TOPIC 3

Resisting the Movement of Charge

Resistance is a property of a substance that hinders motion of electric charge and converts electric energy into other forms of energy. For example, the resistance of the tungsten wire filament in a light bulb is more than 400 times greater than the resistance of a similar copper wire. When current flows through the high-resistance filament of the light bulb, the filament converts much of the energy of the current into light and heat. If the same current flows through a copper wire, the amount of energy converted into heat is so small that you hardly notice it.

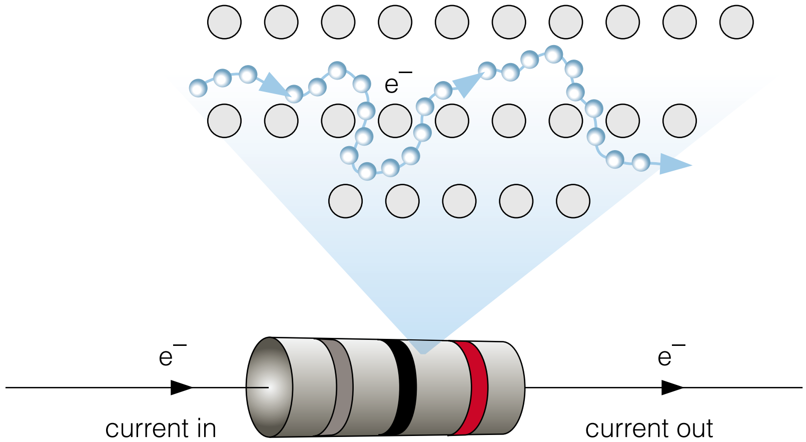


Figure 4.15 Negatively charged electrons must force their way through solids, overcoming resistance caused by the attraction of positively charged atomic nuclei and the repulsion of other electrons.

Did You Know?

Georg Ohm was the first person to publish results of experiments on the resistance of wires of various sizes. Ohm applied a voltage across wires of many different lengths and diameters, and measured the current through them. He discovered that, for each wire, the ratio of voltage to current stayed the same. Today, we would say that the *resistance* of the wires was constant. We would describe the wires as *ohmic resistors*.

Within an electric circuit voltage, current, and resistance are closely related. If current is described as the movement of electrons through conductors, and voltage is what makes the electrons move, then resistance is what opposes the motion of the electrons.

The language of resistance can be tricky. A good conductor, like copper, allows electric charge to move easily through it. That is, a good conductor has *low* resistance. Poor conductors, on the other hand, oppose the movement of charge. In other words, poor conductors have *high* resistance. Just as in a game of golf or hearts, where the best players have the lowest scores, better conductors have lower resistance.

Find Out ACTIVITY

Resistance Roadblock

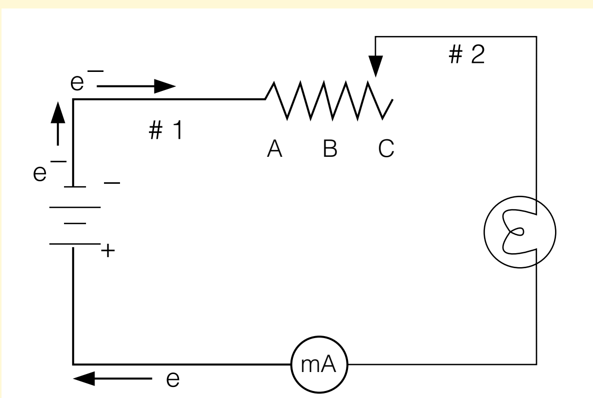
Some electronic components are made of materials that are poor conductors. Why would high resistance be useful in a circuit? How does increasing or decreasing the resistance within a circuit affect the energy of electrons moving in the circuit?

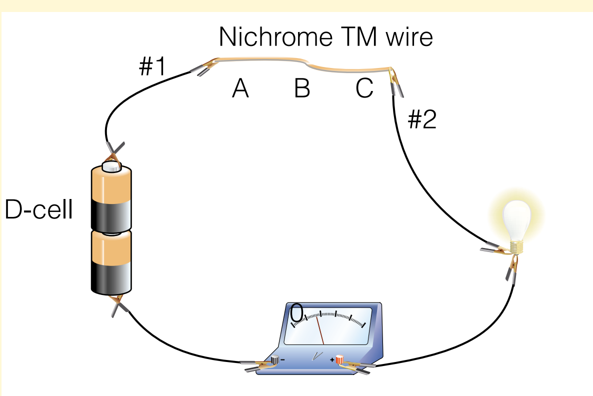
Safety Precautions

Handle the Nichrome™ wire carefully while it is connected to your circuit. It may heat up enough to cause minor burns.

Materials

1 m Nichrome™ wire
2.5 V bulb and holder
2 D-cells in holders
milliammeter
3 copper wires with alligator clips





Procedure — Performing and Recording

1. Copy the table below into your notebook.
2. Complete the prediction portion of the table for different positions of lead #2 (clipped to the Nichrome™ wire).
3. Construct the circuit shown in the diagram.
4. Slide lead #2 to positions A, B, and C and record your observations of the brightness of the bulb and the reading from the ammeter.

Current & Bulb Brightness

Location of lead #2 on Nichrome™	Current (mA)		Bulb brightness	
	Predicted (low, medium, high)	Actual	Predicted (dim, medium, bright)	Actual
A				
B				
C				

What Did You Find Out? — Analyzing and Interpreting

1. How did the amount of current change when you moved the clip and increased the length of Nichrome™ wire in the circuit?
2. In general, suggest how the amount of resistance in the circuit affects the electric current flowing through the circuit.
3. What does the brightness of the bulb tell you about energy of the electrons passing through it?

Extension

1. Into what form was electrical energy converted by the Nichrome™ wire? Give evidence to support your answer.
2. What items in your home offer resistance to the flow of electrons? How do you know?

The standard unit for resistance is the **ohm**, symbolized by the Greek letter omega (Ω). Electronic devices contain resistors with a huge range of values, from a few thousandths of an ohm (milliohms) to many millions of ohms (megohms). Resistance can be measured directly with an **ohmmeter**, but in practice, technicians are more likely to use a multi-purpose electronic measuring instrument (a "multimeter") set to measure resistance.

Calculating Resistance

As you saw in the previous activity, resistance affects the current flowing in a circuit. Resistance also affects the potential differences between different points in complex circuits with several loads. Georg Ohm found that it is possible to calculate the resistance of a circuit, or part of a circuit, from measurements of current and voltage. Can you see how this can be done from the measurements in Table 4.6?

Table 4.6 Resistance, voltage, and current in a simple circuit

Resistance (Ω)	Voltage (V)	Current (A)
1	1	1
1	10	10
2	10	5
5	10	2

Electrical resistance is calculated by finding the ratio of the voltage across the load (V) to the current through the load (I). Using R to represent resistance, the mathematical equation for resistance is

$$R = \frac{V}{I} \qquad \textbf{resistance} = \frac{\textbf{voltage (potential difference)}}{\textbf{current}}$$

According to this relationship, the units of resistance are volts per ampere *(V/A)*, which are equivalent to ohms. The expression above is called **Ohm's law**. Since Ohm's law can be solved for any of its variables, you will also see it expressed in these forms.

$$\text{voltage (potential difference)} = \text{current} \times \text{resistance} \quad V = IR$$

$$\text{current} = \frac{\text{voltage (potential difference)}}{\text{resistance}} \quad I = \frac{V}{R}$$

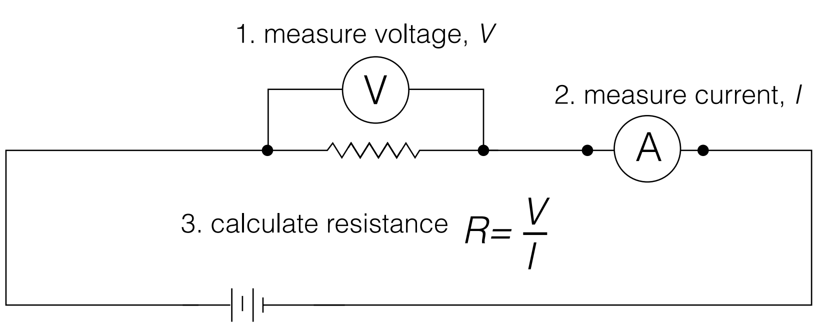


Figure 4.16 Ohm's law allows you to calculate resistance from current and voltage measurements.

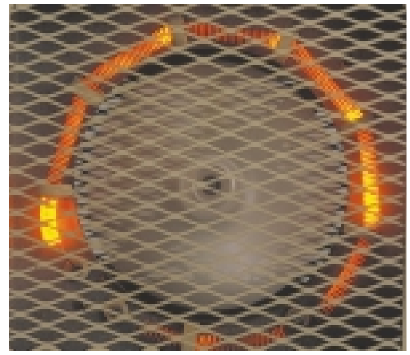
DidYouKnow?

A 100 watt light bulb has resistance of about 144 Ω when connected to a 120 V supply. Typical stereo speakers act as though they have a resistance of 2 Ω to 8 Ω to the current flowing through them. Many headphones and earbuds have resistance of 32 Ω. Dry human skin has resistance of about 500 000 Ω (500 kΩ or 0.5 MΩ).

Pause& Reflect

Add the symbol for resistance *(R)* and the unit ohm (Ω) to your table of symbols and units in your Science Log.

Model Problem



What is the resistance of an electric heater, if a current of 12.5 A runs through it when it is connected to a 120V wall outlet?

Given

I = 12.5 A
V = 120V

Required

Resistance, R, in ohms (Ω)

Analysis

Use the expression $R = \frac{V}{I}$ to find resistance.

Solution

$$R = \frac{V}{I}$$
$$= \frac{120 \text{ V}}{12.5 \text{ A}}$$
$$= 9.60\ \Omega$$

Paraphrase

The resistance of an electric heater is 9.60 Ω, if the current through it is 12.5 A, with a 120 V supply.

Practice Problems

Use an appropriate form of Ohm's law to solve each problem. Show your work for all questions.

1. What is the resistance of a light bulb if a 12 V battery sends a current of 2.4 A through it?
2. A toaster with a resistance of 145 Ω is connected to a 120 V source. What current will flow through the toaster?
3. What is the potential difference across a 1 500 Ω resistor carrying a current of 0.075 A (75 mA)?
4. **Apply** An extension cord rated at 15 A is connected to a 120 V supply. What is the *smallest* resistance with which the cord can safely be used?

Resistors

In electronic circuits, resistance is useful for more than changing the energy of moving charges into heat. One very common type of electronic component — the resistor — is used to control current or voltage to suit the specific needs of other electric devices in the circuit. Circuit resistors are usually made of a heat-conducting ceramic core coated with materials such as carbon, metal oxides, metal film, or resistance wire. Modern "chip" resistors are made of similar materials, but they are very small. Instead of being soldered into holes in a circuit board, as in Figure 4.17, they are mounted directly on the surface of the board.

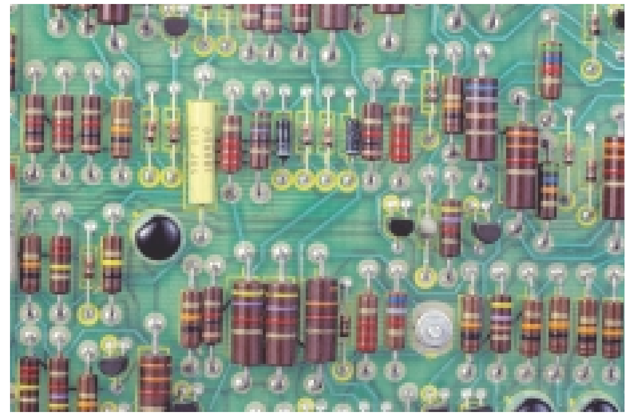
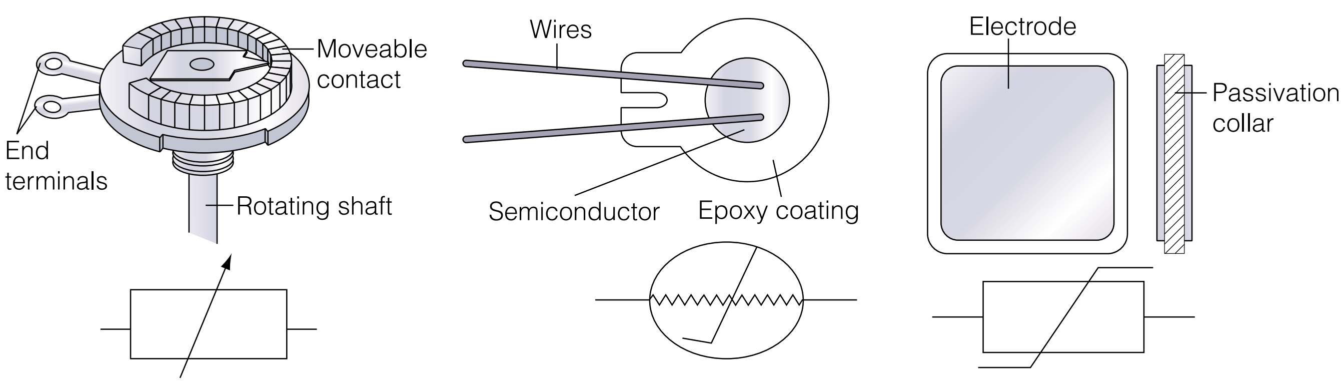


Figure 4.17 The coloured stripes on these resistors show their resistance and quality in coded form.

Variable Resistors

Variable resistors do not have a fixed resistance. Instead, their resistance changes in response to temperature, light, voltage, or some other variable. The Nichrome™ wire that you have used in several activities acted as a variable resistor. When you changed the length of wire, you also varied the resistance in the circuit. Variable resistors are used in a wide variety of electronic devices, from simple light dimmers and motor speed controls to surge protectors and refrigerator and stove temperature controls.

Figure 4.18 Common types of variable resistors



(a) Rheostats have a slide-shaped armature that controls the total resistance. They are usually found in high-current electric circuits, such as power-distribution equipment.

(b) A thermistor is sensitive to changes in temperature. Thermistors are used in thermostats and heat sinks.

(c) Varistors are voltage-dependent resistors used in a circuit to protect it from high-voltage surges.

INQUIRY

INVESTIGATION 4-B

SKILLCHECK

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Voltage, Current, and Resistance

Inside electronic devices such as CD players and radios you can find many small resistors. In this investigation you will examine the relationship between the electric current flowing through a resistor, the voltage across its ends, and the known resistance of the resistor.

Question

What is the relationship between resistance, the voltage across the ends of a radio resistor, and the electric current flowing through it?

Hypothesis

Use Ohm's law to suggest a general answer to the question.

Safety Precautions

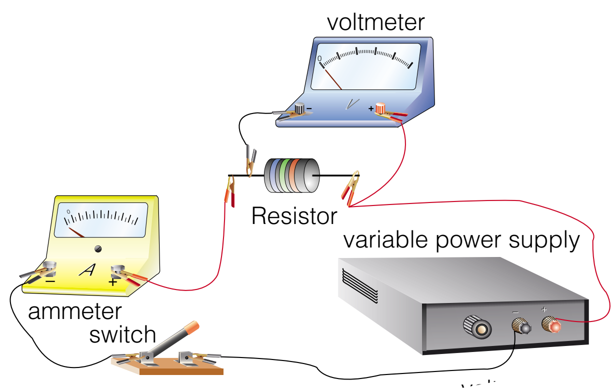
- Avoid touching resistors while current passes through them and immediately afterwards. They can get hot enough to burn you.
- Do not use the power supply to generate currents greater than 0.5A or voltages greater than 15V.

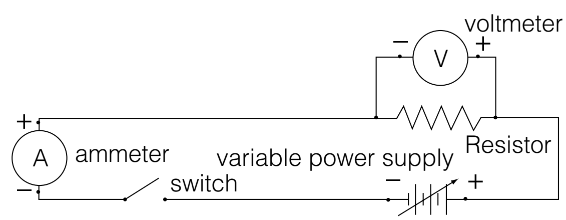
Apparatus

ammeter or milliammeter
voltmeter
variable low-voltage power supply or several batteries
6 copper wires with alligator clips
2 resistors (of different known resistance between 10 and 60 ohms)
switch

Procedure

1. Copy the table below into your notebook.
2. Construct a circuit similar to the one shown in the diagram.
3. Close the switch. Adjust the power supply until the voltmeter shows a convenient potential difference such as 1.0 V across the resistor. **Record** the exact voltage and the corresponding current reading on the ammeter.
4. Repeat step 3 an additional four times for voltages between 1.0 and 6.0 V.
5. Repeat steps 3 and 4 for a second resistor, using the same potential differences as previously.





Analyze

1. What happened to the amount of electric current as you increased the voltage?

2. For similar voltages, compare the amount of current passing through each of the resistors.

Conclude and Apply

3. Using Ohm's Law ($R = V/I$) calculate the resistance for each trial. Remember that if the potential difference (V) is in volts, current (I) must be expressed in amperes. If your current measurements are in milliamperes (mA), you can convert them to amperes by dividing by 1000.

4. For each resistor, how well do the five calculated values for resistance agree? Why are the calculated values not usually identical?

5. How well do the calculated resistance values compare to the value marked on each resistor? Suggest an explanation for any difference in the values.

6. How well do your results support Ohm's law? Give evidence to support your answer.

Extend Your Knowledge and Skill

7. Design an experiment to determine if a light bulb behaves according to Ohm's law. Obtain a light bulb from your teacher. Make the necessary measurement using a wide variety of voltages and currents.

INTERNET CONNECT

www.mcgrawhill.ca/links/sciencefocus9

Investigate a variety of resistor-related web sites where you can find out the latest in resistor design and innovations, as well as on-line guides to the resistor colour code. Use the code to find the rated resistance for some of the resistors you used in this Investigation. Visit the above web site. Go to the web site above, and click on Web Links to find out where to go next.

Electric Current, Voltage, and Resistance

Resistor # (Known resistance) (Ω)	Voltage (V) (V)	Measured Electric current (I) (mA)	Calculated Electric current (I) (A)	Calculated resistance (R) (Ω)
1 (known Ω)				
2 (known Ω)				

Types of Circuits

All the circuits you have constructed so far in this Unit have had a single source of current connected to a single load and, sometimes, a single control switch. In practice, electrical circuits are seldom that simple. Think of your home, for example. Lamps, televisions, stoves, refrigerators, computers, and many other devices operate from the same source of electric energy, yet each appliance seems to operate independently of the others. The circuits are constructed to allow each device to be turned on, while the others remain off. How is this done? You can find out by studying the two basic patterns for connecting several loads into a single circuit.

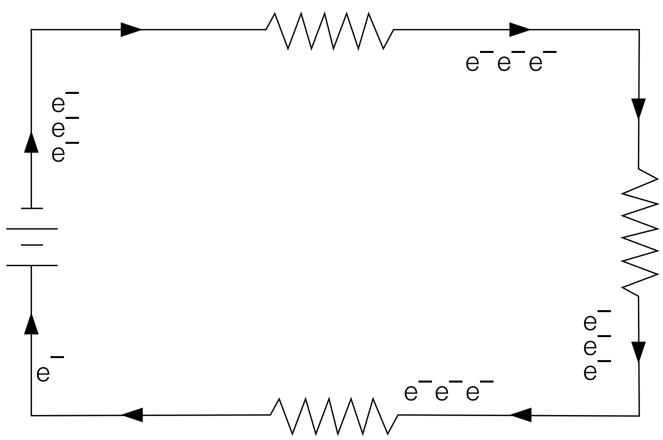


Figure 4.19 A series circuit has a single current path. These three loads are connected in series.

Series circuits have only one current path. All the moving charges travel through each component in the circuit. You can think of a series circuit as a set of parts connected end to end.

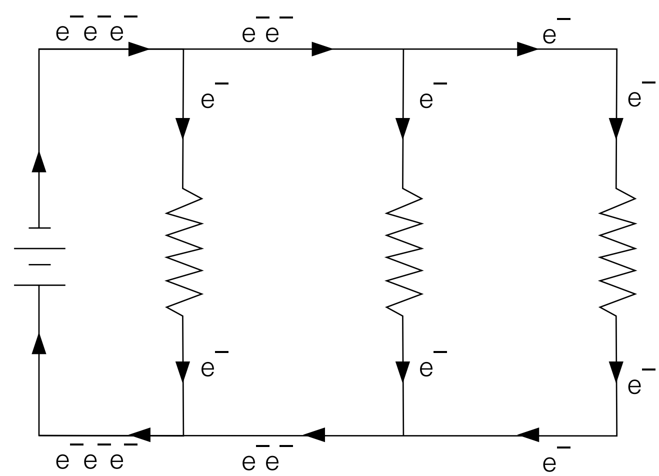


Figure 4.20 A parallel circuit has several current paths. These three loads are connected in parallel.

Parallel circuits have several current paths. The total current is divided, with some of the moving charges travelling through each **branch**, or part of the circuit. You can think of of a parallel circuit as a set of branches connected side by side.

Each type of circuit—series and parallel—has specific characteristics that make it useful in certain situations. As well, circuits can be made with some parts connected in series, and others in parallel. Current sources, as well as loads, can be connected in series and in parallel. You may investigate these complex situations in future courses.

INQUIRY

INVESTIGATION 4-C

SKILLCHECK

Initiating and Planning

Performing and Recording

Analyzing and Interpreting

Communication and Teamwork

Series and Parallel Circuits

Depending on the requirements of a circuit, it may be wired in series or in parallel. You will explore the advantages and disadvantages of each type of circuit in this investigation.

Question

How does adding extra bulbs affect the other bulbs in a series or parallel circuit?

Hypothesis

Write a hypothesis that answers the questions for each type of circuit. In your data tables, predict what will happen to the other bulbs as bulbs are added to either circuit. How will the addition of bulbs affect the amount of current flowing through the circuit?

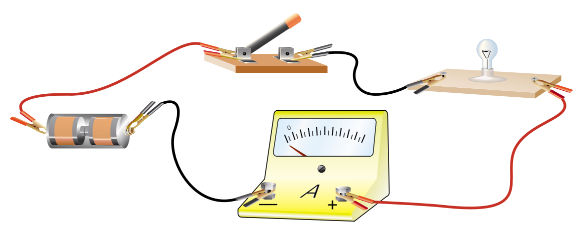
Safety Precaution

Apparatus

2 1.5 V D-cells and cell holders
3 3.7 V bulbs with holders
7 wires with alligator clips
1 ammeter
1 switch

Part A: Current and Brightness in a Series Circuit

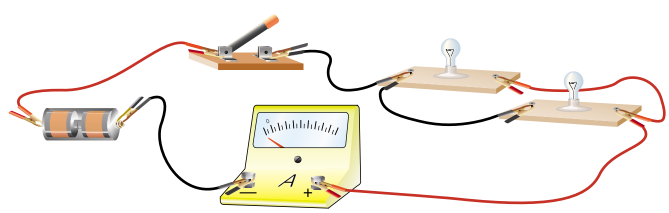
Series circuit layout	Predicted brightness	Observed brightness	Current (A)
1 bulb			
2 bulbs			
3 bulbs			
3 bulbs, 1 unscrewed			



Part A

Part B: Current and Brightness in a Parallel Circuit

Series circuit layout	Predicted brightness	Observed brightness	Current (A)
2 bulbs			
3 bulbs			
3 bulbs, 1 unscrewed			



Part B

CONTINUED ▶

Part A: Series

Procedure

1. Copy the table on the previous page into your notebook.
2. Set up your first series circuit (with one bulb) as shown in the diagram.
3. Close the switch and **record** your observations about the brightness of the bulb and the electric current flowing through the circuit.
4. Repeat steps 2 and 3 with two bulbs and then with three.
5. While all three bulbs are lit, unscrew one of the bulbs and **record** your observations in your table.

Analyze

1. How does the brightness of the bulbs change as more bulbs are added to the series circuit? How did the electric current as measured by the ammeter change?

Conclude and Apply

2. Using your results, explain why the brightness of the bulbs changes. Hint: use your knowledge of Ohm's Law and resistance to answer the question.

3. What happened to the series circuit when one of the bulbs was unscrewed? Using your knowledge of electric circuits, explain why this happened.

Extension

4. Predict what would happen if you continued to add more bulbs to the series circuit. Explain your answer.

5. Think of an example of a real-life circuit that behaves in the same way as the circuit you have just constructed.

6. Based on your observations, describe two advantages and two disadvantages to using this type of circuit.

Part B: Parallel

Procedure

1. Copy the table on the previous page into your notebook.
2. Set up your first parallel circuit (with two bulbs) as shown in the diagram.
3. Close the switch and **record** your observations about the brightness of the bulbs and the electric current flowing through the circuit.
4. Repeat steps 2 and 3 with three bulbs.
5. While all three bulbs are lit, unscrew one of the bulbs and **record** your observations in your table.

Analyze

1. How does the brightness of the bulbs change as more bulbs are added to the parallel circuit? How did the electric current as measured by the ammeter change?

Conclude and Apply

2. Using your results from the activity, explain any changes or lack of changes in the brightness of the bulbs.

3. What happened when one of the bulbs was unscrewed? Using your knowledge of electric circuits, explain why this happened.

Extension

4. Predict what would happen if you continued to add more bulbs to the parallel circuit. Explain your answer.

5. Think of and describe an example of a real-life circuit that behaves in the same way as the circuit you have just constructed.

6. Based on your observations describe two advantages and two disadvantages to using this type of circuit.

House Wiring

Practical electric circuits for the home are parallel circuits. The voltage across each load in a parallel circuit is the same. Turning on one appliance will not reduce the energy available to other loads. Plugging in an electric kettle, for example, will not cause lights on the same circuit to dim.

One potential problem does exist with parallel circuits. Current through wires connected to the source increases whenever another branch in the circuit is closed. When you turn on any appliance in your home, the current in the wires closest to the source increases. More current means the temperature of the conducting wires rises. If you turn on too many appliances at the same time and the current increases too much, the wires could become hot enough to start a fire. To guard against an electrical fire, household circuits always include fuses or circuit breakers (see Topic 7).

Pause& Reflect

Make a chart in your Science Log that summarizes the characteristics of series and parallel circuits. Make two columns, one with the heading "Series Circuits" and the other with the heading "Parallel Circuits." Under each heading, write a summary of the important facts about each type of circuit. Leave room for additional information.

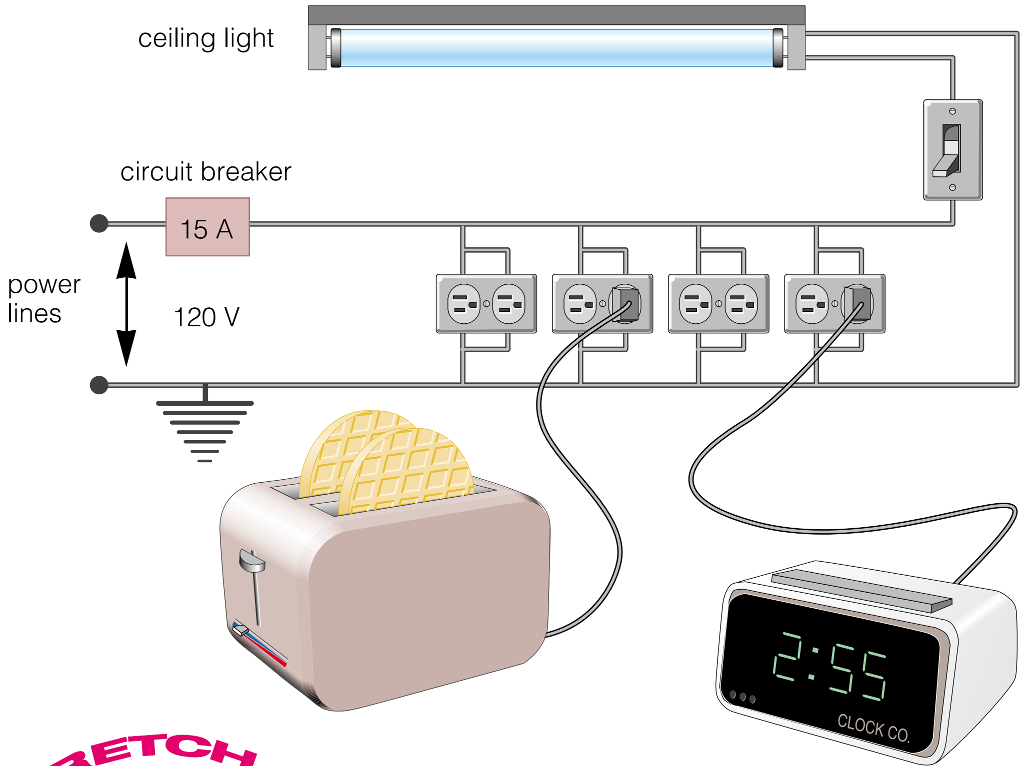


Figure 4.21 Household wiring connects appliances and lights in parallel along each branch circuit.

STRETCH Your Mind

In the series-wired circuits you have constructed in class, if one bulb burns out none of the others will light. In the early days of decorative lighting people had to remove and test each bulb in order to find the one that had burned out, a frustrating task indeed. Modern strings of lights are wired so that if one bulb burns out, the others keep operating. There are two common ways in which this problem has been solved. Can you describe both possible solutions?

PROBLEM-SOLVING

INVESTIGATION 4-D

Is Resistance Futile?

Can you design a simple electric circuit which allows you to dim a light or to turn off one light while leaving others operating? In this investigation you will use your knowledge of circuits and resistors to control electric current in specific, useful ways.

Challenge

Design and construct five separate circuits, each having *one* of the following characteristics.

(a) one bulb can be turned off while the other stays lit
(b) both bulbs can be turned off at the same time
(c) maximum current flows
(d) minimum current flows
(e) one light can be dimmed without affecting the brightness of the other light

Each circuit must use two light bulbs and any other necessary apparatus from the list below.

Apparatus

2 3.7 V bulbs
milliammeter
2 D-cells and holders
1 knife or button switch
2 bulb receptacles
1 m of Nichrome™ wire
1 m of copper wire
1 paper toilet paper roll
1 lead pencil
3 resistors (of various resistance)
6–8 wires with alligator clips

Safety Precautions

Design Specifications

A. Only the materials supplied by the teacher can be used to construct your circuit. You are not required to use *all* materials.

B. Each circuit must meet one of the design challenges.

C. Circuit components may not be added or removed during the operation of your circuit.

Plan and Construct

1. With your group, brainstorm possible designs for each of the five required circuits. Choose one design for each circuit to construct and test.
2. Use correct symbols to draw your five proposed circuit designs. Indicate which challenge each circuit is designed to meet.
3. After receiving teacher approval, construct and test each circuit in turn. Adjust your design until each circuit meets its challenge and also satisfies the general design specifications.

Evaluate

1. Demonstrate the operation of each circuit as directed by your teacher. Describe which types of circuits you constructed (series, parallel,or a combination) and explain why your designs enabled (or did not enable) your circuit to meet its challange.

2. Prepare a revised diagram of any circuit which was changed from its original design. Explain the specific problem which the changes overcame.

3. Label each circuit diagram to show whether the lights were connected in series or in parallel.

4. What energy transformation occurred when current passed through each component listed?

(a) the Nichrome™ wire
(b) the light bulbs
(c) the resistors

5. Describe at least three practical applications for a circuit that has variable resistance.

6. When the bulb in your circuit is being dimmed, where does the "lost" energy go? Could this cause any problems for the designers of variable resistors? Explain your answer.

Even good conductors like copper wires oppose the flow of electric charge. Table 4.7 shows how the actual resistance of a wire depends upon physical properties such as its cross sectional area ("thickness"), which is commonly described by an American Wire Gauge (AWG) number. Thicker wires (larger cross-sectional area) have *lower* resistance for a given length. For example, heavy-duty appliance wiring (#12 AWG) has a relatively large diameter, giving it lower resistance and the ability to carry higher currents without overheating than thinner light-duty extension cords (#16 AWG).

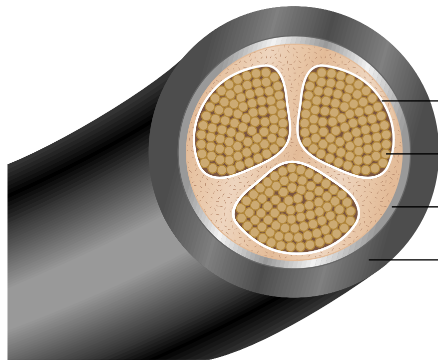


Figure 4.22 Power cables are made of many thin copper strands, which act together like one large-diameter conductor. This reduces resistance and heating and makes the cable more flexible.

Table 4.7 Factors Affecting Resistance of Wire

Factor	Effect
Length	Resistance *increases* with length. If the length doubles, the resistance doubles.
Cross-sectional Area	Resistance *decreases* with area. If the cross-sectional area doubles, the resistance is half as great.
Temperature	As the temperature of the wire increases, the resistance *increases*.
Material	Due to the structure of their atoms, some metals allow electrons to move more freely than others.

TOPIC 3 Review

1. In your own words, explain the meaning of electrical resistance.
2. What combination of units is equivalent to the ohm?
3. State Ohm's Law, and give the standard units for each quantity in it.
4. Explain the differences between a series circuit and a parallel circuit.
5. List three characteristics of a wire that affect its electrical resistance.
6. Which type of circuit, series or parallel, will produce the highest current through three bulbs? Give a reason for your answer.
7. **Apply** What is the voltage across an electric water heater element that has a resistance of 32Ω when the current through it is 6.8 A?
8. **Thinking Critically** Matt says that if the resistance to a load becomes larger, the current through it becomes larger as well. Angela says that if the resistance of a load becomes larger, the current will decrease. Do you agree with Matt or Angela? Explain your answer.

Wrap-up TOPICS 1–3

If you need to check an item, Topic numbers are provided in brackets below.

Key Terms

electric circuit	Laws of Charges	grounding	amperes	Ohm's Law
charged	insulators	battery	galvonometer	series circuit
neutral	conductors	switch	ammeter	parallel circuit
electric current	semiconductors	resistor	potential difference	
static electricity	superconductors	loads	resistance	
unbalanced charges	electrostatic discharge	voltage	ohm	

Reviewing Key Terms

Copy and complete the statements below in your notebook.

1. The behaviour between charged and uncharged particles is explained by the ________________. (1)

2. The term that most accurately describes the electric condition that occurs when two different materials are rubbed together is ________________. (1)

3. A ________________ is a material with higher conductivity than insulators but lower conductivity than metals. (1)

4. Components within an electric circuit that convert electricity to other forms of energy are called ________________. (2)

5. Electric pressure or difference in electric potential is called ________________. (3)

6. The property of substance that hinders the motion of electric charges and converts electric energy into other forms of energy is ________________. (3)

7. A circuit with only one path along which a current can flow is a ________________. (3)

8. The relationship between voltage and electric current can be explained by ________________. (3)

Understanding Key Concepts

9. Explain how electric charges are produced. (1)

10. Can electric charges travel only through wires? Explain your answer and give at least two supporting examples. (1)

11. Describe the kinds of observations that led to the formation of the Laws of Charges. (1)

12. Describe how a buildup of electric charges can be neutralized. Provide at least two examples. (1)

13. What conditions must exist in order for an electric current to flow? (2)

14. Sketch how to connect (a) a voltmeter, and (b) an ammeter into a circuit. (2)

15. Write Ohm's law in the form used to find (a) resistance, (b) current, and (c) potential difference. (3)

16. Sketch circuit diagrams which show three load resistors connected (a) in series, and (b) in parallel. List important facts about current and potential differences in each circuit below the diagram. (3)

17. Describe at least three ways in which the resistance within an electric circuit could be reduced. (3)