- Ohm's law states that the voltage across a linear resistor is directly proportional to the current flowing through it; i.e., $v = Ri$. (Example 2.3)
- The power dissipated by a resistor (which leads to the production of heat) is given by $p = vi = i^2R = v^2/R$. (Example 2.3)
- Wires are typically assumed to have zero resistance in circuit analysis. When selecting a wire gauge for a specific application, however, local electrical and fire codes must be consulted. (Example 2.4)

READING FURTHER

A good book that discusses the properties and manufacture of resistors in considerable depth:

Felix Zandman, Paul-René Simon, and Joseph Szwarc, *Resistor Theory and Technology.* Raleigh, N.C.: SciTech Publishing, 2002.

A good all-purpose electrical engineering handbook:

Donald G. Fink and H. Wayne Beaty, *Standard Handbook for Electrical Engineers,* 13th ed., New York: McGraw-Hill, 1993.

In particular, pp. 1-1 to 1-51, 2-8 to 2-10, and 4-2 to 4-207 provide an in-depth treatment of topics related to those discussed in this chapter.

A detailed reference for the SI is available on the Web from the National Institute of Standards:

Ambler Thompson and Barry N. Taylor, *Guide for the Use of the International System of Units (SI),* NIST Special Publication 811, 2008 edition, www.nist.gov.

EXERCISES

2.1 Units and Scales

1. Convert the following to engineering notation:
   (*a*) 0.045 W (*b*) 2000 pJ
   (*c*) 0.1 ns (*d*) 39,212 as
   (*e*) 3 Ω (*f*) 18,000 m
   (*g*) 2,500,000,000,000 bits (*h*) 10^{15} atoms/cm^3
2. Convert the following to engineering notation:
   (*a*) 1230 fs (*b*) 0.0001 decimeter
   (*c*) 1400 mK (*d*) 32 nm
   (*e*) 13,560 kHz (*f*) 2021 micromoles
   (*g*) 13 deciliters (*h*) 1 hectometer
3. Express the following in engineering units:
   (*a*) 1212 mV (*b*) 10^{11} pA
   (*c*) 1000 yoctoseconds (*d*) 33.9997 zeptoseconds
   (*e*) 13,100 attoseconds (*f*) 10^{-14} zettasecond
   (*g*) 10^{-5} second (*h*) 10^{-9} Gs
4. Expand the following distances in simple meters:
   (*a*) 1 Zm (*b*) 1 Em (*c*) 1 Pm
   (*d*) 1 Tm (*e*) 1 Gm (*f*) 1 Mm

wire size resistance

5. Convert the following to SI units, taking care to employ proper engineering notation:
   (*a*) 212°F (*b*) 0°F (*c*) 0 K
   (*d*) 200 hp (*e*) 1 yard (*f*) 1 mile
6. Convert the following to SI units, taking care to employ proper engineering notation:
   (*a*) 100°C (*b*) 0°C (*c*) 4.2 K
   (*d*) 150 hp (*e*) 500 Btu (*f*) 100 J/s
7. A certain krypton fluoride laser generates 15 ns long pulses, each of which contains 550 mJ of energy. (*a*) Calculate the peak instantaneous output power of the laser. (*b*) If up to 100 pulses can be generated per second, calculate the maximum average power output of the laser.
8. When operated at a wavelength of 750 nm, a certain Ti:sapphire laser is capable of producing pulses as short as 50 fs, each with an energy content of 500 μJ. (*a*) Calculate the instantaneous output power of the laser. (*b*) If the laser is capable of a pulse repetition rate of 80 MHz, calculate the maximum average output power that can be achieved.
9. An electric vehicle is driven by a single motor rated at 40 hp. If the motor is run continuously for 3 h at maximum output, calculate the electrical energy consumed. Express your answer in SI units using engineering notation.
10. Under insolation conditions of 500 W/m^2 (direct sunlight), and 10% solar cell efficiency (defined as the ratio of electrical output power to incident solar power), calculate the area required for a photovoltaic (solar cell) array capable of running the vehicle in Exer. 9 at half power.
11. A certain metal oxide nanowire piezoelectricity generator is capable of producing 100 pW of usable electricity from the type of motion obtained from a person jogging at a moderate pace. (*a*) How many nanowire devices are required to operate a personal MP3 player which draws 1 W of power? (*b*) If the nanowires can be produced with a density of 5 devices per square micron directly onto a piece of fabric, what area is required, and would it be practical?
12. A particular electric utility charges customers different rates depending on their daily rate of energy consumption: \$0.05/kWh up to 20 kWh, and \$0.10/kWh for all energy usage above 20 kWh in any 24 hour period. (*a*) Calculate how many 100 W light bulbs can be run continuously for less than \$10 per week. (*b*) Calculate the daily energy cost if 2000 kW of power is used continuously.
13. The Tilting Windmill Electrical Cooperative LLC Inc. has instituted a differential pricing scheme aimed at encouraging customers to conserve electricity use during daylight hours, when local business demand is at its highest. If the price per kilowatthour is \$0.033 between the hours of 9 p.m. and 6 a.m., and \$0.057 for all other times, how much does it cost to run a 2.5 kW portable heater continuously for 30 days?
14. Assuming a global population of 9 billion people, each using approximately 100 W of power continuously throughout the day, calculate the total land area that would have to be set aside for photovoltaic power generation, assuming 800 W/m^2 of incident solar power and a conversion efficiency (sunlight to electricity) of 10%.

SI

2.2 Charge, Current, Voltage, and Power

15. The total charge flowing out of one end of a small copper wire and into an unknown device is determined to follow the relationship $q(t) = 5e^{-t/2}$ C, where t is expressed in seconds. Calculate the current flowing into the device, taking note of the sign.
16. The current flowing into the collector lead of a certain bipolar junction transistor (BJT) is measured to be 1 nA. If no charge was transferred in or out of the collector lead prior to $t = 0$, and the current flows for 1 min, calculate the total charge which crosses into the collector.

Wire size resistance

23. A path around a certain electric circuit has discrete points labeled A, B, C, and D. To move an electron from points A to C requires 5 pJ. To move an electron from B to C requires 3 pJ. To move an electron from A to D requires 8 pJ. (*a*) What is the potential difference (in volts) between points B and C, assuming a "+" reference at C? (*b*) What is the potential difference (in volts) between points B and D, assuming a "+" reference at D? (*c*) What is the potential difference (in volts) between points A and B (again, in volts), assuming a "+" reference at B?

24. Two metallic terminals protrude from a device. The terminal on the left is the positive reference for a voltage called v_x (the other terminal is the negative reference). The terminal on the right is the positive reference for a voltage called v_y (the other terminal being the negative reference). If it takes 1 mJ of energy to push a single electron into the left terminal, determine the voltages v_x and v_y.

25. The convention for voltmeters is to use a black wire for the negative reference terminal and a red wire for the positive reference terminal. (*a*) Explain why two wires are required to measure a voltage. (*b*) If it is dark and the wires into the voltmeter are swapped by accident, what will happen during the next measurement?

26. Determine the power absorbed by each of the elements in Fig. 2.29.

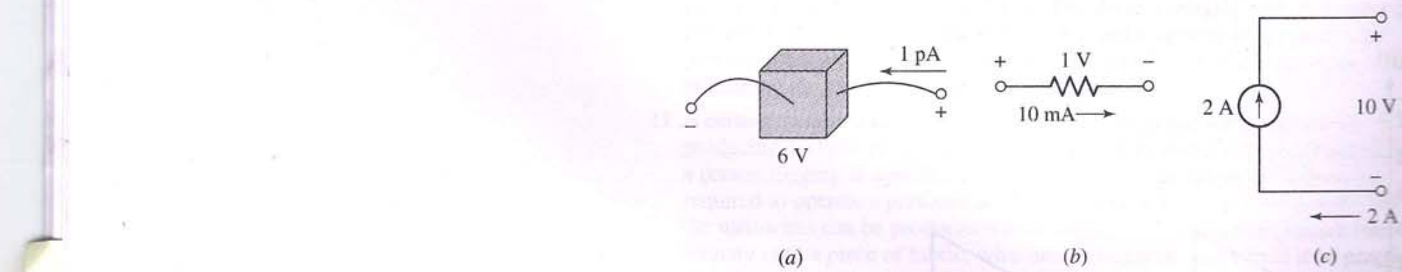

FIGURE 2.29 Elements for Exer. 26.

27. Determine the power absorbed by each of the elements in Fig. 2.30.

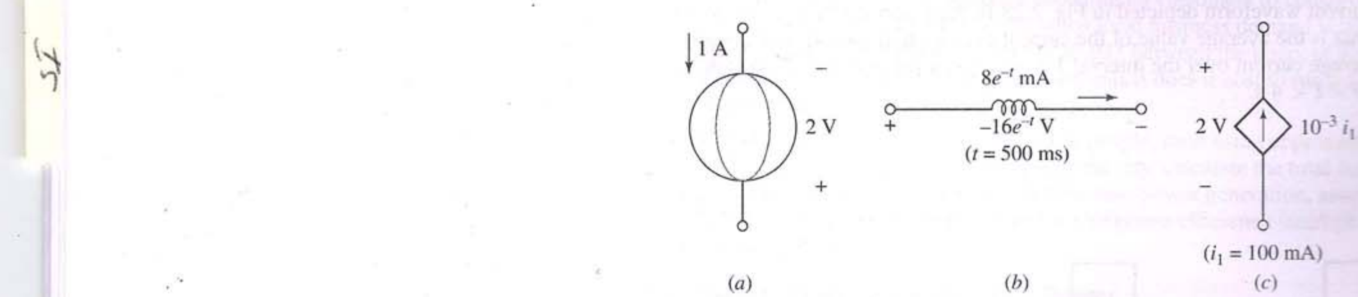

FIGURE 2.30 Elements for Exer. 27.

28. A constant current of 1 ampere is measured flowing into the positive reference terminal of a pair of leads whose voltage we'll call v_p. Calculate the absorbed power at $t = 1$ s if $v_p(t)$ equals (*a*) +1 V; (*b*) −1 V; (*c*) $2 + 5\cos(5t)$ V; (*d*) $4e^{-2t}$ V, (*e*) Explain the significance of a negative value for absorbed power.

5J

29. Determine the power supplied by the leftmost element in the circuit of Fig. 2.31.

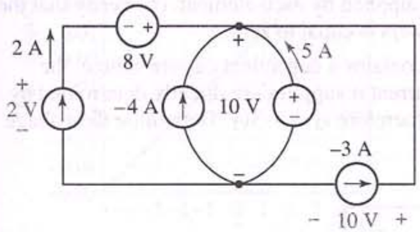

FIGURE 2.31

30. The current-voltage characteristic of a silicon solar cell exposed to direct sunlight at noon in Florida during midsummer is given in Fig. 2.32. It is obtained by placing different-sized resistors across the two terminals of the device and measuring the resulting currents and voltages.
    (*a*) What is the value of the short-circuit current?
    (*b*) What is the value of the voltage at open circuit?
    (*c*) Estimate the maximum power that can be obtained from the device.

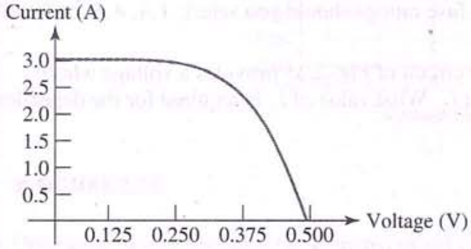

FIGURE 2.32

2.3 Voltage and Current Sources

31. Some of the ideal sources in the circuit of Fig. 2.31 are supplying positive power, and others are absorbing positive power. Determine which are which, and show that the algebraic sum of the power absorbed by each element (taking care to preserve signs) is equal to zero.
32. By careful measurements it is determined that a benchtop argon ion laser is consuming (absorbing) 1.5 kW of electric power from the wall outlet, but only producing 5 W of optical power. Where is the remaining power going? Doesn't conservation of energy require the two quantities to be equal?
33. Refer to the circuit represented in Fig. 2.33, while noting that the same current flows through each element. The voltage-controlled dependent source provides a current which is 5 times as large as the voltage V_x. (a) For $V_R = 10$ V and $V_x = 2$ V, determine the power absorbed by each element. (*b*) Is element *A* likely a passive or active source? Explain.

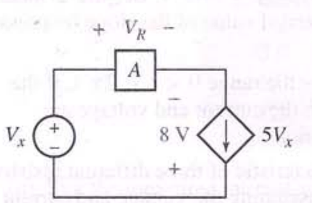

FIGURE 2.33

Wire size resistance

34. Refer to the circuit represented in Fig. 2.33, while noting that the same current flows through each element. The voltage-controlled dependent source provides a current which is 5 times as large as the voltage V_x. (*a*) For $V_R = 100$ V and $V_x = 92$ V, determine the power supplied by each element. (*b*) Verify that the algebraic sum of the supplied powers is equal to zero.

35. The circuit depicted in Fig. 2.34 contains a dependent current source; the magnitude and direction of the current it supplies are directly determined by the voltage labeled v_1. Note that therefore $i_2 = -3v_1$. Determine the voltage v_1 if $v_2 = 33i_2$ and $i_2 = 100$ mA.

FIGURE 2.34

36. To protect an expensive circuit component from being delivered too much power, you decide to incorporate a fast-blowing fuse into the design. Knowing that the circuit component is connected to 12 V, its minimum power consumption is 12 W, and the maximum power it can safely dissipate is 100 W, which of the three available fuse ratings should you select: 1 A, 4 A, or 10 A? Explain your answer.

37. The dependent source in the circuit of Fig. 2.35 provides a voltage whose value depends on the current i_x. What value of i_x is required for the dependent source to be supplying 1 W?

FIGURE 2.35

5I

2.4 Ohm's Law

38. Determine the magnitude of the current flowing through a 4.7 kΩ resistor if the voltage across it is (*a*) 1 mV; (*b*) 10 V; (*c*) $4e^{-t}$ V; (*d*) $100\cos(5t)$ V; (*e*) -7 V.

39. Real resistors can only be manufactured to a specific tolerance, so that in effect the value of the resistance is uncertain. For example, a 1 Ω resistor specified as 5% tolerance could in practice be found to have a value anywhere in the range of 0.95 to 1.05 Ω. Calculate the voltage across a 2.2 kΩ 10% tolerance resistor if the current flowing through the element is (*a*) 1 mA; (*b*) $4\sin 44t$ mA.

40. (*a*) Sketch the current-voltage relationship (current on the *y*-axis) of a 2 kΩ resistor over the voltage range of $-10\text{ V} \le V_{\text{resistor}} \le +10$ V. Be sure to label both axes appropriately. (*b*) What is the numerical value of the slope (express your answer in siemens)?

41. Sketch the voltage across a 33 Ω resistor over the range $0 < t < 2\pi$ s, if the current is given by $2.8\cos(t)$ A. Assume both the current and voltage are defined according to the passive sign convention.

42. Figure 2.36 depicts the current-voltage characteristic of three different resistive elements. Determine the resistance of each, assuming the voltage and current are defined in accordance with the passive sign convention.