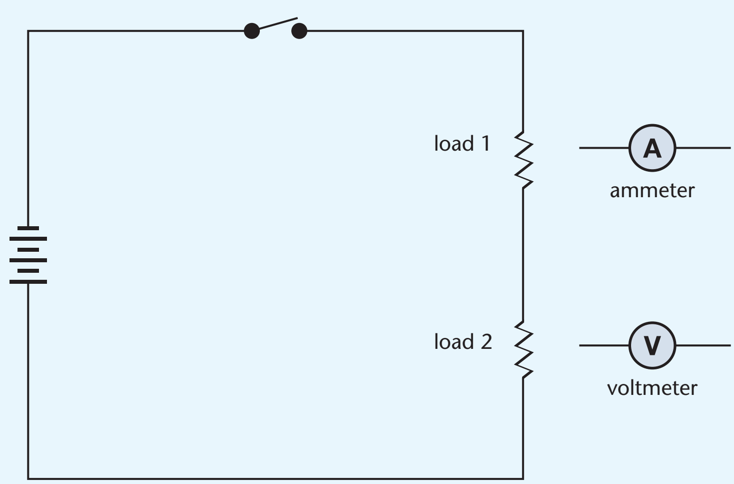
What To Do

Use the diagram below to check your understanding of the use of ammeters and voltmeters. Redraw the circuit, and add the ammeter or voltmeter as described in each of the following cases.

1. Redraw the circuit with the ammeter beside the source.
2. Redraw the circuit with the ammeter between load 1 and load 2.
3. Redraw the circuit with the voltmeter connected so it will measure the potential difference across the source.
4. Redraw the circuit with the voltmeter connected so it will measure the potential difference across load 1.
5. Redraw the circuit with the voltmeter connected so it will measure the potential difference across load 2.

What Did You Find Out?

1. Examine the circuits you have drawn. Use them to make these predictions.
   - **a)** Make a prediction about the ammeter readings when the switch is open.
   - **b)** Assume that the switch is closed. How do you predict the ammeter readings will compare for the two circuits described in steps 1 and 2?
   - **c)** How do you think the voltmeter reading across load 1 will compare with the voltmeter reading across the battery?
   - **d)** How do you think the voltmeter reading across load 2 will compare with the voltmeter reading across the battery?



Investigation 4D

Skill Check

Initiating and Planning

✓ **Performing and Recording**

✓ **Analyzing and Interpreting**

✓ **Communicating**

Safety

- Before turning on any circuit, have your teacher check it to make sure that it is connected properly.

What You Need

ammeter

voltmeter

power supply

switch

2 identical light bulbs with bases

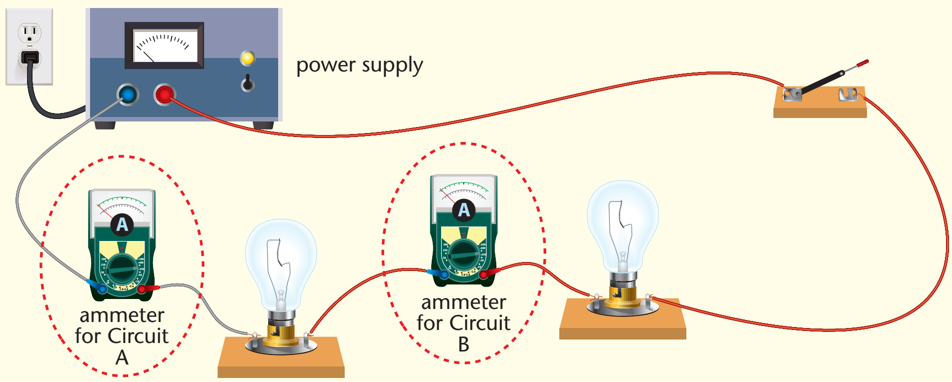
7 wire leads with alligator clips

Using Ammeters and Voltmeters

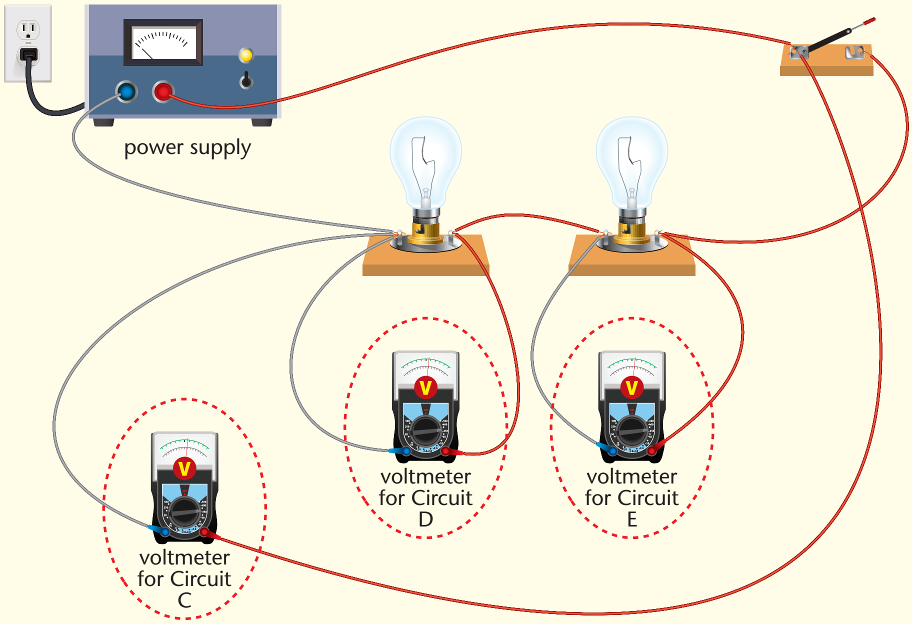
In this investigation, you will practise connecting and reading ammeters and voltmeters. You will also use a power supply, which is a source that provides a potential difference just like batteries do. However, you can choose the potential difference that you need to use.

What To Do

1. Make sure the power supply is off. Build Circuit A as shown in the diagram below. Circuit A includes the ammeter marked "ammeter for Circuit A," but it does not include the other ammeter.



2. Leave the switch open. Turn on the power supply, and set it to 3.0 V. Read the ammeter, and record the value on the ammeter.
3. Close the switch. Read and record the value on the ammeter.
4. Turn off the power supply.
5. Make sure the power supply is off. Build Circuit B as shown in the diagram above. Circuit B includes the ammeter marked "ammeter for Circuit B," but it does not include the other ammeter.
6. Repeat steps 2, 3, and 4.
7. Make sure the power supply is off. Build Circuit C as shown in the diagram at the top of page 287. Circuit C includes the voltmeter marked "voltmeter for Circuit C," but it does not include the other voltmeters.
8. Leave the switch open. Turn on the power supply, and set it to 3.0 V. Read the voltmeter, and record the value of the potential difference across the power supply.
9. Close the switch. Read and record the value on the voltmeter.
10. Turn off the power supply.



11. Make sure the power supply is off. Build Circuit D as shown in the diagram above. Circuit D includes the voltmeter marked "voltmeter for Circuit D," but it does not include the other voltmeters.
12. Repeat steps 8, 9, and 10.
13. Make sure the power supply is off. Build Circuit E as shown in the diagram above. Circuit E includes the voltmeter marked "voltmeter for Circuit E," but it does not include the other voltmeters.
14. Repeat steps 8, 9, and 10.
15. Take apart your circuit, and return the equipment to your teacher.

What Did You Find Out?

1. Look at your results for Circuits A and B. How do the values of the current compare for the two different positions of the ammeter?
2. Look at your results for Circuits C, D, and E. How does the potential difference you measured for each of the circuits compare when the switch was open? Suggest an explanation for your observations.
3. Look at your results for Circuits C, D, and E. How does the potential difference you measured for each of the circuits compare when the switch was closed? Make a general statement about the potential difference across an individual load compared with the potential difference across the source (power supply).

Investigation 4E

Skill Check

Initiating and Planning

✓ Performing and Recording

✓ Analyzing and Interpreting

✓ Communicating

Safety

What You Need

power supply

ammeter

switch

3 identical light bulbs with bases

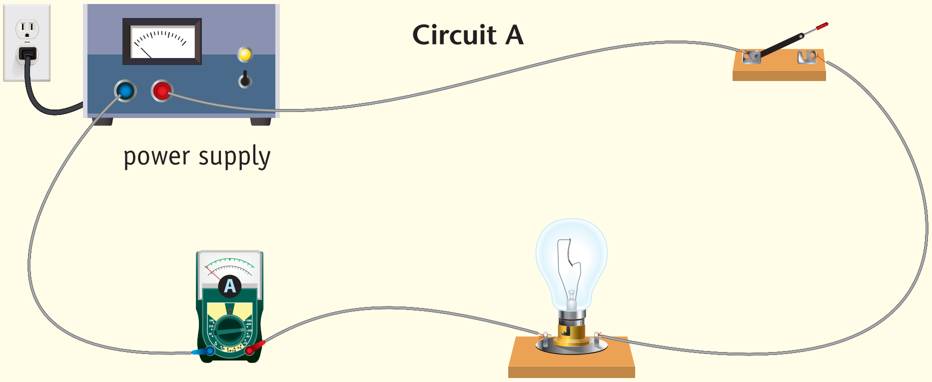
6 wire leads with alligator clips

Observing the Effects of Resistance on Current

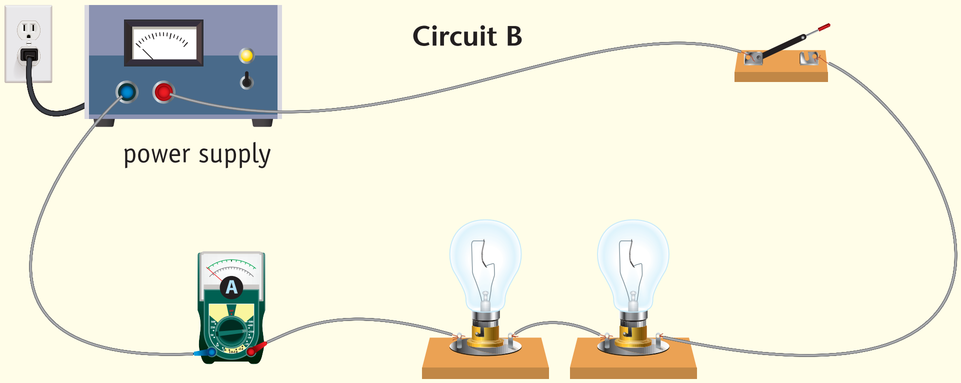
What happens to the current if you keep the potential difference of the source *the same* but *increase* the resistance of the load? You can't change the resistance of a light bulb. But you can increase the total resistance in a circuit by adding more light bulbs, one after the other. In this investigation, you will observe the current and the brightness of the light bulbs as you increase the number of light bulbs in the circuit. Before you start, make a table to record your data.

What To Do

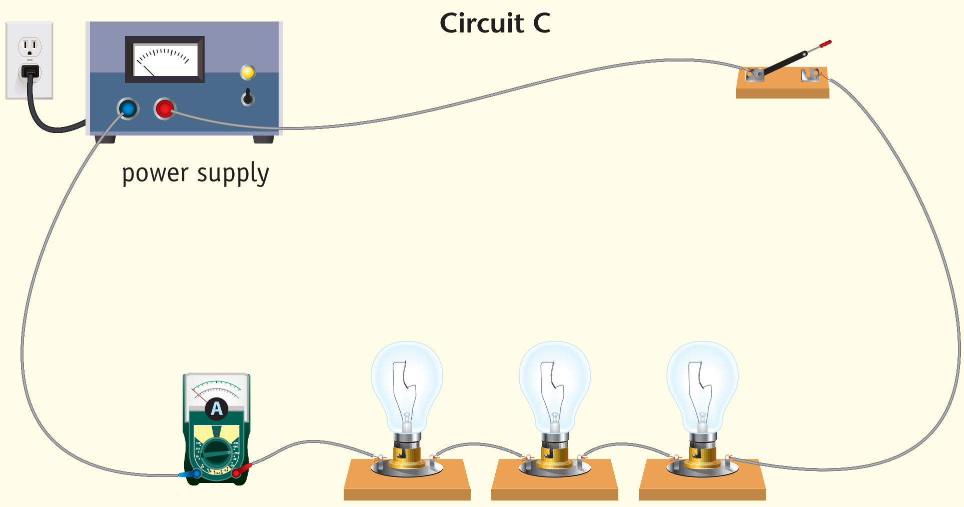
1. With the switch open and the power supply off, build Circuit A.



2. Close the switch. Turn on the power supply, and set it to 3.0 V.
3. Read and record the value on the ammeter.
4. Observe and record the brightness of the light bulb.
5. Turn off the power supply.
6. With the switch open and the power supply off, build Circuit B.



7. Repeat steps 2 and 3.
8. Compare the brightness of the two light bulbs with the brightness of the single light bulb you observed in Circuit A. Record the brightness.
9. Turn off the power supply.
10. With the switch open and the power supply off, build Circuit C.



11. Repeat steps 2 and 3.
12. Compare the brightness of the three light bulbs with the brightness of the two light bulbs you observed in Circuit B. Record the brightness.
13. Take apart your circuit, and return the equipment to your teacher.

What Did You Find Out?

1. What happened to the current when you increased the resistance by adding more light bulbs, one after the other?
2. What happened to the brightness of the light bulbs as you added more light bulbs, one after the other?
3. Describe the relationship between current and resistance in a circuit when you keep the potential difference the same. For example, write a sentence that answers this question: "What happens to the current in a circuit when the resistance changes and the potential difference stays the same?"

Investigation 4F

Skill Check

✓ Initiating and Planning
✓ Performing and Recording
✓ Analyzing and Interpreting
✓ Communicating

Safety

What You Need

power supply
ammeter
switch
light bulb with base
4 wire leads with alligator clips

Potential Difference and Current

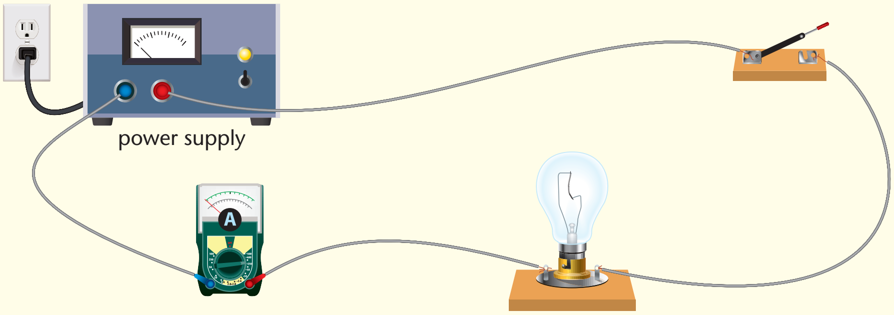
What will happen to the current if you keep the resistance of the load the same while you change the potential difference?

What To Do

1. Make a table like this, but with two extra rows for 4.5 V and 6.0 V.

Potential Difference	Current
1.5 V	
3 V	

2. Examine the diagram of the circuit. With the switch open and the power supply off, build this circuit.



3. Close the switch. Turn on the power supply, and set it to 1.5 V.
4. Read the value on the ammeter and record it in your table.
5. Increase the potential difference of the power supply to 3.0 V. Read and record the value on the ammeter.
6. Repeat step 5 with a value of 4.5 V and then a value of 6.0 V.
7. Take apart your circuit and return the equipment to your teacher.
8. Draw a line graph of your data. Show current on the horizontal axis and potential difference on the vertical axis.

What Did You Find Out?

1. What happened to the current when you increased the potential difference of the source?
2. What did the line on your graph look like? Describe the appearance of your graph.
3. Describe the relationship between current and potential difference in a circuit with a load that stays the same.

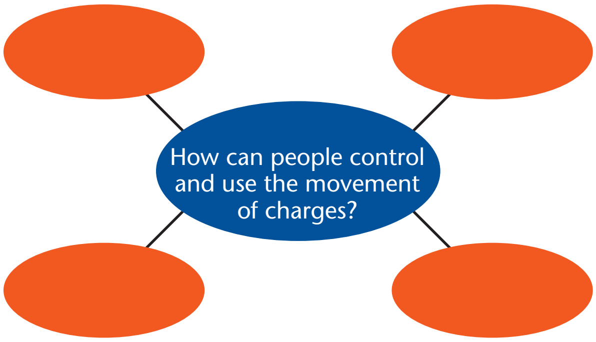
Topic 4.4 Review

Key Concept Summary

- A constant source of electrical energy can drive a steady current (flow of charges).
- An electric current carries energy from the source to an electrical device (a load) that converts it to a useful form.
- A source, load, and connecting wires can form a simple circuit.
- Meters can measure potential difference and current.
- Potential difference and resistance affect current.

Review the Key Concepts

1. K/U Answer the question that is the title of this topic. Copy and complete the graphic organizer below in your notebook. Fill in four examples from the topic using key terms as well as your own words.



2. K/U Refer to **Figure 4.16**, and think about the filament. Use words, diagrams, or a graphic organizer to explain why an electric toaster is considered to be a "load."

3. A Imagine a fast-flowing river. If you were to describe the river's current, you might state the number of litres of water that flow past a certain point every minute. Compare the current in a river with the electrical current flowing in a conductor. Use words or pictures to describe a comparison of your own that illustrates what electrical current is.

4. K/U Refer to **Figure 4.18**. Use words, diagrams, or a graphic organizer to explain what happens to electric charges as they pass through a load.

5. T/I The graphs below show the relationship among potential difference of the source, resistance of the load, and current in a closed electric circuit. Based on the data in the graphs, explain how changing the potential difference of the source and changing the resistance of the load affect the current flowing through this circuit.