Energy and Power

4

Chapter Outline

4–1 Energy and Power
4–2 Power in an Electric Circuit
4–3 Resistor Power Ratings
4–4 Energy Conversion and Voltage Drop in Resistance
4–5 Power Supplies and Batteries
Application Activity

Chapter Objectives

- Define *energy* and *power*
- Calculate power in a circuit
- Properly select resistors based on power consideration
- Explain energy conversion and voltage drop
- Discuss the characteristics of power supplies and batteries

Key Terms

- Energy
- Power
- Joule (J)
- Watt (W)
- Kilowatt-hour (kWh)
- Watt's law
- Voltage drop
- Efficiency
- Ampere-hour (Ah) rating

Application Activity Preview

In this application activity you will see how the theory learned in this chapter is applicable to a resistance substitution box. The resistance box is to be used in testing circuits in which there will be a maximum of 5 V across all the resistors. You will determine the power rating of each resistor and develop a test procedure for the circuit as well as a cost estimate and parts list.

Visit the Companion Website

Study aids for this chapter are available at
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Introduction

From Chapter 3, you know the relationship of current, voltage, and resistance as stated by Ohm's law. The existence of these three quantities in an electric circuit results in the fourth basic quantity known as power. A specific relationship exists between power and I, V, and R.

Energy is the ability to do work, and power is the rate at which energy is used. Current carries electrical energy through a circuit. As the free electrons pass through the resistance of the circuit, they give up their energy when they collide with atoms in the resistive material. The electrical energy given up by the electrons is converted into heat energy. In general, the rate at which the electrical energy is converted into heat is the power dissipated in the circuit. Electrical energy can also be converted to other forms of energy such as sound waves or it can be radiated as electromagnetic waves (light or radio waves).

4–1 Energy and Power

When there is current through a resistance, electrical energy is converted to heat or other form of energy, such as light. A common example of this is an incandescent light bulb that becomes too hot to touch. The current through the filament that produces light also produces unwanted heat because the filament has resistance. Electrical components must be able to dissipate a certain amount of energy in a given period of time.

After completing this section, you should be able to

- **Define *energy* and *power***
  - Express power in terms of energy
  - State the unit of power
  - State the common units of energy
  - Perform energy and power calculations

Energy is the ability to do work, and power is the rate at which energy is used.

Power (P) is a certain amount of energy (W) used in a certain length of time (t), expressed as follows:

$$P = \frac{W}{t}$$

Equation 4–1

where P is power in watts (W), W is energy in joules (J), and t is time in seconds (s). Note that an italic W is used to represent energy in the form of work and a nonitalic W is used for watts, the unit of power. The **joule (J)** is the SI unit of energy.

Energy in joules divided by time in seconds gives power in watts. For example, if 50 J of energy are used in 2 s, the power is 50 J/2 s = 25 W. By definition,

One watt (W) is the amount of power when one joule of energy is used in one second.

Thus, the number of joules used in one second is always equal to the number of watts. For example, if 75 J are used in 1 s, the power is $P = W/t = 75\ \text{J}/1\ \text{s} = 75\ \text{W}$.

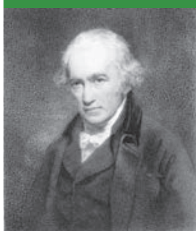
Amounts of power much less than one watt are common in certain areas of electronics. As with small current and voltage values, metric prefixes are used to designate small amounts of power. Thus, milliwatts (mW) and microwatts (μW) are commonly found in some applications.

In the electrical utilities field, kilowatts (kW) and megawatts (MW) are common units. Various types of transmitters including broadcast stations (radio and TV), radar, and even space communications use large amounts of power to transmit signals, so kW and MW are commonly used to state power levels in these fields. Another larger power unit in common use is the **horsepower**. Large electric motors are commonly rated in horsepower (hp) where $1\ \text{hp} = 746\ \text{W}$.

Since power is the rate at which energy is used, as expressed in Equation 4–1, power utilized over a period of time represents energy consumption. If you multiply power in watts and time in seconds, you have energy in joules, symbolized by W.

$$W = Pt$$

HISTORY NOTE



James Watt
1736–1819

Watt was a Scottish inventor and was well known for his improvements to the steam engine that made it practical for industrial use. Watt patented several inventions, including the rotary engine. The unit of power is named in his honor. (Photo credit: Library of Congress.)

EXAMPLE 4–1 An amount of energy equal to 100 J is used in 5 s. What is the power in watts?

Solution

$$P = \frac{\text{energy}}{\text{time}} = \frac{W}{t} = \frac{100\text{ J}}{5\text{ s}} = \mathbf{20\ W}$$

*Related Problem** If 100 W of power occurs for 30 s, how much energy, in joules, is used?

*Answers are at the end of the chapter.

EXAMPLE 4–2 Express the following values of electrical power using appropriate metric prefixes:

(a) 0.045 W **(b)** 0.000012 W **(c)** 3,500 W **(d)** 10,000,000 W

Solution

(a) 0.045 W = **45 mW** **(b)** 0.000012 W = **12 μW**

(c) 3500 W = **3.5 kW** **(d)** 10,000,000 W = **10 MW**

Related Problem Express the following amounts of power in watts without metric prefixes:

(a) 1 mW (b) 1,800 μW (c) 1,000 mW (d) 1 μW

HISTORY NOTE

James Prescott Joule 1818–1889

Joule, a British physicist, is known for his research in electricity and thermodynamics. He formulated the relationship that states that the amount of heat energy produced by an electrical current in a conductor is proportional to the conductor's resistance and the time. The unit of energy is named in his honor. (Photo credit: Library of Congress.)

The Kilowatt-hour (kWh) Unit of Energy

The joule has been defined as a unit of energy. However, there is another way to express energy. Since power is expressed in watts and time in seconds, units of energy called the watt-second (Ws), watt-hour (Wh), and kilowatt-hour (kWh) can be used.

When you pay your electric bill, you are charged on the basis of the amount of energy you use, not the power. Because power companies deal in huge amounts of energy, the most practical unit is the kilowatt-hour. You use a **kilowatt-hour (kWh)** of energy when you use one thousand watts of power for one hour. For example, a 100 W light bulb burning for 10 h uses 1 kWh of energy.

$$W = Pt = (100\text{ W})(10\text{ h}) = 1{,}000\text{ Wh} = 1\text{ kWh}$$

EXAMPLE 4–3 A 10 hp motor in a factory runs 16 h per day at full load. How many kWh are used?

Solution

$$W = Pt = \frac{(10\text{ hp})(746\text{ W/hp})(16\text{ h})}{1{,}000\text{ W/kW}}$$

$$= \mathbf{119\ kWh}$$

Related Problem A 2 hp motor runs 24 h/day, seven days per week. What is the energy in kWh used in one week?

EXAMPLE 4–4

Determine the number of kilowatt-hours (kWh) for each of the following energy consumptions:

(a) 1,400 W for 1 h **(b)** 2,500 W for 2 h **(c)** 100,000 W for 5 h

Solution **(a)** $1{,}400\ \text{W} = 1.4\ \text{kW}$

$W = Pt = (1.4\ \text{kW})(1\ \text{h}) = \mathbf{1.4\ kWh}$

(b) $2{,}500\ \text{W} = 2.5\ \text{kW}$

$W = (2.5\ \text{kW})(2\ \text{h}) = \mathbf{5\ kWh}$

(c) $100{,}000\ \text{W} = 100\ \text{kW}$

$W = (100\ \text{kW})(5\ \text{h}) = \mathbf{500\ kWh}$

Related Problem How many kilowatt-hours are used by a 1/2 hp motor running continuously for 8 h?

SECTION 4–1 CHECKUP

Answers are at the end of the chapter.

1. Define *power*.
2. Write the formula for power in terms of energy and time.
3. Define *watt*.
4. Express each of the following values of power in the most appropriate units:
   (a) 68,000 W (b) 0.005 W (c) 0.000025 W
5. If you use 100 W of power for 10 h, how much energy (in kWh) have you used?
6. Convert 2,000 Wh to kilowatt-hours.
7. Convert 360,000 Ws to kilowatt-hours.
8. How many watts are represented by 1 horsepower?

4–2 Power in an Electric Circuit

The generation of heat, which occurs when electrical energy is converted to heat energy, is usually an unwanted by-product of current through the resistance in the circuit. In some cases, however, the generation of heat is the primary purpose of a circuit as, for example, in an electric resistive heater. In any case, you must frequently deal with power in electrical and electronic circuits.

After completing this section, you should be able to

- **Calculate power in a circuit**
  - Determine power when you know I and R values
  - Determine power when you know V and I values
  - Determine power when you know V and R values

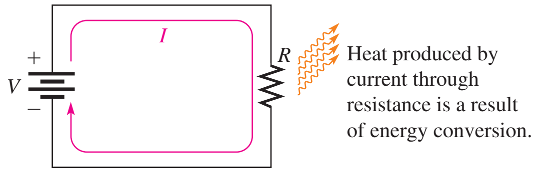
When there is current through resistance, the collisions of the electrons produce heat as a result of the conversion of electrical energy, as indicated in Figure 4–1. The amount of power dissipated in an electric circuit is dependent on the amount of resistance and on the amount of current, expressed as follows:

$$P = I^2R \qquad \text{Equation 4–2}$$

where P is power in watts (W), I is current in amperes (A), and R is resistance in ohms (Ω). You can get an equivalent expression for power in terms of voltage and current by substituting V for IR (I^2 is $I \times I$).

$$P = I^2R = (I \times I)R = I(IR) = (IR)I$$

$$P = VI \qquad \text{Equation 4–3}$$



▲ FIGURE 4–1

Power dissipation in an electric circuit results in heat energy given off by the resistance.

where P is in watts when V is in volts and I is in amperes. Equation 4–3 makes sense from a dimensional point of view. Note that a volt is a joule/coulomb and an ampere is a coulomb/second. Therefore,

$$P = VI = \left(\frac{\text{joules}}{\cancel{\text{coulomb}}}\right)\left(\frac{\cancel{\text{coulombs}}}{\text{sec}}\right) = \frac{\text{joules}}{\text{second}} = \text{watts}$$

It is a good check on your work to verify that the units make sense. This type of check is called *dimensional analysis*.

You can obtain another equivalent expression by substituting V/R for I (Ohm's law).

$$P = VI = V\left(\frac{V}{R}\right)$$

Equation 4–4

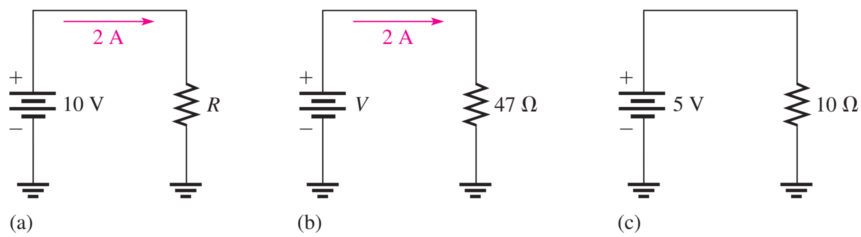
$$P = \frac{V^2}{R}$$

The relationships between power and current, voltage, and resistance expressed in the preceding formulas are known as **Watt's law**. In each case, I must be in amps, V in volts, and R in ohms. To calculate the power in a resistance, you can use any one of the three power formulas, depending on what information you have. For example, assume that you know the values of current and voltage. In this case calculate the power with the formula $P = VI$. If you know I and R, use the formula $P = I^2R$. If you know V and R, use the formula $P = V^2/R$.

EXAMPLE 4–5

Calculate the power in each of the three circuits of Figure 4–2.

▶ FIGURE 4–2



Solution In circuit (a), you know V and I. Therefore, use Equation 4–3.

$$P = VI = (10\text{ V})(2\text{ A}) = \mathbf{20\ W}$$

In circuit (b), you know I and R. Therefore, use Equation 4–2.

$$P = I^2R = (2\text{ A})^2(47\ \Omega) = \mathbf{188\ W}$$

In circuit (c), you know V and R. Therefore, use Equation 4–4.

$$P = \frac{V^2}{R} = \frac{(5\text{ V})^2}{10\ \Omega} = \mathbf{2.5\ W}$$

Related Problem Determine P in each circuit of Figure 4–2 for the following changes:

Circuit (a): I doubled and V remains the same

Circuit (b): R doubled and I remains the same

Circuit (c): V halved and R remains the same

EXAMPLE 4–6 A 100 W light bulb operates on 120 V. How much current does it require?

Solution Use the formula $P = VI$ and solve for I by first transposing the terms to get I on the left side in the equation.

$$VI = P$$

Rearranging,

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

Substituting 100 W for P and 120 V for V yields

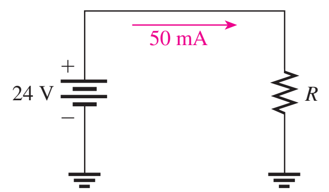
$$I = \frac{P}{V} = \frac{100\text{ W}}{120\text{ V}} = 0.833\text{ A} = \mathbf{833\text{ mA}}$$

Related Problem A light bulb draws 545 mA from a 120 V source. What is the power dissipated?

SECTION 4–2 CHECKUP

1. If there are 10 V across a resistor and a current of 3 A through it, what is the power dissipated?
2. How much power does the source in Figure 4–3 generate? What is the power in the resistor? Are the two values the same? Why?

▶ FIGURE 4–3



3. If there is a current of 5 A through a 56 Ω resistor, what is the power dissipated?
4. How much power is dissipated by 20 mA through a 4.7 kΩ resistor?
5. Five volts are applied to a 10 Ω resistor. What is the power dissipated?
6. How much power does a 2.2 kΩ resistor with 8 V across it dissipate?
7. What is the resistance of a 75 W bulb that uses 0.5 A?

4–3 RESISTOR POWER RATINGS

As you know, a resistor gives off heat when there is current through it. The limit to the amount of heat that a resistor can give off is specified by its power rating.

After completing this section, you should be able to

- **Properly select resistors based on power consideration**
  - Define *power rating*
  - Explain how physical characteristics of resistors determine their power rating
  - Check resistance values with a digital multimeter (DMM) and an analog Volt-Ohmmeter (VOM)

The **power rating** is the maximum amount of power that a resistor can dissipate without being damaged or changed in value by excessive heat. The power rating is not related to the ohmic value (resistance) but rather is determined mainly by the physical composition, size, and shape of the resistor. All else being equal, the larger the surface area of a resistor, the more power it can dissipate. *The surface area of a cylindrically shaped resistor is equal to the length (l) times the circumference (c),* as indicated in Figure 4–4. The area of the ends is not included.

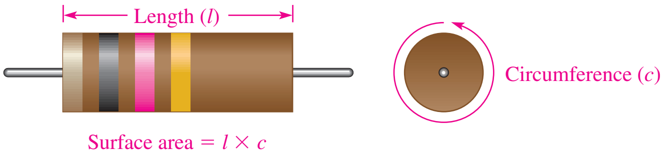


FIGURE 4–4

The power rating of a resistor is directly related to its surface area.

TECH NOTE

Sometimes an overheated resistor is due to another failure in the circuit. After replacing a heat-damaged resistor and before restoring power, check for visual faults that may cause excessive current, such as a short between two conductors.

Metal-film resistors are available in standard power ratings from $\frac{1}{8}$ W to 1 W, as shown in Figure 4–5. Available power ratings for other types of resistors vary. For example, wirewound resistors have ratings up to 225 W or greater. Figure 4–6 shows some of these resistors.

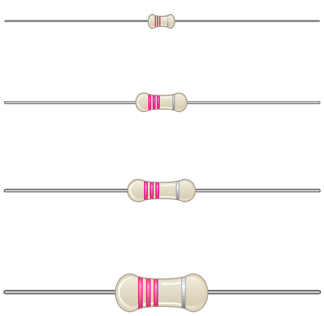
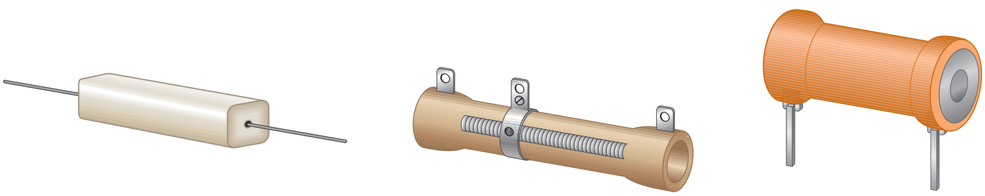


FIGURE 4–5

Relative sizes of metal-film resistors with standard power ratings of $\frac{1}{8}$ W, $\frac{1}{4}$ W, $\frac{1}{2}$ W, and 1 W.



(a) Axial-lead wirewound (b) Adjustable wirewound (c) Radial-lead for PC board insertion

FIGURE 4–6

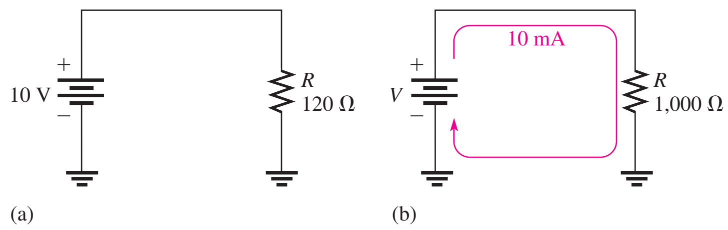
Typical resistors with high power ratings.

The power rating of a resistor must be greater than the maximum power that it will have to handle. Typically, resistors are specified to an ambient temperature of 70°C. At higher ambient temperatures, the resistor power ratings are decreased according to a derating curve provided by the manufacturer. The circuit designer may provide forced convective cooling to maintain a safe temperature. For example, if a resistor is to dissipate 0.75 W in a circuit application, its rating should be at least the next higher standard value which is 1 W. There are a number of factors that engineers must consider in specifying resistor power rating including spacing of components including other resistors, air flow, ambient temperature, altitude, and any heat sinks. As a rule of thumb, engineers tend to pick a resistor power rating that is at least twice the calculated power dissipation to increase component reliability unless there are overriding considerations, such as physical design constraints. At a minimum, choose a rating larger than the actual power when possible to provide a safety margin.

EXAMPLE 4–7

Choose a minimum power rating for each of the metal-film resistors in Figure 4–7 ($\frac{1}{8}$ W, $\frac{1}{4}$ W, $\frac{1}{2}$ W, or 1 W).

▶ FIGURE 4–7



Solution In Figure 4–7(a), the actual power is

$$P = \frac{V^2}{R} = \frac{(10\text{ V})^2}{120\ \Omega} = \frac{100\text{ V}^2}{120\ \Omega} = 0.833\text{ W}$$

Select a resistor with a power rating of **1 W**.

In Figure 4–7(b), the actual power is

$$P = I^2R = (10\text{ mA})^2(1{,}000\ \Omega) = (10 \times 10^{-3}\text{ A})^2(1{,}000\ \Omega) = 0.1\text{ W}$$

At least a **$\frac{1}{8}$ W (0.125 W) resistor** should be used in this case.

Related Problem A certain resistor is required to dissipate 0.25 W. What standard rating should be used?

When the power in a resistor is greater than its rating, the resistor will become excessively hot. As a result, the resistor may burn open or its resistance value may permanently change and/or its lifetime can be reduced. In extreme cases, a fire can result.

A resistor that has been damaged because of overheating can often be detected by the charred or altered appearance of its surface. If there is no visual evidence, a resistor that is suspected of being damaged can be checked with an ohmmeter for an open or incorrect resistance value. Recall that one or both leads of a resistor should be removed from a circuit to measure resistance.

SAFETY NOTE

Some resistors can become very hot in normal operation. To avoid a burn, do not touch a circuit component while the power is connected to the circuit. After power has been turned off, allow time for the components to cool down.

Measuring Resistance with a Digital Multimeter (DMM)

A digital multimeter, such as the one shown in Figure 4–8(a) is the most common method to measure resistance. The large rotary switch is used to select the function to be measured—in this case the ohms function. The resistance to be measured is isolated from other components, and probes are touched (or connected) to the resistor. You should not hold both ends of a resistor or your body resistance will be included in the measurement. The meter will position the decimal automatically to display the resistance reading including inserting the correct metric prefix when necessary.

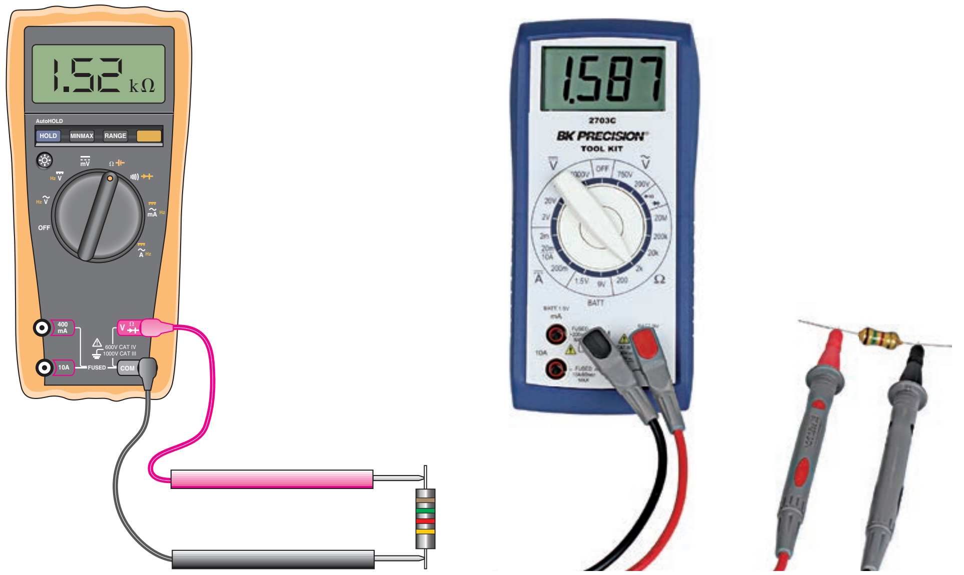
The meter shown in Figure 4–8(b) is a manual ranging meter and is similar in operation to the auto ranging meter but the decimal point is *not* automatically positioned. The user uses the selection switch to choose the function *and* the range. In the OHMS positions there are several ranges in multiples of 10 to choose from. The best resolution will be the range that is just larger than the resistor. If the range selected is too low, the meter typically read 1 with a blank space after it. Move the function selection to the next higher range and try again. If the range setting is too high, the reading will lack significant figures. Choose a lower, more sensitive range to measure with better resolution. In Figure 4–8(b), it is set to the 2kΩ range.

Measuring Resistance with an Analog Volt-Ohmmeter

Figure 4–9 shows an analog volt-ohmmeter (referred to as a VOM). The meter shown is the Simpson 260-8, which is a classic meter still preferred by many people for making measurements in low power applications. The 260-8 has a small function switch

FIGURE 4–8

Typical multimeters measuring resistance with the ohms function.



(a) Auto ranging DMM

(b) Manual ranging DMM

on the left side of the front panel and a central range switch to select one of the available ranges. To measure resistance, the function switch is set to either the +DC or the −DC position and the test leads are connected to the COMMON and the + jack. The range switch is rotated to an appropriate range and the leads are connected together. The ZERO OHMS control is rotated until the pointer indicates zero ohms. Power must be off when connecting the leads to a circuit and the desired resistance must be isolated. The resistance is read on the top scale with increasing resistance to the left side. The resistance reading is multiplied by the factor shown on the range switch. For example, if the pointer is at 50 on the ohms scale and the range switch is set at R $\times$ 10, the resistance being measured is $50 \times 10\,\Omega = 500\,\Omega$. *If the resistor is open, the pointer will stay at full left scale (∞ means infinite) regardless of the range switch setting.*

FIGURE 4–9

The Simpson 260-8 volt-ohmmeter. (Courtesy of Simpson Electric Co.)

EXAMPLE 4–8

Determine whether the resistor in each circuit of Figure 4–10 has possibly been damaged by overheating.

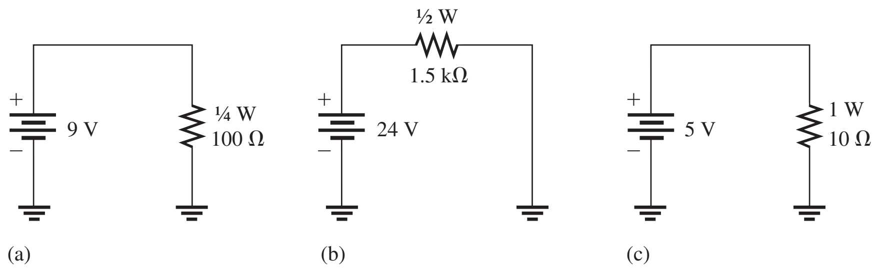


FIGURE 4–10

Solution In the circuit in Figure 4–10(a),

$$P = \frac{V^2}{R} = \frac{(9\text{ V})^2}{100\ \Omega} = 0.810\text{ W} = 810\text{ mW}$$

The rating of the resistor is $1/4$ W (0.25 W), which is insufficient to handle the power. The resistor has been overheated and may be burned out, making it an open.

In the circuit of Figure 4–10(b),

$$P = \frac{V^2}{R} = \frac{(24\text{ V})^2}{1.5\text{ k}\Omega} = 0.384\text{ W} = 384\text{ mW}$$

The rating of the resistor is $1/2$ W (0.5 W), which is sufficient to handle the power.

In the circuit of Figure 4–10(c),

$$P = \frac{V^2}{R} = \frac{(5\text{ V})^2}{10\ \Omega} = 2.5\text{ W}$$

The rating of the resistor is 1 W, which is insufficient to handle the power. The resistor has been overheated and may be burned out, making it an open.

Related Problem A 0.25 W, 1.0 kΩ resistor is connected across a 12 V battery. Is the power rating adequate?

SECTION 4–3 CHECKUP

1. Name two important values associated with a resistor.
2. How does the physical size of a resistor determine the amount of power that it can handle?
3. List the standard power ratings of metal-film resistors.
4. A resistor must handle 0.3 W. What minimum power rating of a metal-film resistor should be used to dissipate the energy properly?
5. What is the maximum voltage that can be applied to a $1/4$ W 100 Ω resistor if the power rating is not to be exceeded?
6. What resistance is indicated by a VOM if the pointer is on 30 and the R × 10,000 range is selected?

4–4 Energy Conversion and Voltage Drop in Resistance

As you have learned, when there is current through a resistance, electrical energy is converted to heat energy. This heat is caused by collisions of the free electrons within the atomic structure of the resistive material. When a collision occurs, heat is given off; and the electron gives up some of its acquired energy as it moves through the material.

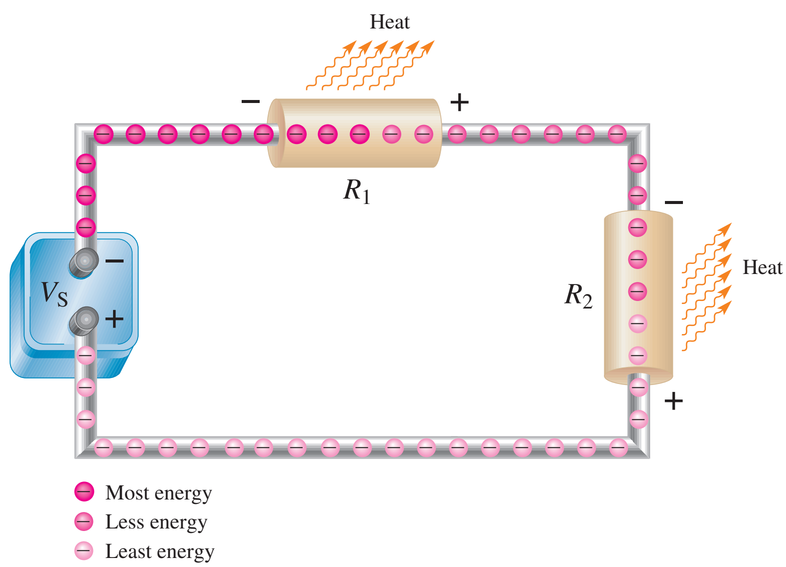
After completing this section, you should be able to

- **Explain energy conversion and voltage drop**
  - Discuss the cause of energy conversion in a circuit
  - Define *voltage drop*
  - Explain the relationship between energy conversion and voltage drop

Figure 4–11 illustrates charge in the form of electrons flowing from the negative terminal of a battery, through a circuit, and back to the positive terminal. As they emerge from the negative terminal, the electrons are at their highest energy level. The electrons flow through each of the resistors that are connected together to form a current path. (This type of connection is called series, as you will learn in Chapter 5). As the electrons flow through each resistor, some of their energy is given up in the form of heat. Therefore, the electrons have more energy when they enter a resistor than when they exit the resistor, as illustrated in the figure by the decrease in the intensity of the red color. When they have traveled through the circuit back to the positive terminal of the battery, the electrons are at their lowest energy level.

FIGURE 4–11

A loss of energy by electrons (charge) as they flow through a resistance creates a voltage drop because voltage equals energy divided by charge.



Recall that voltage equals energy per charge ($V = W/Q$) and charge is a property of electrons. Based on the voltage of the battery, a certain amount of energy is imparted to all of the electrons that flow out of the negative terminal. The same number of electrons flow at each point throughout the circuit, but their energy decreases as they move through the resistance of the circuit.

In Figure 4–11, the voltage at the left end of R_1 is equal to W_{enter}/Q and the voltage at the right end of R_1, is equal to W_{exit}/Q. The same number of electrons that enter R_1 also exit R_1, so Q is constant. However, the energy W_{exit} is less than W_{enter}, so the voltage at the right end of R_1 is less than the voltage at the left end. This decrease in voltage across the resistor due to a loss of energy is called a **voltage drop**. The voltage at the right end of R_1 is less negative (or more positive) than the voltage at the left end. The voltage drop is indicated by $-$ and $+$ signs (the $+$ implies a more positive voltage).

The electrons have lost some energy in R_1 and now they enter R_2 with a reduced energy level. As they flow through R_2 they lose more energy, resulting in another voltage drop across R_2.

SECTION 4–4 CHECKUP

1. What is the basic reason for energy conversion in a resistor?
2. What is a voltage drop?
3. What is the polarity of a voltage drop in relation to conventional current direction?

4–5 Power Supplies and Batteries

Recall that power supplies and batteries were briefly introduced as types of voltage sources in Chapter 2. In general, a *power supply* is a device that converts energy from one form to another for a load. Usually, it converts ac (alternating current) from the utility lines to a dc (direct current) voltage that virtually all electronic circuits and some transducers require. Batteries are also capable of supplying dc; in fact, many systems, such as laptop computers, can run from either a power supply or internal battery. In this section, both types of voltage sources are described.

After completing this section, you should be able to

- **Discuss the characteristics of power supplies and batteries**
  - Describe controls on typical laboratory power supplies
  - Determine the efficiency of a power supply given the input and output power
  - Define ampere-hour rating of batteries

Utilities universally have adopted ac for transmitting electricity from the generating station to the user because it can be readily transformed to high voltages for transmission and low voltages for the end user. High voltages are much more efficient and cost-effective to transmit over long distances. For a given amount of power, a higher voltage means less current; as a result resistance loss in power lines is greatly reduced. In the United States, the standard voltage supplied to outlets is approximately 120 V or 240 V at 60 Hz, but in Europe and other countries, the outlet voltage is 240 V at 50 Hz.

Virtually all electronic systems require stable dc for the integrated circuits and other devices to work properly. Power supplies fulfill this function by converting ac to stable dc and are usually built into the product. Many electronic systems have a recessed and protected switch that allows the internal power supply to be set for either the 120 V standard or for the 240 V standard. That switch must be set correctly, or serious damage can occur to the equipment. Some ac/dc adapters are autoswitching thus eliminating the need to select the correct voltage.

In the laboratory, circuits are developed and tested. Generally, a laboratory **power supply** is required for testing electronic circuits to convert ac line voltage to dc required by the circuit under test. In some cases a battery can provide the necessary dc. The test circuit can be anything from a simple resistive network to a complex amplifier or logic circuit. To meet the requirement for a constant voltage, with almost no noise or ripple, laboratory power supplies are **regulated,** meaning the output is constantly sensed and automatically adjusted if it tries to change because of a change in the line voltage or the load.

Many circuits require multiple voltages, as well as the ability to set the voltage to a precise value or change it a small amount for testing. For this reason, laboratory power supplies usually have two or three outputs that are independent of each other and can be controlled separately. Output metering is normally part of a good laboratory power supply, in order to set and monitor the output voltage or current. Control may include fine and coarse controls or digital inputs to set precise voltages.

Figure 4–12 shows a triple output bench supply such as the type used in many electronic laboratories. The model shown has two 0–30 V independent supplies and a 4–6.5 V high current supply (commonly referred to a logic supply). Voltages can be precisely set using coarse and fine controls. The 0–30 V supplies have floating outputs, meaning they are not referenced to ground. This allows the user to set them up as a positive or negative supply, wire them in series to obtain up to 60 V out, wire them in parallel for greater current, or even connect them to another external supply. They can also be set up to track changes in the other supply, a useful feature for circuits requiring positive and negative voltages. Another feature of this supply is that it can be set up as a current source, with a maximum voltage set for constant current applications.

FIGURE 4–12

A triple output power supply. (Courtesy B+K Precision)

As in many power supplies, there are three output jacks for each of the 0–30 V supplies. The output is taken between the red (more positive) and black terminals. The green jack is referenced to the chassis, which is earth ground, and can be connected to either the red or black jacks. In addition, current and voltage can be monitored using the built-in digital meters.

The power delivered by a power supply is the product of the absolute voltage and current. For example, if a power supply is providing −15.0 V at 3.0 A, the supplied power is 45 W. For a triple output supply, the total power supplied by all three supplies is the sum of the power from each one individually.

EXAMPLE 4–9

What is the total power delivered by a triple output power supply if the output voltage and current are as follows?

Source 1: 18 V at 2.0 A

Source 2: −18 V at 1.5 A

Source 3: 5.0 V at 1.0 A

Solution Power delivered from each supply is the product of voltage and current (ignoring the sign).

Source 1: $P_1 = V_1I_1 = (18\text{ V})(2.0\text{ A}) = 36\text{ W}$

Source 2: $P_2 = V_2I_2 = (18\text{ V})(1.5\text{ A}) = 27\text{ W}$

Source 3: $P_3 = V_3I_3 = (5.0\text{ V})(1.0\text{ A}) = 5.0\text{ W}$

The total power is

$$P_T = P_1 + P_2 + P_3 = 36\text{ W} + 27\text{ W} + 5.0\text{ W} = \mathbf{68\text{ W}}$$

Related Problem How will the total power delivered change if the current from Source 1 increases to 2.5 A?

Power Supply Efficiency

An important characteristic of electronic power supplies is efficiency. **Efficiency** is the ratio of the output power delivered to a load to the input power to a circuit.

$$\text{Efficiency} = \frac{P_{OUT}}{P_{IN}} \quad \text{Equation 4–5}$$

Efficiency is often expressed as a percentage. For example, if the input power is 100 W and the output power is 50 W, the efficiency is $(50\text{ W}/100\text{ W}) \times 100\% = 50\%$.

All electronic power supplies require that power be put into them; for this reason, they are considered to be energy converters. For example, an electronic power supply generally uses the ac power from a wall outlet as its input. Its output is usually a regulated dc voltage. The output power is *always* less than the input power because some of the total power must be used internally to operate the power supply circuitry. This internal power dissipation is normally called the *power loss.* The output power is the input power minus the power loss.

$$P_{OUT} = P_{IN} - P_{LOSS} \quad \text{Equation 4–6}$$

High efficiency means that very little power is dissipated in the power supply and there is a higher proportion of output power for a given input power.

EXAMPLE 4–10

A certain electronic power supply requires 25 W of input power. It can produce an output power of 20 W. What is its efficiency, and what is the power loss?

Solution

$$\text{Efficiency} = \frac{P_{OUT}}{P_{IN}} = \frac{20\text{ W}}{25\text{ W}} = \mathbf{0.8}$$

Expressed as a percentage,

$$\text{Efficiency} = \left(\frac{20\text{ W}}{25\text{ W}}\right)100\% = 80\%$$

The power loss is

$$P_{LOSS} = P_{IN} - P_{OUT} = 25\text{ W} - 20\text{ W} = \mathbf{5\text{ W}}$$

Related Problem A power supply has an efficiency of 92%. If P_{IN} is 50 W, what is P_{OUT}?

Ampere-Hour Ratings of Batteries

Batteries convert stored chemical energy to electrical energy. They are widely used to power small systems, such as laptop computers and cell phones, to supply the stable dc required. The batteries used in these small systems are normally rechargeable, meaning that the chemical reaction can be reversed from an external source. The capacity for any battery is measured in ampere-hours (Ah). For a rechargeable battery, the Ah rating is the capacity before it needs to be recharged. The **ampere-hour (Ah) rating** determines the length of time a battery can deliver a certain amount of current at the rated voltage. The Ah rating is a general guideline; there are other factors that affect the rating including temperature and depth of discharge.

A rating of one ampere-hour means that a battery can deliver an average of one ampere of current to a load for one hour at the rated voltage output. The ampere hour rating is derated if the current exceeds some limit. As the current draw is increased, the Ah rating goes down. In practice, a battery usually is rated for a specified current level and output voltage. For example, a lead-acid 12 V automobile battery may be rated for 100 Ah at 5 A. This means that it can produce an average of 5 A for 20 h at the rated voltage. Most lead-acid batteries are rated based on 20 hours of current draw. If the load takes more current than this rated current, the battery will need to be derated, so that it is no longer able to provide 100 Ah. All lead-acid batteries share this characteristic; there is less energy available at higher discharge rates and the battery life is shortened by higher discharge rates.

EXAMPLE 4–11

For how many hours can a battery deliver 2 A if it is rated at 70 Ah?

Solution The ampere-hour rating is the current times the number of hours (x).

$$70\text{ Ah} = (2\text{ A})(x\text{ h})$$

Solving for the number of hours, x, yields

$$x = \frac{70\text{ Ah}}{2\text{ A}} = \mathbf{35\text{ h}}$$

Related Problem A certain battery delivers 10 A for 6 h. What is its Ah rating?

SECTION 4-5 CHECKUP

1. When a loading device draws an increased amount of current from a power supply, does this change represent a greater or a smaller load on the supply?
2. A power supply produces an output voltage of 10 V. If the supply provides 0.5 A to a load, what is the power to a load?
3. If a battery has an ampere-hour rating of 100 Ah, how long can it provide 5 A to a load?
4. If the battery in Question 3 is a 12 V device, what is its power to a load for the specified value of current?
5. An electronic power supply used in the lab operates with an input power of 14 W. It can provide an output power of 10 W. What is its efficiency? Determine the power loss under these conditions.
6. What is the purpose of the green terminal on a laboratory power supply?

Application Activity

In this application, you will work on a resistor substitution box used in testing circuits with up to 5.0 V. The required resistors range from 10 Ω to 4.7 kΩ. Your job is to determine wattage rating for the required resistors, prepare a parts list, determine the cost of the parts, draw a schematic, and prepare a test procedure for the circuit. You will apply Watt's law in order to complete the assignment.

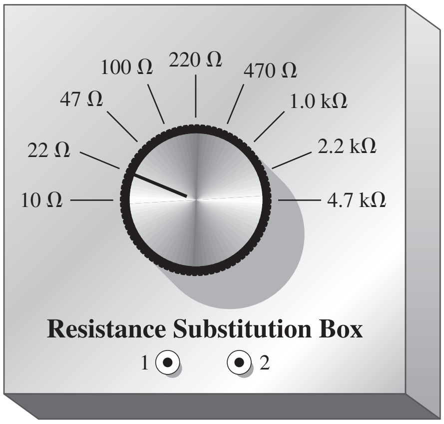
Specifications

- Each resistor is switch-selectable from a rotary switch, so that only one resistor is connected across the output terminals at a time.
- Resistors range in value from 10 Ω to 4.7 kΩ. Each of the sizes required is about twice the size of the previous resistor. In order to use standard values, the following sizes have been selected: 10 Ω, 22 Ω, 47 Ω, 100 Ω, 220 Ω, 470 Ω, and 1.0 kΩ, 2.2 kΩ, and 4.7 kΩ. Resistors are to be ±5%, with a minimum of ¼ W rating (more as needed). Small resistors (½ W or less) are carbon composition; resistors larger than ½ W are metal oxide.
- The maximum voltage that will be applied to the resistor box is 5 V.
- The box is to have two binding posts to connect to the resistors.

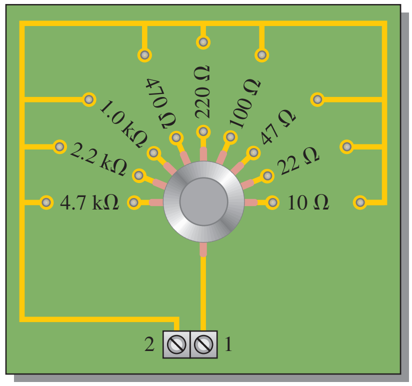
Power Ratings

The resistor box has been prepared with values silk-screened onto the enclosure box, and the reverse side of the PC board has been prepared as shown in Figure 4–13.

1. Use Watt's law and the specified resistor values to determine the power rating of the resistors needed for the project. Table 4–1 indicates the cost in small quantities for the various power ratings of the resistors.



(a) Top view of enclosure box



(b) Bottom view of PC board

▲ FIGURE 4–13

▶ TABLE 4–1

COMPONENT	COST PER ITEM
¼ W resistor (carbon comp.)	$0.08
½ W resistor (carbon comp.)	$0.09
1 W resistor (metal oxide)	$0.09
2 W resistor (metal oxide)	$0.10
5 W resistor (metal oxide)	$0.33
1 pole, 9 position rotary switch	$10.30
Knob	$3.30
Enclosure (4″ × 4″ × 2″ Al)	$8.46
Screw terminal (dual)	$0.20
Binding posts	$1.78
PC board (etched with pattern)	$1.78
Miscellaneous standoffs, etc.	$0.50

Materials List and Estimate of the Total Cost of the Project

2. Based on the specific resistors required, prepare a complete materials list showing quantities and cost.
3. Estimate the total cost of the project, not counting labor.

The Schematic

4. From the requirements and the board layout, develop a schematic for the circuit.
5. Show the resistor values including the wattage rating next to each resistor.

Test Procedure

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

Troubleshooting

Describe the most likely fault for each of the following problems and how you would check to verify the problem:

8. An ohmmeter reads infinite resistance between terminals 1 and 2 for the 10 Ω position.
9. An ohmmeter reads infinite resistance between terminals 1 and 2 for all positions of the switch.
10. All resistors read 10% higher than the listed value.

Review

11. Explain how Watt's law was applied to this problem.
12. Could the resistors you specified be used in circuits with a 7 V output? Explain.

SUMMARY

- The power rating in watts of a resistor determines the maximum power that it can handle safely.
- Resistors with a larger surface area can dissipate more power in the form of heat than smaller ones.
- A resistor should have a power rating higher than the maximum power that it is expected to handle in the circuit.
- Power rating is not related to resistance value.
- A resistor normally opens when it overheats and fails.
- Energy is the ability to do work and is equal to power multiplied by time.
- The kilowatt-hour is a unit of energy.
- One kilowatt-hour equals one thousand watts used for one hour or any other combination of watts and hours that has a product of one.
- A power supply converts energy from one form to another for a load.
- A battery is one type of power supply that converts chemical energy into electrical energy.
- An electronic power supply converts commercial energy (ac from the power company) to regulated dc at various voltage levels.
- The output power of a supply is the output voltage times the load current.
- A load is a device that draws current from the power supply.
- The capacity of a battery is measured in ampere-hours (Ah).
- One ampere-hour equals one ampere used for one hour, or any other combination of amperes and hours that has a product of one.
- For a battery, the greater the discharge rate, the lower the amount of energy that can be delivered.
- A circuit with a high efficiency has a smaller percentage power loss than one with a lower efficiency.

KEY TERMS

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

Ampere-hour (Ah) rating A capacity rating for batteries determined by multiplying the current (A) times the length of time (h) a battery can deliver that current to a load.

Efficiency The ratio of the output power delivered to a load to the input power to a circuit, usually expressed as a percentage.

Energy The ability to do work.

Joule (J) The SI unit of energy.

Kilowatt-hour (kWh) A large unit of energy used mainly by utility companies.

Power The rate of energy usage. The unit is the watt.

Voltage drop The decrease in voltage across a resistor due to a loss of energy.

Watt (W) The unit of power. One watt is the power when 1 J of energy is used in 1 s.

Watt's law A law that states the relationships of power to current, voltage, and resistance.

FORMULAS

4–1	$P = \dfrac{W}{t}$	Power equals energy divided by time.
4–2	$P = I^2R$	Power equals current squared times resistance.
4–3	$P = VI$	Power equals voltage times current.
4–4	$P = \dfrac{V^2}{R}$	Power equals voltage squared divided by resistance.
4–5	$\text{Efficiency} = \dfrac{P_{OUT}}{P_{IN}}$	Power supply efficiency
4–6	$P_{OUT} = P_{IN} - P_{LOSS}$	Output power is input power less power loss.

TRUE/FALSE QUIZ

Answers are at the end of the chapter.

1. The kilowatt-hour is a unit of power.
2. One watt is equal to one joule per second.
3. 0.050 W is the same as 50 mW.
4. The power dissipated in a resistor can be found by multiplying the voltage drop by the resistance.
5. The kilowatt and the horsepower are both units of energy.
6. The power rating of a resistor should always be less than the required power dissipation in the resistor.
7. The amount of heat that a resistor can dissipate is proportional to its surface area.
8. If the voltage across a resistor doubles, the power also doubles.
9. Watt's law states that power equals voltage times current.
10. If the current through a resistor doubles, the power increases by four.
11. Within limits, a regulated power supply can automatically keep the output voltage constant even if the load changes.
12. The efficiency of a power supply can be expressed as the power out divided by the power in.
13. A power supply that has a negative output voltage absorbs power from the load.
14. A battery Ah rating is a guide to the amount of energy it can provide.
15. When analyzing a circuit problem, you should consider the conditions under which it failed.

SELF-TEST

Answers are at the end of the chapter.

1. Power can be defined as
   (a) energy **(b)** heat
   (c) the rate at which energy is used **(d)** the time required to use energy
2. Two hundred joules of energy are consumed in 10 s. The power is
   (a) 2,000 W **(b)** 10 W **(c)** 20 W **(d)** 2 W
3. If it takes 300 ms to use 10,000 J of energy, the power is
   (a) 33.3 kW **(b)** 33.3 W **(c)** 33.3 mW
4. In 50 kW, there are
   (a) 500 W **(b)** 5,000 W **(c)** 0.5 MW **(d)** 50,000 W
5. In 0.045 W, there are
   (a) 45 kW **(b)** 45 mW **(c)** 4,500 μW **(d)** 0.00045 MW
6. For 10 V and 50 mA, the power is
   (a) 500 mW **(b)** 0.5 W **(c)** 5000,000 μW **(d)** answers (a), (b), and (c)
7. When the current through a $10\ \text{k}\Omega$ resistor is 10 mA, the power is
   (a) 1 W **(b)** 10 W **(c)** 100 mW **(d)** 1,000 μW
8. A $2.2\ \text{k}\Omega$ resistor dissipates 0.5 W. The current is
   (a) 15.1 mA **(b)** 0.227 mA **(c)** 1.1 mA **(d)** 4.4 mA
9. A $330\ \Omega$ resistor dissipates 2 W. The voltage is
   (a) 2.57 V **(b)** 660 V **(c)** 6.6 V **(d)** 25.7 V
10. If you used 500 W of power for 24 h, you have used
    (a) 0.5 kWh **(b)** 2,400 kWh **(c)** 12,000 kWh **(d)** 12 kWh
11. How many watt-hours represent 75 W used for 10 h?
    (a) 75 Wh **(b)** 750 Wh **(c)** 0.75 Wh **(d)** 7,500 Wh
12. A $100\ \Omega$ resistor must carry a maximum current of 35 mA. Its rating should be at least
    (a) 35 W **(b)** 35 mW **(c)** 123 mW **(d)** 3,500 mW

13. The power rating of a resistor that is to handle up to 1.1 W should be
    (a) 0.25 W **(b)** 1 W **(c)** 2 W **(d)** 5 W
14. A 22 Ω half-watt resistor and a 220 Ω half-watt resistor are connected across a 10 V source. Which one(s) will overheat?
    (a) 22 Ω **(b)** 220 Ω **(c)** both **(d)** neither
15. When the needle of an analog ohmmeter indicates infinity, the resistor being measured is
    (a) overheated **(b)** shorted **(c)** open **(d)** reversed
16. A 12 V battery is connected to a 600 Ω load. Under these conditions, it is rated at 50 Ah. How long can it supply current to the load?
    (a) 2,500 h **(b)** 50 h **(c)** 25 h **(d)** 4.16 h
17. A given power supply is capable of providing 8 A for 2.5 h. Its ampere-hour rating is
    (a) 2.5 Ah **(b)** 20 Ah **(c)** 8 Ah
18. A power supply produces a 0.5 W output with an input of 0.6 W. Its percentage of efficiency is
    (a) 50% **(b)** 60% **(c)** 83.3% **(d)** 45%

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 power in 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 power in 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 power in the resistor
   (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 power
   (a) increases **(b)** decreases **(c)** stays the same
5. If the resistance of a load connected to a battery is increased, the amount of time the battery can supply current
   (a) increases **(b)** decreases **(c)** stays the same
6. If the amount of time that a battery supplies current to a load is decreased, its ampere-hour rating
   (a) increases **(b)** decreases **(c)** stays the same
7. If the current that a battery supplies to a load is increased, the battery life
   (a) increases **(b)** decreases **(c)** stays the same
8. If there is no load connected to a battery, its ampere-hour rating
   (a) increases **(b)** decreases **(c)** stays the same
9. If the output voltage of a power supply increases, the power to a constant load
   (a) increases **(b)** decreases **(c)** stays the same
10. For a constant power supply output voltage, if the current to a load decreases, the load power
    (a) increases **(b)** decreases **(c)** stays the same
11. For a constant power supply output voltage, if the resistance of a load increases, the power in the load
    (a) increases **(b)** decreases **(c)** stays the same
12. If the load is removed leaving the power supply terminals open, ideally the power supply output voltage
    (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 4–1 Energy and Power

1. Prove that the unit for power (the watt) is equivalent to one volt $\times$ one amp.
2. Show that there are 3.6×10^6 joules in a kilowatt-hour.
3. What is the power when energy is consumed at the rate of 350 J/s?
4. How many watts are used when 7,500 J of energy are consumed in 5 h?
5. How many watts does 1,000 J in 50 ms equal?
6. Convert the following to kilowatts:
   (a) 1,000 W **(b)** 3,750 W **(c)** 160 W **(d)** 50,000 W
7. Convert the following to megawatts:
   (a) 1,000,000 W **(b)** 3.6×10^6 W **(c)** 15×10^7 W **(d)** 8,700 kW
8. Convert the following to milliwatts:
   (a) 1 W **(b)** 0.4 W **(c)** 0.002 W **(d)** 0.0125 W
9. Convert the following to microwatts:
   (a) 2 W **(b)** 0.0005 W **(c)** 0.25 mW **(d)** 0.00667 mW
10. Convert the following to watts:
   (a) 1.5 kW **(b)** 0.5 MW **(c)** 350 mW **(d)** 9,000 μW
11. A particular electronic device uses 100 mW of power. If it runs for 24 h, how many joules of energy does it consume?

*12. If a 300 W bulb is allowed to burn continuously for 30 days, how many kilowatt-hours of energy does it consume?

*13. At the end of a 31-day period, your utility bill shows that you have used 1,500 kWh. What is your average daily power usage?

14. Convert 5×10^6 watt-minutes to kWh.
15. Convert 6,700 watt-seconds to kWh.
16. For how many seconds must there be 5 A of current through a 47 Ω resistor in order to consume 25 J?

SECTION 4–2 Power in an Electric Circuit

17. If a 75 V source is supplying 2 A to a load, what is the resistance value of the load?
18. If a resistor has 5.5 V across it and 3 mA through it, what is the power?
19. An electric heater works on 120 V and draws 3 A of current. How much power does it use?
20. What is the power when there are 500 mA of current through a 4.7 kΩ resistor?
21. Calculate the power dissipated by a 10 kΩ resistor carrying 100 μA.
22. If there are 60 V across a 680 Ω resistor, what is the power?
23. A 56 Ω resistor is connected across the terminals of a 1.5 V battery. What is the power dissipation in the resistor?
24. If a resistor is to carry 2 A of current and handle 100 W of power, how many ohms must it be? Assume that the voltage can be adjusted to any required value.
25. A 12 V source is connected across a 10 kΩ resistor.
   (a) How much energy is used in two minutes?
   (b) If the resistor is disconnected after one minute, is the power during the first minute greater than, less than, or equal to the power during a two minute interval?

SECTION 4–3 Resistor Power Ratings

26. Refer to the Application Activity in Chapter 3 and determine the required power rating of the resistors in the motor speed-control circuit.

27. The maximum voltage is 1 V and the maximum current is 1 A in a given resistor. Should a 1 W or a 2 W resistor be used? Why?

28. A 6.8 kΩ resistor has burned out in a circuit. You must replace it with another resistor with the same resistance value. If the resistor carries 10 mA, what should its power rating be? Assume that you have available resistors in all the standard power ratings.

29. A certain type of power resistor comes in the following ratings: 3 W, 5 W, 8 W, 12 W, 20 W. Your particular application requires a resistor that can handle approximately 8 W. Which rating would you use for a minimum safety margin of 20% above the rated value? Why?

SECTION 4–4 Energy Conversion and Voltage Drop in Resistance

30. For each circuit in Figure 4–14, assign the proper polarity for the voltage drop across the resistor.

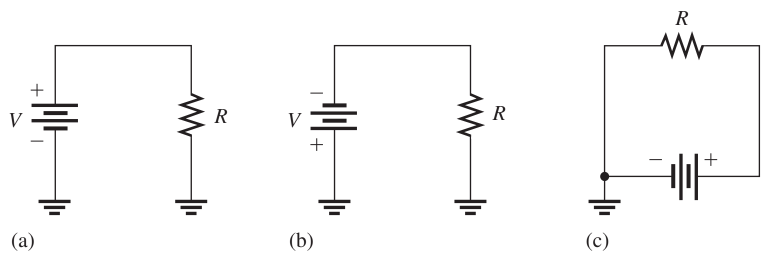


FIGURE 4–14

SECTION 4–5 Power Supplies and Batteries

31. A 50 Ω load uses 1 W of power. What is the output voltage of the power supply?

32. Assume that an alkaline D-cell battery can maintain an average voltage of 1.25 V for 90 h in a 10 Ω load before becoming unusable. What average power is delivered to the load during the life of the battery?

33. What is the total energy in joules that is delivered during the 90 h for the battery in Problem 32?

34. A battery can provide an average of 1.5 A of current for 24 h. What is its ampere-hour rating?

35. How much average current can be drawn from an 80 Ah battery for 20 h?

36. If a battery is rated at 650 mAh, how much average current will it provide for 48 h?

37. If the input power is 500 mW and the output power is 400 mW, how much power is lost? What is the efficiency of this power supply?

38. To operate at 85% efficiency, how much output power must a source produce if the input power is 5 W?

***39.** A certain power supply provides a continuous 2 W to a load. It is operating at 60% efficiency. In a 24-h period, how many kilowatt-hours does the power supply use?

Multisim Troubleshooting and Analysis

These problems require Multisim.

40. Open file P04-40 and determine the current, voltage, and resistance. Using the measured values, calculate the power.

41. Open file P04-41 and determine the current, voltage, and resistance. Calculate the power from these values.

42. Open file P04-42. Measure the current in the lamp and determine if the value agrees with that determined using the power and voltage rating of the lamp.

ANSWERS

SECTION CHECKUPS

SECTION 4–1 Energy and Power

1. Power is the rate at which energy is used.
2. $P = W/t$
3. Watt is the unit of power. One watt is the power when 1 J of energy is used in 1 s.
4. **(a)** 68,000 W = 68 kW **(b)** 0.005 W = 5 mW **(c)** 0.000025 W = 25 μW
5. $W = (0.1\text{ kW})(10\text{ h}) = 1\text{ kWh}$
6. 2,000 Wh = 2 kWh
7. 360,000 Ws = 0.1 kWh
8. 746 W

SECTION 4–2 Power in an Electric Circuit

1. $P = (10\text{ V})(3\text{ A}) = 30\text{ W}$
2. $P = (24\text{ V})(50\text{ mA}) = 1.2\text{ W}$; 1.2 W; the values are the same because all energy generated by the source is dissipated by the resistance.
3. $P = (5\text{ A})^2(56\ \Omega) = 1{,}400\text{ W}$
4. $P = (20\text{ mA})^2(4.7\text{ k}\Omega) = 1.88\text{ W}$
5. $P = (5\text{ V})^2/10\ \Omega = 2.5\text{ W}$
6. $P = (8\text{ V})^2/2.2\text{ k}\Omega = 29.1\text{ mW}$
7. $R = 75\text{ W}/(0.5\text{ A})^2 = 300\ \Omega$

SECTION 4–3 Resistor Power Ratings

1. Resistors have resistance and a power rating.
2. A larger surface area of a resistor dissipates more power.
3. 0.125 W, 0.25 W, 0.5 W, 1 W
4. A 0.5 W rating should be used for 0.3 W.
5. 5 V
6. 300,000 Ω

SECTION 4–4 Energy Conversion and Voltage Drop in Resistance

1. Energy conversion in a resistor is caused by collisions of free electrons with the atoms in the material.
2. Voltage drop is a decrease in voltage across a resistor due to a loss of energy.
3. Voltage drop is positive to negative in the direction of conventional current.

SECTION 4–5 Power Supplies and Batteries

1. More current means a greater load.
2. $P = (10\text{ V})(0.5\text{ A}) = 5\text{ W}$
3. $t = 100\text{ Ah}/5\text{ A} = 20\text{ h}$
4. $P = (12\text{ V})(5\text{ A}) = 60\text{ W}$
5. Eff $= (10\text{ W}/14\text{ W})100\% = 71\%$; $P_{\text{LOSS}} = 14\text{ W} - 10\text{ W} = 4\text{ W}$
6. To connect to the chassis ground

RELATED PROBLEMS FOR EXAMPLES

4–1 3,000 J

4–2 **(a)** 0.001 W **(b)** 0.0018 W **(c)** 1 W **(d)** 0.000001 W

4–3 3.73 kW

4–4 2.98 kWh

4–5 **(a)** 40 W **(b)** 376 W **(c)** 625 mW

4–6 65.4 W

4–7 0.5 W

4–8 Yes

4–9 77 W

4–10 46 W

4–11 60 Ah

TRUE/FALSE QUIZ

1. F **2.** T **3.** T **4.** F **5.** F **6.** F **7.** T **8.** F
9. T **10.** T **11.** T **12.** T **13.** F **14.** T **15.** T

SELF-TEST

1. (c) **2.** (c) **3.** (a) **4.** (d) **5.** (b) **6.** (d) **7.** (a) **8.** (a)
9. (d) **10.** (d) **11.** (b) **12.** (c) **13.** (c) **14.** (a) **15.** (c) **16.** (a)
17. (b) **18.** (c)

CIRCUIT DYNAMICS QUIZ

1. (a) **2.** (b) **3.** (a) **4.** (a) **5.** (a) **6.** (c)
7. (b) **8.** (c) **9.** (a) **10.** (b) **11.** (b) **12.** (c)