

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 $0.500\text{-}\mu\text{s}$ 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: $P = I^2 R$.)

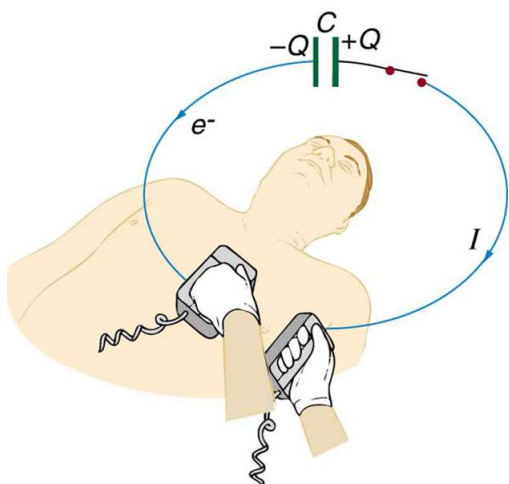


Figure 20.34 The capacitor in a defibrillation unit drives a current through the heart of a patient.

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 $10,000\text{ C}$ 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 20.35](#).) How many electrons are in the beam?

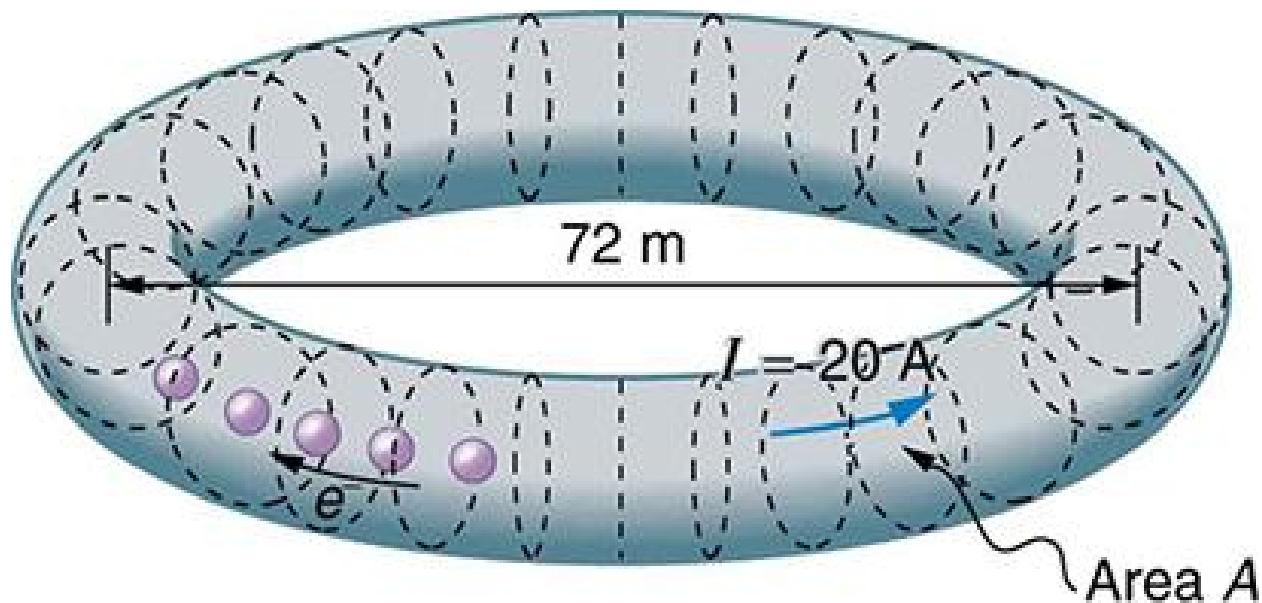


Figure 20.35 Electrons circulating in the storage ring called SPEAR constitute a 20.0-A current. Because they travel close to the speed of light, each electron completes many orbits in each second.

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 $1.00 \times 10^9\ \Omega$. 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 0.010-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 1.00×10^3 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 $12 \times 10^{-6}/^{\circ}\text{C}$. (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 1.00×10^2 MV lightning bolt having a current of 2.00×10^4 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 20.36](#).)



Figure 20.36 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 6.00×10^2 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 $0.300\text{ }\Omega$.

45.

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

46.

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

47.

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

48.

Verify the energy unit equivalence that $1\text{ kW} \cdot \text{h} = 3.60 \times 10^6\text{ J}$.

49.

Electrons in an X-ray tube are accelerated through 1.00×10^2 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 cents/kW \cdot h? See Figure 20.37.



Figure 20.37 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 cents/kW · 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 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 A · 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 cents/kW · 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 1.00×10^2 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 20.38.)

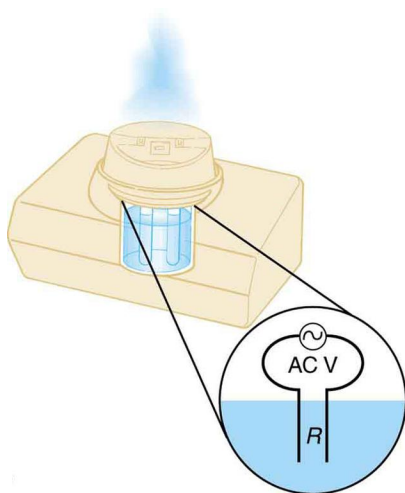


Figure 20.38 This cold vaporizer passes current directly through water, vaporizing it directly with relatively little temperature increase.

60.

Integrated Concepts

(a) What energy is dissipated by a lightning bolt having a 20,000-A current, a voltage of 1.00×10^2 MV, and a length of 1.00 ms? (b) What mass of tree sap could be raised from 18.0°C 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 3.00×10^2 g of aluminum from 20.0°C to 90.0°C 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 37.0°C to 100°C 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 20.39) at Hoover Dam produce a maximum current of 8.00×10^3 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?

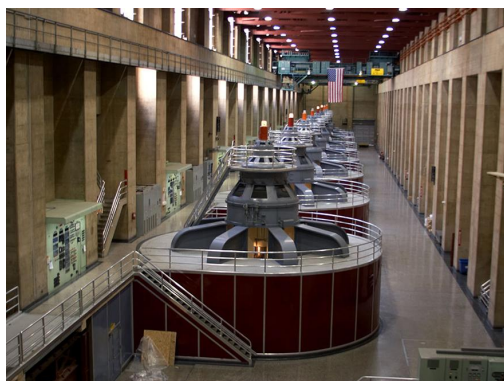


Figure 20.39 Hydroelectric generators at the Hoover dam. (credit: Jon Sullivan)

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 2.00×10^2 -m-high hill in 2.00 min at a constant 25.0-m/s speed while exerting 5.00×10^2 N of force to overcome air resistance and friction? (c) To travel at a constant 25.0-m/s speed, exerting a 5.00×10^2 N force to overcome air resistance and friction? See Figure 20.40.

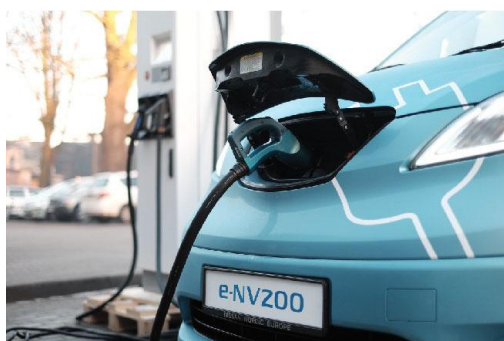


Figure 20.40 This REVAi, an electric car, gets recharged on a street in London. (credit: Frank Hebbert)

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 5.30×10^4 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 1.00×10^2 -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 cents/ $\text{kW} \cdot \text{h}$. (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 1.00×10^2 MW of power at 480 V? (b) What power is dissipated by the transmission lines if they have a $1.00\ \Omega$ 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 1.00×10^2 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°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 220-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 $4500\ \Omega$.

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 their 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 20.31](#) to determine the heart rate in beats per minute assuming a constant time between beats.

96.

Integrated Concepts

(a) Referring to [Figure 20.31](#), find the time systolic pressure lags behind the middle of the QRS complex. (b) Discuss the reasons for the time lag.

97.

Critical Thinking A copper wire of length 1.25 m is in a circuit. A current of 2.50 A flows through the wire. (a) Initially, the circuit is at 20.0°C . If there is an energy loss of 3.25 MJ in the first second caused by the wire as soon as the circuit is turned on, what is the radius of the wire? (b) After the wire heats 3.000°C , how much energy is being dissipated by the circuit per second? Neglect the effects of thermal expansion since the wire is considered to be physically constrained from expanding. Assume the current is maintained. (c) At what temperature will the energy dissipation be 1.00% higher than it was at the beginning of the experiment?