16.3 Resistance and Ohm's Law

You can apply the same voltage to different circuits and different amounts of current will flow. For example, when you plug in a desk lamp, the current through it is 1 amp. If a hair dryer is plugged into the same outlet (with the same voltage) the current is 10 amps. For a given voltage, the amount of current that flows depends on the *resistance* of the circuit.

VOCABULARY

resistance - determines how much current flows for a given voltage. Higher resistance means less current.

Electrical resistance

Current and resistance **Resistance** is the measure of how strongly a wire or other object resists current flowing through it. A device with low resistance, such as a copper wire, can easily carry a large current. An object with a high resistance, such as a rubber band, can only carry a current so tiny it can hardly be measured.

A water analogy The relationship between electric current and resistance can be compared with water flowing from the open end of a bottle (Figure 16.10). If the opening is large, the resistance is low and lots of water flows out quickly. If the opening is small, the resistance is greater and the water flow is slow.

Circuits The total amount of resistance in a circuit determines the amount of current in the circuit for a given voltage. Every device that uses electrical energy adds resistance to a circuit. The more resistance the circuit has, the less the current. For example, if you string several light bulbs together in a circuit, the resistance in the circuit increases and the current decreases, making each bulb dimmer than a single bulb in the same circuit would be.

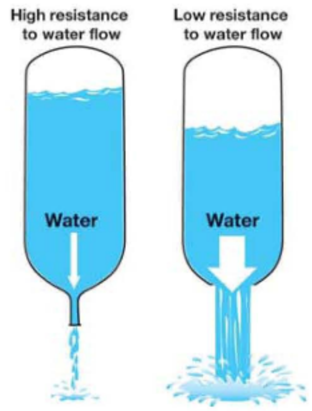
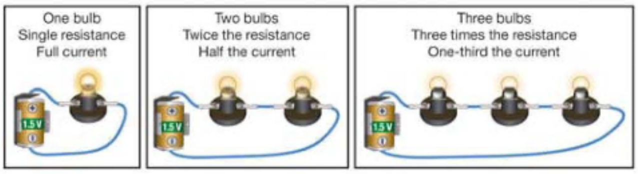


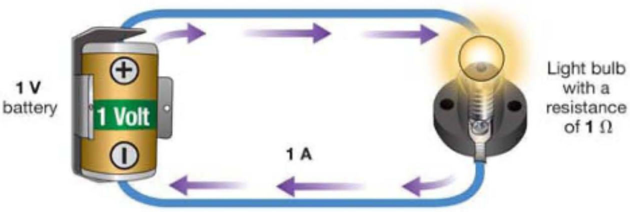
Figure 16.10: *The current is less when the resistance is greater.*



Measuring resistance

The ohm Electrical resistance is measured in units called **ohms**. This unit is abbreviated with the Greek letter *omega* (Ω). When you see Ω in a sentence, think or read "ohms." For a given voltage, the greater the resistance, the less the current. If a circuit has a resistance of 1 ohm, then a voltage of 1 volt causes a current of 1 amp to flow.

1 volt creates a current of 1 amp through a resistance of 1 ohm



Resistance of wires The wires used to connect circuits are made of metals that have low resistance such as copper or aluminum. The resistance of wires is usually so low compared with other devices in a circuit that you can ignore wire resistances when measuring or calculating the total resistance. The exception is when there are large currents. If the current is large, the resistance of wires might be important.

Measuring resistance You can use a multimeter to measure the resistance of wires, light bulbs, and other devices (Figure 16.11). You must first remove the device from the circuit. Then set the dial on the multimeter to the resistance setting and touch the probes to each end of the device. The meter will display the resistance in ohms (Ω), kilo-ohms (× 1,000 Ω), or mega-ohms (× 1,000,000 Ω).

VOCABULARY

ohm - the unit of measurement for resistance.

Figure 16.11: *A multimeter can be used to measure resistance of a device.*

TECHNOLOGY

How Resistance Is Measured

A multimeter contains a battery with a fixed voltage. When the fixed voltage is applied to the device, the meter measures the resulting current and calculates the resistance. For example, if you want to measure the resistance of a light bulb, you would remove it from the circuit so the meter can apply a precise amount of voltage to the bulb and give an accurate resistance value. If you left the bulb in the circuit, other circuit current might interfere with the operation of the meter.

Ohm's law

Ohm's law The current in a circuit depends on the battery's voltage and the circuit's resistance. Voltage and current are *directly* related. Doubling the voltage doubles the current. Resistance and current are *inversely* related. Doubling the resistance cuts the current in half. These two relationships form **Ohm's law**. The law relates current, voltage, and resistance with one formula. If you know two of the three quantities, you can use Ohm's law to find the third. You might think it seems strange to use *I* as the variable symbol for current, rather than *C*. This is a convention that started many years ago and is still used today.

OHM'S LAW

$$\text{Current (A)} \quad I = \frac{V}{R} \quad \begin{matrix}\text{Voltage (V)} \\ \text{Resistance } (\Omega)\end{matrix}$$

Applying Ohm's law Ohm's law shows how resistance is used to control the current. If the resistance is low, then a given voltage will result in a large amount of current. Devices that need a large amount of current typically have lower resistance, to allow the device to get the large amount of current it needs. For example, a small electric motor might have a resistance of only 1 ohm. When connected in a circuit with a 1.5-volt battery, the motor draws 1.5 amps of current. By comparison, a small light bulb with a resistance of 2.5 ohms in the same type of circuit would draw only 0.6 amps.

Equation	Gives you...	If you know...
$I = V/R$	current (I)	voltage and resistance
$V = IR$	voltage (V)	current and resistance
$R = V/I$	resistance (R)	voltage and current

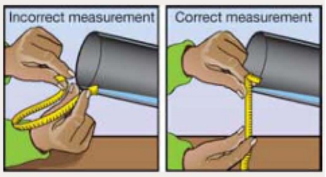
VOCABULARY

Ohm's law - states that the current is *directly* related to the voltage and *inversely* related to the resistance.

SCIENCE FACT

Why does a meter show no voltage when the leads are placed on the same point in a closed circuit?

Placing multimeter leads on only one side of a component in a circuit is like trying to measure the height difference of a tipped water pipe by placing both ends of the measuring tape at the same point—it simply doesn't work! The pipe's height *difference* is what allows the water to move. Likewise, the charge separation, or voltage, in a circuit, is what allows charge to flow. To measure how much voltage there is at different places in a circuit, you must place the multimeter leads *across* a component. Similarly, if you want to measure the height difference of the water pipe, you must place the measuring tape across the distance, not just at the raised end.



Solving Problems: Using Ohm's Law

A toaster oven has a resistance of 12 Ω and is plugged into a 120-V outlet. How much current does it draw?

1. Looking for: You are asked for the current in amperes.

2. Given: You are given the resistance in ohms and voltage in volts.

3. Relationships: Ohm's law: $I = \frac{V}{R}$

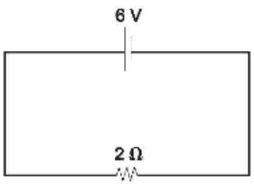
4. Solution: Plug in the values for V and R: $I = \frac{120\ \text{V}}{12\ \Omega} = 10\ \text{A}$

Your turn...

a. A laptop computer runs on a 24-V battery. If the resistance of the circuit inside is 16 Ω, how much current does it use?

b. A motor in a toy car needs 2 A of current to work properly. If the car runs on four 1.5-V batteries (in series), what is the motor's resistance?

c. What is the current in the circuit below?



KEYWORDS

Superconductivity

A *superconductor* allows current to flow without losing any energy as heat or light. Do some research. What kinds of technology have been developed on the principles of superconductivity? What future technologies are being explored?

The levitated dipole experiment (LDX) at the Massachusetts Institute of Technology (MIT) uses a superconducting coil to explore fusion technology.

SOLVE FIRST LOOK LATER

a. 1.5 A

b. 3 Ω

c. 3 A

The resistance of common objects

Resistance matches operating voltage The resistance of electrical devices ranges from small (0.001 ohms) to large (10×10^6 ohms). Every electrical device is designed with a resistance that causes the right amount of current to flow when the device is connected to the proper voltage. For example, a 100-watt light bulb has a resistance of 144 ohms. When connected to 120 volts from a wall socket, the current is 0.83 amps and the bulb lights (Figure 16.12). If you connect the same light bulb to a 1.5-volt battery it will not light. According to Ohm's law, the current is only 0.01 amps when 1.5 volts is applied to a resistance of 144 ohms. This amount of current will not light the bulb. All electrical devices draw the right amount of power only when connected to the voltage they were designed for.

The resistance of skin Electrical outlets are dangerous because you can get a fatal shock by touching the wires inside. So, why can you safely handle a 9-volt battery? The reason is Ohm's law. The typical resistance of dry skin is 100,000 ohms or more. According to Ohm's law, 9 V ÷ 100,000 Ω is only 0.00009 A. This is not enough current to be harmful. On average, nerves in the skin can feel a current of around 0.0005 amps. You can get a dangerous shock from 120 volts from a wall socket because that is enough voltage to force 0.0012 amps (120 V ÷ 100,000 Ω) through your skin, and you certainly can feel that!

Water lowers skin's resistance Wet skin has much lower resistance than dry skin. Because of the lower resistance, the same voltage will cause more current to pass through your body when your skin is wet. The combination of water and 120-volt electricity is especially dangerous because the high voltage and lower resistance make it possible for large (possibly fatal) currents to flow.

Changing resistance The resistance of many electrical devices varies with temperature. For example, the amount of resistance a light bulb contributes to a circuit increases as its temperature increases (due to the current running through it). Devices that have a variable resistance like this are referred to as *non-ohmic*, because you can't use Ohm's law to predict the current when there is an ever-changing resistance (Figure 16.13). The small light bulbs in your circuit kit are non-ohmic, so you will use *fixed* resistors to apply Ohm's law to your simple circuits.

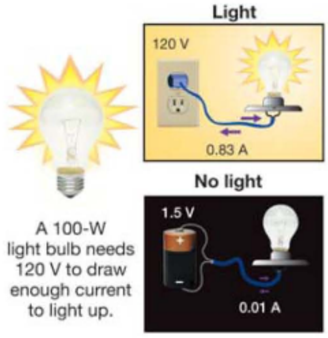


Figure 16.12: *A light bulb designed for use in a 120-volt household circuit does not light when connected to a 1.5-volt battery.*

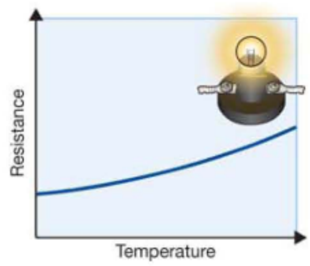


Figure 16.13: *The resistance of many materials, including those in light bulbs, increases as their temperature increases. A light bulb is said to be* non-ohmic *for this reason.*

Conductors and insulators

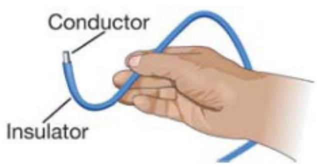
Conductors Current passes easily through some materials, such as copper, which are called conductors. A **conductor** can *conduct*, or carry, electric current. The electrical resistance of wires made from conductors is low. Most metals are good conductors.

Insulators Other materials, such as rubber, glass, and wood, do not allow current to easily pass through them. These materials are called **insulators** because they insulate against, or block, the flow of current.

Semiconductors Some materials are in between conductors and insulators. These materials are called **semiconductors** because their ability to carry current is higher than an insulator but lower than a conductor. Computer chips, televisions, and portable radios are among the many devices that use semiconductors. You might have heard of a region in California called Silicon Valley. Silicon is a semiconductor commonly used in computer chips. This area south of San Francisco is called Silicon Valley because many semiconductor and computer companies are located there.

Comparing materials No material is a perfect conductor or insulator. Some amount of current will always flow through any material if a voltage is applied, and even copper (a good conductor) has some resistance. Figure 16.14 shows how the resistances of various conductors, semiconductors, and insulators compare.

Applications of conductors and insulators Both conductors and insulators are necessary materials in technology. For example, a wire has one or more conductors on the inside and an insulator on the outside. An electrical cable might have twenty or more conductors, each separated from the others by a thin layer of insulator. The insulating layer prevents the other wires or other objects from being exposed to the current and voltage carried by the conducting core of the wire.



VOCABULARY

conductor - a material with low electrical resistance. Metals such as copper and aluminum are conductors.

insulator - a material with high electrical resistance. Plastic and rubber are good insulators.

semiconductor - a material between conductor and insulator in its ability to carry current.

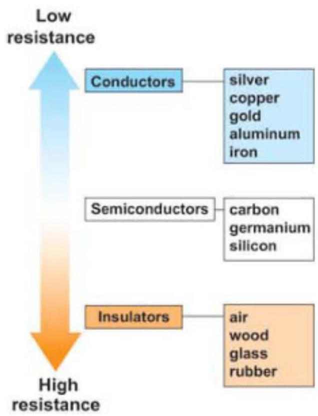
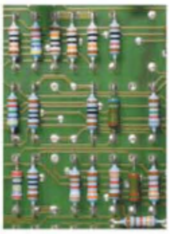


Figure 16.14: *Comparing the resistance of materials.*

Resistors

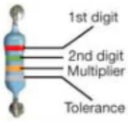
Resistors are used to control current As you have learned, resistors are used to control the current in circuits. They are found in many common electronic devices such as computers, televisions, telephones, and stereos.

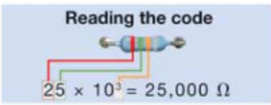
Fixed resistors There are two main types of resistors: fixed and variable. Fixed resistors have a resistance that cannot be changed. If you have ever looked at a circuit board inside a computer or other electrical device, you have seen fixed resistors. They are small, skinny cylinders or rectangles with colored stripes on them. Because resistors are so tiny, it is impossible to label each one with the value of its resistance in numbers. Instead, the colored stripes are a code that tells you the resistance (see below).



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

Color	Tolerance
silver	+/- 10%
gold	+/- 5%
brown	+/- 1%





Variable resistors Variable resistors, also called **potentiometers**, can be adjusted to have a resistance within a certain range. If you have ever turned a dimmer switch or volume control, you have used a potentiometer. When the resistance of a dimmer switch increases, the current decreases, and the bulb gets dimmer. Inside a potentiometer is a circular resistor and a little sliding contact called a wiper (Figure 16.15). If the circuit is connected at A and C, the resistance is always 100 ohms. But if the circuit is connected at A and B, the resistance can vary from 0 ohms to 100 ohms. Turning the dial changes the resistance between A and B and also changes either the current or the voltage in the circuit.

VOCABULARY

potentiometer - a type of variable resistor that can be adjusted to give resistance within a certain range.

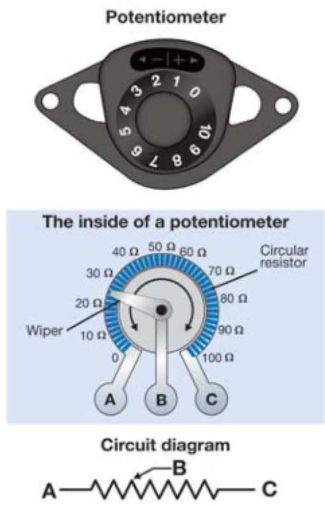


Figure 16.15: *The resistance of this potentiometer can vary from 0 ohms to 100 ohms.*

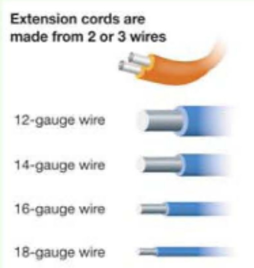
Section 16.3 Review

1. List the units and their abbreviations for resistance, voltage, and current.
2. What happens to the current if a circuit's resistance increases?
3. What happens to the current if a circuit's voltage increases?
4. A circuit contains one light bulb and a battery. What happens to the total resistance in the circuit if you replace the one light bulb with a string of four identical bulbs? Why?
5. Why can you safely handle a 1.5-V battery without being electrocuted?
6. A flashlight bulb has a resistance of about 6 Ω. It works in a flashlight with two AA alkaline batteries. About how much current does the bulb draw?
7. What voltage produces a 6-A current in a circuit that has a total resistance of 3 Ω?
8. What is a circuit's resistance if 12 V produces 2 A of current?
9. If you plug a device that has a resistance of 15 Ω into a 120-V outlet, how much current does the device draw?
10. What is the difference between a conductor and an insulator? Give an example of each.
11. Do some research to find out why semiconductors are so important to computer technology. Don't forget to include website and/or book citations.
12. What is a fixed resistor, and where could you find fixed resistors in your home?
13. What is a variable resistor, and where could you find variable resistors in your home?
14. Look on the back or underside of different appliances and devices in your home. Find two that list the current and voltage each uses. Calculate the resistance of each.

TECHNOLOGY

Extension Cord Safety

The label on an extension cord will tell you how many amps of current it can safely carry. The length and wire thickness are both important. Always check to see if the extension cord can carry at least as much current as the device you plug in will require. Many fires have been caused by using the wrong extension cord!



Wire Gauge	Current (amps)
12-gauge	20
14-gauge	15
16-gauge	10
18-gauge	7