Exercise 25.3

Description: A I current runs through a 12-gauge copper wire (diameter 2.05 mm) and through a light bulb. Copper has 8.5 * 10^28 free electrons per cubic meter. (a) How many electrons pass through the light bulb each second? (b) What is the current density in...

A 4.50 A current runs through a 12-gauge copper wire (diameter 2.05 mm) and through a light bulb. Copper has 8.5×10^{28} free electrons per cubic meter.

Part A

How many electrons pass through the light bulb each second?

ANSWER:

$N = \frac{I}{1.602 \cdot 10^{-19}} = 2.81 \times 10^{19}$

Part B

What is the current density in the wire?

ANSWER:

$J = \frac{4I}{\pi (2.05 \cdot 10^{-3})^2} = 1.36 \times 10^6 \ \mathrm{A/m^2}$

Part C

At what speed does a typical electron pass by any given point in the wire?

Express your answer using two significant figures.

ANSWER:

$v_d = \frac{4I}{\pi (2.05 \cdot 10^{-3})^2 \cdot 8.5 \cdot 10^{28} \cdot 1.6 \cdot 10^{-19}} = 1.0 \times 10^{-4} \ \mathrm{m/s}$

Part D

If you were to use wire of twice the diameter, which of the above answers would change? Would they increase or decrease?

ANSWER:

- (selected) J would decrease and v_d would decrease, N would not change
- J would increase and v_d would increase, N would not change
- N would increase and v_d would increase, J would not change
- N would increase and v_d would decrease, J would not change
- J would increase and v_d would decrease, N would not change

Exercise 25.12

Description: A copper wire has a square cross section a on a side. The wire is L long and carries a current of I. The density of free electrons is 8.5* 10^28 (m^-3). (a) Find the magnitude of the current density in the wire. (b) Find the magnitude of the...

A copper wire has a square cross section 2.3 mm on a side. The wire is 4.5 m long and carries a current of 3.4 A . The density of free electrons is $8.5 \times 10^{28} \ \mathrm{m^{-3}}$.

Part A

Find the magnitude of the current density in the wire.

Express your answer using two significant figures.

ANSWER:

$J = \frac{I}{a^2} = 6.4 \times 10^5 \ \mathrm{A/m^2}$

Part B

Find the magnitude of the electric field in the wire.

Express your answer using two significant figures.

ANSWER:

$E = \frac{1.72 \cdot 10^{-8} I}{a^2} = 1.1 \times 10^{-2} \ \mathrm{V/m}$

Part C

How much time is required for an electron to travel the length of the wire?

Express your answer using two significant figures.

ANSWER:

$t = \frac{L \cdot 8.5 \cdot 10^{28} \cdot 1.602 \cdot 10^{-19} a^2}{I} = 9.5 \times 10^4 \ \mathrm{s}$

Exercise 25.18

Description: (a) What diameter must a copper wire have if its resistance is to be the same as that of an equal length of aluminum wire with diameter d?

Part A

What diameter must a copper wire have if its resistance is to be the same as that of an equal length of aluminum wire with diameter 3.63 mm ?

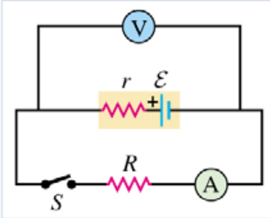
ANSWER:

$d = d\sqrt{\frac{1.72}{2.75}} = 2.87 \ \mathrm{mm}$

Exercise 25.33

Description: When switch S in the figure is open, the voltmeter V of the battery reads V_1. When the switch is closed, the voltmeter reading drops to V_2, and the ammeter A reads I. Assume that the two meters are ideal, so they don't affect the circuit. (...

When switch S in the figure is open, the voltmeter V of the battery reads 3.09 V. When the switch is closed, the voltmeter reading drops to 2.97 V, and the ammeter A reads 1.69 A. Assume that the two meters are ideal, so they don't affect the circuit.



Part A

Find the emf.

ANSWER:

$\mathcal{E} = V_1 = 3.09$ V

Part B

Find the internal resistance of the battery.

ANSWER:

$r = \dfrac{V_1 - V_2}{I} = 7.10 \times 10^{-2}$ Ω

Part C

Find the circuit resistance R.

ANSWER:

$R = \dfrac{V_2}{I} = 1.76$ Ω

Exercise 25.52

Description: A typical small flashlight contains two batteries, each having an emf of V connected in series with a bulb having a resistance of R. (a) If the internal resistance of the batteries is negligible, what power is delivered to the bulb? (b) If the...

A typical small flashlight contains two batteries, each having an emf of 1.50 V connected in series with a bulb having a resistance of 14 Ω.

Part A

If the internal resistance of the batteries is negligible, what power is delivered to the bulb?

Express your answer using two significant figures.

ANSWER:

$P = \dfrac{(2V)^2}{R} = 0.64$ W

Part B

If the batteries last for a time of 5.0 h, what is the total energy delivered to the bulb?

Express your answer using two significant figures.

ANSWER:

$W = \dfrac{(2V)^2}{R} t = 1.2 \times 10^4$ J

Part C

The resistance of real batteries increases as they run down. If the initial internal resistance is negligible, what is the combined internal resistance of both batteries when the power to the bulb has decreased to half its initial value? (Assume that the resistance of the bulb is constant. Actually, it will change somewhat when the current through the filament changes, because this changes the temperature of the filament and hence the resistivity of the filament wire.)

Express your answer using two significant figures.

ANSWER:

$r = \left(\sqrt{2} - 1\right) R = 5.8$ Ω

Exercise 25.53

Description: A P - Welectric heater is designed to operate from 120-V lines. (a) What is its resistance? (b) What current does it draw? (c) If the line voltage drops to 110 V, what power does the heater take? (Assume that the resistance is constant. Actually....

A 500 - W electric heater is designed to operate from 120-V lines.

Part A

What is its resistance?

ANSWER:

$R = \dfrac{120^2}{P} = 28.8$ Ω

Part B

What current does it draw?

ANSWER:

$I = \dfrac{P}{120} = 4.17$ A

Part C

If the line voltage drops to 110 V, what power does the heater take? (Assume that the resistance is constant. Actually, it will change because of the change in temperature.)

ANSWER:

$P = \frac{P \cdot 110^2}{120^2} = 420$ W

Part D

The heater coils are metallic, so that the resistance of the heater decreases with decreasing temperature. If the change of resistance with temperature is taken into account, will the electrical power consumed by the heater be larger or smaller than what you calculated in part C?

ANSWER:

- (selected) larger
- smaller

Part E

Explain your answer in part D.

ANSWER:

Answer Key:
The resistance will be less so the current drawn will increase, increasing the power.

25.72. **IDENTIFY:** The cost of operating an appliance is proportional to the amount of energy consumed. The energy depends on the power the item consumes and the length of time for which it is operated.

SET UP: At a constant power, the energy is equal to *Pt*, and the total cost is the cost per kilowatt-hour (kWh) times the energy (in kWh).

EXECUTE: **(a)** Use the fact that $1.00\ \text{kWh} = (1000\ \text{J/s})(3600\ \text{s}) = 3.60\times10^6\ \text{J}$, and one year contains 3.156×10^7 s.

$$(75\ \text{J/s})\left(\frac{3.156\times10^7\ \text{s}}{1\ \text{yr}}\right)\left(\frac{\$0.120}{3.60\times10^6\ \text{J}}\right) = \$78.90$$

(b) At 8 h/day, the refrigerator runs for 1/3 of a year. Using the same procedure as above gives

$$(400\ \text{J/s})\left(\frac{1}{3}\right)\left(\frac{3.156\times10^7\ \text{s}}{1\ \text{yr}}\right)\left(\frac{\$0.120}{3.60\times10^6\ \text{J}}\right) = \$140.27$$

EVALUATE: Electric lights can be a substantial part of the cost of electricity in the home if they are left on for a long time!

25.78. **IDENTIFY:** Compact fluorescent bulbs draw much less power than incandescent bulbs and last much longer. Hence they cost less to operate.

SET UP: A kWh is power of 1 kW for a time of 1 h. $P = \frac{V^2}{R}$.

EXECUTE: **(a)** In 3.0 yr the bulbs are on for $(3.0\ \text{yr})(365.24\ \text{days/yr})(4.0\ \text{h/day}) = 4.38\times10^3\ \text{h}$.

Compact bulb: The energy used is $(23\ \text{W})(4.38\times10^3\ \text{h}) = 1.01\times10^5\ \text{Wh} = 101\ \text{kWh}$. The cost of this energy is $(\$0.080/\text{kWh})\ (101\ \text{kWh}) = \$8.08$. One bulb will last longer than this. The bulb cost is \$11.00, so the total cost is \$19.08.

Incandescent: The energy used is $(100\ \text{W})(4.38\times10^3\ \text{h}) = 4.38\times10^5\ \text{Wh} = 438\ \text{kWh}$. The cost of this energy is $(\$0.080/\text{kWh})(438\ \text{kWh}) = \$35.04$. Six bulbs will be used during this time and the bulb cost will be \$4.50. The total cost will be \$39.54.

(b) The compact bulb will save $\$39.54 - \$19.08 = \$20.46$.

(c) $R = \frac{V^2}{P} = \frac{(120\ \text{V})^2}{23\ \text{W}} = 626\ \Omega$.

EVALUATE: The initial cost of the bulb is much greater for the compact fluorescent bulb but the savings soon repay the cost of the bulb. The compact bulb should last for over six years, so over a 6-year period the savings per year will be even greater. The cost of compact fluorescent bulbs has come down dramatically, so the savings today would be considerably greater than indicated here.

25.77. **IDENTIFY:** The power supplied to the house is $P = VI$. The rate at which electrical energy is dissipated in the wires is I^2R, where $R = \dfrac{\rho L}{A}$.

SET UP: For copper, $\rho = 1.72\times10^{-8}\ \Omega\cdot\text{m}$.

EXECUTE: **(a)** The line voltage, current to be drawn, and wire diameter are what must be considered in household wiring.

(b) $P = VI$ gives $I = \dfrac{P}{V} = \dfrac{4200\ \text{W}}{120\ \text{V}} = 35\ \text{A}$, so the 8-gauge wire is necessary, since it can carry up to 40 A.

(c) $P = I^2R = \dfrac{I^2\rho L}{A} = \dfrac{(35\ \text{A})^2\,(1.72\times10^{-8}\ \Omega\cdot\text{m})(42.0\ \text{m})}{(\pi/4)(0.00326\ \text{m})^2} = 106\ \text{W}$.

(d) If 6-gauge wire is used, $P = \dfrac{I^2\rho L}{A} = \dfrac{(35\ \text{A})^2\,(1.72\times10^{-8}\ \Omega\cdot\text{m})\,(42\ \text{m})}{(\pi/4)\,(0.00412\ \text{m})^2} = 66\ \text{W}$. The decrease in energy consumption is $\Delta E = \Delta Pt = (40\ \text{W})(365\ \text{days/yr})\,(12\ \text{h/day}) = 175\ \text{kWh/yr}$ and the savings is $(175\ \text{kWh/yr})(\$0.11/\text{kWh}) = \$19.25$ per year.

EVALUATE: The cost of the 4200 W used by the appliances is \$2020. The savings is about 1%.

25.80. **IDENTIFY:** Apply $R = \dfrac{\rho L}{A}$ for each material. The total resistance is the sum of the resistances of the rod and the wire. The rate at which energy is dissipated is I^2R.

SET UP: For steel, $\rho = 2.0\times10^{-7}\ \Omega\cdot\text{m}$. For copper, $\rho = 1.72\times10^{-8}\ \Omega\cdot\text{m}$.

EXECUTE: **(a)** $R_{\text{steel}} = \dfrac{\rho L}{A} = \dfrac{(2.0\times10^{-7}\,\Omega\cdot\text{m})(2.0\ \text{m})}{(\pi/4)(0.018\ \text{m})^2} = 1.57\times10^{-3}\ \Omega$ and

$R_{\text{Cu}} = \dfrac{\rho L}{A} = \dfrac{(1.72\times10^{-8}\ \Omega\cdot\text{m})(35\ \text{m})}{(\pi/4)(0.008\ \text{m})^2} = 0.012\ \Omega$. This gives

$V = IR = I(R_{\text{steel}} + R_{\text{Cu}}) = (15000\ \text{A})\,(1.57\times10^{-3}\ \Omega + 0.012\ \Omega) = 204\ \text{V}$.

(b) $E = Pt = I^2Rt = (15000\ \text{A})^2(0.0136\ \Omega)(65\times10^{-6}\ \text{s}) = 199\ \text{J}$.

EVALUATE: I^2R is large but t is very small, so the energy deposited is small. The wire and rod each have a mass of about 1 kg, so their temperature rise due to the deposited energy will be small.