in circuits. This is analogous to water flowing through a closed network of pipes with no leaks.

Kirchhoff 's First Law: The sum of all currents entering a junction point must be equal to the sum of all currents leaving that junction point.

Kirchhoff 's Second Law: The sum of the voltage drops (or rises) across all the elements around any closed loop must equal zero.

Think About It
Think about conservation of energy.

Summary

- Electric charges are positive and negative.
- Coulomb's law is described as an inverse square law for static charges.
- Electric field lines show the direction that a positive test charge would travel.
- The electrical potential difference (voltage) is a measure of the work done per unit charge.
- Conventional current indicates the flow of positive charge in a circuit.
- Ohm's law relates the voltage in a circuit to the current and electrical resistance.
- Series circuits have the same current throughout, but the potential drops are shared proportionally among the various resistors.
- Parallel circuits have the same potential difference across each resistor, but the current is divided along the circuits inversely proportional to amount of resistance in a branch.
- Kirchhoff's rule says that the sum of the currents entering a branch must equal the sum of the currents leaving a branch in a parallel circuit.

Practice Exercises

In each case, select the choice that best answers the question or completes the statement.

1. The leaves of a negatively charged electroscope diverged more when a charged object was brought near the knob of the electroscope. The object must have been

(A) a rubber rod
(B) an insulator
(C) a conductor

(D) negatively charged
(E) positively charged

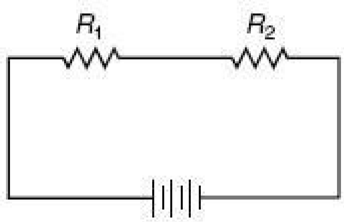
Questions 2 and 3

Two point charges repel each other with a force of 4×10^{-5} newton at a distance of 1 meter.

2. The two charges are
(A) both positive
(B) both negative
(C) alike
(D) unlike
(E) equal

3. If the distance between the charges is increased to 2 meters, the force of repulsion will be, in newtons,
(A) 1×10^{-5}
(B) 2×10^{-5}
(C) 4×10^{-5}
(D) 8×10^{-5}
(E) 16×10^{-5}

4. A proton (electric charge = 1.6×10^{-19} coulomb) is placed midway between two parallel metallic plates that are 0.2 meter apart. The plates are connected to an 80-volt battery. What is the magnitude of the electric force on the proton, in newtons?
(A) 3.2×10^{-20}
(B) 6.4×10^{-17}
(C) 400
(D) 16
(E) 80

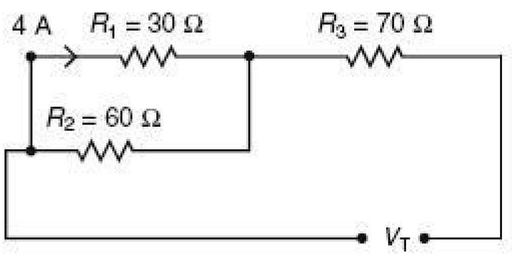


5. In the circuit shown above, R_1 and R_2 are 30 ohms and 60 ohms, respectively, and I_1 = 4 amperes. The potential difference across R_2 is equal to
(A) 30 V
(B) 60 V
(C) 120 V

(D) 240 V
(E) a quantity that can’t be calculated with the given information

Questions 6–9

In the circuit shown, 4 amperes is the current through R_1.



6. The potential difference across R_1 is, in volts,
   (A) 7.5
   (B) 30
   (C) 60
   (D) 120
   (E) 160
7. V_T is equal to, in volts,
   (A) 90
   (B) 160
   (C) 400
   (D) 500
   (E) 540
8. The rate at which R_1 uses electrical energy
   (A) is 120 W
   (B) is 240 W
   (C) is 360 W
   (D) is 480 W
   (E) can’t be calculated with the given information
9. The heat developed by R_1 in 5 seconds is
   (A) 120 J
   (B) 600 J
   (C) 1,800 J
   (D) 2,400 J
   (E) none of the above
10. One thousand watts of electric power are transmitted to a device by means of a series of two wires, each of which has a resistance of 2 ohms. If the resulting potential difference across the device is 100 volts, the potential

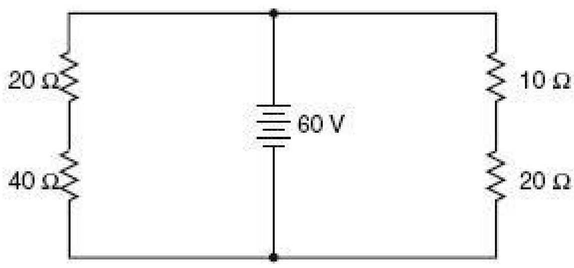
difference across the source supplying the power is
(A) 20 V
(B) 40 V
(C) 100 V
(D) 140 V
(E) 500 V

Questions 11 and 12

A battery has an electromotive force (emf) of 6.0 volts and an internal resistance of 0.4 ohm. It is connected to a 2.6-ohm resistor through a SPST (single pole, single throw) switch.

11. When the switch is open, the potential difference between the terminals of the battery is, in volts,
(A) 0
(B) 0.8
(C) 2.6
(D) 5.2
(E) 6.0

12. When the switch is closed, the potential difference between the terminals of the battery is, in volts,
(A) 0
(B) 0.8
(C) 2.6
(D) 5.2
(E) 6.0



13. The current through the 10-ohm resistor shown above is, in amperes,
(A) 6
(B) 2
(C) 1
(D) ⅔
(E) 0

Answer Key

1. **(D)**	5. **(D)**	9. **(D)**
2. **(C)**	6. **(D)**	10. **(D)**
3. **(A)**	7. **(E)**	11. **(E)**
4. **(B)**	8. **(D)**	12. **(D)**
		13. **(B)**

Answers Explained

1. **D** The leaves of a negatively charged electroscope have an excess of electrons. Since like charges repel, the negatively charged object will repel some (negatively charged) electrons from the knob of the electroscope to the leaves, increasing the amount of negative charge on the leaves. Since the force of repulsion increases with the charge, the leaves will diverge more. The negatively charged object may be rubber, but it may also be some other insulator or a metal.
2. **C** Two like charges repel each other. Both may be positive or both may be negative. They may be equal or unequal.
3. **A** The force between two point charges varies inversely as the square of the distance between them. Since the distance is doubled, the force of repulsion becomes one-fourth as great, or 1×10^{-5} N.
4. **B** The plates are charged oppositely by the battery, producing a uniform electric field between the plates. The intensity of this force is equal to the ratio of the difference of potential between the plates to the distance between the plates:

$$\begin{aligned} \mathrm{E} &= V/d \\ &= (80\ \mathrm{V}/0.2\ \mathrm{m}) = 400\ \mathrm{N/C} \end{aligned}$$

The field intensity is defined as the force on a unit positive charge placed in the field:

$$\begin{aligned} \mathrm{E} &= \mathrm{F}/q \\ 400\ \mathrm{N/C} &= \mathrm{F}/(1.6 \times 10^{-19}\ \mathrm{C}) \\ \mathrm{F} &= 6.4 \times 10^{-17}\ \mathrm{N} \end{aligned}$$

5. **D** This is a series circuit and the current is the same in every part of the circuit: $I_1 = I_2 = 4$ A. The potential difference across $R_2 = I_2R_2 = 4\ \mathrm{A} \times 60\ \Omega = 240$ V.

6. **D** The potential difference across R_1 is merely the IR drop:

$$V_1 = I_1 R_1$$
$$V_1 = 4\text{ A} \times 30\ \Omega = 120\text{ V}$$

7. **E** Since R_1 and R_2 are in parallel, $V_1 = V_2$

$$\therefore\ I_1 R_1 = I_2 R_2$$
$$4\text{ A} \times 30\ \Omega = I_2 \times 60\ \Omega$$
$$I_2 = 2\text{ A}$$
$$I_3 = I_1 + 2\text{ A} = 6\text{ A}$$
$$V_3 = I_3 R_3 = 6\text{ A} \times 70\ \Omega = 420\text{ V}$$
$$\text{But } V_T = V_3 + V_1 = 420\text{ V} + 120\text{ V} = 540\text{ V}$$

8. **D** The rate of using energy is power.

$$P_1 = I_1^2 R_1 = (4\text{ A})^2 \times 30\ \Omega = 480\text{ W}$$

9. **D** $\text{Energy} = \text{power} \times \text{time} = 480\text{ W} \times 5\text{ s}$
$= 2{,}400\text{ W-s} = 2{,}400\text{ J}$

The energy used by a resistor is converted to heat. Therefore the heat developed by the resistor is 2,400 J. Notice that any unit of energy may be used. If desired, we may convert to calories.

10. **D** The power used by the device can be expressed as $P = VI$.

$$1{,}000\text{ W} = 100\text{ V} \times I$$
$$I = 10\text{ A}$$

Since this is a series circuit, the current in each wire is also 10 A. The voltage across each wire is an IR drop = 10 A × 2 Ω = 20 V. The voltage across the source = voltage across device + voltage across the wires = 100 V + 20 V + 20 V = 140 V.

11. **E** When the switch is open, the circuit is incomplete and no current flows. When a battery supplies no current, the potential difference between its terminals is the emf; in this problem, 6.0 V.

12. **D** When the switch is closed, current flows. The terminal voltage = emf - Ir, where I is the current flowing and r is the internal resistance of the battery.

$$I = \frac{\text{total voltage}}{\text{total resistance}} = \frac{6.0\text{ V}}{(2.6 + 0.4)\ \Omega}$$

$$I = 2\text{ A}$$

$$\text{terminal voltage} = 6.0\text{ V} - (2\text{ A} \times 0.4\ \Omega) = 5.2\text{ V}$$

13. **B** This is really a parallel circuit with the two branches drawn on opposite sides of the battery. You may be able to see it better if you draw both branches on the same side of the battery. In any case, the full 60 V is applied across the branch containing the 10-Ω and the 20-Ω resistors in series. For that branch $R_T = 30\ \Omega$, $V_T = 60$ V, and

$$I = V/R = 60\text{ V}/30\ \Omega = 2\text{ A}.$$

Problems & Exercises

20.1 Current

1. What is the current in milliamperes produced by the solar cells of a pocket calculator through which 4.00 C of charge passes in 4.00 h?

2. A total of 600 C of charge passes through a flashlight in 0.500 h. What is the average current?

3. What is the current when a typical static charge of $0.250\ \mu\text{C}$ moves from your finger to a metal doorknob in $1.00\ \mu\text{s}$?

4. Find the current when 2.00 nC jumps between your comb and hair over a $0.500 - \mu\text{s}$ time interval.

5. A large lightning bolt had a 20,000-A current and moved 30.0 C of charge. What was its duration?

6. The 200-A current through a spark plug moves 0.300 mC of charge. How long does the spark last?

7. (a) A defibrillator sends a 6.00-A current through the chest of a patient by applying a 10,000-V potential as in the figure below. What is the resistance of the path? (b) The defibrillator paddles make contact with the patient through a conducting gel that greatly reduces the path resistance. Discuss the difficulties that would ensue if a larger voltage were used to produce the same current through the patient, but with the path having perhaps 50 times the resistance. (Hint: The current must be about the same, so a higher voltage would imply greater power. Use this equation for power: $P = I^2R$.)

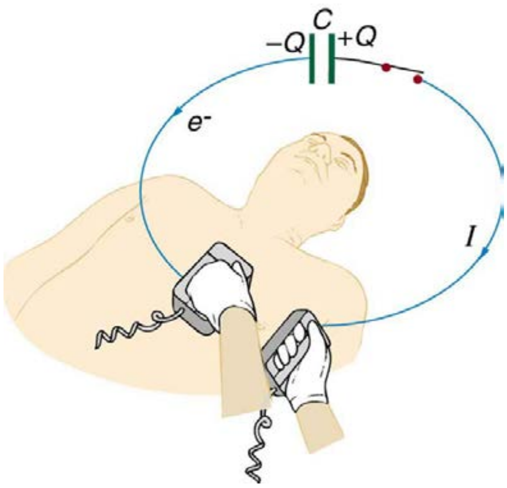


Figure 20.41 The capacitor in a defibrillation unit drives a current through the heart of a patient.

8. During open-heart surgery, a defibrillator can be used to bring a patient out of cardiac arrest. The resistance of the path is $500\ \Omega$ and a 10.0-mA current is needed. What voltage should be applied?

9. (a) A defibrillator passes 12.0 A of current through the torso of a person for 0.0100 s. How much charge moves? (b) How many electrons pass through the wires connected to the patient? (See figure two problems earlier.)

10. A clock battery wears out after moving 10,000 C of charge through the clock at a rate of 0.500 mA. (a) How long did the clock run? (b) How many electrons per second flowed?

11. The batteries of a submerged non-nuclear submarine supply 1000 A at full speed ahead. How long does it take to move Avogadro's number (6.02×10^{23}) of electrons at this rate?

12. Electron guns are used in X-ray tubes. The electrons are accelerated through a relatively large voltage and directed onto a metal target, producing X-rays. (a) How many electrons per second strike the target if the current is 0.500 mA? (b) What charge strikes the target in 0.750 s?

13. A large cyclotron directs a beam of He^{++} nuclei onto a target with a beam current of 0.250 mA. (a) How many He^{++} nuclei per second is this? (b) How long does it take for 1.00 C to strike the target? (c) How long before 1.00 mol of He^{++} nuclei strike the target?

14. Repeat the above example on **Example 20.3**, but for a wire made of silver and given there is one free electron per silver atom.

15. Using the results of the above example on **Example 20.3**, find the drift velocity in a copper wire of twice the diameter and carrying 20.0 A.

16. A 14-gauge copper wire has a diameter of 1.628 mm. What magnitude current flows when the drift velocity is 1.00 mm/s? (See above example on **Example 20.3** for useful information.)

17. SPEAR, a storage ring about 72.0 m in diameter at the Stanford Linear Accelerator (closed in 2009), has a 20.0-A circulating beam of electrons that are moving at nearly the speed of light. (See **Figure 20.42**.) How many electrons are in the beam?

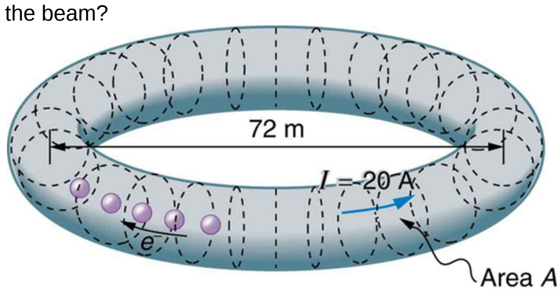


Figure 20.42 Electrons circulating in the storage ring called SPEAR constitute a 20.0-A current. Because they travel close to the speed of light, each electron completes many orbits in each second.

20.2 Ohm's Law: Resistance and Simple Circuits

18. What current flows through the bulb of a 3.00-V flashlight when its hot resistance is $3.60\ \Omega$?

19. Calculate the effective resistance of a pocket calculator that has a 1.35-V battery and through which 0.200 mA flows.

20. What is the effective resistance of a car's starter motor when 150 A flows through it as the car battery applies 11.0 V to the motor?

21. How many volts are supplied to operate an indicator light on a DVD player that has a resistance of $140\ \Omega$, given that 25.0 mA passes through it?

22. (a) Find the voltage drop in an extension cord having a $0.0600\text{-}\ \Omega$ resistance and through which 5.00 A is flowing. (b) A cheaper cord utilizes thinner wire and has a resistance of $0.300\ \ \Omega$. What is the voltage drop in it when 5.00 A flows? (c) Why is the voltage to whatever appliance is being used reduced by this amount? What is the effect on the appliance?

23. A power transmission line is hung from metal towers with glass insulators having a resistance of $1.00\times10^9\ \ \Omega$. What current flows through the insulator if the voltage is 200 kV? (Some high-voltage lines are DC.)

20.3 Resistance and Resistivity

24. What is the resistance of a 20.0-m-long piece of 12-gauge copper wire having a 2.053-mm diameter?

25. The diameter of 0-gauge copper wire is 8.252 mm. Find the resistance of a 1.00-km length of such wire used for power transmission.

26. If the 0.100-mm diameter tungsten filament in a light bulb is to have a resistance of $0.200\ \Omega$ at 20.0°C, how long should it be?

27. Find the ratio of the diameter of aluminum to copper wire, if they have the same resistance per unit length (as they might in household wiring).

28. What current flows through a 2.54-cm-diameter rod of pure silicon that is 20.0 cm long, when $1.00\times10^3\ \text{V}$ is applied to it? (Such a rod may be used to make nuclear-particle detectors, for example.)

29. (a) To what temperature must you raise a copper wire, originally at 20.0°C, to double its resistance, neglecting any changes in dimensions? (b) Does this happen in household wiring under ordinary circumstances?

30. A resistor made of Nichrome wire is used in an application where its resistance cannot change more than 1.00% from its value at 20.0°C. Over what temperature range can it be used?

31. Of what material is a resistor made if its resistance is 40.0% greater at 100°C than at 20.0°C?

32. An electronic device designed to operate at any temperature in the range from -10.0°C to 55.0°C contains pure carbon resistors. By what factor does their resistance increase over this range?

33. (a) Of what material is a wire made, if it is 25.0 m long with a 0.100 mm diameter and has a resistance of $77.7\ \ \Omega$ at 20.0°C? (b) What is its resistance at 150°C?

34. Assuming a constant temperature coefficient of resistivity, what is the maximum percent decrease in the resistance of a constantan wire starting at 20.0°C?

35. A wire is drawn through a die, stretching it to four times its original length. By what factor does its resistance increase?

36. A copper wire has a resistance of $0.500\ \ \Omega$ at 20.0°C, and an iron wire has a resistance of $0.525\ \ \Omega$ at the same temperature. At what temperature are their resistances equal?

37. (a) Digital medical thermometers determine temperature by measuring the resistance of a semiconductor device called a thermistor (which has $\alpha = -0.0600/^\circ\text{C}$) when it is at the same temperature as the patient. What is a patient's temperature if the thermistor's resistance at that temperature is 82.0% of its value at 37.0°C (normal body temperature)? (b) The negative value for α may not be maintained for very low temperatures. Discuss why and whether this is the case here. (Hint: Resistance can't become negative.)

38. Integrated Concepts

(a) Redo **Exercise 20.25** taking into account the thermal expansion of the tungsten filament. You may assume a thermal expansion coefficient of $12\times10^{-6}/^\circ\text{C}$. (b) By what percentage does your answer differ from that in the example?

39. Unreasonable Results

(a) To what temperature must you raise a resistor made of constantan to double its resistance, assuming a constant temperature coefficient of resistivity? (b) To cut it in half? (c) What is unreasonable about these results? (d) Which assumptions are unreasonable, or which premises are inconsistent?

20.4 Electric Power and Energy

40. What is the power of a $1.00\times10^2\ \text{MV}$ lightning bolt having a current of $2.00\times10^4\ \text{A}$?

41. What power is supplied to the starter motor of a large truck that draws 250 A of current from a 24.0-V battery hookup?

42. A charge of 4.00 C of charge passes through a pocket calculator's solar cells in 4.00 h. What is the power output, given the calculator's voltage output is 3.00 V? (See **Figure 20.43**.)

Figure 20.43 The strip of solar cells just above the keys of this calculator convert light to electricity to supply its energy needs. (credit: Evan-Amos, Wikimedia Commons)

43. How many watts does a flashlight that has $6.00\times10^2\ \text{C}$ pass through it in 0.500 h use if its voltage is 3.00 V?

44. Find the power dissipated in each of these extension cords: (a) an extension cord having a $0.0600\text{-}\ \Omega$ resistance and through which 5.00 A is flowing; (b) a cheaper cord utilizing thinner wire and with a resistance of $0.300\ \ \Omega$.

45. Verify that the units of a volt-ampere are watts, as implied by the equation $P = IV$.

46. Show that the units $1\ \text{V}^2/\ \Omega\ = 1\text{W}$, as implied by the equation $P = V^2/R$.

47. Show that the units $1\ \text{A}^2 \cdot\ \Omega\ = 1\ \text{W}$, as implied by the equation $P = I^2R$.

48. Verify the energy unit equivalence that $1\ \text{kW} \cdot \text{h} = 3.60\times10^6\ \text{J}$.

49. Electrons in an X-ray tube are accelerated through $1.00\times10^2\ \text{kV}$ and directed toward a target to produce X-rays. Calculate the power of the electron beam in this tube if it has a current of 15.0 mA.

50. An electric water heater consumes 5.00 kW for 2.00 h per day. What is the cost of running it for one year if electricity costs $12.0\ \text{cents/kW} \cdot \text{h}$? See **Figure 20.44**.

Figure 20.44 On-demand electric hot water heater. Heat is supplied to water only when needed. (credit: aviddavid, Flickr)

51. With a 1200-W toaster, how much electrical energy is needed to make a slice of toast (cooking time = 1 minute)? At $9.0\ \text{cents/kW} \cdot \text{h}$, how much does this cost?

52. What would be the maximum cost of a CFL such that the total cost (investment plus operating) would be the same for both CFL and incandescent 60-W bulbs? Assume the cost of the incandescent bulb is 25 cents and that electricity costs $10\ \text{cents/kWh}$. Calculate the cost for 1000 hours, as in the cost effectiveness of CFL example.

53. Some makes of older cars have 6.00-V electrical systems. (a) What is the hot resistance of a 30.0-W headlight in such a car? (b) What current flows through it?

54. Alkaline batteries have the advantage of putting out constant voltage until very nearly the end of their life. How long will an alkaline battery rated at $1.00\ \text{A} \cdot \text{h}$ and 1.58 V keep a 1.00-W flashlight bulb burning?

55. A cauterizer, used to stop bleeding in surgery, puts out 2.00 mA at 15.0 kV. (a) What is its power output? (b) What is the resistance of the path?

56. The average television is said to be on 6 hours per day. Estimate the yearly cost of electricity to operate 100 million TVs, assuming their power consumption averages 150 W and the cost of electricity averages $12.0\ \text{cents/kW} \cdot \text{h}$.

57. An old lightbulb draws only 50.0 W, rather than its original 60.0 W, due to evaporative thinning of its filament. By what factor is its diameter reduced, assuming uniform thinning along its length? Neglect any effects caused by temperature differences.

58. 00-gauge copper wire has a diameter of 9.266 mm. Calculate the power loss in a kilometer of such wire when it carries $1.00\times10^2\ \text{A}$.

59. Integrated Concepts

Cold vaporizers pass a current through water, evaporating it with only a small increase in temperature. One such home device is rated at 3.50 A and utilizes 120 V AC with 95.0% efficiency. (a) What is the vaporization rate in grams per minute? (b) How much water must you put into the vaporizer for 8.00 h of overnight operation? (See **Figure 20.45**.)

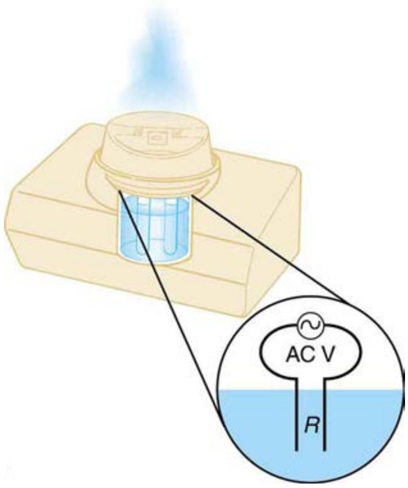


Figure 20.45 This cold vaporizer passes current directly through water, vaporizing it directly with relatively little temperature increase.

60. Integrated Concepts

(a) What energy is dissipated by a lightning bolt having a 20,000-A current, a voltage of $1.00\times10^2\ \text{MV}$, and a length of 1.00 ms? (b) What mass of tree sap could be raised from $18.0ºC$ to its boiling point and then evaporated by this energy, assuming sap has the same thermal characteristics as water?

61. Integrated Concepts

What current must be produced by a 12.0-V battery-operated bottle warmer in order to heat 75.0 g of glass, 250 g of baby formula, and $3.00\times10^2\ \text{g}$ of aluminum from $20.0ºC$ to $90.0ºC$ in 5.00 min?

62. Integrated Concepts

How much time is needed for a surgical cauterizer to raise the temperature of 1.00 g of tissue from $37.0ºC$ to $100ºC$ and then boil away 0.500 g of water, if it puts out 2.00 mA at 15.0 kV? Ignore heat transfer to the surroundings.

63. Integrated Concepts

Hydroelectric generators (see **Figure 20.46**) at Hoover Dam produce a maximum current of $8.00 \times 10^3\ \text{A}$ at 250 kV. (a) What is the power output? (b) The water that powers the generators enters and leaves the system at low speed (thus its kinetic energy does not change) but loses 160 m in altitude. How many cubic meters per second are needed, assuming 85.0% efficiency?

Figure 20.46 Hydroelectric generators at the Hoover dam. (credit: Jon Sullivan)

64. Integrated Concepts

(a) Assuming 95.0% efficiency for the conversion of electrical power by the motor, what current must the 12.0-V batteries of a 750-kg electric car be able to supply: (a) To accelerate from rest to 25.0 m/s in 1.00 min? (b) To climb a $2.00 \times 10^2\text{-m}$ -high hill in 2.00 min at a constant 25.0-m/s speed while exerting $5.00 \times 10^2\ \text{N}$ of force to overcome air resistance and friction? (c) To travel at a constant 25.0-m/s speed, exerting a $5.00 \times 10^2\ \text{N}$ force to overcome air resistance and friction? See **Figure 20.47**.

Figure 20.47 This REVAi, an electric car, gets recharged on a street in London. (credit: Frank Hebbert)

65. Integrated Concepts

A light-rail commuter train draws 630 A of 650-V DC electricity when accelerating. (a) What is its power consumption rate in kilowatts? (b) How long does it take to reach 20.0 m/s starting from rest if its loaded mass is $5.30 \times 10^4\ \text{kg}$, assuming 95.0% efficiency and constant power? (c) Find its average acceleration. (d) Discuss how the acceleration you found for the light-rail train compares to what might be typical for an automobile.

66. Integrated Concepts

(a) An aluminum power transmission line has a resistance of $0.0580\ \Omega/\text{km}$. What is its mass per kilometer? (b) What is the mass per kilometer of a copper line having the same resistance? A lower resistance would shorten the heating time. Discuss the practical limits to speeding the heating by lowering the resistance.

67. Integrated Concepts

(a) An immersion heater utilizing 120 V can raise the temperature of a $1.00 \times 10^2\text{-g}$ aluminum cup containing 350 g of water from 20.0°C to 95.0°C in 2.00 min. Find its resistance, assuming it is constant during the process. (b) A lower resistance would shorten the heating time. Discuss the practical limits to speeding the heating by lowering the resistance.

68. Integrated Concepts

(a) What is the cost of heating a hot tub containing 1500 kg of water from 10.0°C to 40.0°C, assuming 75.0% efficiency to account for heat transfer to the surroundings? The cost of electricity is $9\ \text{cents/kW}\cdot\text{h}$. (b) What current was used by the 220-V AC electric heater, if this took 4.00 h?

69. Unreasonable Results

(a) What current is needed to transmit $1.00 \times 10^2\ \text{MW}$ of power at 480 V? (b) What power is dissipated by the transmission lines if they have a $1.00\text{-}\Omega$ resistance? (c) What is unreasonable about this result? (d) Which assumptions are unreasonable, or which premises are inconsistent?

70. Unreasonable Results

(a) What current is needed to transmit $1.00 \times 10^2\ \text{MW}$ of power at 10.0 kV? (b) Find the resistance of 1.00 km of wire that would cause a 0.0100% power loss. (c) What is the diameter of a 1.00-km-long copper wire having this resistance? (d) What is unreasonable about these results? (e) Which assumptions are unreasonable, or which premises are inconsistent?

71. Construct Your Own Problem

Consider an electric immersion heater used to heat a cup of water to make tea. Construct a problem in which you calculate the needed resistance of the heater so that it increases the temperature of the water and cup in a reasonable amount of time. Also calculate the cost of the electrical energy used in your process. Among the things to be considered are the voltage used, the masses and heat capacities involved, heat losses, and the time over which the heating takes place. Your instructor may wish for you to consider a thermal safety switch (perhaps bimetallic) that will halt the process before damaging temperatures are reached in the immersion unit.

20.5 Alternating Current versus Direct Current

72. (a) What is the hot resistance of a 25-W light bulb that runs on 120-V AC? (b) If the bulb's operating temperature is 2700°C, what is its resistance at 2600°C?

73. Certain heavy industrial equipment uses AC power that has a peak voltage of 679 V. What is the rms voltage?

74. A certain circuit breaker trips when the rms current is 15.0 A. What is the corresponding peak current?

75. Military aircraft use 400-Hz AC power, because it is possible to design lighter-weight equipment at this higher frequency. What is the time for one complete cycle of this power?

76. A North American tourist takes his 25.0-W, 120-V AC razor to Europe, finds a special adapter, and plugs it into 240 V AC. Assuming constant resistance, what power does the razor consume as it is ruined?

77. In this problem, you will verify statements made at the end of the power losses for **Example 20.10**. (a) What current is needed to transmit 100 MW of power at a voltage of 25.0 kV? (b) Find the power loss in a $1.00\text{-}\ \Omega$ transmission line. (c) What percent loss does this represent?

78. A small office-building air conditioner operates on 408-V AC and consumes 50.0 kW. (a) What is its effective resistance? (b) What is the cost of running the air conditioner during a hot summer month when it is on 8.00 h per day for 30 days and electricity costs $9.00\ \text{cents/kW}\cdot\text{h}$?

79. What is the peak power consumption of a 120-V AC microwave oven that draws 10.0 A?

80. What is the peak current through a 500-W room heater that operates on 120-V AC power?

81. Two different electrical devices have the same power consumption, but one is meant to be operated on 120-V AC and the other on 240-V AC. (a) What is the ratio of their resistances? (b) What is the ratio of their currents? (c) Assuming its resistance is unaffected, by what factor will the power increase if a 120-V AC device is connected to 240-V AC?

82. Nichrome wire is used in some radiative heaters. (a) Find the resistance needed if the average power output is to be 1.00 kW utilizing 120-V AC. (b) What length of Nichrome wire, having a cross-sectional area of 5.00mm^2, is needed if the operating temperature is $500^\circ\ \text{C}$? (c) What power will it draw when first switched on?

83. Find the time after $t = 0$ when the instantaneous voltage of 60-Hz AC first reaches the following values: (a) $V_0/2$ (b) V_0 (c) 0.

84. (a) At what two times in the first period following $t = 0$ does the instantaneous voltage in 60-Hz AC equal V_{rms}? (b) $-V_{\text{rms}}$?

20.6 Electric Hazards and the Human Body

85. (a) How much power is dissipated in a short circuit of 240-V AC through a resistance of $0.250\ \ \Omega$? (b) What current flows?

86. What voltage is involved in a 1.44-kW short circuit through a $0.100\text{-}\ \Omega$ resistance?

87. Find the current through a person and identify the likely effect on her if she touches a 120-V AC source: (a) if she is standing on a rubber mat and offers a total resistance of $300\ \text{k}\,\Omega$; (b) if she is standing barefoot on wet grass and has a resistance of only $4000\ \text{k}\,\Omega$.

88. While taking a bath, a person touches the metal case of a radio. The path through the person to the drainpipe and ground has a resistance of $4000\ \ \Omega$. What is the smallest voltage on the case of the radio that could cause ventricular fibrillation?

89. Foolishly trying to fish a burning piece of bread from a toaster with a metal butter knife, a man comes into contact with 120-V AC. He does not even feel it since, luckily, he is wearing rubber-soled shoes. What is the minimum resistance of the path the current follows through the person?

90. (a) During surgery, a current as small as $20.0\ \mu\text{A}$ applied directly to the heart may cause ventricular fibrillation. If the resistance of the exposed heart is $300\ \ \Omega$, what is the smallest voltage that poses this danger? (b) Does your answer imply that special electrical safety precautions are needed?

91. (a) What is the resistance of a 220-V AC short circuit that generates a peak power of 96.8 kW? (b) What would the average power be if the voltage was 120 V AC?

92. A heart defibrillator passes 10.0 A through a patient's torso for 5.00 ms in an attempt to restore normal beating. (a) How much charge passed? (b) What voltage was applied if 500 J of energy was dissipated? (c) What was the path's resistance? (d) Find the temperature increase caused in the 8.00 kg of affected tissue.

93. Integrated Concepts

A short circuit in a 120-V appliance cord has a $0.500\text{-}\ \Omega$ resistance. Calculate the temperature rise of the 2.00 g of surrounding materials, assuming their specific heat capacity is $0.200\ \text{cal/g}\cdot^\circ\text{C}$ and that it takes 0.0500 s for a circuit breaker to interrupt the current. Is this likely to be damaging?

94. Construct Your Own Problem

Consider a person working in an environment where electric currents might pass through her body. Construct a problem in which you calculate the resistance of insulation needed to protect the person from harm. Among the things to be considered are the voltage to which the person might be exposed, likely body resistance (dry, wet, …), and acceptable currents (safe but sensed, safe and unfelt, …).

20.7 Nerve Conduction–Electrocardiograms

95. Integrated Concepts

Use the ECG in **Figure 20.37** to determine the heart rate in beats per minute assuming a constant time between beats.

96. Integrated Concepts

(a) Referring to **Figure 20.37**, find the time systolic pressure lags behind the middle of the QRS complex. (b) Discuss the reasons for the time lag.

Test Prep for AP® Courses

20.1 Current

1. Which of the following can be explained on the basis of conservation of charge in a closed circuit consisting of a battery, resistor, and metal wires?

a. The number of electrons leaving the battery will be equal to the number of electrons entering the battery.
b. The number of electrons leaving the battery will be less than the number of electrons entering the battery.
c. The number of protons leaving the battery will be equal to the number of protons entering the battery.
d. The number of protons leaving the battery will be less than the number of protons entering the battery.

2. When a battery is connected to a bulb, there is 2.5 A of current in the circuit. What amount of charge will flow though the circuit in a time of 0.5 s?

a. 0.5 C
b. 1 C
c. 1.25 C
d. 1.5 C

3. If 0.625×10^{20} electrons flow through a circuit each second, what is the current in the circuit?

4. Two students calculate the charge flowing through a circuit. The first student concludes that 300 C of charge flows in 1 minute. The second student concludes that 3.125×10^{19} electrons flow per second. If the current measured in the circuit is 5 A, which of the two students (if any) have performed the calculations correctly?

20.2 Ohm's Law: Resistance and Simple Circuits

5. If the voltage across a fixed resistance is doubled, what happens to the current?

a. It doubles.
b. It halves.
c. It stays the same.
d. The current cannot be determined.

6. The table below gives the voltages and currents recorded across a resistor.

Table 20.4

Voltage (V)	2.50	5.00	7.50	10.00	12.50
Current (A)	0.69	1.38	2.09	2.76	3.49

a. Plot the graph and comment on the shape.
b. Calculate the value of the resistor.

7. What is the resistance of a bulb if the current in it is 1.25 A when a 4 V voltage supply is connected to it? If the voltage supply is increased to 7 V, what will be the current in the bulb?

20.3 Resistance and Resistivity

8. Which of the following affect the resistivity of a wire?

a. length
b. area of cross section
c. material
d. all of the above

9. The lengths and diameters of four wires are given as shown.

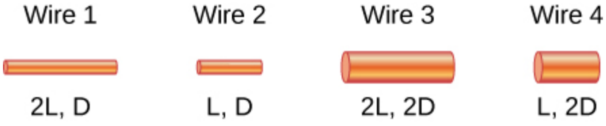


Figure 20.48

If the four wires are made from the same material, which of the following is true? Select *two* answers.

a. Resistance of Wire 3 > Resistance of Wire 2
b. Resistance of Wire 1 > Resistance of Wire 2
c. Resistance of Wire 1 < Resistance of Wire 4
d. Resistance of Wire 4 < Resistance of Wire 3

10. Suppose the resistance of a wire is R Ω. What will be the resistance of another wire of the same material having the same length but double the diameter?

a. $R/2$
b. $2R$
c. $R/4$
d. $4R$

11. The resistances of two wires having the same lengths and cross section areas are 3 Ω and 11 Ω. If the resistivity of the 3 Ω wire is 2.65×10^{-8} Ω·m, find the resistivity of the 1 Ω wire.

12. The lengths and diameters of three wires are given below. If they all have the same resistance, find the ratio of their resistivities.

Table 20.5

Wire	*Length*	*Diameter*
Wire 1	2 m	1 cm
Wire 2	1 m	0.5 cm
Wire 3	1 m	1 cm

13. Suppose the resistance of a wire is 2 Ω. If the wire is stretched to three times its length, what will be its resistance? Assume that the volume does not change.

20.4 Electric Power and Energy

14.

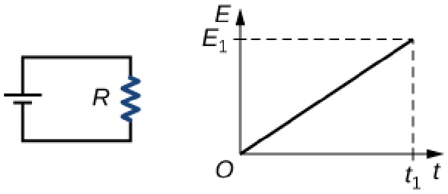


Figure 20.49 The circuit shown contains a resistor *R* connected to a voltage supply. The graph shows the total energy *E* dissipated by the resistance as a function of time. Which of the following shows the corresponding graph for double resistance, i.e., if *R* is replaced by 2*R*?

a.

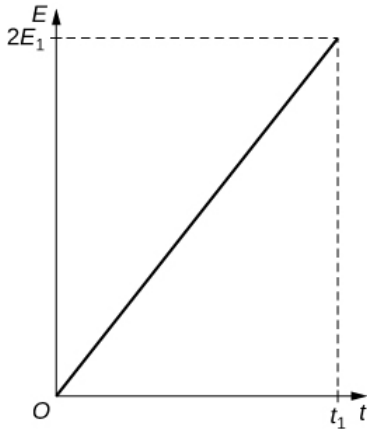


Figure 20.50

b.

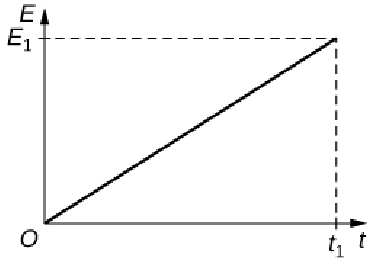


Figure 20.51

c.

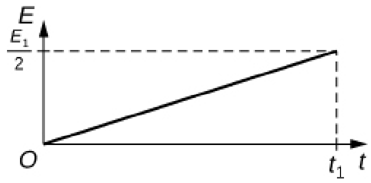


Figure 20.52

d.

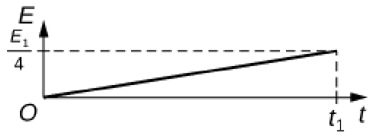


Figure 20.53

15. What will be the ratio of the resistance of a 120 W, 220 V lamp to that of a 100 W, 110 V lamp?

(a)

Chapter 20

Problems & Exercises

1

0.278 mA

3

0.250 A

5

1.50ms

7

(a) $1.67\text{k}\ \Omega$

(b) If a 50 times larger resistance existed, keeping the current about the same, the power would be increased by a factor of about 50 (based on the equation $P = I^2R$), causing much more energy to be transferred to the skin, which could cause serious burns. The gel used reduces the resistance, and therefore reduces the power transferred to the skin.

9

(a) 0.120 C

(b) 7.50×10^{17} electrons

11

96.3 s

13

(a) $7.81 \times 10^{14}\ \text{He}^{++}\ \text{nuclei/s}$

(b) $4.00 \times 10^{3}\ \text{s}$

(c) $7.71 \times 10^{8}\ \text{s}$

15

$-1.13\times 10^{-4}\ \text{m/s}$

17

9.42×10^{13} electrons

18

0.833 A

20

$7.33\times 10^{-2}\ \Omega$

22

(a) 0.300 V

(b) 1.50 V

(c) The voltage supplied to whatever appliance is being used is reduced because the total voltage drop from the wall to the final output of the appliance is fixed. Thus, if the voltage drop across the extension cord is large, the voltage drop across the appliance is significantly decreased, so the power output by the appliance can be significantly decreased, reducing the ability of the appliance to work properly.

24

$0.104\ \Omega$

26

$2.8\times10^{-2}\ \text{m}$

28

$1.10\times10^{-3}\ \text{A}$

30

$-5^\circ\text{C to } 45^\circ\text{C}$

32

1.03

34

0.06%

36

-17°C

38

(a) $4.7\ \ \Omega$ (total)

(b) 3.0% decrease

40

$2.00\times10^{12}\ \text{W}$

44

(a) 1.50 W

(b) 7.50 W

46

$$\frac{\text{V}^2}{\Omega} = \frac{\text{V}^2}{\text{V/A}} = \text{AV} = \left(\frac{\text{C}}{\text{s}}\right)\left(\frac{\text{J}}{\text{C}}\right) = \frac{\text{J}}{\text{s}} = 1\ \text{W}$$

48

$$1\ \text{kW}\cdot\text{h}=\left(\frac{1\times10^3\ \text{J}}{1\ \text{s}}\right)(1\ \text{h})\left(\frac{3600\ \text{s}}{1\ \text{h}}\right) = 3.60\times10^6\ \text{J}$$

50

\$438/y

52

\$6.25

54

1.58 h

56

\$3.94 billion/year

58

25.5 W

60

(a) $2.00\times10^9\ \text{J}$

(b) 769 kg

62

45.0 s

64

(a) 343 A

(b) $2.17\times10^3\ \text{A}$

(c) $1.10\times10^3\ \text{A}$

66

(a) $1.23\times10^{3}\ \text{kg}$

(b) $2.64\times10^{3}\ \text{kg}$

69

(a) $2.08\times10^{5}\ \text{A}$

(b) $4.33\times10^{4}\ \text{MW}$

(c) The transmission lines dissipate more power than they are supposed to transmit.

(d) A voltage of 480 V is unreasonably low for a transmission voltage. Long-distance transmission lines are kept at much higher voltages (often hundreds of kilovolts) to reduce power losses.

73
480 V
75
2.50 ms
77

(a) 4.00 kA

(b) 16.0 MW

(c) 16.0%

79
2.40 kW
81

(a) 4.0

(b) 0.50

(c) 4.0

83

(a) 1.39 ms

(b) 4.17 ms

(c) 8.33 ms

85

(a) 230 kW

(b) 960 A

87

(a) 0.400 mA, no effect

(b) 26.7 mA, muscular contraction for duration of the shock (can't let go)

89
$1.20\times10^{5}\ \Omega$
91

(a) $1.00\ \Omega$

(b) 14.4 kW

93
Temperature increases 860°C. It is very likely to be damaging.
95
80 beats/minute

Test Prep for AP® Courses

1
(a)
3
10 A

5

(a)

7

3.2 Ω, 2.19 A

9

(b), (d)

11

9.72×10^{-8} Ω·m

13

18 Ω

15

10:3 or 3.33

Chapter 21

Electricity Problems Solved.

1/ $I = \frac{Q}{t} = \frac{4}{4.3600} = 2.78.10^{-4} A = 0.278 mA$

9/ a/ $Q = It = 0.12 C$

b/ number of $e^- = \frac{Q}{\text{charge of } e^-} = \frac{0.12}{1.6\,10^{-19}} = 7.5\,10^{17}\,e^-$

11/ $t = \frac{Q}{I} = \frac{Q_e \cdot N_e}{I} = 96.3\,s$

20/ $R = \frac{U}{I} = 0.073\,\Omega$

24/ $R = \frac{\rho . L}{A}$; $\rho_{copper} = 1.72.10^{-8}\,\Omega.m$ (resistivity)

$\rightarrow R = \frac{\rho . L}{\pi\left(\frac{d}{2}\right)^2} = 0.106\,\Omega$

26/ Resistivity ~~depends on~~ varies with Temperature ~~$\rho = \rho_0(1 + \alpha \Delta T)$~~ ~~coeff of resistivity~~

~~$\alpha_{copper} = 3.9 \cdot 10^{-3} \rightarrow \rho = 1.72 \cdot 10^{-8}$~~

$\alpha_{Tungsten} = 4.5 . 10^{-3}$
$\rho_{0\,Tungsten} = 5.6\,10^{-8}$ $\Big\} \rightarrow \rho = 6.104 . 10^{-8}$

26/ Resistivity varies with Temperature as

$$\rho = \rho_0 \left(1 + \underset{\uparrow}{\alpha}(T - T_0)\right)$$; ρ is resistivity at $T = T$

coef of Resistivity

ρ_0 is resistivity at $T = T_0$ and is usually taken to be $T_0 = 20°C$

$\Delta T = T - T_0 = 0°C \rightarrow \rho = \rho_0 (\text{Tungsten}) = 5.6 \, 10^{-8} \, \Omega . m$

$$\rightarrow L = \frac{R . A}{\rho} = \frac{0.2 . \pi \left(\frac{0.1 \, 10^{-3}}{2}\right)^2}{5.6 \, 10^{-8}} = 0.028 \, m$$

44/ a/ $P = RI^2 = 1.5 \, W$

b/ $P = RI^2 = 4.5 \, W$

48/ $1 \, kW . h = \left(10^3 \frac{J}{\cancel{s}}\right) . \left(3600 \, \cancel{s}\right) = 3.6 \, 10^6 \, J$

Power.t

Energy

50/ keep in mind ~~[illegible]~~ 5 kW for 2 h doesn't mean it consumes 5 kW every 2 hours, No! power consumption is constant (5 kW) but the device is working 2 hours a day and the government every charges you in this example 12 cents/kW.h so we can first ~~[illegible]~~ see how much the water heater costs per day : 12 . 5 . 2 = 120 cents and so in a year it's

$120 \cdot 365 = 43800$ cents which is of course 438 $

73/ $V_{rms} = \frac{V_0}{\sqrt{2}} = 480V.$

75/ $T = \frac{1}{f} = \frac{1}{400} = 2.5 \, 10^{-3} s = 2.5 \, ms$

79/ $P_0 = I_0 V_0 = \sqrt{2} I \cdot \sqrt{2} V = 2 VI = 2400 \, W$