8.3 Resistance and Ohm's Law

Resistance slows down the flow of electrons and transforms electrical energy. Resistance is measured in ohms (Ω). We calculate resistance by applying a voltage and measuring the current. Ohm's law states that the relationship of voltage (V), current (I), and resistance (R) is given by: $V = IR$. Resistors are electrical components used in circuits to decrease current and convert electrical energy into other forms of energy.

Words to Know

electrical resistance
ohm
Ohm's law
resistance
resistor

Summertime in British Columbia means long road vacations for many families. Perhaps you can remember some trips on busy highways when you were excitedly waiting to arrive at your destination. Suddenly, to your dismay, a sign announced "Road Construction, Single Lane Traffic Only." As the cars merged into one lane, the flow of traffic slowed down. Maybe you were also slowed down when the road became gravel instead of pavement or was full of potholes.

Resistance and the Flow of Electrons

The flow of cars in the situation above is similar to the flow of electrons in a circuit. For example, the load in the circuit might be a light bulb as shown in Figure 8.15 on the next page. The filament of the light bulb resists the flow of the electrons and therefore slows down the current. **Resistance** is the property of any material that slows down the flow of electrons and converts electrical energy into other forms of energy. The filament's high resistance causes the electrons' electrical energy to be converted into heat and light energy. The wire that connects the battery to the light bulb has very little resistance, and therefore the electrons travelling through this wire lose almost no electrical energy.

Did You Know?

The electrical resistance of your hands when the skin is dry is 100 times greater than if your hands are wet.

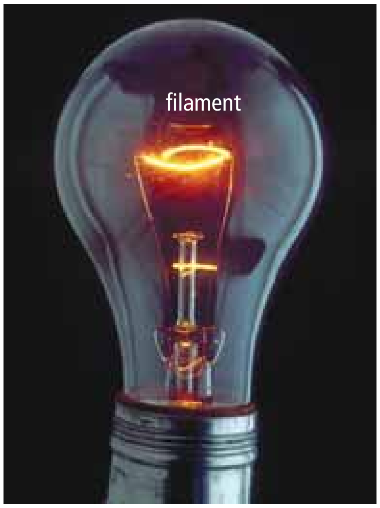


Figure 8.15A Electrons move through the filament in a light bulb.

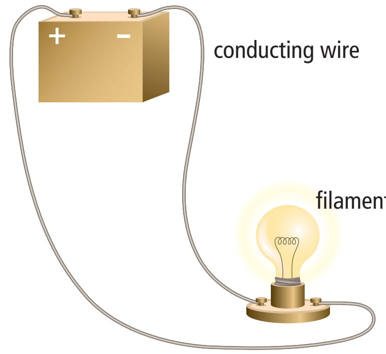


Figure 8.15B The filament has more resistance than the conducting wire. As the electrons "squeeze" through the filament, heat and light energy are produced.

8-3A Resist Your Thirst

Find Out ACTIVITY

In this activity, you will investigate how resistance affects the flow of a fluid through a straw.

Safety

- Do not share straws, cups, or water.

Materials

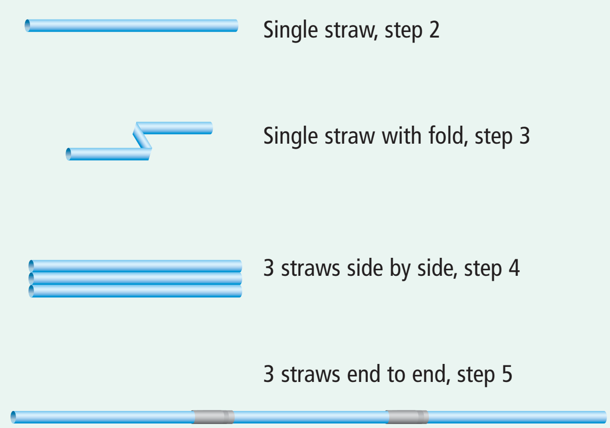
- water
- plastic disposable cup
- 4 drinking straws
- stopwatch
- clear adhesive tape

What to Do

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

Description of Straws	Time (s)
Single straw	
Single straw with folds	
3 straws side by side	
3 straws end to end	

2. Measure 100 mL of water into a cup. Have your partner time how long it takes you to drink the 100 mL of water using a single straw. Record this time.
3. Make an accordion fold in the straw as shown in the diagram. Repeat step 2 using the folded straw.
4. Repeat step 2 using three straws side by side.
5. Insert the ends of the three straws to make one long straw. Be sure to tape the joints so that the joints are sealed. Repeat step 2 using the long straw.



What Did You Find Out?

1. List the four straw types, from your data table, in order from least resistance to most resistance.
2. State the relationship between the amount of resistance and the time required to drink the fluid.
3. What factors do you think influence the amount of resistance?

Resistance and Current

Marbles in a tube can represent electrons being pushed through a circuit. Suppose you have a hollow tube filled with identical-sized marbles. If you hold the tube level, the marbles will leave both ends of the tube (Figure 8.16A). That is, there will not be a "current" of marbles all flowing the same direction. In order to have all the marbles flow out of one end of the tube you must lift one end so that the two ends of the tube are at different heights or "potentials." The higher you lift one end of the tube the greater the number of marbles flowing out of the tube (Figure 8.16B).

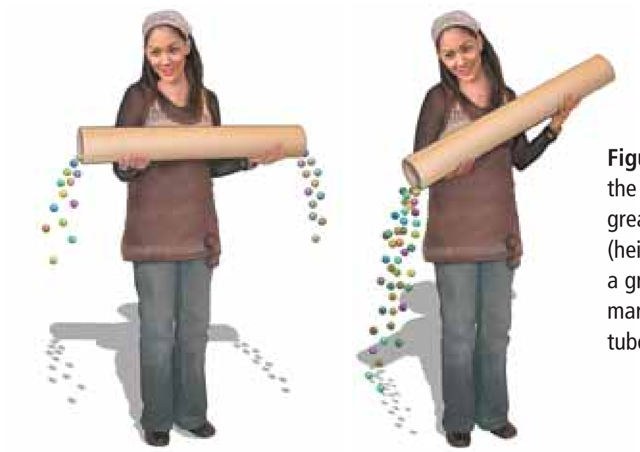


Figure 8.16A Both ends of the tube are at the same potential (height). The marbles in the tube do not all flow in the same direction.

Figure 8.16B The ends of the tube in (B) have a greater potential difference (height) than in (A). There is a greater "current" of marbles in tube (B) than in tube (A).

Voltage is the difference in potential energy per unit of charge between one point in the circuit and another point in the circuit. When you increase the voltage connected to the circuit, the current will also increase. In other words, voltage is directly proportional to current.

Georg Ohm, a German physicist (Figure 8.17), studied the relationship between voltage and current and realized that there was another factor involved. Two *different* tubes filled with identical marbles tipped the same amount do not have to have the same current. Figure 8.18 shows a tube with a large diameter and a tube with a smaller diameter both held at the same angle. The number of marbles leaving the larger tube is greater than that of the smaller tube. Even though both tubes have the same potential difference, they have different "currents" of marbles. The smaller tube does not allow the marbles to flow as freely as the larger tube. In other words, the smaller tube has more resistance.

Figure 8.17 Georg Ohm (1789–1854)

If a battery is connected to an electric circuit that has a large resistance, less current will flow than if the same battery is connected to a lower resistance circuit.

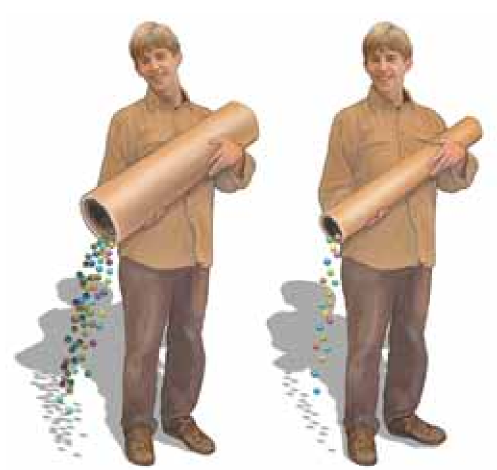


Figure 8.18 Even though both tubes have the same potential difference, the tube on the left has a greater "current" of marbles.

Ohm's Law

By measuring the amount of current that a given voltage produces, Ohm was able to calculate the circuit's resistance. **Electrical resistance** is the ratio of the voltage to the current. The unit of measurement for electrical resistance is the **ohm** (Ω). The mathematical relationship comparing voltage (V), current (I), and resistance (R) is called **Ohm's law** and is written as:

$$R = \frac{V}{I}$$

Ohm's law is more commonly written in the form:

$$V = IR$$

Word Connect

The symbol for the unit of the ohm is the Greek letter omega (Ω) instead of the first letter of ohm (O). This is because the (O) might be confused as the number zero. The symbol "I" for current stands for "intensity."

You can use Ohm's law to calculate resistance.

Read the question:

What is the resistance of a flashlight bulb if there is a current of 0.75 A through the bulb when connected to a 3.0 V battery?

Use the formula:

$$R = \frac{V}{I}$$

$$= \frac{3.0\ \text{V}}{0.75\ \text{A}}$$

$$= 4.0\ \Omega$$

State your answer:

The resistance of the flashlight bulb is 4.0 Ω.

Practice Problems

Try the following Ohm's law problems. Show each step of your solution.

1. The current through a load in a circuit is 1.5 A. If the potential difference across the load is 12 V, what is the resistance of the load?
2. The resistance of a car headlight is 15 Ω. If there is a current of 0.80 A through the headlight, what is the voltage across the headlight?
3. A 60 V potential difference is measured across a load that has a resistance of 15 Ω. What is the current through this load?

Answers

1. 8.0 Ω
2. 12 V
3. 4.0 A

Converting prefixes

Prefixes are used to indicate the magnitude of a value.

milli (m) represents one-thousandth (example: 25 mA = $\frac{25}{1000}$ A = 0.025 A)

kilo (k) represents one thousand (example: 5.0 kΩ = 5000 Ω)

mega (M) represents one million (example: 12 MV = 12 000 000 V)

When solving a problem where some of the units contain prefixes, first convert the prefixes before you do your calculation.

Read the question:

What is the voltage across a 12 kΩ load that allows a current of 6.0 mA?

Use the formula:

$$
\begin{aligned}
V &= IR \\
&= (6.0\ \text{mA})(12\ \text{k}\Omega) \\
&= (0.0060\ \text{A})(12\ 000\ \Omega) \\
&= 72\ \text{V}
\end{aligned}
$$

State your answer:

The voltage across a 12 kΩ load is 72 V.

Practice Problems

Try the following Ohm's law problems. Show each step of your solution. Remember to convert prefixes before calculating.

1. A 15 mA current flows through a 400 Ω lamp. What is the voltage across the lamp?
2. A 12 kΩ load is connected to a 90 V power supply. What is the current through the load in milliamperes (mA)?
3. A device draws a current of 1.2 mA when connected to 120 V. What is the resistance of this device? Give your answer in both ohms and kilo-ohms.

Answers

1. 6.0 V
2. 7.5 mA
3. 100 000 Ω; 100 kΩ

Determining the Resistance

There are several methods you can use to determine the resistance.

Method 1: To experimentally measure the resistance of a device or load, the load must be connected to a source of potential difference, such as a battery. You can use a voltmeter to measure the voltage across the load and an ammeter to measure the current through the load. Then you can use Ohm's law to calculate the resistance.

To obtain more accurate results, you can place several different voltages across the load. You then measure the current through the load for each voltage. Using Ohm's law, you can calculate the load's resistance for each set of data. These resistances can then be compared.

Method 2: In your classroom, you may have used a digital multimeter to take your voltage and current measurements. Most multimeters also have a setting for measuring resistance. An **ohmmeter** is a device that measures resistance. When a multimeter is used as an ohmmeter, the meter uses its internal battery to provide a voltage across the load. The meter measures the current leaving the battery and calculates the resistance. This calculated resistance is then shown on the display screen.

Did You Know?

The current flowing in an MP3 player is very small, perhaps one-thousandth of an ampere. The current produced by a car's battery to start the car is almost 100 A.

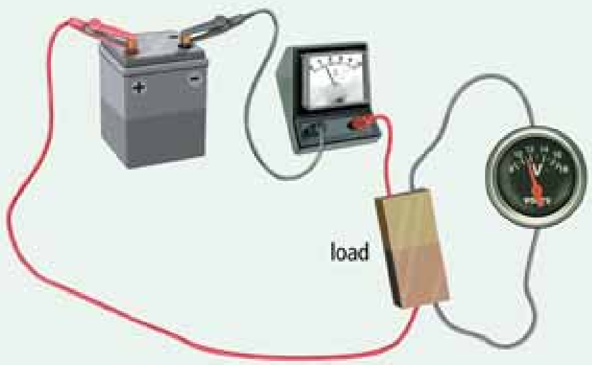
8-3B Calculating Resistance

Think About It

The resistance of a load can be determined by analyzing the relationship between the voltage across the load and the current. In this activity, you will use voltage and current data obtained from an experiment to calculate the resistance of the load.

What to Do

1. A battery is connected to a load as shown. The voltage across the device and the current through the device is measured.



A battery is connected to a load, and the voltage and current are measured.

2. Different batteries are connected to this same load and the following data is obtained. Copy this data table into your notebook. Give it a title.

Voltage (V)	Current (A)	Resistance (Ω)
3.0	1.2	
4.5	1.7	
6.0	2.5	
9.0	3.6	
12.0	5.0	

3. Using Ohm's law, calculate the resistance for each set of voltage-current data.
4. Calculate the average resistance of your five calculated resistances. To find the average, add the five resistances and divide the sum by 5. Record the average resistance. Include correct units.

What Did You Find Out?

1. How did the resistances you calculated for the sets of data compare? Were they exactly the same, close, or very different?
2. Given that the same load was used, explain why you think the values calculated might not be exactly the same for each set of data.

The Resistor

Any electrical component that has electrical resistance slows down current and transforms electrical energy into other forms of energy. A **resistor** is an electrical component that has a specific resistance. Resistors (Figure 8.19) can be used to control current or potential difference in a circuit to provide the correct voltage and current to the other components of the circuit. The circuit symbol for a resistor is shown below in Figure 8.20.

Figure 8.20 The circuit symbol for a resistor

Figure 8.19 Resistors are used to control current and voltage in electrical circuits.

8-3C Circuit Diagrams with Resistors

Think About It

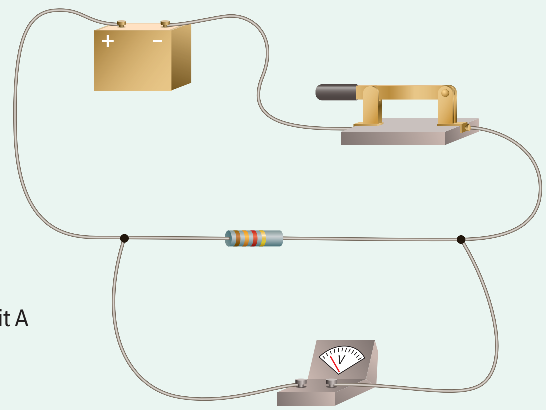
In this activity, you will draw circuit diagrams for circuits that contain resistors.

What to Do

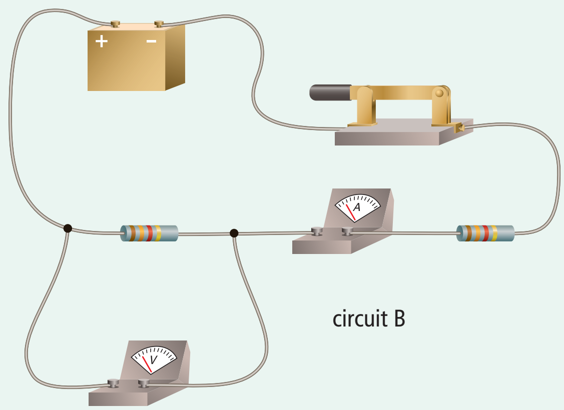
1. Draw the corresponding circuit diagrams for circuit A and circuit B.

What Did You Find Out?

1. Compare your circuit diagrams with those of a classmate. List any similarities and differences.
2. Explain the advantage of the circuit diagram you drew as compared to the original illustration in this student book.



circuit A



circuit B

Did You Know?

The resistance of the tungsten wire in a light bulb is 400 times greater than the resistance of the copper wire leading to the light bulb. This is why the tungsten wire heats up more than the copper wire.

Resistance Is a Big Loser

It takes less effort to slide a heavy box across a smooth polished floor compared to pushing the same box across a rough floor (Figure 8.21). The rough floor provides resistance to the motion of the box. This resistance, or friction, of the rough floor produces much more heat than the smooth floor.

There is a similar effect when a battery tries to "push" electrons through a circuit. When the charge encounters resistance, some of the electrical energy stored in the electrons is transformed into other forms of energy, such as heat. When we say that energy is lost in a resistor, it really means that electrical energy has been transformed to other forms of energy. These other forms of energy do not easily get changed back into electrical energy.

Figure 8.21 Since the rough floor provides more resistance, more energy is transferred into heat by the friction.

Resistor Colour Code

Resistors are marked with coloured bands. These stripes are not for decoration but instead indicate the resistance of the resistor. Table 8.2 gives the numeric values associated with each colour.

Table 8.2 Colour Coding on Resistors

Colour	Numeric Value
black	0
brown	1
red	2
orange	3
yellow	4
green	5
blue	6
violet	7
grey	8
white	9

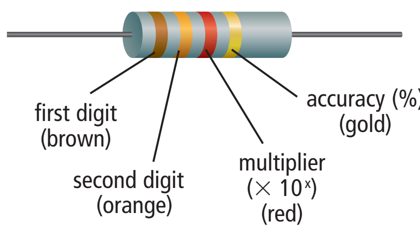


Figure 8.22 The resistor in this illustration would have the first digit 1, the second digit 3, the power of 10 to the second power, and an accuracy within 5 percent. Therefore this resistor's value would be 13×10^2 or 1300 Ω and is accurate within 5 percent.

Suggested Activity

Conduct an Investigation 8-3D on page 298

Figure 8.22 displays the colour code of a resistor. The first band is the first digit of the resistance. The second band is the second digit of the resistance. The third band represents the multiplier or power of 10 factor of the resistance (the number of zeros that follow the second digit in the resistance value). If the resistor has a fourth band, it represents the percentage of accuracy between the indicated value and actual value (gold 5 percent, silver 10 percent, no colour 20 percent).

Reading Check

1. How does resistance affect current?
2. What will happen to the current in a circuit if the voltage applied to that circuit is increased?
3. State Ohm's law, which is the relationship of voltage (V), current (I), and resistance (R).
4. What are the units of electrical resistance?
5. What happens to the electrical energy when electrons flow through a resistor?
6. What does it mean when we say that energy is "lost" in a resistor?
7. How do manufacturers of resistors indicate the value of the resistance?

Explore More

Decreasing the resistance allows more current with less energy lost to heat. Scientists have produced materials that have almost zero resistance. These materials are called superconductors. Find out how superconductors are produced and what applications they may have. Begin your research at **www.bcscience9.ca.**

8-3D Resistors and Ohm's Law

SkillCheck

- Observing
- Measuring
- Controlling variables
- Evaluating information

Safety

- If any of the wires or resistors become hot, open the switch immediately.
- Make sure that the positive terminal of the ammeter is connected to the positive terminal of the battery. The negative terminal of the ammeter should be connected to the negative terminal of the battery.
- Never connect an ammeter directly across the terminals of a battery.
- There must be a load, in this case the resistor, in the circuit to limit the flow of electrons.

Materials

- 2 different resistors (100–300 Ω)
- ammeter
- voltmeter
- conducting wires
- four 1.5 V cells
- switch

In Part 1 of this activity, you will construct a circuit from a circuit diagram and measure voltage and current using a voltmeter and ammeter. In Part 2, you will calculate resistance.

Question

How do the calculated value and measured value of resistors compare?

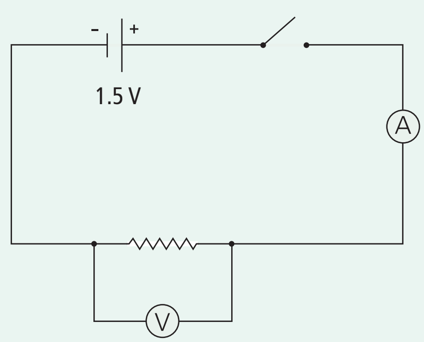
Procedure

Part 1 Measuring Voltage and Current

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

Resistor Value (Ω)	Voltage (V)	Current (A)	Calculated Resistance (Ω)
#1			
#2			

2. Using the resistor colour code, record the value of each of your resistors in your data table.
3. Construct the following circuit using one of your resistors and one 1.5 V cell. Be sure to leave the switch open until instructed by your teacher to close the switch.



Construct this circuit in step 3.

Science Skills

Go to Science Skill 11 for information about how to use an ammeter and voltmeter.

4. Close the switch briefly and measure the voltage and current. Open the switch as soon as you have measured your values. Record these values in your data table. If your ammeter is measuring in milliamperes, be sure to convert this to amperes.
5. Replace your 1.5 V cell with two 1.5 V cells connected together. Make sure the cells are connected positive (+) to negative (−). When instructed by your teacher, repeat step 4.
6. Connect three 1.5 V cells together, again positive to negative. When instructed by your teacher, repeat step 4.
7. Connect four 1.5 V cells together, again positive to negative. When instructed by your teacher, repeat step 4.
8. Remove your first resistor and replace it with your second resistor. Repeat steps 4 to 7.
9. Clean up and put away the equipment you have used.

Part 2 Calculating Resistance

10. Using your measured voltage and current, calculate the resistance for each set of data. Record these values in the "Calculated Resistance" column of your data table.

Analyze

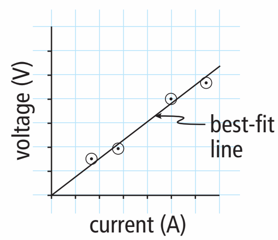
1. Using the calculated resistances for resistor #1, calculate the average resistance. Record this value. Include correct units.
2. Using the calculated resistances for resistor #2, calculate the average resistance. Record this value. Include correct units.

Conclude and Apply

1. For each resistor, compare the average value of the resistance to the value obtained from the colour code.
2. Give a possible reason for the calculated value and colour code value not being exactly the same.
3. As the current through an individual resistor is increased, what happens to the voltage across that same resistor?

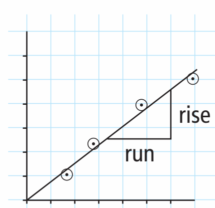
Using a Line Graph to Analyze Voltage and Current Data

Measurements taken during scientific investigations are not always perfectly accurate. This could be due to the inaccuracy of the measuring device or the inability to observe the exact value. When you plot your data on a line graph, the points may not line up perfectly on a line. The line that is drawn is therefore called a best-fit line. Think of the data points you have plotted as being good approximations of the exact values. The best-fit line should show the trends and therefore might not hit every point exactly.



In the graph above, you can see that as the voltage increases (vertical axis) the value of the current (horizontal axis) also increases. Using a mathematical tool called slope, you can obtain even more information from your graph line. The slope of a line is very similar to the slope of a hill or ramp. If you were hiking up a hill that had a large slope, the hill would be very steep. If the hill had a small slope, the hill would be less steep.

Mathematics defines slope of a line as "rise over run." Slope is the ratio of how much the line rises (vertical axis) as compared to how much change there is on the horizontal axis.



$$\text{slope} = \frac{\text{rise}}{\text{run}}$$

The rise on the voltage and current graph indicates the change in voltage. The run indicates the change in current. Therefore, by finding the slope, you are calculating the ratio of voltage to current.

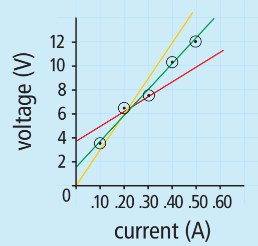
Slope = rise/run

Slope = voltage/current

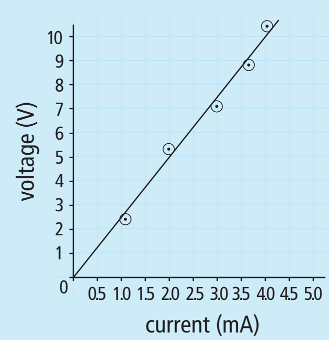
According to Ohm's law: $R = \frac{V}{I}$. Therefore, on a voltage vs. current graph, the slope of the line is the resistance of the load. If the data from two different loads were plotted on the same graph, the line with the steeper slope would indicate a higher resistance.

Questions

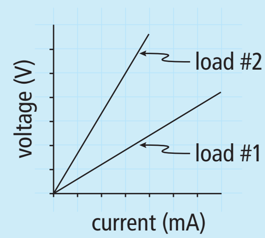
1. Which of the following lines represents the best-fit line for the plotted data points?



2. Using the best-fit line, what would be the current through the load if it were connected to 5.0 V?



3. The data for two different loads are plotted on the following graph. Which load has the higher resistance? Explain your answer.



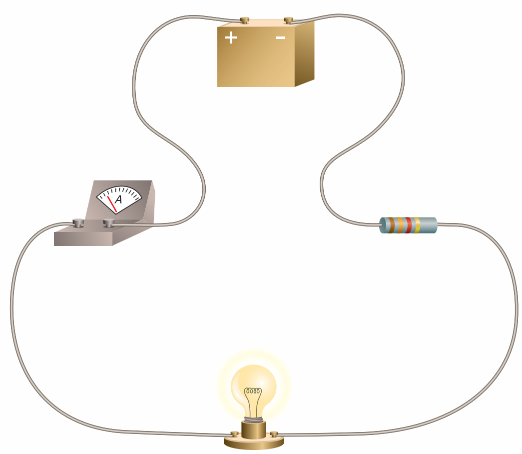
Check Your Understanding

Checking Concepts

1. What is the name of the property of a material that slows down current and converts electrical energy into other forms of energy?
2. Using Ohm's law, state the relationship of current, resistance, and voltage.
3. What two values do you need in order to calculate resistance?
4. (a) What is the unit of resistance?
   (b) What is its symbol?
5. What is used to control current and potential difference in a circuit?
6. Explain how manufacturers indicate the value of resistance on each resistor.
7. Draw the symbol used to represent a resistor in a circuit diagram.

Understanding Key Ideas

8. A 1.2 A current flows through a 250 Ω resistor. Calculate the voltage across this resistor.
9. A 120 Ω resistor is connected to a 12 V battery. Calculate the current through the resistor.
10. An unknown resistor transforms 2.0 mA of current when connected to a 9.0 V battery. Calculate the value of this resistor.
11. A classmate hands you a resistor that has the following colour bands: yellow, orange, red, and silver. What is the resistance of this resistor?
12. A light bulb is connected to a battery and the brightness of the light is observed. A resistor is then connected between the battery and the light bulb and the brightness of the light decreases. Explain this observation using what you know about energy and circuit components.
13. Draw a circuit diagram for the following circuit.



Pause and Reflect

Suppose you are given several batteries, an ammeter, voltmeter, connecting wires, and a resistor that has no coloured bands indicating its value. How could you determine an accurate value for this resistor?

Chapter Review

Prepare Your Own Summary

In this chapter, you investigated the relationship between current, voltage, and resistance. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 12 for help with using graphic organizers.) Use the following headings to organize your notes:

1. Electrical Energy
2. Current
3. Voltage
4. Resistance and Ohm's Law
5. Circuits

Checking Concepts

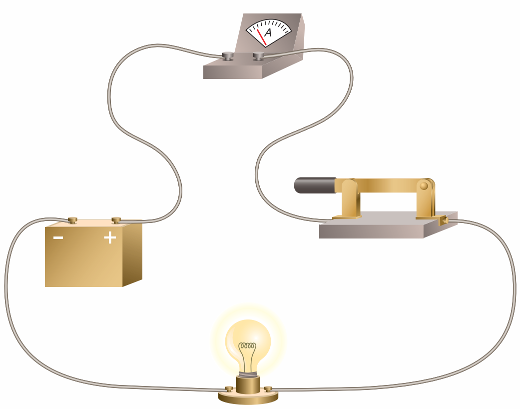
1. What is the purpose of a battery?
2. In a battery, what form of energy is converted into electric potential energy?
3. What is the relationship of electric potential energy, charge, and potential difference (voltage)?
4. What materials are needed to produce an electrochemical cell?
5. List five methods of producing electric energy.
6. What unit is used for measuring voltage?
7. What is the purpose of a voltmeter?
8. What is the purpose of an ammeter?
9. Copy and complete the following table in your notebook.

	Symbol	Unit	Unit Symbol
Voltage	V		
Current		amperes	
Resistance			Ω

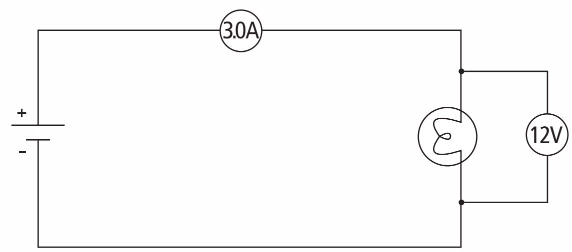
10. Draw the following circuit symbols.
    (a) battery
    (b) bulb
    (c) resistor
    (d) voltmeter
    (e) ammeter
    (f) switch
11. What is the relationship between amperes (A) and milliamperes (mA)?
12. What is the difference between conventional current and electron flow?
13. What are the four basic components of an electric circuit?
14. Explain the relationship between resistance and resistor.
15. State the relationship of voltage (V), current (I), and resistance (R).
16. When an electron passes through a resistor, what happens to its electric energy?
17. What is the purpose of an ohmmeter?
18. Resistors have a maximum of four coloured bands stamped on their surface. What does each band represent?

Understanding Key Ideas

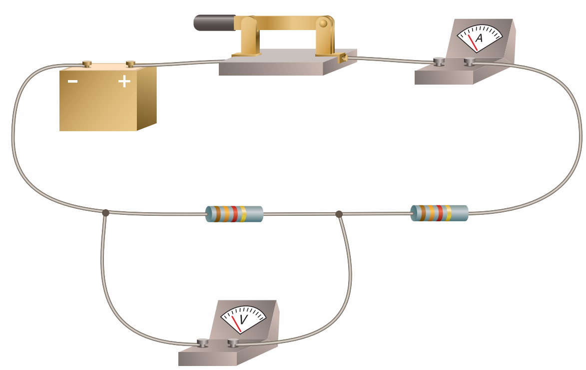
19. In order for skiers to have potential energy, they must travel to the top of the hill. Explain how this is similar to electrons in an electrochemical cell.
20. A voltmeter is connected to the (+) and (−) terminals of a battery and measures 6.0 V. If the lead on the (−) terminal is removed and now touches the (+) terminal, what would now be the reading on the meter? Explain your answer.
21. Explain how two 9.0 V batteries could have different amounts of electric potential energy.
22. Explain the difference between static electricity and current electricity.
23. By looking at an electrical set-up, explain how you would determine if it is a complete circuit.
24. You enter a dark room and press the light switch on the wall. The ceiling light turns on immediately. Explain why you do not have to wait for the electrons at the switch to travel to the ceiling light before the light goes on.
25. Draw a circuit diagram for the circuit below.



26. Convert each of the following:
    (a) 400 mA = ______ A
    (b) 18 kΩ = ______ Ω
    (c) 12 MV = ______ V
27. The current through a 120Ω resistor is 2.0 A. Calculate the voltage across this resistor.
28. The current through a load is 75 mA. If the potential difference across the load is 12 V, what is the resistance of the load?
29. Calculate the resistance of the bulb in the following circuit:



30. A fellow student hands you a resistor and the bands of colour are brown, black, and orange. What is the resistance of this resistor?
31. Draw a circuit diagram for the circuit shown below.



Pause and Reflect

A common flashlight contains a battery, a light bulb, and a switch. Draw a possible circuit diagram for the flashlight. In your circuit diagram, does it matter where the switch is located? Explain your answer.