Applied Physics For Engineers

Contents:

Ohm's Law

In Chapter 2 we learned that voltage is a measure of the ability of a source of emf to produce current; the greater the voltage, the greater the current that the source can produce in a fixed resistance. In other words, (the current produced in a resistance is *directly proportional* to the voltage of the source.) We also observed that resistance *reduces* the flow of current: The greater the resistance, the smaller the current produced through it by a fixed voltage. In short, current is *inversely proportional* to resistance. The way in which voltage and resistance affect current can be combined in a single mathematical expression called *Ohm's law*, which is one of the most important laws in the theory of electricity:

$$I = \frac{E}{R} \tag{3.1}$$

In the SI system, I is in amperes when E is in volts and R is in ohms. Notice that Ohm's law correctly expresses the relationships we have described: For a fixed R, I increases when E increases, and for a fixed E, I decreases when R increases.

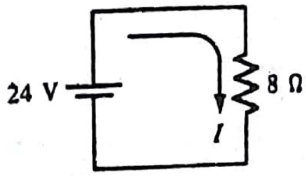

FIGURE 3.1 (Example 3.1)

Example 3.1

With reference to Figure 3.1:

(a) Find the current I in the resistance.
(b) Find the current when the voltage of the source is doubled.
(c) Find the current when the voltage is restored to its original value and the resistance is doubled.

SOLUTION

(a) $I = \frac{E}{R} = \frac{24\text{ V}}{8\ \Omega} = 3\text{A}$

(b) $I = \frac{48\text{ V}}{8\ \Omega} = 6\text{ A}$

Note that doubling the voltage doubled the current.

(c) $I = \frac{24\text{ V}}{16\ \Omega} = 1.5\text{ A}$

Note that doubling the resistance reduced the current by one-half.

Drill Exercise 3.1

Find the current in a 0.04-kΩ resistance when it is connected across a 720-mV voltage source.

ANSWER: 18 mA. □

Figure 3.1, showing a resistance connected to a voltage source, is an example of an electric *circuit*. As we shall study in Chapter 4, a circuit is any configuration of electrical components connected in such a way that current can flow in the components.

In many practical circuits, we know values for two of the quantities I, E, or R, and we are required to find the third. Toward that end, Ohm's law can be expressed in the equivalent forms

$$E = IR \quad \text{and} \quad R = \frac{E}{I} \tag{3.2}$$

Example 3.2

Find the unknown quantity in each circuit shown in Figure 3.2.

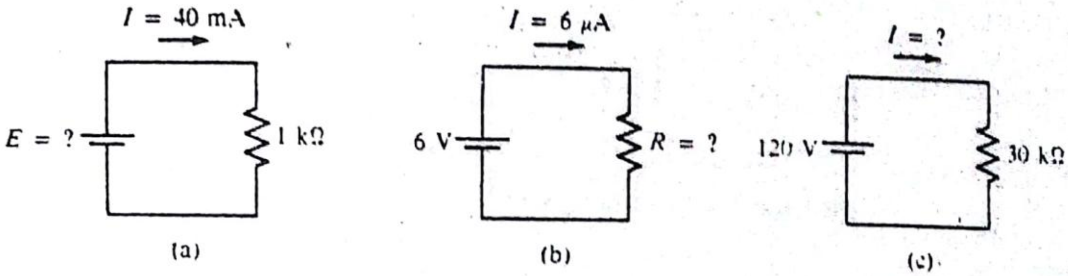

FIGURE 3.2 (Example 3.2)

SOLUTION

(a) $E = IR = (40 \text{ mA})(1 \text{ k}\Omega) = (40 \times 10^{-3} \text{ A})(1 \times 10^{3} \text{ }\Omega) = 40 \text{ V}$

(b) $R = \dfrac{E}{I} = \dfrac{6 \text{ V}}{6 \text{ }\mu\text{A}} = \dfrac{6 \text{ V}}{6 \times 10^{-6} \text{ A}} = 1 \text{ M}\Omega$

(c) $I = \dfrac{E}{R} = \dfrac{120 \text{ V}}{30 \text{ k}\Omega} = \dfrac{120 \text{ V}}{30 \times 10^{3} \text{ }\Omega} = 4 \text{ mA}$

Drill Exercise 3.2

How much voltage is necessary to create a flow of 0.24 C in 0.8 s through a resistance of 500 Ω?

ANSWER: 150 V. □

3.2 Measuring Voltage, Current, and Resistance

As mentioned in Chapter 2, a *voltmeter* is an instrument designed to measure voltage. In our discussion of that instrument, we stated that it can be connected *across* the terminals of a voltage source to measure the voltage produced by the source. Figure 3.3(b) shows a voltmeter, indicated by a circle with a V inside it, that is connected across a voltage source. Figure 3.3(c) and (d) show the voltmeter connections when resistance is also connected across the source. Note that the value of the voltage measured is the *same* (6 V) in every case. The voltmeter is connected across the resistance as well as the voltage source, and we say that the *voltage across the resistance* is 6 V. It is important to realize that voltage measurements are always made *across* components; that is, *it is not necessary to disconnect any components for the purpose of connecting a voltmeter* and making a voltage measurement. The + and − symbols on the voltmeter symbol show the *polarity* of the connections (red terminal to + and black terminal to −) and the polarity of the measured voltage. We say that the voltage on the + side is 6 V *with respect to* the − side (an interpretation that will be discussed in more detail

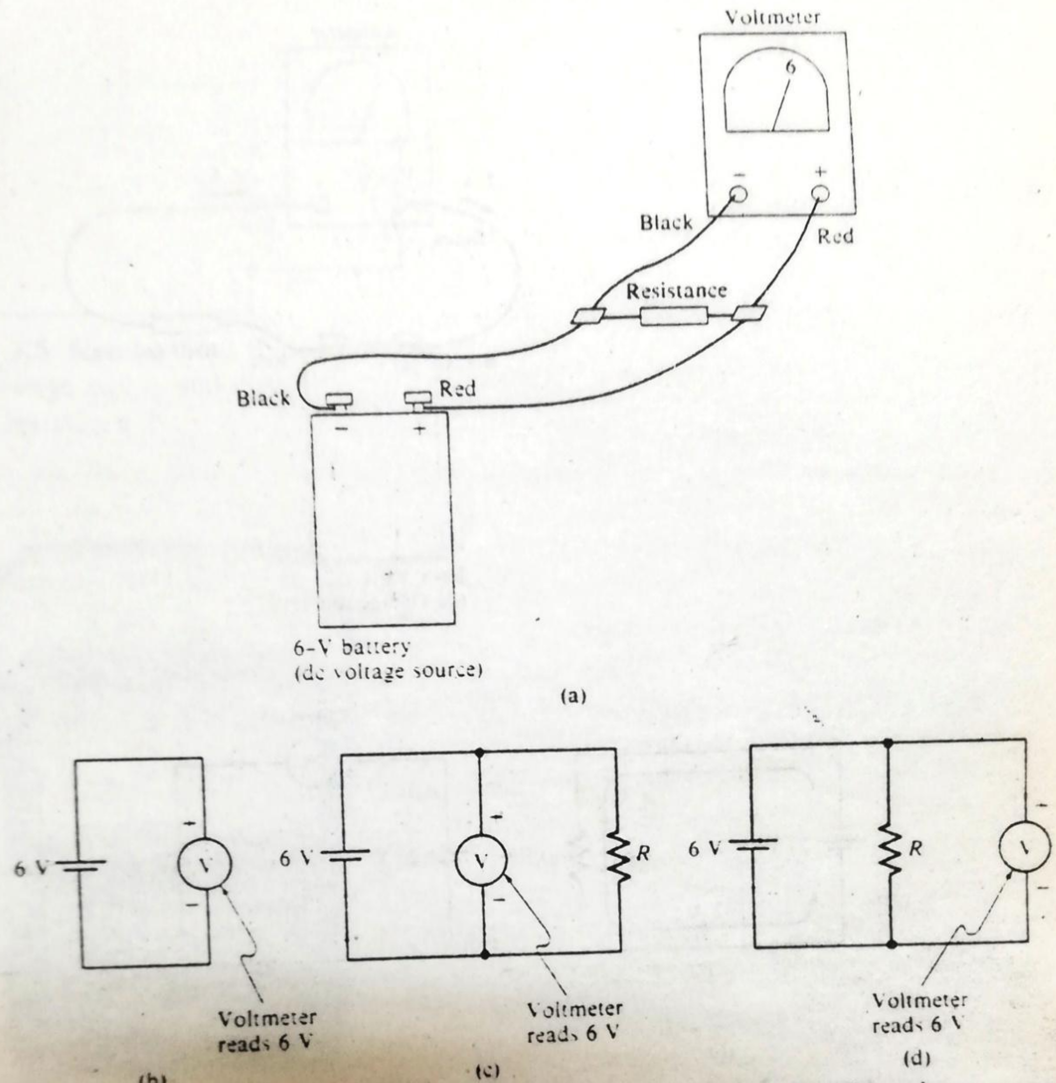

FIGURE 3.3 Voltmeter connections. The voltage measured across the voltage source is the same as that measured across the resistance. (a) Pictorial representation of a voltmeter connected *across* a battery and a resistance. (b) Voltmeter connected across voltage source alone. (c) Voltmeter connected across voltage source with resistance present. (d) Voltmeter connected across resistance [same as part (c)].

in Chapter 4). If the voltmeter connections were reversed (red terminal to − and black terminal to +), the reading would be − 6 V. Some voltmeters are not capable of indicating a negative voltage.

Current is measured by an instrument called an *ammeter*. To measure the current flowing in a resistance, it is necessary to disconnect the resistance and insert an ammeter in such a way that all the current flowing in the resistance also flows through the ammeter. This connection is shown in Figure 3.4. As illustrated, the side of the resistor on which the ammeter is connected does not affect the reading, since the same current flows into the resistor as flows out of it. The polarity of an ammeter requires that it be connected

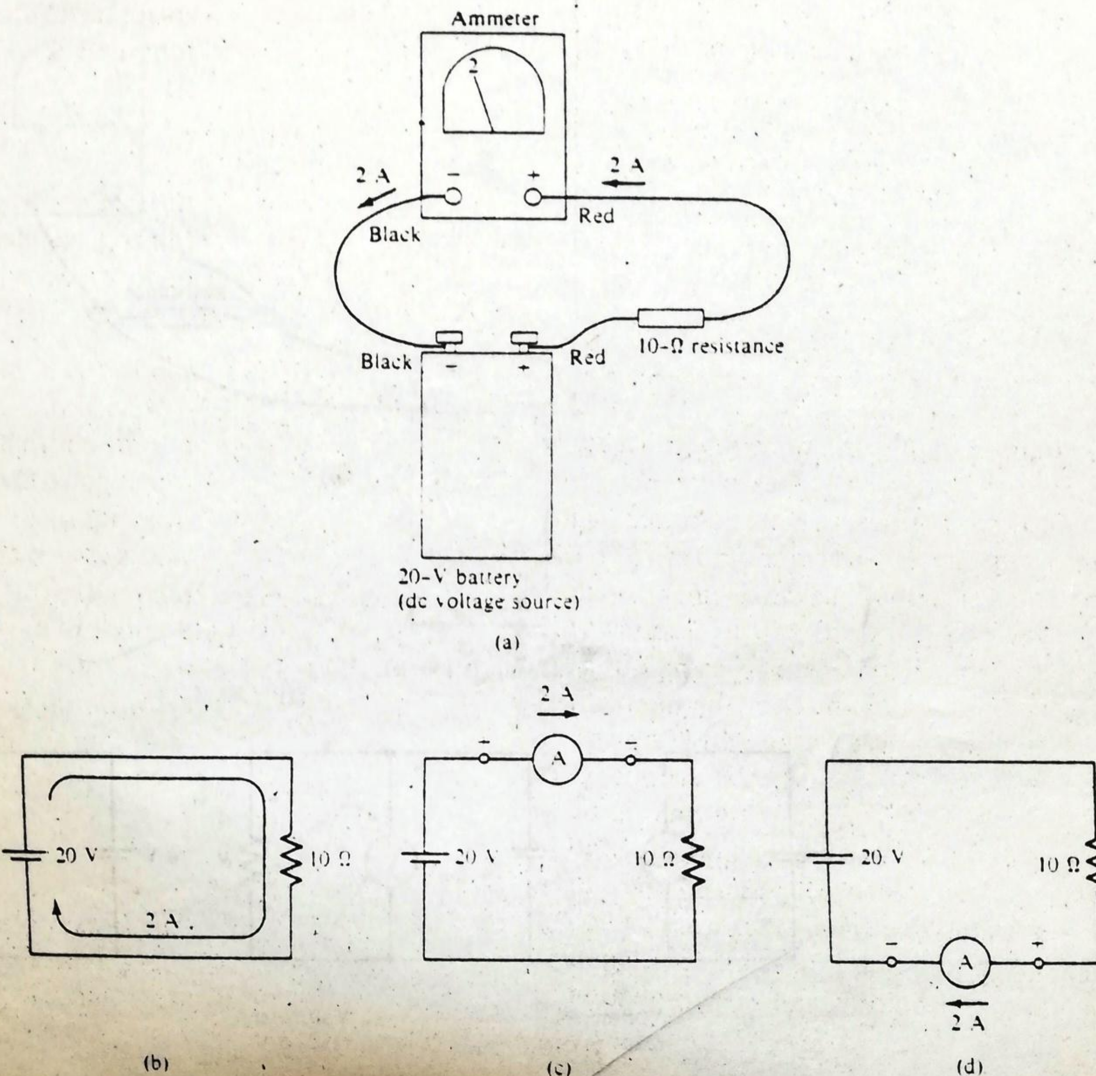

FIGURE 3.4 Ammeter connections. (a) Pictorial representation of an ammeter connected to measure the current in a 10-Ω resistance. (b) $I = E/R = 20\ \text{V}/10\ \Omega = 2\ \text{A}$. (c) Ammeter inserted. (d) The ammeter reading is the same as in part (c).

so that (conventional) current flows into the + terminal of the meter and out of the − terminal. If the connections are reversed, a negative value of current will be indicated. Some ammeters are not capable of showing negative current.

The importance of proper voltmeter and ammeter connections, as shown in Figures 3.3 and 3.4, cannot be overstressed. If a voltmeter is connected as if it were an ammeter, or vice versa, the instrument may be severely damaged. Figure 3.5 shows the correct way to connect a voltmeter and an ammeter in a circuit for simultaneous measurement of the voltage across and current through a resistance.

An *ohmmeter* is an instrument designed to measure resistance. It is basically a voltage source and an ammeter. The built-in voltage source is effectively connected across the resistance to be measured and the ammeter measures the current that flows. Since the

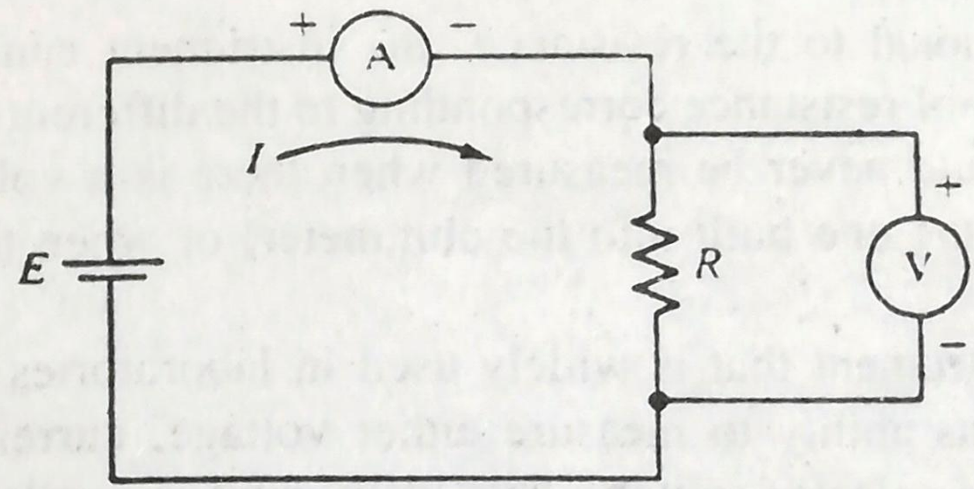

FIGURE 3.5 Simultaneous measurement of the voltage across and current through resistance R.

current is inversely proportional to the resistance, the instrument can be calibrated to indicate the number of ohms of resistance corresponding to the different values of current it measures. Resistance should never be measured when there is a voltage source connected across it (other than the one built into the ohmmeter) or when there is any other component connected to it.

There is one type of instrument that is widely used in laboratories and for general-purpose testing because of its ability to measure either voltage, current, or resistance, depending on the setting of a selector switch. This instrument is available with either a *digital* display, like that of a calculator, or with a "needle" (pointer) that moves across a continuous scale. The latter is called an *analog*-type display. Figure 3.6 shows examples of each type of instrument. These instruments are known variously as multimeters, volt-ohm-ammeters (VOMs), and digital multimeters (DMMs). The same precautions discussed previously in regards to proper meter connections also apply to multimeters. In particular, the instrument must not be set to measure current when it is connected as a voltmeter, nor set to measure voltage when it is connected as an ammeter.