OHM'S LAW

3

CHAPTER OUTLINE

CHAPTER OBJECTIVES

- Explain Ohm's law
- Calculate current in a circuit
- Calculate voltage in a circuit
- Calculate resistance in a circuit
- Describe a basic approach to troubleshooting

KEY TERMS

- Ohm's law
- Directly proportional
- Linear
- Inversely proportional
- Troubleshooting

APPLICATION ACTIVITY PREVIEW

In this application activity, you will see how Ohm's law is used in a practical circuit. The circuit is an array of switch-selectable resistors of various values used to control the speed of a fan. The resistance values will be determined based on fan motor data and by the application of Ohm's law. A test procedure will be developed once the modifications have been made.

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INTRODUCTION

In Chapter 2, you studied the concepts of voltage, current, and resistance. You also were introduced to a basic electric circuit. In this chapter, you will learn how voltage, current, and resistance are interrelated. You will also learn how to analyze a simple electric circuit.

Ohm's law is perhaps the single most important tool for the analysis of electric circuits, and you *must* know how to apply it.

In 1826 Georg Simon Ohm found that current, voltage, and resistance are related in a specific and predictable way. Ohm expressed this relationship with a formula that is known today as Ohm's law. In this chapter, you will learn Ohm's law and how to use it in solving circuit problems. A general approach to troubleshooting using an *analysis, planning*, and *measurement* (APM) approach is also introduced.

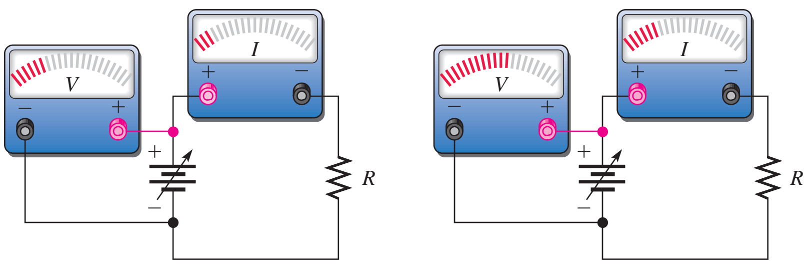
3–1 THE RELATIONSHIP OF CURRENT, VOLTAGE, AND RESISTANCE

Ohm's law describes mathematically how voltage, current, and resistance in a resistive circuit are related. Ohm's law is expressed in three equivalent forms depending on which quantity you need to determine. As you will learn, in a resistive circuit, current and voltage are directly proportional. However, current and resistance are inversely proportional.

After completing this section, you should be able to

- **Explain Ohm's law**
  - Describe how V, I, and R are related
  - Express I as a function of V and R
  - Express V as a function of I and R
  - Express R as a function of V and I
  - Show graphically that I and V are directly proportional
  - Show graphically that I and R are inversely proportional
  - Explain why I and V are linearly proportional

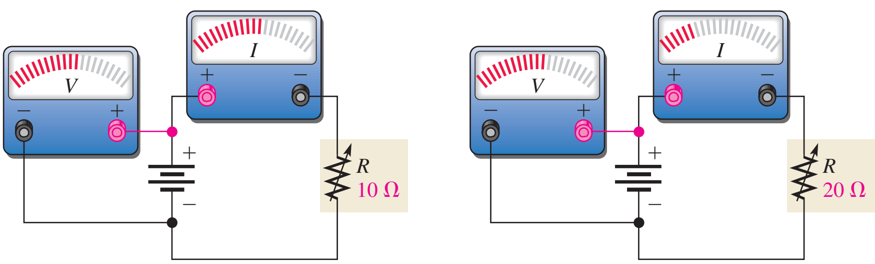
Ohm determined experimentally that if the voltage across a resistor is increased, the current through the resistor will also increase; and, likewise, if the voltage is decreased, the current will decrease. For example, if the voltage is doubled, the current will double. If the voltage is halved, the current will also be halved. This relationship is illustrated in Figure 3–1, with relative meter indications of voltage and current.



(a) Less V, less I (b) More V, more I

FIGURE 3–1 Effect on the current of changing the voltage with the resistance at a constant value.

Ohm also determined that if the voltage is held constant, less resistance results in more current, and, also, more resistance results in less current. For example, if the resistance is halved, the current doubles. If the resistance is doubled, the current is halved. This concept is illustrated by the meter indications in Figure 3–2, where the resistance is increased and the voltage is held constant.



(a) Less R, more I (b) More R, less I

FIGURE 3–2 Effect on the current of changing the resistance with the voltage at a constant value.

Ohm's law states that current is directly proportional to voltage and inversely proportional to resistance. In mathematics, if two variables are **directly proportional**, their ratio is equal to a constant ($x/y = k$). The circuits in Figures 3–1 and 3–2 illustrate Ohm's law, which is given in the following formula:

Equation 3–1

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

where I is current in amperes (A), V is voltage in volts (V), and R is resistance in ohms (Ω). For a constant value of R, if the value of V is increased, the value of I increases; if V is decreased, I decreases. If V is constant and R is increased, I decreases. Similarly, if V is constant and R is decreased, I increases.

Using Equation 3–1, you can calculate the current if you know the values of voltage and resistance. By manipulating Equation 3–1, you can obtain expressions for voltage and resistance.

Equation 3–2

$$V = IR$$

Equation 3–3

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

With Equation 3–2, you can calculate voltage if you know the values of current and resistance. With Equation 3–3, you can calculate resistance if you know the values of voltage and current.

The three expressions—Equations 3–1, 3–2, and 3–3—are all equivalent. They are simply three ways of stating Ohm's law.

The Linear Relationship of Current and Voltage

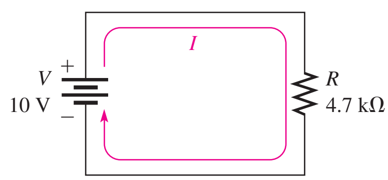
In mathematics, the term **linear** refers to a relationship between variables that plots a straight line. A graph of a linear equation may or may not pass through the origin. When the line passes through the origin, the variables are directly proportion (or linearly proportional). In this case, the form of the equation is $y = kx$.

In resistive circuits, current and voltage are linearly proportional. If one of the quantities is increased or decreased by a certain percentage, the other will increase or decrease by the same percentage, assuming that the resistance is constant in value. For example, if the voltage across a resistor is tripled, the current will triple.

EXAMPLE 3–1

Show that if the voltage in the circuit of Figure 3–3 is increased to three times its present value, the current will triple in value.

▶ FIGURE 3–3



Solution With 10 V, the current is

$$I = \frac{V}{R} = \frac{10\text{ V}}{4.7\text{ k}\Omega} = \mathbf{2.13\text{ mA}}$$

If the voltage is increased to 30 V, the current will be

$$I = \frac{V}{R} = \frac{30\text{ V}}{4.7\text{ k}\Omega} = \mathbf{6.38\text{ mA}}$$

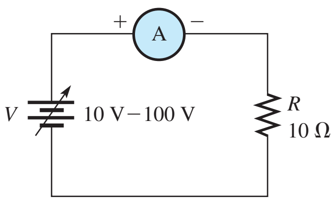
The current went from 2.13 mA to 6.38 mA when the voltage was tripled to 30 V.

Related Problem[*] If the voltage in Figure 3–3 is quadrupled, will the current also quadruple?

Use Multisim file E03-01 to verify the calculated results in this example and your calculation for the related problem.

* Answers are at the end of the chapter.

Let's take a constant value of resistance, for example, 10 Ω, and calculate the current for several values of voltage ranging from 10 V to 100 V in the circuit in Figure 3–4(a). The current values obtained are shown in Figure 3–4(b). The graph of the *I* values versus the *V* values is shown in Figure 3–4(c). Note that it is a straight line graph with a slope equal to the conductance. (Recall that conductance is the reciprocal of resistance.) This graph tells us that a change in voltage results in a linearly proportional change in current. No matter what value *R* is, assuming that *R* is constant, the graph of *I* versus *V* will always be a straight line.

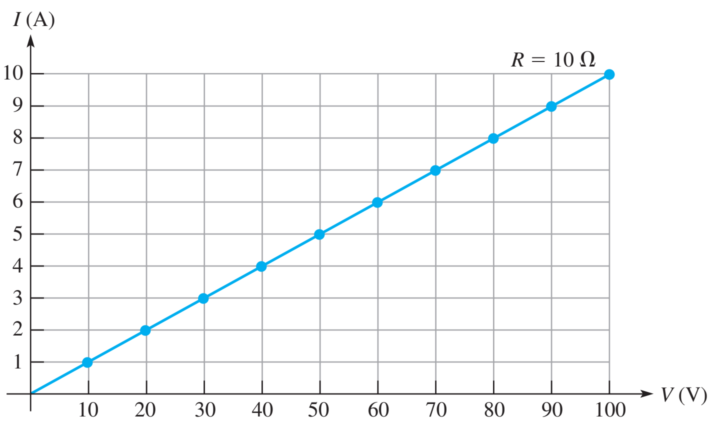


(a) Circuit

V	I
10 V	1 A
20 V	2 A
30 V	3 A
40 V	4 A
50 V	5 A
60 V	6 A
70 V	7 A
80 V	8 A
90 V	9 A
100 V	10 A

$$I = \frac{V}{10\ \Omega}$$

(b) Tabulated values



(c) Graph of current versus voltage for the circuit in part (a)

▲ FIGURE 3–4

EXAMPLE 3–2

Assume that you are measuring the current in a resistive circuit that is operating with 25 V. The ammeter reads 50 mA. Later, you notice that the current has dropped to 40 mA. Assuming that the resistance did not change, you must conclude that the voltage source has changed. How much has the voltage changed, and what is its new value?

Solution The current has dropped from 50 mA to 40 mA, which is 80% of the original 50 mA. The new voltage must be 80% of the original voltage.

$$\text{New voltage} = 0.80 \times 25\ \text{V} = \mathbf{20\ V}$$

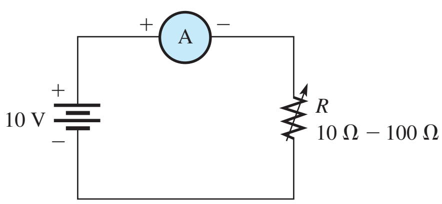
Notice that you did not need the resistance value in order to find the new voltage.

Related Problem If the current drops to 10 mA under the same conditions stated in the example, what is the voltage?

The Inverse Relationship of Current and Resistance

As you have seen, current varies inversely with resistance as expressed by Ohm's law, $I = V/R$. When the resistance is reduced, the current goes up; when the resistance is increased, the current goes down. For example, if the source voltage is held constant and the resistance is halved, the current doubles in value; when the resistance is doubled, the current is reduced by half.

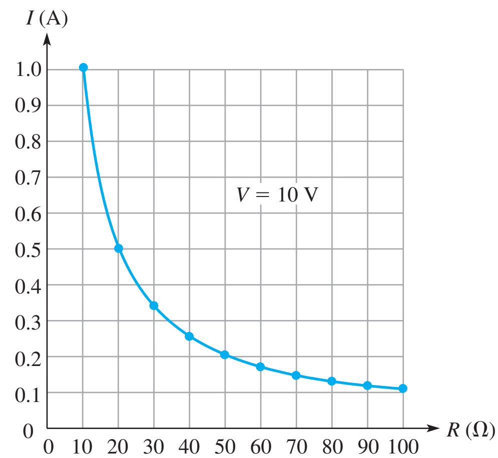
Let's take a constant value of voltage, for example, 10 V, and calculate the current for several values of resistance ranging from 10 Ω to 100 Ω in the circuit in Figure 3–5(a). The values obtained are shown in Figure 3–5(b). The graph of the I values versus the R values is shown in Figure 3–5(c). When two variables are **inversely proportional**, the product of the two variables is a constant and the equation has the form $xy = \mathrm{k}$.



(a) Circuit

R (Ω)	I (A)
10	1.000
20	0.500
30	0.333
40	0.250
50	0.200
60	0.167
70	0.143
80	0.125
90	0.111
100	0.100

(b) Tabulated values



(c) Graph of current versus resistance for the circuit in part (a)

▲ FIGURE 3–5

SECTION 3–1 CHECKUP
Answers are at the end of the chapter.

1. Ohm's law defines how three basic quantities are related. What are these quantities?
2. Write the Ohm's law formula for current.
3. Write the Ohm's law formula for voltage.
4. Write the Ohm's law formula for resistance.
5. If the voltage across a fixed-value resistor is tripled, does the current increase or decrease, and by how much?
6. If the voltage across a fixed resistor is cut in half, how much will the current change?
7. There is a fixed voltage across a resistor, and you measure a current of 1 A. If you replace the resistor with one that has twice the resistance value, how much current will you measure?
8. In a circuit the voltage is doubled and the resistance is cut in half. Would the current increase or decrease and if so, by how much?
9. In a circuit, $V = 2$ V and $I = 10$ mA. If V is changed to 1 V, what will I equal?
10. If $I = 3$ A at a certain voltage, what will it be if the voltage is doubled?

3–2 CURRENT CALCULATIONS

Examples in this section illustrate the Ohm's law formula $I = V/R$.

After completing this section, you should be able to

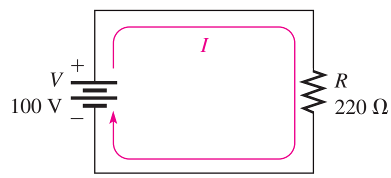
- **Calculate current in a circuit**
  - Use Ohm's law to find current when you know voltage and resistance values
  - Calculate the current when voltage and resistance values are expressed with metric prefixes

Measuring current often requires opening the current path to insert an ammeter. For this reason, it is common to determine current in a circuit indirectly by measuring the voltage across a known resistor and applying Ohm's law. In some cases, a special "sense" resistor is put into a circuit for the purpose of determining current from the measured voltage. Often times, this sense resistor is a low-value precision resistor that will develop a small voltage. There are, of course, many other instances where you will want to determine a current from a voltage measurement across a known resistor. The following examples use the formula $I = V/R$ to find the current from a known voltage and resistance. When V is given in volts and R is given in ohms, the current (I) will be in amperes.

EXAMPLE 3–3

How many amperes of current are in the circuit of Figure 3–6?

FIGURE 3–6



Solution Use the formula $I = V/R$, and substitute 100 V for V and 220 Ω for R.

$$I = \frac{V}{R} = \frac{100\ \text{V}}{220\ \Omega} = \mathbf{0.455\ A}$$

Related Problem If R is changed to 330 Ω in Figure 3–6, what is the current?

Use Multisim file E03-03 to verify the calculated results in this example and your calculation for the related problem.

EXAMPLE 3–4

Assume a precision 0.50 Ω sense resistor has a voltage of 1.20 V across it. What is the current in the sense resistor?

Solution Substitute $V = 1.20$ V and $R = 0.50\ \Omega$ into the formula $I = V/R$.

$$I = \frac{V}{R} = \frac{1.20\ \text{V}}{0.50\ \Omega} = \mathbf{2.40\ A}$$

Related Problem If the sense resistor develops 0.8 V across it, what is the current in it?

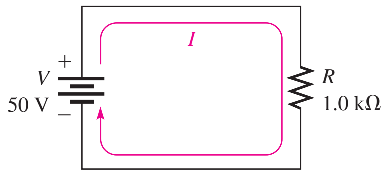
Units with Metric Prefixes

In electronics, resistance values of thousands of ohms or even millions of ohms are common. The metric prefixes *kilo* (k) and *mega* (M) are used to indicate large values. Thus, thousands of ohms are expressed in kilohms (kΩ), and millions of ohms are expressed in megohms (MΩ). The following four examples illustrate how to use kilohms and megohms to calculate current. Volts (V) divided by kilohms (kΩ) results in milliamperes (mA). Volts (V) divided by megohms (MΩ) results in microamperes (μA). In general, if the answer is not between 1 and 1,000, you should adjust it to follow this convention using a different metric prefix. (Most calculators do this automatically.)

EXAMPLE 3–5

Calculate the current in Figure 3–7.

▶ FIGURE 3–7



Solution Remember that 1.0 kΩ is the same as $1 \times 10^3\ \Omega$. Use the formula $I = V/R$ and substitute 50 V for V and $1 \times 10^3\ \Omega$ for R.

$$I = \frac{V}{R} = \frac{50\text{ V}}{1.0\text{ k}\Omega} = \frac{50\text{ V}}{1 \times 10^3\ \Omega} = 50 \times 10^{-3}\text{ A} = \mathbf{50\text{ mA}}$$

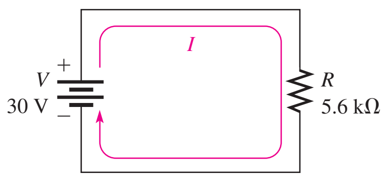
Related Problem Calculate the current in Figure 3–7 if R is changed to 10 kΩ.

In Example 3–5, 50×10^{-3} A is expressed as 50 milliamperes (50 mA). This can be used to advantage when you divide volts by kilohms. The current will be in milliamperes, as Example 3–6 illustrates.

EXAMPLE 3–6

How many milliamperes are in the circuit of Figure 3–8?

▶ FIGURE 3–8



Solution When you divide volts by kilohms, you get current in milliamperes.

$$I = \frac{V}{R} = \frac{30\text{ V}}{5.6\text{ k}\Omega} = \mathbf{5.36\text{ mA}}$$

Related Problem What is the current in milliamperes if R is changed to 2.2 kΩ?

MultiSim

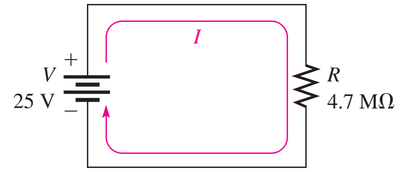
Use Multisim file E03-06 to verify the calculated results in this example and to confirm your calculation for the related problem.

If you divide volts by resistance in megohms, the current is in microamperes (μA), as Examples 3–7 and 3–8 show.

EXAMPLE 3–7

Determine the amount of current in the circuit of Figure 3–9.

▶ FIGURE 3–9



Solution Recall that 4.7 MΩ equals $4.7 \times 10^6\ \Omega$. Substitute 25 V for V and $4.7 \times 10^6\ \Omega$ for R.

$$I = \frac{V}{R} = \frac{25\text{ V}}{4.7\text{ M}\Omega} = \frac{25\text{ V}}{4.7 \times 10^6\ \Omega} = 5.32 \times 10^{-6}\text{ A} = \mathbf{5.32\ \mu A}$$

Related Problem What is the current if V is increased to 100 V in Figure 3–6?

EXAMPLE 3–8

Change the value of R in Figure 3–9 to 1.8 MΩ. What is the new value of current?

Solution When you divide volts by megohms, you get current in microamperes.

$$I = \frac{V}{R} = \frac{25\text{ V}}{1.8\text{ M}\Omega} = \mathbf{13.9\ \mu A}$$

Related Problem If R is doubled in the circuit of Figure 3–6, what is the new value of current?

Small voltages, usually much less than 50 V, are common in semiconductor circuits. Occasionally, however, large voltages are encountered. For example, the high-voltage supply in some older television receivers is around 20,000 V (20 kilovolts, or 20 kV), and transmission voltages generated by the power companies may be as high as 765,000 V (765 kV). The following two examples illustrate how to use voltage values in the kilovolt range to calculate current.

EXAMPLE 3–9

How much current is produced by a voltage of 24 kV across a 12 kΩ resistor?

Solution Since kilovolts are divided by kilohms, the prefixes cancel; therefore, the current is in amperes.

$$I = \frac{V}{R} = \frac{24\text{ kV}}{12\text{ k}\Omega} = \frac{24 \times 10^3\text{ V}}{12 \times 10^3\ \Omega} = \mathbf{2\ A}$$

Related Problem What is the current in mA produced by 1 kV across a 27 kΩ resistor?

EXAMPLE 3–10

How much current is there through a 100 MΩ resistor when 50 kV is applied?

Solution In this case, divide 50 kV by 100 MΩ to get the current. Substitute 50×10^3 V for 50 kV and $100 \times 10^6\ \Omega$ for 100 MΩ.

$$I = \frac{V}{R} = \frac{50\text{ kV}}{100\text{ M}\Omega} = \frac{50 \times 10^3\text{ V}}{100 \times 10^6\ \Omega} = 0.5 \times 10^{-3}\text{ A} = \mathbf{0.5\ mA}$$

Remember that the power of ten in the denominator is subtracted from the power of ten in the numerator. So 50 was divided by 100, giving 0.5, and 6 was subtracted from 3, giving 10^{-3}.

Related Problem How much current is there through a 6.8 MΩ resistor when 10 kV is applied?

SECTION 3–2 CHECKUP

In Problems 1–4, calculate I.

1. $V = 10$ V and $R = 5.6\ \Omega$.
2. $V = 100$ V and $R = 560\ \Omega$.
3. $V = 5$ V and $R = 2.2\ \text{k}\Omega$.
4. $V = 15$ V and $R = 4.7\ \text{M}\Omega$.
5. If a 4.7 MΩ resistor has 20 kV across it, how much current is there?
6. How much current will 10 kV across a 2.2 MΩ resistor produce?

3–3 VOLTAGE CALCULATIONS

Examples in this section illustrate the Ohm's law expression $V = IR$.

After completing this section, you should be able to

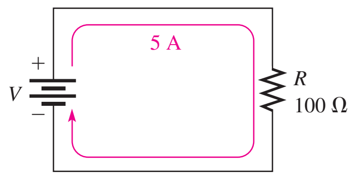
- **Calculate voltage in a circuit**
  - Use Ohm's law to find voltage when you know current and resistance values
  - Calculate the voltage when current and resistance values are expressed with metric prefixes

The following examples use the formula $V = IR$. When I is given in amperes and R is given in ohms, the voltage (V) will be in volts.

EXAMPLE 3–11

In the circuit of Figure 3–10, how much voltage is needed to produce 5 A of current?

▶ FIGURE 3–10



Solution Substitute 5 A for I and 100 Ω for R into the formula $V = IR$.

$$V = IR = (5\ \text{A})(100\ \Omega) = \mathbf{500\ V}$$

Thus, 500 V are required to produce 5 A of current through a 100 Ω resistor.

Related Problem In Figure 3–10, how much voltage is required to produce 2.0 A of current?

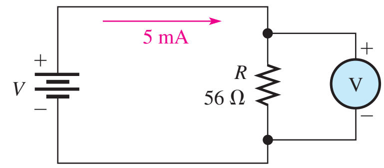
Units with Metric Prefixes

The milliamp (mA) and microampere (μA) are common in electronic circuits. The following two examples illustrate how to use current values in the milliampere (mA) and microampere (μA) ranges to calculate voltage.

EXAMPLE 3–12

How much voltage will be measured across the resistor in Figure 3–11?

FIGURE 3–11



Solution Five milliamperes equals 5×10^{-3} A. Substitute the values for I and R into the formula $V = IR$.

$$V = IR = (5\text{ mA})(56\ \Omega) = (5 \times 10^{-3}\text{ A})(56\ \Omega) = 280 \times 10^{-3}\text{ V} = \mathbf{280\ mV}$$

Related Problem How much voltage is measured across R if $R = 33\ \Omega$ and $I = 1.5$ mA in Figure 3–11?

Use Multisim file E03-12 to verify the calculated results in this example and to confirm your calculation for the related problem.

EXAMPLE 3–13

Suppose that a solar cell produces a current of 180 μA through a 100 Ω resistor. How much voltage is across the resistor?

Solution 180 microamperes equals 180×10^{-6} A. Substitute the values for I and R into the formula $V = IR$.

$$V = IR = (180\ \mu\text{A})(100\ \Omega) = (180 \times 10^{-6}\text{ A})(100\ \Omega) = 18 \times 10^{-3}\text{ V} = \mathbf{18\ mV}$$

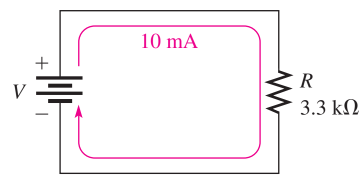
Related Problem If there are 3.2 μA through a 47 Ω resistor, what is the voltage across the resistor?

The following two examples illustrate how to use resistance values in the kilohm (kΩ) and megohm (MΩ) ranges to calculate voltage.

EXAMPLE 3–14

The circuit in Figure 3–12 has a current of 10 mA. What is the voltage?

FIGURE 3–12



Solution Ten milliamperes equals 10×10^{-3} A and 3.3 kΩ equals 3.3×10^{3} Ω. Substitute these values into the formula $V = IR$.

$$V = IR = (10\text{ mA})(3.3\text{ k}\Omega) = (10 \times 10^{-3}\text{ A})(3.3 \times 10^{3}\ \Omega) = \mathbf{33\ V}$$

Notice that 10^{-3} and 10^{3} cancel. Therefore, milliamperes cancel kilohms when multiplied, and the result is volts.

Related Problem If the current in Figure 3–12 is 25 mA, what is the voltage?

Use Multisim file E03-14 to verify the calculated results in this example and to confirm your calculation for the related problem.

EXAMPLE 3–15

If there is a current of 50 μA through a 4.7 MΩ resistor, what is the voltage?

Solution Fifty microamperes equals 50×10^{-6} A and 4.7 MΩ is $4.7 \times 10^{6}\ \Omega$. Substitute these values into the formula $V = IR$.

$$V = IR = (50\ \mu\text{A})(4.7\ \text{M}\Omega) = (50 \times 10^{-6}\ \text{A})(4.7 \times 10^{6}\ \Omega) = \mathbf{235\ V}$$

Notice that 10^{-6} and 10^{6} cancel. Therefore, microamperes cancel megohms when multiplied, and the result is volts.

Related Problem If there are 450 μA through a 3.9 MΩ resistor, what is the voltage?

SECTION 3–3 CHECKUP

In Problems 1–7, calculate V.

1. $I = 1$ A and $R = 10\ \Omega$.
2. $I = 8$ A and $R = 470\ \Omega$.
3. $I = 3$ mA and $R = 100\ \Omega$.
4. $I = 25\ \mu$A and $R = 56\ \Omega$.
5. $I = 2$ mA and $R = 1.8$ kΩ.
6. $I = 5$ mA and $R = 100$ MΩ.
7. $I = 10\ \mu$A and $R = 2.2$ MΩ.
8. How much voltage is required to produce 100 mA through a 4.7 kΩ resistor?
9. What voltage do you need to cause 3 mA of current in a 3.3 kΩ resistor?
10. A battery produces 2 A through a 6.8 Ω resistive load. What is the battery voltage?

3–4 RESISTANCE CALCULATIONS

Examples in this section illustrate the Ohm's law expression $R = V/I$.

After completing this section, you should be able to

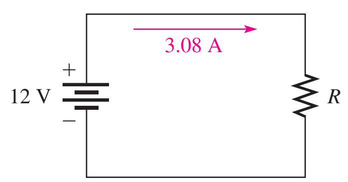
- **Calculate resistance in a circuit**
  - Use Ohm's law to find resistance when you know voltage and current values
  - Calculate resistance when current and voltage values are expressed with metric prefixes

The following examples use the formula $R = V/I$. When V is given in volts and I is given in amperes the resistance (R) will be in ohms.

EXAMPLE 3–16

In the circuit of Figure 3–13, how much resistance is needed to draw 3.08 A of current from the battery?

▶ FIGURE 3–13



Solution Substitute 12 V for V and 3.08 A for I into the formula $R = V/I$.

$$R = \frac{V}{I} = \frac{12\text{ V}}{3.08\text{ A}} = \mathbf{3.90\ \Omega}$$

Related Problem In Figure 3–13, to what value must R be changed for a current of 5.45 A?

EXAMPLE 3–17

Use Ohm's law to calculate the resistance of a rear window defroster grid in a certain vehicle. When it is connected to 12.6 V, it draws 15.0 A from the battery. What is the resistance of the defroster grid?

Solution

$$R = \frac{V}{I} = \frac{12.6\text{ V}}{15.0\text{ A}} = \mathbf{0.84\ \Omega}$$

Related Problem If one of the grid wires opens, the current drops to 13.0 A. What is the new resistance?

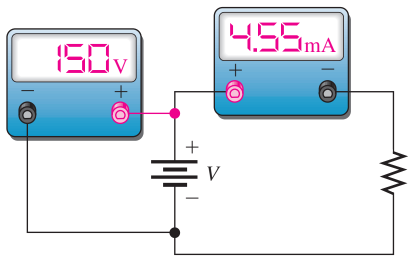
Units with Metric Prefixes

The following two examples illustrate how to use current values in the milliampere (mA) and microampere (μA) ranges to calculate resistance.

EXAMPLE 3–18

Suppose that the ammeter in Figure 3–14 indicates 4.55 mA of current and the voltmeter reads 150 V. What is the value of R?

▶ FIGURE 3–14



Solution 4.55 mA equals 4.55×10^{-3} A. Substitute the voltage and current values into the formula $R = V/I$.

$$R = \frac{V}{I} = \frac{150\text{ V}}{4.55\text{ mA}} = \frac{150\text{ V}}{4.55 \times 10^{-3}\text{ A}} = 33 \times 10^{3}\ \Omega = \mathbf{33\ k\Omega}$$

When volts are divided by milliamperes, the resistance is in kilohms.

Related Problem If the ammeter indicates 1.10 mA and the voltmeter reads 75 V, what is the value of R?

Use Multisim file E03-18 to verify the calculated results in this example and to confirm your calculation for the related problem.

EXAMPLE 3–19

Suppose that the value of the resistor in Figure 3–14 is changed. If the battery voltage is still 150 V and the ammeter reads 68.2 μA, what is the new resistor value?

Solution 68.2 μA equals 68.2×10^{-6} A. Substitute V and I values into the equation for R.

$$R = \frac{V}{I} = \frac{150\text{ V}}{68.2\ \mu\text{A}} = \frac{150\text{ V}}{68.2 \times 10^{-6}\text{ A}} = 2.2 \times 10^{6}\ \Omega = \mathbf{2.2\ M\Omega}$$

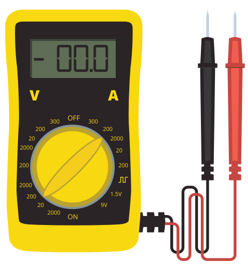
Related Problem If the resistor is changed in Figure 3–14 so that the ammeter reads 48.5 μA, what is the new resistor value? Assume $V = 150$ V.

SECTION 3–4 CHECKUP

In Problems 1–5, calculate R.

1. $V = 10$ V and $I = 2.13$ A.
2. $V = 270$ V and $I = 10$ A.
3. $V = 20$ kV and $I = 5.13$ A.
4. $V = 15$ V and $I = 2.68$ mA.
5. $V = 5$ V and $I = 2.27$ μA.
6. You have a resistor across which you measure 25 V, and your ammeter indicates 53.2 mA of current. What is the resistor's value in kilohms? In ohms?

3–5 Introduction to Troubleshooting



Technicians must be able to diagnose and repair malfunctioning circuits and systems. In this section, you learn a general approach to troubleshooting using a simple example. Troubleshooting coverage is an important part of this textbook, so you will find a troubleshooting section in many of the chapters and troubleshooting problems, including Multisim circuits, for skill building.

After completing this section, you should be able to

- **Describe a basic approach to troubleshooting**
  - List three steps in troubleshooting
  - Explain what is meant by half-splitting
  - Discuss and compare the three basic measurements of voltage, current, and resistance

Troubleshooting is the application of logical thinking combined with a thorough knowledge of circuit or system operation to correct a malfunction. The basic approach to troubleshooting consists of three steps: *analysis*, *planning*, and *measuring*. We will refer to this three-step approach as APM.

Analysis

The first step in troubleshooting a circuit is to analyze clues or symptoms of the failure. The analysis can begin by determining the answer to certain questions:

1. Has the circuit ever worked?
2. If the circuit once worked, under what conditions did it fail?
3. What are the symptoms of the failure?
4. What are the possible causes of failure?

Planning

The second step in the troubleshooting process, after analyzing the clues, is formulating a logical plan of attack. Much time can be saved by proper planning. A working knowledge of the circuit is a prerequisite to a plan for troubleshooting. If you are not certain how the circuit is supposed to operate, take time to review circuit diagrams (schematics), operating instructions, and other pertinent information. A schematic with proper voltages marked at various test points is particularly useful. Although logical thinking is perhaps the most important tool in troubleshooting, it rarely can solve the problem by itself.

Measuring

The third step is to narrow the possible failures by making carefully thought out measurements. These measurements usually confirm the direction you are taking in solving the problem, or they may point to a new direction that you should take. Occasionally, you may find a totally unexpected result.

An APM Example

The thought process that is part of the APM approach can be illustrated with a simple example. Suppose you have a string of eight decorative 12 V bulbs connected in series to a 120 V source V_S, as shown in Figure 3–15. Assume that this circuit worked properly at one time but stopped working after it was moved to a new location. When plugged in at the new location, the lamps fail to turn on. How do you go about finding the trouble?

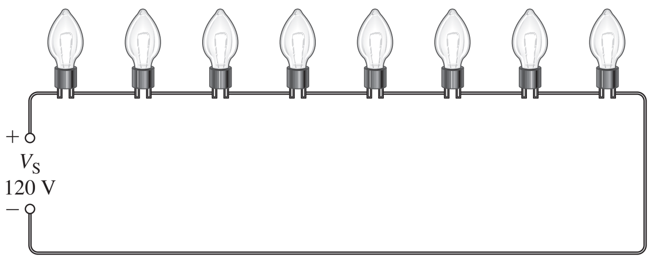


FIGURE 3–15
A string of bulbs connected to a voltage source.

The Analysis Thought Process You may think like this as you proceed to analyze the situation:

- Since the circuit worked before it was moved, the problem could be that there is no voltage at the new location.
- Perhaps the wiring was loose and pulled apart when moved.
- It is possible that a bulb is burned out or loose in its socket.

With this reasoning, you have considered possible causes and failures that may have occurred. The thought process continues:

- The fact that the circuit once worked eliminates the possibility that the original circuit was improperly wired.
- If the fault is due to an open path, it is unlikely that there is more than one break which could be either a bad connection or a burned out bulb.

You have now analyzed the problem and are ready to plan the process of finding the fault in the circuit.

The Planning Thought Process The first part of your plan is to measure for voltage at the new location. If the voltage is present, then the problem is in the string of lights. If voltage is not present, check the circuit breaker at the distribution box in the house. Before resetting breakers, you should think about why a breaker may be tripped. Let's assume that you find the voltage is present. This means that the problem is in the string of lights.

The second part of your plan is to measure either the resistance in the string of lights or to measure voltages across the bulbs. The decision whether to measure resistance or voltage is a toss-up and can be made based on the ease of making the test. Seldom is a troubleshooting plan developed so completely that all possible contingencies are included. You will frequently need to modify the plan as you go along.

The Measurement Process You proceed with the first part of your plan by using a multimeter to check the voltage at the new location. Assume the measurement shows a voltage of 120 V. Now you have eliminated the possibility of no voltage. You know that, since you have voltage across the string and there is no current because no bulb is on, there must be an open in the current path. Either a bulb is burned out, a connection at the lamp socket is broken, or the wire is broken.

Next, you decide to locate the break by measuring resistance with your multimeter. Applying logical thinking, you decide to measure the resistance of each half of the string instead of measuring the resistance of each bulb. By measuring the resistance of half the bulbs at once, you can usually reduce the effort required to find the open. This technique is a type of troubleshooting procedure called **half-splitting**.

Once you have identified the half in which the open occurs, as indicated by an infinite resistance, you use half-splitting again on the faulty half and continue until you narrow the fault down to a faulty bulb or connection. This process is shown in Figure 3–16, assuming for purposes of illustration that the seventh bulb is burned out.

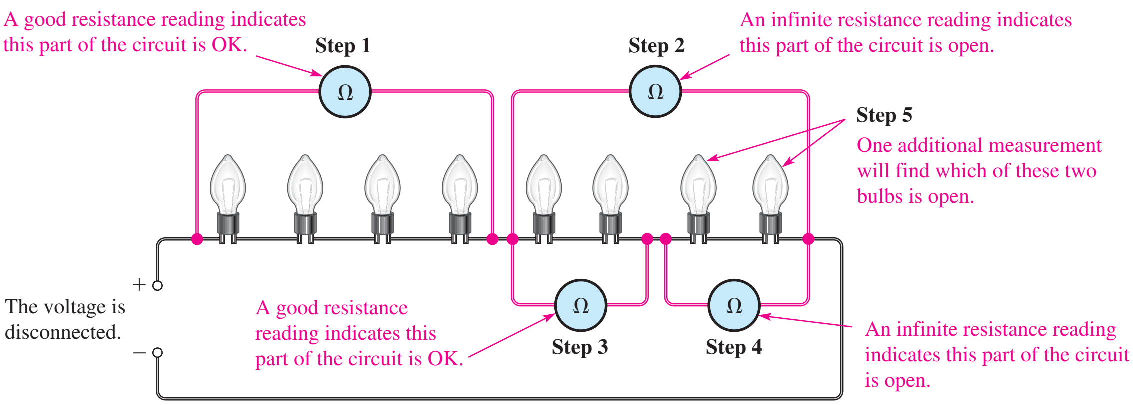


FIGURE 3–16

Illustration of the half-splitting method of troubleshooting. The numbered steps indicate the sequence in which the multimeter is moved from one position to another.

As you can see in the figure, the half-splitting approach in this particular case takes a maximum of five measurements to identify the open bulb. If you had decided to measure each bulb individually and had started at the left, you would have needed seven measurements. Sometimes half-splitting saves steps; sometimes it doesn't. The number of steps required depends on where you make your measurements and in what sequence.

Unfortunately, most troubleshooting is more difficult than this example. However, analysis and planning are essential for effective troubleshooting in any situation. As measurements are made, the plan is often modified; the experienced troubleshooter narrows the search by fitting the symptoms and measurements into a probable cause. In some cases, low-cost equipment is simply discarded when troubleshooting and repair costs are comparable to replacement costs.

Comparison of *V*, *R*, and *I* Measurements

As you know from Section 2–7, you can measure voltage, current, or resistance in a circuit. To measure voltage, place the voltmeter in parallel across the component; that is, place one lead on each side of the component. This makes voltage measurements the easiest of the three types of measurements.

To measure resistance, connect the ohmmeter across a component; however, the voltage must be first disconnected, and generally one end of the component itself must be removed from the circuit to isolate it. Therefore, resistance measurements are generally more difficult than voltage measurements.

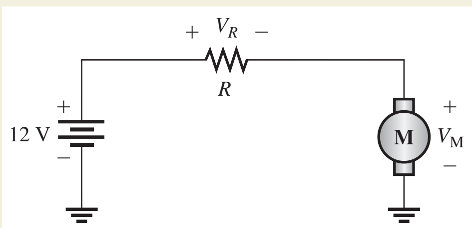
To measure current, place the ammeter in series with the component; that is, the ammeter must be in line with the current path. To do this you must disconnect a component lead or a wire before you connect the ammeter. This usually makes a current measurement the most difficult to perform.

SECTION 3–5 CHECKUP

1. Name the three steps in the APM approach to troubleshooting.
2. Explain the basic idea of the half-splitting technique.
3. Why are voltages easier to measure than currents in a circuit?

Application Activity

In this application, a resistive circuit is developed for controlling the speed of a small dc motor used to drive a fan for cooling electronic equipment mounted in a cabinet. One way to control the speed of a dc motor is to connect a resistor to the motor, as shown in Figure 3–17. The resistor reduces the current to the motor and therefore reduces its speed. This method is only recommended for small motors because energy is wasted in the resistance, and the overall efficiency is low.



▲ FIGURE 3–17

A circuit is required that will allow a selection of four motor speeds. The control circuit is to be mounted in a small box that will be attached to the equipment cabinet to control the fan motor speed, as shown in Figure 3–18.

The application requires four distinct switchable speeds. Your job is to develop a schematic, determine the values for the required resistors, and prepare a test procedure for the circuit. You will apply Ohm's law in order to complete the assignment. Motor data in graphical form is provided in Figure 3–19.

Specifications

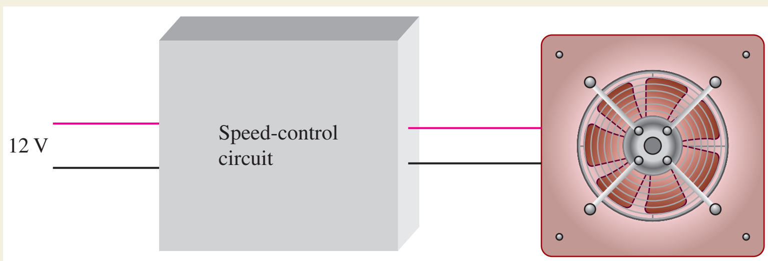
- Each resistor is switch selectable from a rotary switch, so that only one resistor is connected to the motor at a time.
- The four approximate speed settings are 800 rpm, 600 rpm, 400 rpm, and 200 rpm.
- The motor is rated for a maximum of 12 V at 800 rpm.
- The circuit board is to be connected to a 12 V dc source and to the fan motor with wiring that is available inside the cabinet.

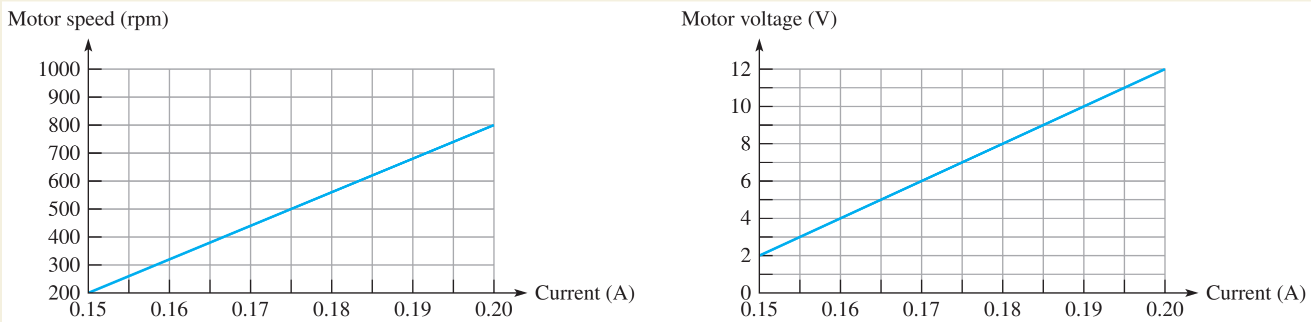
Resistance Calculations

The resistor box has been prepared with speed-value labels and the PC board has been prepared as shown in Figure 3–20.

1. Use the graphical motor data in Figure 3–19 and Ohm's law to determine the nearest standard resistor values needed for the project. *Hint:* To find the voltage across the resistor, V_R, subtract the motor voltage, V_M, from 12 V. This is based on a law introduced in Chapter 5 called Kirchhoff's law.

► FIGURE 3–18



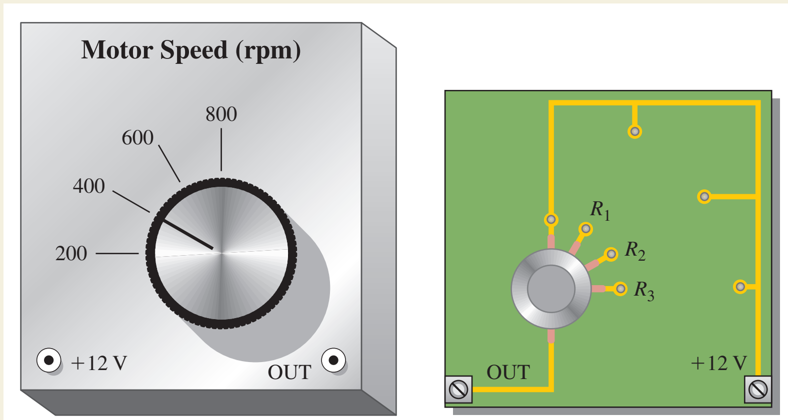


(a) Graph of motor speed versus current

(b) Graph of motor voltage versus current

▲ FIGURE 3–19

▶ FIGURE 3–20



(a) Top view of box

(b) Circuit board

The Schematic

2. From the requirements and the board layout, develop a schematic for the circuit.
3. Show the standard resistor values next to each resistor.

Test Procedure

4. After the resistor box is constructed, list steps you would take to ensure that it works properly.
5. List the instruments you would use in testing it.

Troubleshooting

Describe the most likely fault on the circuit board for each of the following problems:

6. When connected between the +12 V terminal and the OUT terminal, an ohmmeter reads infinite resistance for the 600 rpm position.
7. When connected between the +12 V terminal and the OUT terminal, an ohmmeter reads infinite resistance for all positions of the switch.
8. All resistors read 10% higher than the listed value.

Review

9. Explain how Ohm's law was applied to this problem.
10. Describe the relationship between current and motor speed.

SUMMARY

- Voltage and current are directly proportional.
- Ohm's law gives the relationship of voltage, current, and resistance.
- Current is inversely proportional to resistance.
- A kilohm ($k\Omega$) is one thousand ohms.
- A megohm ($M\Omega$) is one million ohms.
- A microampere (μA) is one-millionth of an ampere.
- A milliampere (mA) is one-thousandth of an ampere.
- Use $I = V/R$ to calculate current.
- Use $V = IR$ to calculate voltage.
- Use $R = V/I$ to calculate resistance.
- APM is a three-step troubleshooting approach, consisting of analysis, planning, and measuring.
- Half-splitting is a troubleshooting technique that can be used to reduce the number of measurements required to find a problem.

KEY TERMS

Key terms and other bold terms in the chapter are defined in the end-of-book glossary.

Directly proportional Two variables are related to each other such that one is the product of a constant multiplied by the other ($y = kx$). A graph will produce a straight line that passes through the origin.

Inversely proportional Two variables are related to each other such that their product is a constant ($xy = k$).

Linear Characterized by a straight-line relationship.

Ohm's law A law stating that current is directly proportional to voltage and inversely proportional to resistance.

Troubleshooting A systematic process of isolating, identifying, and correcting a fault in a circuit or system.

FORMULAS

3–1	$I = \dfrac{V}{R}$	Form of Ohm's law for calculating current
3–2	$V = IR$	Form of Ohm's law for calculating voltage
3–3	$R = \dfrac{V}{I}$	Form of Ohm's law for calculating resistance

TRUE/FALSE QUIZ

Answers are at the end of the chapter.

1. If the total resistance of a circuit increases and the voltage is unchanged, the current decreases.
2. Ohm's law for finding resistance is $R = I/V$.
3. When milliamps and kilohms are multiplied together, the result is volts.
4. If a 10 $k\Omega$ resistor is connected to a 10 V source, the current in the resistor will be 1 A.
5. The current in a fixed resistor is directly proportional to the voltage across it.
6. Ohm's law for finding current is $I = V/R$.
7. When microamps and megohms are multiplied, the result is microvolts.
8. When voltage is constant, current is inversely proportional to resistance.
9. Ohm's law for finding voltage is $V = I/R$.
10. When I is plotted as a function of V for a fixed resistor, the slope of the line represents the conductance.

SELF-TEST

Answers are at the end of the chapter.

1. Ohm's law states that
   (a) current equals voltage times resistance
   (b) voltage equals current times resistance
   (c) resistance equals current divided by voltage
   (d) voltage equals current squared times resistance
2. When the voltage across a resistor is doubled, the current will
   (a) triple (b) halve (c) double (d) not change
3. When 10 V are applied across a 20 Ω resistor, the current is
   (a) 10 A (b) 0.5 A (c) 200 A (d) 2 A
4. When there are 10 mA of current through 1.0 kΩ resistor, the voltage across the resistor is
   (a) 100 V (b) 0.1 V (c) 10 kV (d) 10 V
5. If 20 V are applied across a resistor and there are 6.06 mA of current, the resistance is
   (a) 3.3 kΩ (b) 33 kΩ (c) 330 kΩ (d) 3.03 kΩ
6. A current of 250 μA through a 4.7 kΩ resistor produces a voltage drop of
   (a) 53.2 V (b) 1.18 mV (c) 18.8 V (d) 1.18 V
7. A resistance of 2.2 MΩ is connected across a 1 kV source. The resulting current is approximately
   (a) 2.2 mA (b) 0.455 mA (c) 45.5 μA (d) 0.455 A
8. How much resistance is required to limit the current from a 10 V battery to 1 mA?
   (a) 100 Ω (b) 1.0 kΩ (c) 10 Ω (d) 10 kΩ
9. An electric heater draws 2.5 A from a 110 V source. The resistance of the heating element is
   (a) 275 Ω (b) 22.7 mΩ (c) 44 Ω (d) 440 Ω
10. The current through a flashlight bulb is 20 mA and the total battery voltage is 4.5 V. The resistance of the bulb is
   (a) 90 Ω (b) 225 Ω (c) 4.44 Ω (d) 45 Ω

CIRCUIT DYNAMICS QUIZ

Answers are at the end of the chapter.

1. If the current through a fixed resistor goes from 10 mA to 12 mA, the voltage across the resistor
   (a) increases (b) decreases (c) stays the same
2. If the voltage across a fixed resistor goes from 10 V to 7 V, the current through the resistor
   (a) increases (b) decreases (c) stays the same
3. A variable resistor has 5 V across it. If you reduce the resistance, the current through it
   (a) increases (b) decreases (c) stays the same
4. If the voltage across a resistor increases from 5 V to 10 V and the current increases from 1 mA to 2 mA, the resistance
   (a) increases (b) decreases (c) stays the same

Refer to Figure 3–4.

5. If larger voltages are applied and results are plotted on the same plot, the slope of the line will
   (a) increase (b) decrease (c) remain the same

6. If the IV curve for a larger value resistor is plotted on the same plot, the slope of the line will
   (a) increase **(b)** decrease **(c)** remain the same

Refer to Figure 3–14.

7. If the voltmeter reading changes to 175 V, the ammeter reading
   (a) increases **(b)** decreases **(c)** stays the same
8. If R is changed to a larger value and the voltmeter reading stays at 150 V, the current
   (a) increases **(b)** decreases **(c)** stays the same
9. If the resistor is removed from the circuit leaving an open, the ammeter reading
   (a) increases **(b)** decreases **(c)** stays the same
10. If the resistor is removed from the circuit leaving an open, the voltmeter reading
    (a) increases **(b)** decreases **(c)** stays the same

Refer to Figure 3–25.

11. If the rheostat is adjusted to increase the resistance, the current through the heating element
    (a) increases **(b)** decreases **(c)** stays the same
12. If the rheostat is adjusted to increase the resistance, the source voltage
    (a) increases **(b)** decreases **(c)** stays the same
13. If the fuse opens, the voltage across the heating element
    (a) increases **(b)** decreases **(c)** stays the same
14. If the source voltage increases, the voltage across the heating element
    (a) increases **(b)** decreases **(c)** stays the same
15. If the fuse is changed to one with a higher rating, the current through the rheostat
    (a) increases **(b)** decreases **(c)** stays the same

Refer to Figure 3–27.

16. If the lamp burns out (opens), the current
    (a) increases **(b)** decreases **(c)** stays the same
17. If the lamp burns out, the voltage across it
    (a) increases **(b)** decreases **(c)** stays the same

PROBLEMS

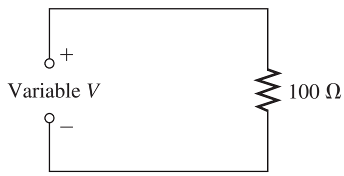
More difficult problems are indicated by an asterisk (*).
Answers to odd-numbered problems are at the end of the book.

SECTION 3–1 The Relationship of Current, Voltage, and Resistance

1. In a circuit consisting of a voltage source and a resistor, describe what happens to the current when
   (a) the voltage is tripled
   (b) the voltage is reduced by 75%
   (c) the resistance is doubled
   (d) the resistance is reduced by 35%
   (e) the voltage is doubled and the resistance is cut in half
   (f) the voltage is doubled and the resistance is doubled
2. State the formula used to find I when the values of V and R are known.
3. State the formula used to find V when the values of I and R are known.
4. State the formula used to find R when the values of V and I are known.

5. A variable voltage source is connected to the circuit of Figure 3–21. Start at 0 V and increase the voltage in 10 V steps up to 100 V. Determine the current at each voltage point, and plot a graph of V versus I. Is the graph a straight line? What does the graph indicate?

▶ FIGURE 3–21

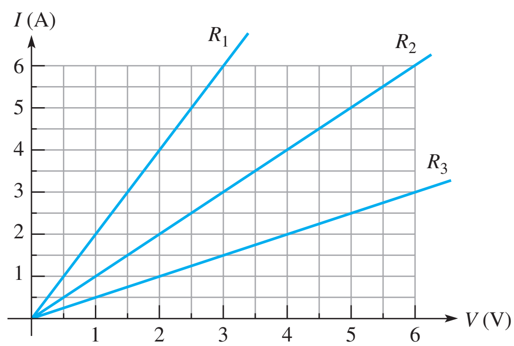


6. In a certain circuit, $I = 5$ mA when $V = 1$ V. Determine the current for each of the following voltages in the same circuit:

(a) $V = 1.5$ V **(b)** $V = 2$ V **(c)** $V = 3$ V
(d) $V = 4$ V **(e)** $V = 10$ V

7. Figure 3–22 is a graph of current versus voltage for three resistance values. Determine R_1, R_2, and R_3.

▶ FIGURE 3–22

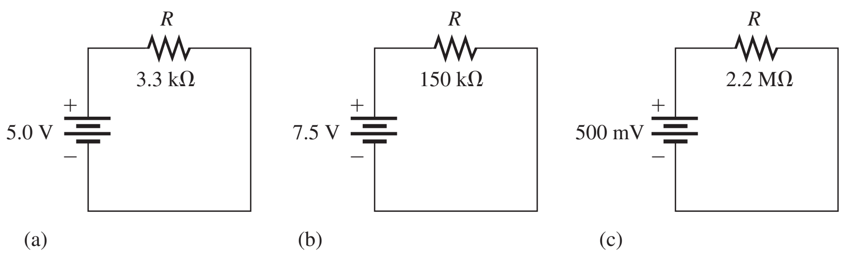


8. Plot the current–voltage relationship for a four-band resistor with the color code gray, red, red, gold.

9. Plot the current–voltage relationship for a five-band resistor with the color code brown, green, gray, brown, red.

10. Determine the current in each circuit in Figure 3–23.

▶ FIGURE 3–23



***11.** You are measuring the current in a circuit that is operated on a 10 V battery. The ammeter reads 50 mA. Later, you notice that the current has dropped to 30 mA. Eliminating the possibility of a resistance change, you must conclude that the voltage has changed. How much has the voltage of the battery changed, and what is its new value?

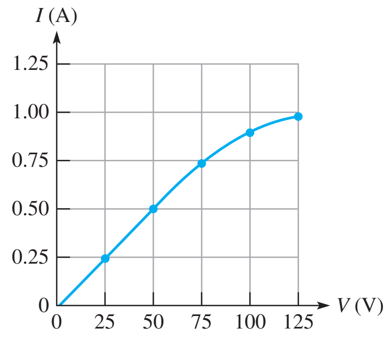
***12.** (a) If you wish to increase the amount of current in a resistor from 10 mA to 15 mA by changing the 20 V source, by how many volts should you change the source? (b) To what new value should you set it? (c) What is the value of the resistor?

13. Plot a graph of current versus voltage for voltage values ranging from 10 V to 100 V in 10 V steps for each of the following resistance values:
(a) 1.0 Ω **(b)** 5.0 Ω **(c)** 20 Ω **(d)** 100 Ω

14. Does the graph in Problem 13 indicate a linear relationship between voltage and current? Explain.

15. Figure 3–24 shows an *IV* curve for a certain light bulb. From the graph, what happens to the resistance as the voltage increases?

FIGURE 3–24



16. For the bulb graphed in Figure 3–24, what is the resistance when the voltage is 25 V?

SECTION 3–2 Current Calculations

17. Determine the current in each case:
(a) $V = 5$ V, $R = 1.0$ Ω **(b)** $V = 15$ V, $R = 10$ Ω **(c)** $V = 50$ V, $R = 100$ Ω
(d) $V = 30$ V, $R = 15$ kΩ **(e)** $V = 250$ V, $R = 5.6$ MΩ

18. Determine the current in each case:
(a) $V = 9$ V, $R = 2.7$ kΩ **(b)** $V = 5.5$ V, $R = 10$ kΩ **(c)** $V = 40$ V, $R = 68$ kΩ
(d) $V = 1$ kV, $R = 2.2$ kΩ **(e)** $V = 66$ kV, $R = 10$ MΩ

19. Assume 200 mV is across a 330 mΩ current sensing resistor. What is the current through the resistor?

20. A certain resistor has the following color code: orange, orange, red, gold. Determine the maximum and minimum currents you should expect to measure when a 12 V source is connected across the resistor.

21. A 4-band resistor is connected across the terminals of a 25 V source. Determine the current in the resistor if the color code is yellow, violet, orange, silver.

22. A 5-band resistor is connected across a 12 V source. Determine the current if the color code is orange, violet, yellow, gold, brown.

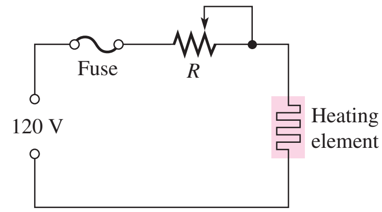
23. If the voltage in Problem 22 is doubled, will a 0.5 A fuse blow? Explain your answer.

24. A certain rear window defroster has a resistance of 1.4 Ω. What is the current when it is connected to a battery that has a voltage of 12.6 V?

***25.** If the voltage of the battery in problem 24 drops to 10.5 V, what *change* is there to the current in the defroster?

***26.** The potentiometer connected as a rheostat in Figure 3–25 is used to control the current to a heating element. When the rheostat is adjusted to a value of 8 Ω or less, the heating element can burn out. What is the rated value of the fuse needed to protect the circuit if the voltage across the heating element at the point of maximum current is 100 V and the voltage across the rheostat is the difference between the heating element voltage and the source voltage?

▶ FIGURE 3–25



27. A 270 Ω current-limiting resistor has a voltage of 3 V across it. What is the current in the resistor?

SECTION 3–3 Voltage Calculations

28. A small solar cell is connected to a 27 kΩ resistor. In bright sunlight, the solar cell looks like a current source that can supply 180 μA to the resistor. What is the voltage across the resistor?

29. Calculate the voltage for each value of I and R:

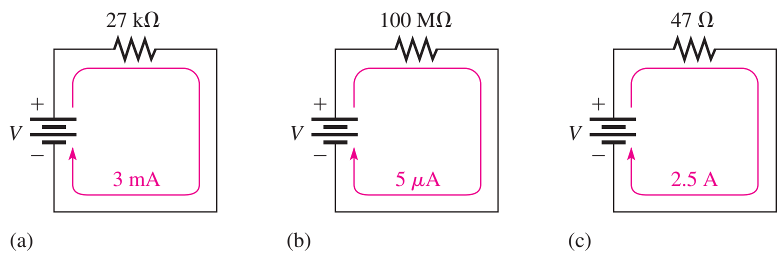
(a) $I = 2$ A, $R = 18\ \Omega$
(b) $I = 5$ A, $R = 56\ \Omega$
(c) $I = 2.5$ A, $R = 680\ \Omega$
(d) $I = 0.6$ A, $R = 47\ \Omega$
(e) $I = 0.1$ A, $R = 560\ \Omega$

30. Calculate the voltage for each value of I and R:

(a) $I = 1$ mA, $R = 10\ \Omega$
(b) $I = 50$ mA, $R = 33\ \Omega$
(c) $I = 3$ A, $R = 5.6$ kΩ
(d) $I = 1.6$ mA, $R = 2.2$ kΩ
(e) $I = 250\ \mu$A, $R = 1.0$ kΩ
(f) $I = 500$ mA, $R = 1.5$ MΩ
(g) $I = 850\ \mu$A, $R = 10$ MΩ
(h) $I = 75\ \mu$A, $R = 47\ \Omega$

31. Three amperes of current are measured through a 27 Ω resistor connected across a voltage source. How much voltage does the source produce?

32. Assign a voltage value to each source in the circuits of Figure 3–26 to obtain the indicated amounts of current.



▲ FIGURE 3–26

***33.** A 6 V source is connected to a 100 Ω resistor by two 12 ft lengths of 18 gauge copper wire. The total resistance is the resistance of both wires added to the 100 Ω resistor. Determine the following:

(a) Current
(b) Resistor voltage drop
(c) Voltage drop across each length of wire

SECTION 3–4 Resistance Calculations

34. Calculate the resistance of a rheostat for each value of V and I:

(a) $V = 10$ V, $I = 2$ A
(b) $V = 90$ V, $I = 45$ A
(c) $V = 50$ V, $I = 5$ A
(d) $V = 5.5$ V, $I = 10$ A
(e) $V = 150$ V, $I = 0.5$ A

35. Calculate the resistance of a rheostat for each set of V and I values:

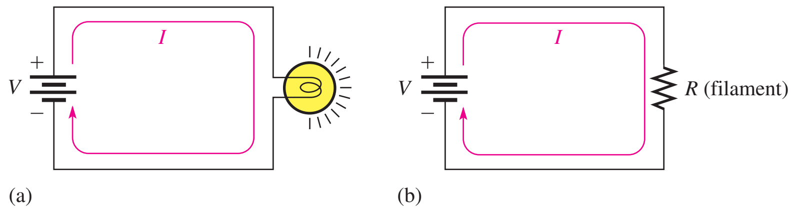
(a) $V = 10\ \text{kV}, I = 5\ \text{A}$ **(b)** $V = 7\ \text{V}, I = 2\ \text{mA}$

(c) $V = 500\ \text{V}, I = 250\ \text{mA}$ **(d)** $V = 50\ \text{V}, I = 500\ \mu\text{A}$

(e) $V = 1\ \text{kV}, I = 1\ \text{mA}$

36. Six volts is applied across a resistor. A current of 2 mA is measured. What is the value of the resistor?

37. The filament of a lamp in the circuit of Figure 3–27(a) has a certain amount of resistance, represented by an equivalent resistance in Figure 3–27(b). If the lamp operates with 120 V and 0.8 A of current, what is the resistance of its filament when it is on?

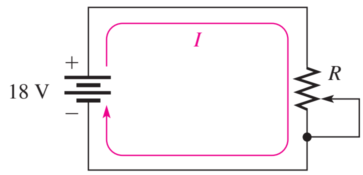


▲ FIGURE 3–27

38. A certain electrical device has an unknown resistance. You have available a 12 V battery and an ammeter. How would you determine the value of the unknown resistance? Draw the necessary circuit connections.

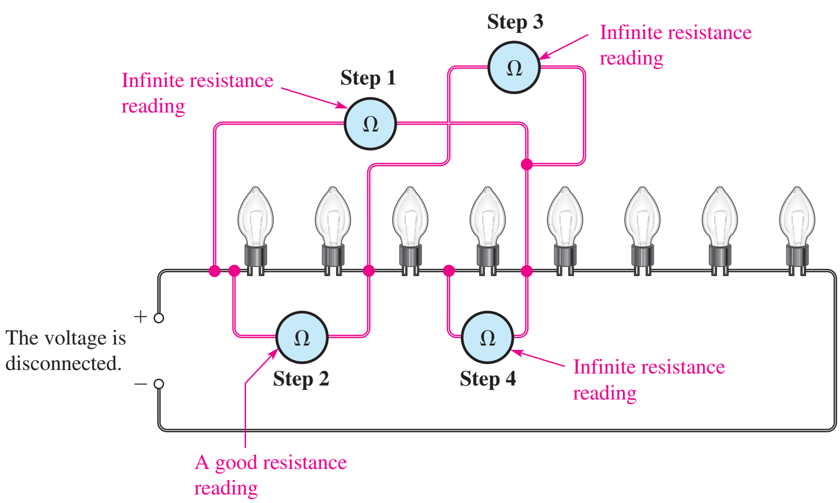
39. By varying the rheostat (variable resistor) in the circuit of Figure 3–28, you can change the amount of current. (a) The setting of the rheostat is such that the current is 50 mA. What is the resistance value of this setting? (b) To adjust the current to 100 mA, to what resistance value must you set the rheostat? (c) What is the problem with this circuit?

► FIGURE 3–28



SECTION 3–5 Introduction to Troubleshooting

40. In the light circuit of Figure 3–29, identify the faulty bulb based on the series of ohmmeter readings shown.



▲ FIGURE 3–29

41. Assume you have a 32-light string and one of the bulbs is burned out. Using the half-splitting approach and starting in the left half of the circuit, how many resistance measurements will it take to find the faulty bulb if it is seventeenth from the left?

Multisim Troubleshooting and Analysis

These problems require Multisim.

42. Open file P03-42 and determine which one of the three circuits is not working properly.
43. Open file P03-43 and measure the resistance values of the resistors.
44. Open file P03-44 and determine the values of the current and voltage.
45. Open file P03-45 and determine the value of the source voltage and the resistance.
46. Open file P03-46 and find the problem with the circuit.

ANSWERS

SECTION CHECKUPS

SECTION 3–1 The Relationship of Current, Voltage, and Resistance

1. Current, voltage, and resistance
2. $I = V/R$
3. $V = IR$
4. $R = V/I$
5. When voltage is tripled, current increases by three times.
6. When voltage is halved, current reduces to one-half of original value.
7. 0.5 A
8. The current would increase by four times if the voltage doubles and the resistance is halved.
9. $I = 5$ mA
10. $I = 6$ A

SECTION 3–2 Current Calculations

1. $I = 10\text{ V}/5.6\ \Omega = 1.79\text{ A}$
2. $I = 100\text{ V}/560\ \Omega = 179\text{ mA}$
3. $I = 5\text{ V}/2.2\text{ k}\Omega = 2.27\text{ mA}$
4. $I = 15\text{ V}/4.7\text{ M}\Omega = 3.19\ \mu\text{A}$
5. $I = 20\text{ kV}/4.7\text{ M}\Omega = 4.26\text{ mA}$
6. $I = 10\text{ kV}/2.2\text{ M}\Omega = 4.55\text{ mA}$

SECTION 3–3 Voltage Calculations

1. $V = (1\text{ A})(10\ \Omega) = 10\text{ V}$
2. $V = (8\text{ A})(470\ \Omega) = 3.76\text{ kV}$
3. $V = (3\text{ mA})(100\ \Omega) = 300\text{ mV}$
4. $V = (25\ \mu\text{A})(56\ \Omega) = 1.4\text{ mV}$
5. $V = (2\text{ mA})(1.8\text{ k}\Omega) = 3.6\text{ V}$
6. $V = (5\text{ mA})(100\text{ M}\Omega) = 500\text{ kV}$
7. $V = (10\ \mu\text{A})(2.2\text{ M}\Omega) = 22\text{ V}$
8. $V = (100\text{ mA})(4.7\text{ k}\Omega) = 470\text{ V}$
9. $V = (3\text{ mA})(3.3\text{ k}\Omega) = 9.9\text{ V}$
10. $V = (2\text{ A})(6.8\ \Omega) = 13.6\text{ V}$

SECTION 3–4 Resistance Calculations

1. $R = 10\text{ V}/2.13\text{ A} = 4.7\ \Omega$
2. $R = 270\text{ V}/10\text{ A} = 27\ \Omega$
3. $R = 20\text{ kV}/5.13\text{ A} = 3.9\text{ k}\Omega$
4. $R = 15\text{ V}/2.68\text{ mA} = 5.6\text{ k}\Omega$
5. $R = 5\text{ V}/2.27\ \mu\text{A} = 2.2\text{ M}\Omega$
6. $R = 25\text{ V}/53.2\text{ mA} = 0.47\text{ k}\Omega = 470\ \Omega$

SECTION 3–5 Introduction to Troubleshooting

1. Analysis, planning, and measurement
2. Half-splitting identifies the fault by successively isolating half of the remaining circuit.
3. Voltage is measured across a component; current is measured in series with the component.

RELATED PROBLEMS FOR EXAMPLES

3–1	Yes	**3–8**	2.66 μA	**3–15**	1755 V
3–2	5 V	**3–9**	37.0 mA	**3–16**	2.20 Ω
3–3	0.303 A	**3–10**	1.47 mA	**3–17**	0.97 Ω
3–4	1.6 A	**3–11**	200 V	**3–18**	68.2 kΩ
3–5	5.0 mA	**3–12**	49.5 mV	**3–19**	3.09 MΩ
3–6	13.6 mA	**3–13**	0.150 mV		
3–7	21.3 μA	**3–14**	82.5 V		

TRUE/FALSE QUIZ

1. T	**4.** F	**7.** F	**10.** T
2. F	**5.** T	**8.** T	
3. T	**6.** T	**9.** F	

SELF-TEST

1. (b)	**5.** (a)	**9.** (c)
2. (c)	**6.** (d)	**10.** (b)
3. (b)	**7.** (b)	
4. (d)	**8.** (d)	

CIRCUIT DYNAMICS QUIZ

1. (a)	**7.** (a)	**13.** (b)
2. (b)	**8.** (b)	**14.** (a)
3. (a)	**9.** (b)	**15.** (c)
4. (c)	**10.** (c)	**16.** (b)
5. (c)	**11.** (b)	**17.** (c)
6. (b)	**12.** (c)	