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
A Circuit Application

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 power supplies and their characteristics

KEY TERMS

- Energy
- Power
- Joule (J)
- Watt (W)
- Kilowatt-hour
- Voltage drop
- Power supply
- Ampere-hour rating
- Efficiency

A CIRCUIT APPLICATION PREVIEW

In the application you will see how the theory learned in this chapter is applicable to the resistance box introduced in the last chapter. Suppose that the resistance box is to be used in testing a circuit in which there will be a maximum of 4 V across all the resistors. You will evaluate the power rating of each resistor and, if it is not sufficient, to replace the resistor with one that has an adequate power rating.

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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. The rate at which the electrical energy is used is the power in the circuit.

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 a 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:

Equation 4–1

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

where: P = power in watts (W)
W = energy in joules (J)
t = 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 J/1 s = 75 W.

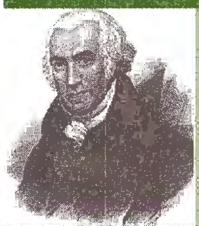
Amounts of power much less than one watt are common in certain areas of electronics. As with small current and voltage values, metric prefixes are used to designate small amounts of power. Thus, milliwatts (mW), microwatts (μW), and even picowatts (pW) are commonly found in some applications.

In the electrical utilities field, kilowatts (kW) and megawatts (MW) are common units. Radio and television stations also use large amounts of power to transmit signals. Electric motors are commonly rated in horsepower (hp) where 1 hp = 746 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.

$$W = Pt$$

BIOGRAPHY



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

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

*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)** 3500 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)** 1800 μW **(c)** 1000 mW **(d)** 1 μW

BIOGRAPHY

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** 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.

$$W = Pt = (100\text{ W})(10\text{ h}) = 1000\text{ Wh} = 1\text{ kWh}$$

EXAMPLE 4–3

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

(a) 1400 W for 1 h **(b)** 2500 W for 2 h **(c)** 100,000 W for 5 h

Solution

(a) 1400 W = 1.4 kW

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

(b) 2500 W = 2.5 kW

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

(c) 100,000 W = 100 kW

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

Related Problem How many kilowatt-hours are used by a 250 W bulb burning for 8 h?

SECTION 4–1 REVIEW
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 2000 Wh to kilowatt-hours.
7. Convert 360,000 Ws to kilowatt-hours.

4–2 POWER IN AN ELECTRIC CIRCUIT

The generation of heat, which occurs when electrical energy is converted to heat energy, in an electric circuit is often 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:

Equation 4–2
$$P = I^2R$$

where: P = power in watts (W)
I = current in amperes (A)
R = resistance in ohms (Ω)

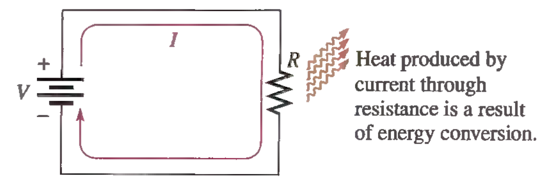
You can get an equivalent expression for power in terms of voltage and current by substituting V for IR (I^2 is $I \times I$).

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

Equation 4–3
$$P = VI$$

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

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

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

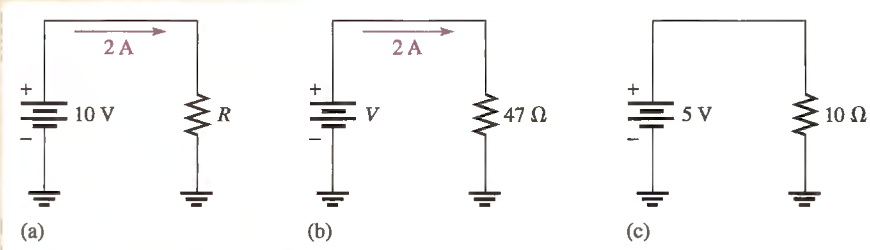
Equation 4–4

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 4–4

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 4–5

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

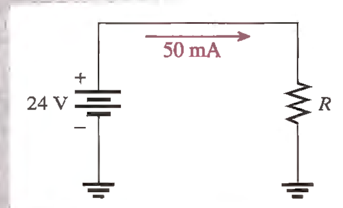
$$I = \frac{P}{V} = \frac{100\text{ W}}{120\text{ V}} = 0.833\text{ A} = \mathbf{833\text{ mA}}$$

Related Problem A light bulb draws 545 mA from a 110 V source. What is the power dissipated?

SECTION 4–2 REVIEW

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 takes 0.5 A?

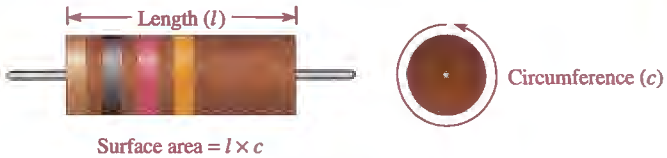
4–3 RESISTOR POWER RATINGS

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 for resistor failure with an ohmmeter

The **power rating** is the maximum amount of power that a resistor can dissipate without being damaged by excessive heat buildup. 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.



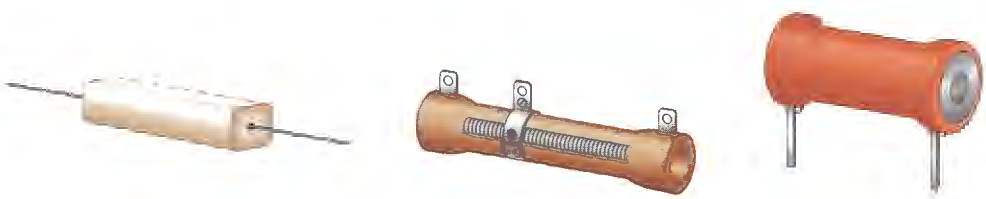
▶ FIGURE 4–4

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

Metal-film resistors are available in standard power ratings from ⅛ 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 ⅛ W, ¼ W, ½ W, and 1 W.



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

▲ FIGURE 4–6

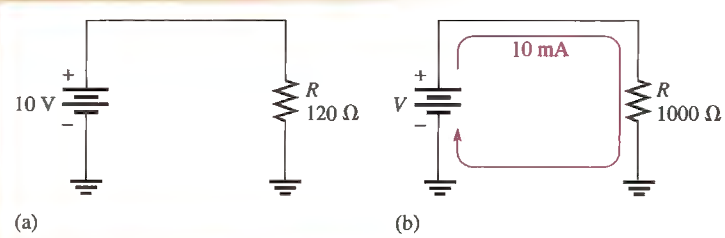
Typical resistors with high power ratings.

When a resistor is used in a circuit, its power rating must be greater than the maximum power that it will have to handle. 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. *A rating larger than the actual power should be used when possible as a safety margin.*

EXAMPLE 4–6

Choose an adequate power rating for each of the metal-film resistors in Figure 4–7 (⅛ W, ¼ W, ½ 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 higher than the actual power. In this case, a **1 W resistor** should be used.

In Figure 4–7(b), the actual power is

$$P = I^2R = (10\text{ mA})^2(1000\ \Omega) = (10 \times 10^{-3}\text{ A})^2(1000\ \Omega) = 0.1\text{ W}$$

At least a ⅛ **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, either the resistor will burn open or its resistance value will be greatly altered.

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.

NOTE

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.

Checking a Resistor with an Ohmmeter

A typical digital multimeter and an analog multimeter are shown in Figures 4–8(a) and 4–8(b), respectively. For the digital meter in Figure 4–8(a), you use the round function switch to select ohms (Ω). You do not have to manually select a range because this particular meter is autoranging and you have a direct digital readout of the resistance value. The large round switch on the analog meter is called a *range switch*. Notice the resistance (OHMS) settings on both meters.

For the analog meter in part (b), each setting indicates the amount by which the ohms scale (top scale) on the meter is to be multiplied. For example, if the pointer is at 50 on the

(a) Digital multimeter

(b) Analog multimeter

◆ FIGURE 4–8

Typical portable multimeters.
(a) Courtesy of Fluke Corporation. Reproduced with permission.
(b) Courtesy of B+K Precision.

ohms scale and the range switch is set at ×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.*

EXAMPLE 4–7

Determine whether the resistor in each circuit of Figure 4–9 has possibly been damaged by overheating.

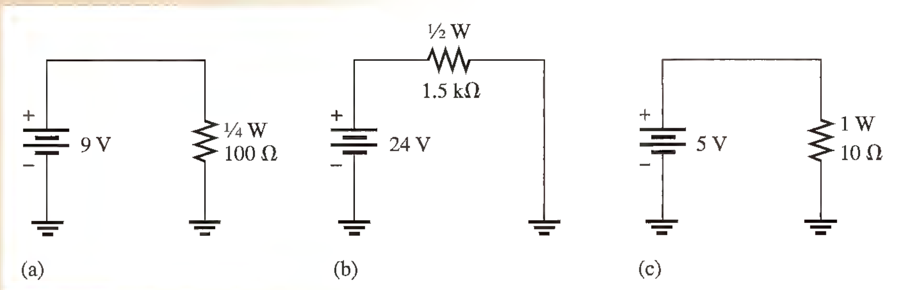


FIGURE 4–9

Solution In the circuit in Figure 4–9(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 ¼ 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 4–9(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 ½ W (0.5 W), which is sufficient to handle the power.

In the circuit of Figure 4–9(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 REVIEW

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?

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 4–10 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.

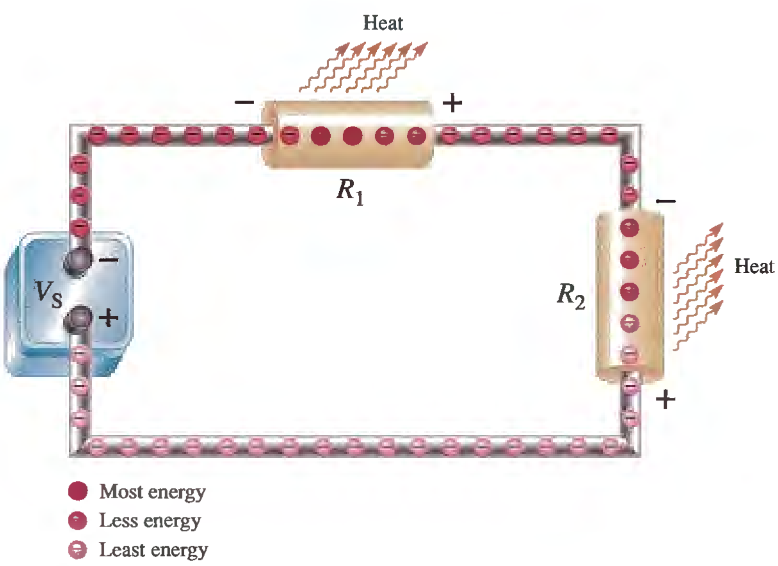


FIGURE 4–10

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 4–10, 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 less negative or 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 REVIEW

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

In general, a **power supply** is a device that provides power to a load. Recall that a load is any electrical device or circuit that is connected to the output of the power supply and draws current from the supply.

After completing this section, you should be able to

- **Discuss power supplies and their characteristics**
  - Define *ampere-hour rating* of batteries
  - Discuss electronic power supply efficiency

Figure 4–11 shows a representation of a power supply with a loading device connected to it. The load can be anything from a light bulb to a computer. The power supply produces a voltage across its two output terminals and provides current through the load, as indicated in the figure. The product IV_{OUT} is the amount of power produced by the supply and consumed by the load. For a given output voltage (V_{OUT}), more current drawn by the load means more power from the supply.

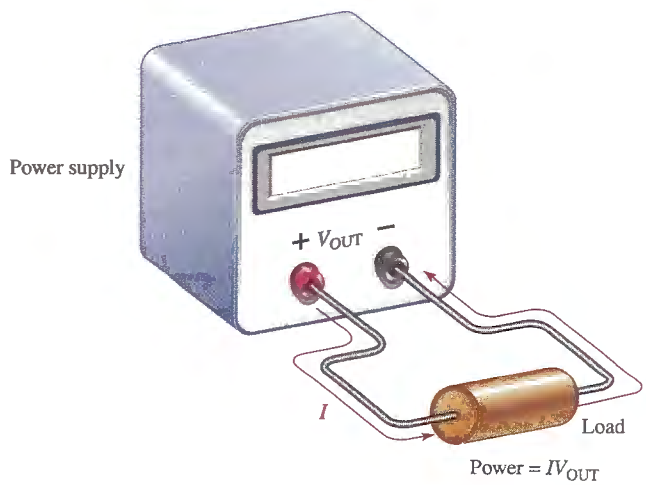


FIGURE 4–11

Power supply and load.

Power supplies range from simple batteries to regulated electronic circuits where an accurate output voltage is automatically maintained. A battery is a dc power supply that converts chemical energy into electrical energy. Electronic power supplies normally convert 110 V ac (alternating current) from a wall outlet into a regulated dc (direct current) voltage at a level suitable for electronic components.

Ampere-hour Ratings of Batteries

Batteries convert chemical energy into electrical energy. Because of their limited source of chemical energy, batteries have a certain capacity that limits the amount of time over which they can produce a given power level. This capacity is measured in ampere-hours. The **ampere-hour (Ah) rating** determines the length of time that a battery can deliver a certain amount of average current to a load at the rated voltage.

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. This same battery can deliver an average of two amperes for one-half hour. The more current the battery is required to deliver, the shorter the life of the battery. In practice, a battery usually is rated for a specified current level and output voltage. For example, a 12 V automobile battery may be rated for 70 Ah at 3.5 A. This means that it can produce an average of 3.5 A for 20 h at the rated voltage.

EXAMPLE 4–8 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

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

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

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.

Equation 4–5

$$\text{Efficiency} = \frac{P_{OUT}}{P_{IN}}$$

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 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.

Equation 4–6

$$P_{OUT} = P_{IN} - P_{LOSS}$$

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 4–9 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,

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

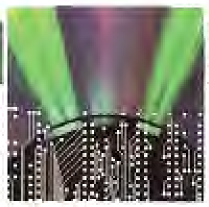
The power loss is

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

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

SECTION 4–5 REVIEW

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 1 W. It can provide an output power of 750 mW. What is its efficiency? Determine the power loss.



A Circuit Application

In this application, the resistance box that you modified in Chapter 3 is back. The last time, you verified that all the resistor values were correct. This time you must make sure each resistor has a sufficient power rating; and if the power rating is insufficient, replace the resistor with one that is adequate.

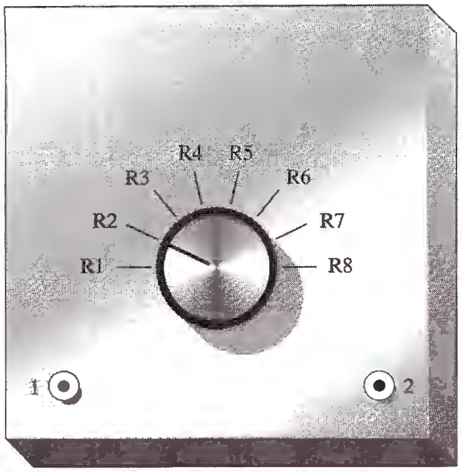
Power Ratings

Assume the power rating of each resistor in the resistance box as modified in Chapter 3 is ⅛ W. The box is shown in Figure 4–12.

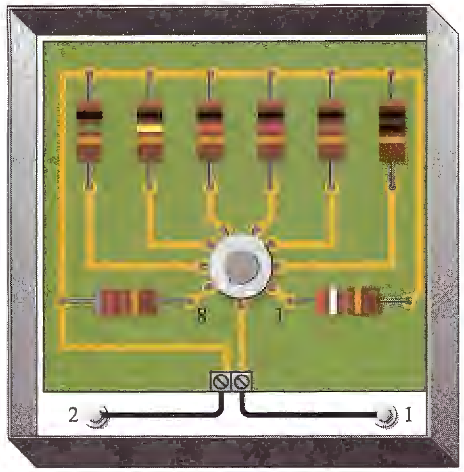
- Determine if the power rating of each resistor is adequate for a maximum of 4 V.
- If a rating is not adequate, determine the lowest rating required to handle the maximum power. Choose from standard ratings of ⅛ W, ¼ W, ½ W, 1 W, 2 W, and 5 W.
- Add the power rating of each resistor to the schematic developed in Chapter 3.

Review

1. How many resistors were replaced because of inadequate power ratings?
2. If the resistance must operate with 10 V maximum, which resistors must be changed and to what minimum power ratings?



(a) Top view



(b) Bottom view

FIGURE 4–12

SUMMARY

- The power rating in watts of a resistor determines the maximum power that it can handle safely.
- Resistors with a larger physical size 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 is an energy source used to operate electrical and electronic devices.
- 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.
- 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 number given in ampere-hours 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.

Power supply A device that provides power to a load.

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.

FORMULAS

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

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) 2000 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) 5000 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) 500,000 μW (d) answers (a), (b), and (c)
7. When the current through a 10 kΩ resistor is 10 mA, the power is
   (a) 1 W (b) 10 W (c) 100 mW (d) 1000 μW
8. A 2.2 kΩ 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 Ω 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) 2400 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) 7500 Wh
12. A 100 Ω 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) 3500 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) 2500 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

Refer to Figure 4–11.

9. If the output voltage of the power supply increases, the power to the constant load

(a) increases (b) decreases (c) stays the same

10. For a constant output voltage, if the current to the load decreases, the load power

(a) increases (b) decreases (c) stays the same

11. For a constant output voltage, if the resistance of the load increases, the power in the load

(a) increases (b) decreases (c) stays the same

12. If the load is removed from the circuit leaving an 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 × 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 7500 J of energy are consumed in 5 h?
5. How many watts does 1000 J in 50 ms equal?
6. Convert the following to kilowatts:
   (a) 1000 W (b) 3750 W (c) 160 W (d) 50,000 W
7. Convert the following to megawatts:
   (a) 1,000,000 W (b) 3×10^6 W (c) 15×10^7 W (d) 8700 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) 9000 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 1500 kWh. What is your average daily power usage?

14. Convert 5×10^6 watt-minutes to kWh.
15. Convert 6700 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 Ω 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?

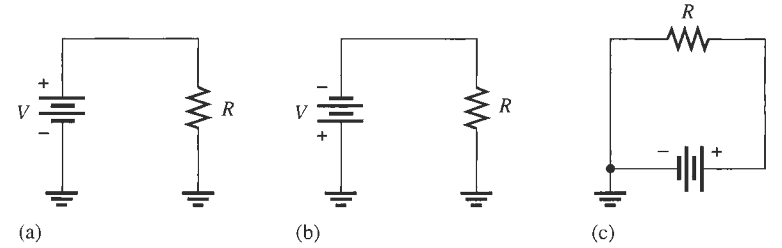
SECTION 4–3 Resistor Power Ratings

26. 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.

27. 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

28. For each circuit in Figure 4–13, assign the proper polarity for the voltage drop across the resistor.



▲ FIGURE 4–13

SECTION 4–5 Power Supplies

29. A 50 Ω load uses 1 W of power. What is the output voltage of the power supply?
30. Assume that an alkaline D-cell battery can maintain an average voltage of 1.25 V for 90 hours in a 10 Ω load before becoming unusable. What average power is delivered to the load during the life of the battery?
31. What is the total energy in joules that is delivered during the 90 hours for the battery in Problem 30?
32. A battery can provide an average of 1.5 A of current for 24 h. What is its ampere-hour rating?
33. How much average current can be drawn from an 80 Ah battery for 10 h?
34. If a battery is rated at 650 mAh, how much average current will it provide for 48 h?
35. 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?
36. To operate at 85% efficiency, how much output power must a source produce if the input power is 5 W?
*37. 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 your Multisim CD-ROM.

38. Open file P04-38 and determine the current, voltage, and resistance. Using the measured values, calculate the power.
39. Open file P04-39 and determine the current, voltage, and resistance. Calculate the power from these values.
40. Open file P04-40. 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 REVIEWS

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 kW)(10 h) = 1 kWh
6. 2000 Wh = 2 kWh
7. 360,000 Ws = 0.1 kWh

SECTION 4–2 Power in an Electric Circuit

1. P = (10 V)(3 A) = 30 W
2. P = (24 V)(50 mA) = 1.2 W; 1.2 W; the values are the same because all energy generated by the source is dissipated by the resistance.
3. $P = (5\text{ A})^2(56\ \Omega) = 1400$ W
4. $P = (20\text{ mA})^2(4.7\text{ k}\Omega) = 1.88$ W
5. $P = (5\text{ V})^2/10\ \Omega = 2.5$ W
6. $P = (8\text{ V})^2/2.2\text{ k}\Omega = 29.1$ 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.

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

1. More current means a greater load.
2. P = (10 V)(0.5 A) = 5 W
3. t = 100 Ah/5 A = 20 h
4. P = (12 V)(5 A) = 60 W
5. Eff = (0.75 W/1 W)100% = 75%; P_{LOSS} = 1000 mW − 750 mW = 250 mW

A Circuit Application

1. Two
2. 10 Ω, 10 W; 100 Ω, 1 W; 400 Ω, ¼ W

RELATED PROBLEMS FOR EXAMPLES

4–1 3000 J
4–2 (a) 0.001 W (b) 0.0018 W (c) 1 W (d) 0.000001 W
4–3 2 kWh
4–4 (a) 40 W (b) 376 W (c) 625 mW
4–5 60 W
4–6 0.5 W
4–7 Yes
4–8 60 Ah
4–9 46 W

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)