Answer to Essential Question 18.1: The statement that a battery is a source of constant potential difference (until it runs out, at least) is closer to the truth. As we will see in Section 18-2, the current provided by a battery depends on what the battery is connected to.

18-2 Resistance and Ohm's Law

For many objects we find that the current through them is proportional to the potential difference across them. Such objects are said to be ohmic, because they obey Ohm's Law.

The current *I* through an ohmic device is proportional to the potential difference ΔV across it:

$$\Delta V = IR \qquad \text{(Equation 18.2: \textbf{Ohm's Law})}$$

R here is known as the electrical resistance. The smaller the resistance of an object the more current flows the object for a given potential difference. An object in a circuit that contributes a relatively large resistance to a circuit is known as a resistor.

Many resistors are simply wires of length *L* and cross-sectional area *A*. The electrical resistance of such an object is given by:

$$R = \frac{\rho L}{A}. \qquad \text{(Equation 18.3: \textbf{Electrical resistance})}$$

The unit of resistance is the ohm (Ω). $1\ \Omega = 1$ V/A.

ρ in Equation 18.3 is the resistivity, a parameter that depends on the material the resistor is made from. Table 18.1 shows some resistivity values for different materials.

Material	Resistivity	Material	Resistivity	Material	Resistivity
Copper	$1.7\times10^{-8}\ \Omega$ m	Nichrome	$1.0\times10^{-6}\ \Omega$ m	Hard rubber	$1\times10^{13}\ \Omega$ m
Tungsten	$5.6\times10^{-8}\ \Omega$ m	Silicon	$640\ \Omega$ m	Teflon	$1.0\times10^{16}\ \Omega$ m

Table 18.1: Resistivity values for various materials.

EXAMPLE 18.2 – Factors contributing to resistance
Three cylindrical resistors are made from the same material and have the same volume. The first resistor has a length *L*, a cross-sectional area *A*, and a resistance *R*. The second has a length *L*/2 and cross-sectional area 2*A*. The third has length 2*L* and cross-sectional area *A*/2.
(a) Draw a picture of these three situations.
(b) Rank the three cases in terms of the total resistance.
(c) Determine the resistance, in terms of *R*, of the second and third resistors.

SOLUTION

(a) The three situations are shown in Figure 18.2.

(b) The ranking by resistance goes as 3 > 1 > 2. Resistance increases as length increases and cross-sectional area decreases, so case 3, with the longest length and smallest cross-sectional area, has the largest resistance. Case 2 has the smallest resistance because it has the smallest length and the largest area.
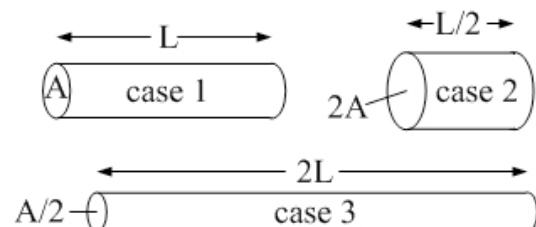

Figure 18.2: The three situations of the resistors described in Example 18.2.

(c) Applying Equation 18.2, we have the resistance in case 1 is $R = \rho L / A$. In case 2, applying Equation 18.2 gives

$$R_2 = \rho(L/2)/2A = \rho L / 4A = R/4.$$

Doing a similar analysis in case 3 gives

$$R_3 = \rho(2L)/(A/2) = 4\rho L / A = 4R.$$

On a circuit diagram, a resistor is usually represented as shown in Figure 18.3(a), although if the resistor is a light bulb the symbol can look like that in Figure 18.3(b), which looks a lot like the actual light bulb.
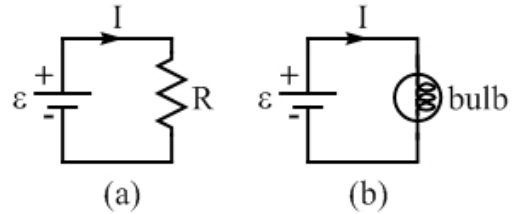

(a)   (b)

Figure 18.3: (a) A circuit diagram showing a battery, at left, connected to a resistor, such as a toaster element, at right. (b) A similar circuit, but this time the resistor is a light bulb.

Temperature dependence of resistance
An object's resistance also generally depends on its temperature. To understand this, consider a simple model of resistance. When there is no potential difference between the ends of a wire the conduction electrons move about at random, much like atoms in an ideal gas. With a potential difference, however, a net drift of electrons toward the higher potential end is superimposed on the random motion, as in Figure 18.4. The drift speed is of the order of millimeters/second, compared to the typical electron speeds of a thousand kilometers per second.
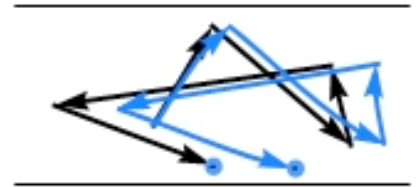

Figure 18.4: With no potential difference a conduction electron follows the random motion illustrated by the darker path. With a potential difference, the electron follows the lighter path, drifting to the right in this case.

A potential difference between the ends of a wire creates an electric field within the wire. Conduction electrons respond to this field, accelerating along the wire. However, as electrons bump into atoms in the wire the collisions transfer energy from the electrons to the atoms. This is where the resistance of the wire comes from – the energy lost by electrons in these collisions.

At higher temperatures atoms vibrate more energetically, making it harder for electrons to move past – thus, resistance generally increases with temperature. In some materials, however, such as semiconductors, increasing the temperature frees more electrons to serve as conduction electrons and is thus associated with a decrease in resistance. We can use a simple model to describe the change in resistivity with temperature:

$$\rho = \rho_i(1 + \alpha\,\Delta T), \qquad \text{(Equation 18.4: \textbf{Temperature dependence of resistivity})}$$

where α is the temperature coefficient of resistivity, which depends on the material.
Equation 18.4 is reminiscent of Equation 13.5, describing an object's change in length when it changes temperature. When a resistor changes temperature both the resistivity and the dimensions change, but the change in size is generally negligible compared to the change in the resistivity.

Related End-of-Chapter Exercises: 16 – 19.

Essential Question 18.2: In what direction is the electric field that gives rise to the drift velocity to the right, shown by the lighter path in Figure 18.4? Which end of the wire is at a higher potential?