Key Terms
Ohm's law
ohm (Ω)
superconductor
non-ohmic

11.4 Measuring Electrical Resistance

The most common component inside most of the devices you use—including a computer, a television, and a radio—is a simple resistor. The filament of an incandescent bulb is also a type of resistor. We use the filament of a bulb for the light it produces, although more energy is transformed into heat than into light. Some energy is transformed into heat by the resistors inside a computer, and this is why a computer is warm when it is being used. The resistors in **Figure 11.24** control current and potential difference in circuits. People who design and check circuits need to know how a resistor affects the potential difference and current in a circuit.

Ohm's Law

Ohm's law the ratio of potential difference to current is a constant called *resistance*

Georg Ohm, a German physicist, measured the current and potential difference in circuits that contained metal wires. When he changed the potential difference across a wire, he measured a different current through it. Ohm discovered that for most wires, the ratio of potential difference (V) to current (I) is a constant. The constant is called the resistance (R).

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

Known as **Ohm's law**, this relationship is often written as $V = IR$.

One consequence of Ohm's law is that the larger the resistance in a particular circuit is, the smaller the current is. Thus, a resistor *resists*, or reduces, the current in a circuit. A resistor is an electrical component with a specific resistance.

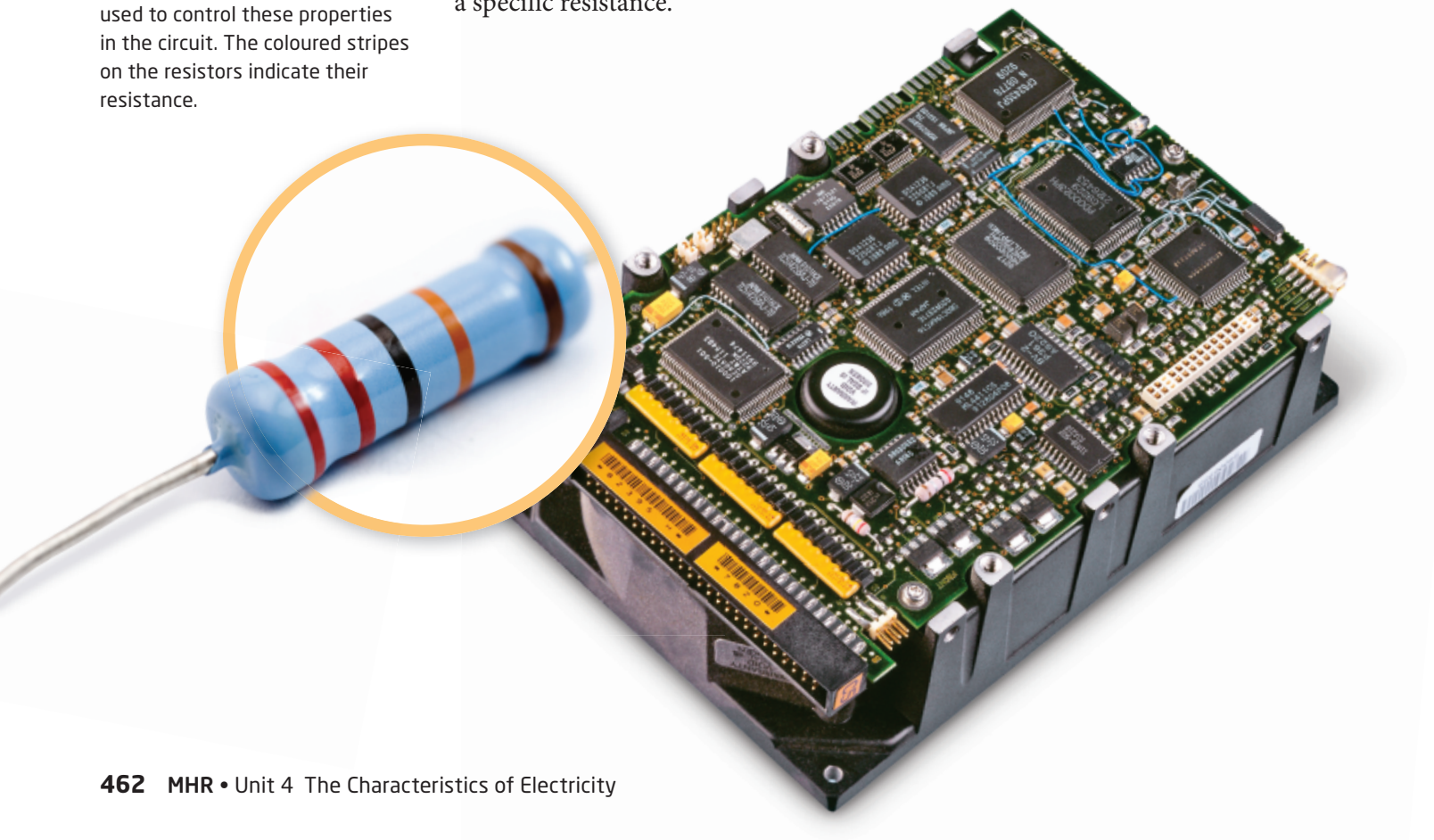

Figure 11.24 Some of the components in this circuit operate at a specific current and potential difference. The many resistors are used to control these properties in the circuit. The coloured stripes on the resistors indicate their resistance.

Methods of Changing Potential Difference

When Ohm did his experiments, he added cells in series to change the potential difference between the ends of a wire. You could use the same method as Ohm, or substitute different batteries in the circuit, or connect a variable power supply. Your teacher will give you instructions.

The Units of Resistance

Substituting units into the Ohm's law equation gives the units for resistance:

$$V = IR$$

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

$$\text{units:} \quad \frac{\text{volt}}{\text{ampere}} = \frac{\text{V}}{\text{A}} = \Omega$$

ohm (Ω) the unit for resistance, equivalent to one volt per ampere (V/A)

Thus, the unit for resistance is volt per ampere (V/A). This combination of units is called the **ohm**, in honour of Ohm's discovery. The symbol for the ohm is the Greek letter omega, Ω. If a potential difference of 1 V across the ends of a load results in a current of 1 A through the load, then the load has a resistance of 1 Ω.

Suggested Investigation

Inquiry Investigation 11-D, Testing Ohm's Law, on page 478

Solving Problems using Ohm's Law

The colour bands on a resistor are a code for the value of the resistance. A technician can determine whether a resistor has failed by using a multimeter or Ohm's law to find its resistance and compare it to the resistance indicated by the colour code.

Sample Problem: Determining Resistance

Problem

A technician is checking the circuits on a vehicle. The technician measures the current entering a component as 0.47 A. The potential difference across the component is 12 V. What is its resistance?

Solution

Current, $I = 0.47$ A

Potential difference, $V = 12$ V

$V = IR$

$$R = \frac{V}{I} = \frac{12\text{ V}}{0.47\text{ A}} = 25.53\text{ V/A} = 26\ \Omega$$

The resistance of the component is 26 Ω.

Check Your Solution

The numerical value of the answer is reasonable. The current is roughly half an ampere. Estimating, 12 V ÷ 0.5 A is 24 Ω, in the range of the answer given. The answer has two significant digits, the same as in each given measurement. The units, V/A, are equivalent to the unit given in the answer, ohm (Ω).

GRASP

Go to **Science Skills Toolkit 9** to learn about an alternative problem solving method.

GRASP
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Sample Problem: How Many Cells?

Problem

An electric toy has a resistance of 120 Ω and requires a current of 0.050 A to work properly. How many 1.5 V cells does the toy require?

Solution

The toy is an electric load. First, find the potential difference across the toy. Then determine how many cells it requires.

Finding potential difference:

$$R = 120\ \Omega$$
$$= 120\ \text{V/A}$$
$$I = 0.050\ \text{A}$$
$$V = IR$$
$$= 0.050\ \text{A} \times 120\ \text{V/A}$$
$$= 6.0\ \text{V}$$

Finding number of cells:

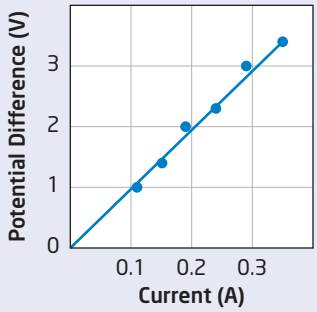
$$\text{Number of cells} = \frac{6.0\ \text{V}}{1.5\ \text{V/cell}}$$
$$= 4\ \text{cells}$$

The toy requires four 1.5 V cells.

Check Your Solution

The number of cells is reasonable for an electric toy.

Potential Difference vs. Current for a Resistor



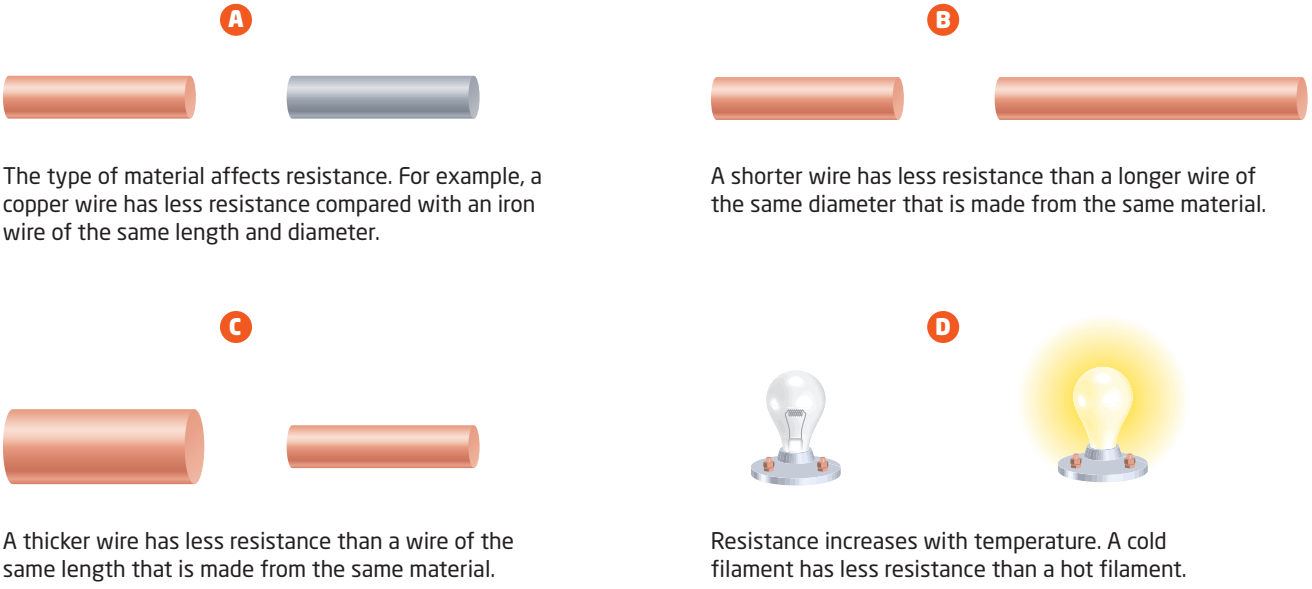
Practice Problems

1. In the graph on the left, the potential difference between the ends of a resistor in a circuit is plotted against the current through the resistor. What is the value of the resistance?
2. A television that is plugged into a wall socket has a potential difference of 120 V across its terminals. If the television uses a current of 1.45 A, what is its resistance?
3. A toaster uses a current of 10.4 A when it is plugged into a 110 V outlet. What is the resistance of the heating coils?
4. How will the current passing through a resistor change when the potential difference across the resistor is doubled?
5. The filament of a flashlight bulb has a resistance of 40 Ω. If a 6.0 V battery is used in the circuit, what is the current?
6. A circuit board has a resistance of 12 Ω and requires a current of 0.25 A. What potential difference is required to operate the circuit board?

Factors That Affect the Resistance of Wires

Ohm found that the resistance of different wires of the same length are different, as shown in **Figure 11.25A**. The resistance of wires made from the same metal, with the same diameter, increases in direct proportion to their length. If the only variable is the length of the wire, doubling its length will double its resistance, as shown in **Figure 11.25B**. For wires made from the same metal, with the same length, Ohm found that the resistance decreases as the diameter of the wire increases, as shown in **Figure 11.25C**.

Temperature also affects resistance. Resistance is caused when a current of free electrons collides with the ions and other electrons in a substance. If the temperature increases, these atoms and ions move much more rapidly about their fixed positions. The number of collisions between the free electrons in a current and the atoms and ions in the substance is greater at a higher temperature. Thus, the resistance is greater. This is shown in **Figure 11.25D**.



The type of material affects resistance. For example, a copper wire has less resistance compared with an iron wire of the same length and diameter.

A shorter wire has less resistance than a longer wire of the same diameter that is made from the same material.

A thicker wire has less resistance than a wire of the same length that is made from the same material.

Resistance increases with temperature. A cold filament has less resistance than a hot filament.

Figure 11.25 Several factors affect the resistance of wires.

Learning Check

1. What is the unit of electrical resistance?
2. State three characteristics of a copper wire that affect its electrical resistance. See **Figure 11.25**.
3. How will the intensity of a flashlight bulb change if you add a resistor in series with the bulb? Explain your answer.
4. The resistance of the incandescent light bulb in a lamp is about 100 times greater than the resistance of the cord on the lamp. Which properties of the bulb account for this difference?

superconductor a material through which electric charge can flow with no resistance

non-ohmic not following Ohm's law

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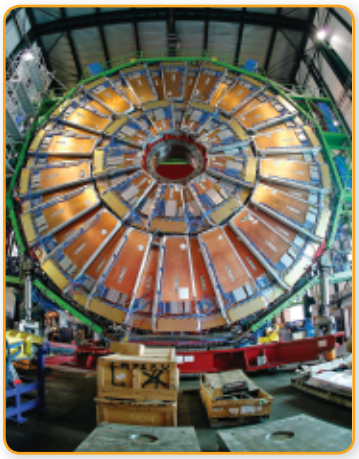

Figure 11.26 The enormous magnet in the Large Hadron Collider at the European Centre for Nuclear Research (CERN) is the largest superconducting magnet ever built. It uses a current of 21 000 A, but it has a potential difference of only about 9 V.

Superconductors

The resistance of a wire increases as its temperature increases. How does its resistance change if the temperature becomes very low? Heike Kamerlingh Onnes, a Dutch physicist, was the first person to liquefy helium. By chance, he discovered that mercury loses all of its electrical resistance at the temperature of liquid helium. Many other metals have the same property. When electric charge can flow through a material with no resistance, the material is called a **superconductor**. A superconducting wire does not transform electrical energy into heat. If wires that were superconducting at room temperature could be made, they would vastly increase the efficiency of supplying electrical energy.

A magnet can be made with a coil of wire that is carrying an electric current. Very powerful magnets are made using superconducting wires, which are cooled to a few degrees above absolute zero by liquid helium. These magnets are used to accelerate particles. When beams of particles smash together at almost the speed of light, scientists can investigate the fundamental nature of matter and the forces within atoms. The collider shown in **Figure 11.26** was built beneath the border between Switzerland and France. It uses nearly 7000 superconducting magnets and 96 tonnes of liquid helium.

Non-ohmic Conductors

Electrical resistance is the ratio of the potential difference between the ends of a load to the current through the load. If this ratio changes as the potential difference varies, the load does not have constant resistance. Thus, it does not obey Ohm's law, so it is called a **non-ohmic** conductor.

The filament of an incandescent bulb is non-ohmic because its resistance increases with temperature. The greater the resistance of the filament is, the more electrical energy is converted into light energy and the brighter the bulb glows. The graph of the potential difference between the connections to an incandescent bulb and the current through the bulb is not a straight line. **Figure 11.27** compares a graph for an ohmic load with a graph for a non-ohmic load, such as an incandescent light bulb.

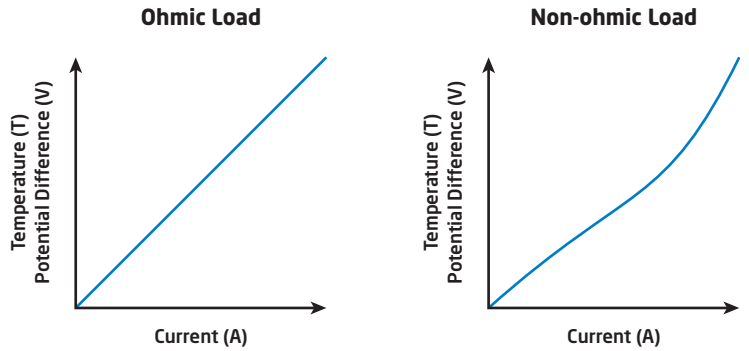

Figure 11.27 A resistor that obeys Ohm's law has constant resistance, as shown in the graph on the left. The current through the filament of a light bulb does not increase as much as would be expected according to Ohm's law, because its resistance increases as temperature increases, as shown in the graph on the right.

Section 11.4 Review

Section Summary

- Ohm's law states that, for most conductors, the ratio of potential difference (V) to current (I) is a constant called the resistance (R).
- A resistor is an electrical component with a specific resistance.
- The unit of electrical resistance is the ohm (Ω). One ohm is equivalent to one volt per ampere (V/A).
- Four factors affect the resistance of a wire:
  1. the type of material
  2. the length (A longer wire has greater resistance.)
  3. the diameter (A wire with a larger diameter has lower resistance.)
  4. the temperature (A hotter wire has greater resistance.)
- A superconductor is a material through which electric charge can flow with no resistance.
- A non-ohmic conductor does not obey Ohm's law.

Review Questions

A **1.** The current in an automobile headlight, which is connected to a 12 V battery, is 0.80 A. What is the resistance of the headlight?

K/U **2.** The resistance of a particular circuit board is 5.0 Ω. What potential difference must be supplied to the circuit board if it requires a current of 0.030 A to operate?

K/U **3.** An electric motor has a resistance of 7.41 Ω. What current is there through the motor when it is connected to a 100 V source?

A **4.** If you happen to be looking at the filament of an incandescent light bulb just before it burns out, you might notice that the filament glows brighter just before it burns out. Explain these observations.

C **5.** You have been asked to write part of the user's manual for an electric lawn mower. Explain why the user of an electric lawn mower must not connect several extension cords together when using a lawn mower, and why the extension cord must have wires that are relatively thick.

T/I **6.** When connected in the same circuit, two incandescent light bulbs glow with different intensities. Compare the filaments in the two light bulbs.

A **7.** Why is it very important that the wires used in incandescent light bulbs have a specific constant diameter?

T/I **8.** Refer to **Figure 11.27**. Does a superconducting wire obey Ohm's law? Explain your answer.