

If you ride your bike down a smooth road and then through some mud, you would immediately notice that it is difficult to maintain the same speed. You would experience a resistance to your movement. In a similar way, all matter has some resistance to the flow of electric current. **Electrical resistance ( $R$ )** is a measure of how difficult it is for electric current to travel through a material. Some materials have a high resistance—they do not allow electrical currents through easily. Insulators such as plastics and rubber have high resistance. Other materials have a low resistance—they allow electrical currents through more easily. Metals have low resistance and are good conductors of electric current.

**Resistors** are electrical devices that have a specific resistance. In an electric circuit, you can use a high resistance or a low resistance, depending on the desired effect. For example, for a speaker wire you would use a resistor with a low resistance because you want a large current to reach the speaker to produce loud sounds. If you want a low current in a circuit so that the fine wires are not damaged, it makes more sense to use a resistor with a high resistance. When more power is required, resistors are typically wire wound (a wire is wound several times to reach the desired resistance value). Since these resistors handle a lot of power, they will heat up, so the wire is encased in a ceramic material. Resistors can also be variable. Their resistance can be changed by typically using a dial. These types of resistors are called rheostats. The symbol for a resistor is .

**electrical resistance ( $R$ )** a property of matter that describes how difficult it is for electric current to travel through a material

**resistor** an electrical device that has a specific resistance value

## Mini Investigation

### Determining Unknown Resistance

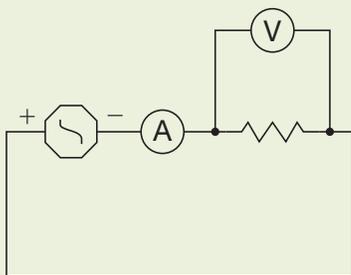
**Skills:** Performing, Observing, Analyzing

SKILLS HANDBOOK  A2.1, A2.2, A6.5

In this investigation, your teacher will provide you with a resistor of unknown value and you will determine its resistance.

**Equipment and Materials:** variable DC power supply; ceramic resistors of different values for each group; 5–6 alligator clip leads; voltmeter; ammeter

1. Be sure that the power supply is off, and then connect the circuit as shown in **Figure 1**. Have your teacher check the circuit.



**Figure 1** Circuit diagram

2. Turn the power supply to its lowest setting, and then turn it on.
3. Turn the power supply voltage up slowly until there is a reading on the ammeter. Record the voltage in volts and the current in amperes.

4. Increase the voltage slightly until you notice a change in the current. Record the voltage and current again. Repeat until you have five measurements of voltage and five measurements of current. Once you have completed your measurements, turn off the power supply and let the resistor cool. 

 Always make sure that the power supply is off before connecting your circuit. Always have your teacher check the circuit before turning on the power supply, and turn it up slowly. Do not touch the resistor, it may become very hot.

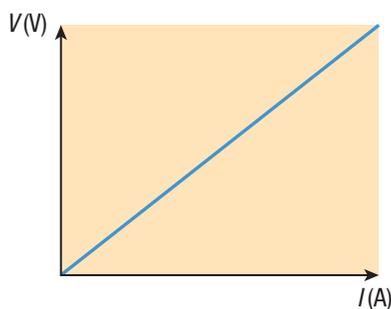
- A. Plot a graph with voltage on the  $y$ -axis and current on the  $x$ -axis. Include a line of best fit and calculate the slope.  
- B. Take your calculated slope to your teacher and compare values from your graph to the resistance of the resistor. What is the percentage difference? 
- C. Look at another student's graph for a different resistor. What do you notice? 

## Ohm's Law

When you perform a scientific investigation on the properties of a material, you are trying to learn something new about the material. You do a controlled investigation to observe a cause-and-effect relationship between two variables while keeping all other conditions constant.

In the Mini Investigation on the previous page, the two variables that you investigated were the voltage applied to the resistor and the electric current going through the resistor. As the amount of voltage increased, the amount of electric current also increased. If you repeated the investigation with a completely different resistor (with all other conditions being the same), you would observe different values for voltage and current, but the resulting relationship is the same—when the voltage increases, the current increases. Georg Simon Ohm did similar investigations, and his results revealed the property of electrical resistance. The unit of resistance is called the ohm ( $\Omega$ ) in honour of Ohm's contributions to our understanding of electrical resistance. **Ohm's law** is stated as follows:

**Ohm's law** the potential difference between any two points in a conductor varies directly with the current between two points if the temperature remains constant



**Figure 2** Graph of applied voltage against current. Note that the graph has a constant slope.

### Ohm's Law

The voltage in a conductor is proportional to the current if the temperature remains constant. So  $V \propto I$ .

A graph of voltage against current is a straight line (**Figure 2**). The slope of the graph is constant, and this constant is the electrical resistance,  $R$ :

$$V \propto I$$

Therefore,

$$V = \text{constant} \times I$$

$$\text{constant} = \frac{V}{I}$$

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

where  $R$  = resistance measured in volts per ampere, or ohms ( $\Omega$ ),  $V$  = electric potential difference or voltage measured in volts (V), and  $I$  = electric current measured in amperes (A). In the following Tutorial, you will use Ohm's law to calculate an unknown resistance.

### LEARNING TIP

#### Remembering Ohm's Law

The equation for Ohm's law can be rewritten as  $V = IR$ , which is easier to remember if you use a mnemonic:  $VIR$  = Very Important Resistance.

### Tutorial 1 Using Ohm's Law

Ohm's law can be used to determine an unknown resistance in a circuit. In the following Sample Problem, we will use the voltage and current to solve for the resistance of a load.

#### Sample Problem 1

Calculate the resistance of a load with a voltage of 25 V and a current of 410 mA.

**Given:**  $V = 25 \text{ V}$ ;  $I = 410 \text{ mA}$

**Required:**  $R$

**Analysis:**  $R = \frac{V}{I}$

**Solution:** Convert the current to amperes to get the answer in ohms:

$$I = 410 \text{ mA} \times \frac{1 \text{ A}}{1000 \text{ mA}}$$

$$I = 0.41 \text{ A}$$

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

$$= \frac{25 \text{ V}}{0.41 \text{ A}}$$

$$R = 61 \Omega$$

**Statement:** The resistance is 61  $\Omega$ .

### Practice

1. What is the resistance of a toaster element with a voltage of 120 V and a current of 6.5 A?  $\frac{V}{I}$  [ans: 18  $\Omega$ ]
2. What is the resistance of a car starter with 450 A of current and a voltage of 12 V?  $\frac{V}{I}$  [ans: 0.027  $\Omega$ ]

## Consequences of Resistance

All of the electrical components in a circuit have electrical resistance. The connecting wires and control devices, such as switches, typically have small resistances. If you touch an insulated alligator clip lead while performing an investigation, you will notice that the lead has become warmer. This is because of its resistance; some of the electrical energy is being converted into thermal energy. Some loads depend on this conversion to function, such as incandescent light bulbs. The bulb converts electrical energy into thermal energy and light energy, because of the electrical resistance of its tiny wire filament. Even batteries can get warm if operated continuously, because they have an internal resistance.

When electrical energy from a power plant travels through conducting wires to reach your home, some electrical energy is transformed into thermal energy because of the resistance of the wires. This thermal energy is wasted; it is not being used by any electrical device. This decreases the efficiency of the transfer of energy. The wires need to be manufactured from a material with low resistance.

Superconductors are special materials that have no electrical resistance. There is a lot of interest in these because of the potential to eliminate the thermal energy wasted in wires. Initially, superconductivity was only observed in liquid helium at  $-269 \text{ }^\circ\text{C}$ . It would not be practical to make a conductor out of helium, and it is extremely difficult to reach such a low temperature. Research has steadily moved the temperature upward. Currently, superconductivity has been demonstrated in a special material nicknamed Hg-1223 (actually  $\text{HgBa}_2\text{Ca}_2\text{Cu}_3\text{O}_8$ ) at  $-135 \text{ }^\circ\text{C}$ . The goal is to be able to make circuits from superconducting material at room temperature. Imagine a computer that does not need cooling, or power plant transmission wires that are 100 % efficient.

Even though superconductivity requires very low temperatures, it is still being actively used in technologies around the world. One example is the magnetic resonance imaging (MRI) device, which you will learn about in Section 12.7. The MRI uses superconductors to create a very strong magnet. Superconductors are also used in particle accelerators like the Large Hadron Collider.

## Measuring Resistance

An **ohmmeter** is a device used to measure electrical resistance. Ohmmeters are connected in parallel and must never be used on a circuit if the circuit is live. Always turn the power off before using an ohmmeter. The symbol for an ohmmeter is  $\Omega$ .

An ohmmeter is useful for testing whether a load works. Typically, loads have low resistance. When you test a load with an ohmmeter, the resistance should read low. If the resistance reads off the scale, the load likely has a bad connection and will not work (**Figure 3**).



**Figure 3** The load in this circuit is not functioning. The display on the ohmmeter shows that the reading is off the scale of the device. Note that the circuit must be switched off before measurements are made with an ohmmeter.

**ohmmeter** a device that measures electrical resistance

## 11.7 Summary

- Electrical resistance is a property of all matter that describes how difficult it is for an electric current to travel through the matter.
- Resistors are devices with specific electrical resistance.
- Ohm's law states that the voltage in a conductor is proportional to the current if the temperature remains constant.
- Ohm's law can be stated as an equation:  $R = \frac{V}{I}$ .
- All electrical components have an electrical resistance.
- Resistance in a wire will cause some of the electrical energy flowing through the wire to be converted into thermal energy. This thermal energy is often wasted.
- Superconductors are special materials with no electrical resistance.
- An ohmmeter is a device used to measure electrical resistance and should be connected in parallel to a circuit that is switched off.
- The symbol for an ohmmeter is  $\text{---}\Omega\text{---}$ .

## 11.7 Questions

- Rearrange the equation for resistance to solve for (a) current and (b) voltage. **K/U**
- A portable electric fan is operating on a 9.0 V battery. The current going into the motor is 160 mA. Determine the resistance of the portable fan. **T/I**
- Dry human skin has a resistance of approximately 100 000  $\Omega$ . If a person were accidentally to touch the terminals of a 9.0 V battery, what would be the current going through the skin? **T/I**
- Wet human skin has a resistance of approximately 1000  $\Omega$ . If a person were accidentally to touch a live circuit with 120 V of electric potential difference, what would be the current going through the skin? **T/I**
- A home theatre system has a speaker with a resistance of 8.0  $\Omega$ . It is connected to an amplifier that has a voltage of 5.2 V. Determine the current going to the speaker. **T/I**
- A laptop computer charger has a current of 2.07 A. The resistance of the charger is 8.05  $\Omega$ . Determine the voltage of the charger. **T/I**
- Describe electrical resistance in your own words. **K/U C**
- Graph the data in **Table 1** and determine the resistance. **K/U T/I**

Table 1

Voltage (V)	Current (mA)
12	151
15	188
18	226
21	261

- Which line on the graph in **Figure 4** represents the higher value of resistance? Explain. **K/U C**

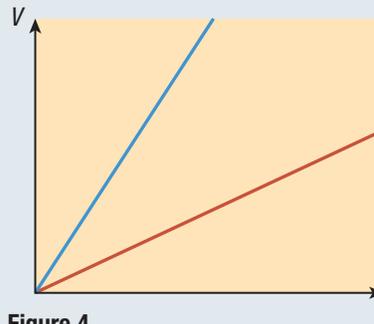


Figure 4

- A student connects an ohmmeter in series to an operating circuit. What two things has the student done incorrectly? **K/U**
- Describe and explain a situation where electrical resistance is desirable and a situation where it is undesirable. **C A**
- Find the missing values in **Table 2** below. Take care with units. **T/I**

Table 2

Current	Voltage (V)	Resistance ( $\Omega$ )
25 mA	12	
1.2 A		510
375 $\mu$ A	0.25	
(answer in A)	120	33
(answer in mA)	1.5	1500