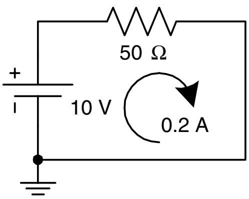

FIGURE 12.1 Simple resistive circuit.

$10 \div 50 = 0.2$ A, or 200 mA. If any of the wires are broken, the current flow instantly drops to zero, because charge cannot return to the battery. Remember that all circuits are a collection of loops. Making and breaking loops using switches (transistors) is fundamentally how digital systems operate.

Voltage is a relative measurement, and its effects can be quantified only between pairs of conductors. This is why a bird can sit on a high-voltage power line without being electrocuted and why a person can walk around on a carpet while insulated from nearby conductors and develop a high voltage static electric charge of several thousand volts. Not until the conductor (e.g., bird or person) comes into contact with another conductor (e.g., another wire or a metal door handle) does the effect of voltage become apparent. To facilitate circuit analysis, a common reference point called a *ground* node is assigned a relative voltage of zero. The ground symbol is shown attached to the battery's negative terminal in Fig. 12.1. All other nodes in the circuit can now be measured relative to ground, resulting in meaningful absolute voltage levels. This is why electrical communication signals between systems require either a common ground or a differential signaling scheme. A receiver cannot properly detect the voltage on a signal wire unless it has a valid reference to compare it against.

An important parameter derived from Ohm's law is power, expressed in *watts* (W). Power (P) is the product of current and voltage. In this simple circuit, 10 V is dropped through the circuit (all by the resistor) at a current of 0.2 A, yielding 2 W of power supplied by the battery and dissipated by the resistor. Power is an instantaneous measurement and is not energy, but the rate of flow of energy. Energy (E) is measured in *Joules* and is the product of how much power is delivered over a span of time: $E = Pt$. The resistor in this circuit converts 2 J of energy each second into heat. Per the first law of thermodynamics, energy cannot be created or destroyed. Therefore, electrical energy that is dissipated by a component is converted into thermal energy. The charge still returns to the battery, but it does so at a relative potential of 0 V. A circuit is typically characterized by its power dissipation (watts) rather than by its energy dissipation (joules) because of the time invariant nature of power.

Power can be restated depending on the unknown variable in the equation. $P = VI$ can be manipulated using Ohm's law in several common forms: $P = I^2R$ and $P = V^2 \div R$. In the first instance, the $V = IR$ definition is substituted to yield a power calculation that only considers the current passing through a resistance. Alternatively, current can be effectively removed ($I = V \div R$), and power can be restated as the square of the voltage developed across a resistance.

12.2 LOOP AND NODE ANALYSIS

The example in Fig. 12.1 is a basic application of *loop analysis*. Loop analysis is based on the rules that the sum of the voltage drops in any continuous circuit is 0 and that the instantaneous current around the loop is constant. Of course, current can change over time, and those changes apply to each component in the circuit. Based on these rules, the following general loop equation can be written for any circuit, where R_N are discrete resistors and VS_N are discrete voltage sources (e.g., a battery):

$$\sum V_N = I_{LOOP}\sum R_N + \sum VS_N = 0$$

This equation shows that a uniform loop current develops a voltage drop across one or more resistances in the circuit and that this total voltage must be offset by voltage sources. A loop equation can be written for Fig. 12.1, but special attention should be paid to the polarity of the voltage source versus the voltage drop through the resistor. The convention used to specify polarity does not change the final answer as long as the convention is applied consistently. Mistakes in loop analysis can arise from inconsistent representation of voltage polarities. In this case, the current is shown to circulate clockwise, so positive currents are clockwise currents. This means that the 50-Ω resistor will exhibit a voltage drop as the current moves through it from left to right. At the same time, the voltage source exhibits a voltage rise as the clockwise loop current passes through it. The voltage of the resistor and the voltage of the source are of opposite polarity as expressed in the following loop equation:

$$I_{LOOP}\sum R_N + \sum VS_N = I_{LOOP} \times 50\ \Omega - 10\ \text{V} = 0$$

$$I_{LOOP} = \frac{10\ \text{V}}{50\ \Omega} = 0.2\ \text{A}$$

Keep in mind that polarity notation is a convention and not a physical rule. As long as polarities are treated consistently, the correct answer will result. Figure 12.2 shows an example of a loop circuit wherein consistent polarity notation is critical to a correct answer. Two voltage sources are present in this circuit, but they are inserted with different polarities.

Circulating around the loop clockwise starting from the ground node, there is a 10-V rise, a voltage drop through the resistor, and a 5-V drop through the voltage source. The loop equation for this circuit is written as follows, yielding $I_{LOOP} = 0.1$ A:

$$I_{LOOP}\sum R_N + \sum VS_N = I_{LOOP} \times 50\ \Omega - 10\ \text{V} + 5\ \text{V} = 0$$

Loop analysis in the context of a single loop circuit may not sound very different from the basics of Ohm's law. It can be truly helpful when multiple loops are present in a circuit. The double-loop circuit in Fig. 12.3 is a somewhat contrived example but one that serves as a quick illustration of the concept. There are three unknowns in this circuit: the two loop currents and the voltage at the intermediate node, V_X. Once the loop currents are known, V_X can be calculated in three different ways. The voltage drop across either R1 or R3 can be calculated. Alternatively, the current through R2 can be determined as the sum of I_{LOOP1} and I_{LOOP2}. Because these currents are both shown using the clockwise convention, they pass each other through R2 with opposite polarities and end up subtracting.

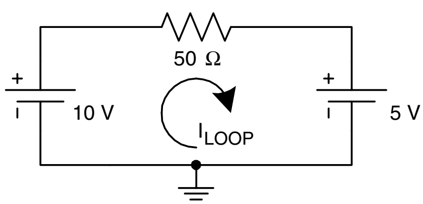

FIGURE 12.2 Circuit with two voltage sources.