1. How long does it take electrons to get from a car battery to the starting motor? Assume the current is 300 A and the electrons travel through a copper wire with cross-sectional area 0.21 cm² and length 0.85 m. The number of charge carriers per unit volume is $8.49 \times 10^{28} \text{ m}^{-3}$.

**Sol**

We use $v_d = J/ne = i/Ane$. Thus,

$$v_d = \frac{L}{i/(Ane)} = \frac{L}{i} \cdot \frac{Ane}{i} = \frac{(0.85 \text{ m}) \left(0.21 \times 10^{-14} \text{ m}^2\right) \left(8.47 \times 10^{28} / \text{m}^3\right) \left(1.60 \times 10^{-19} \text{ C}\right)}{300 \text{ A}}$$

$= 8.1 \times 10^2 \text{ s} = 13 \text{ min}$.

2. Figure 26-28 shows wire section 1 of diameter $D_1 = 4.00R$ and wire section 2 of diameter $D_2 = 2.00R$, connected by a tapered section. The wire is copper and carries a current. Assume that the current is uniformly distributed across any cross-sectional area through the wire’s width. The electric potential change $V$ along the length $L = 2.00$ m shown in section 2 is 10.0 mV. The number of charge carriers per unit volume is $8.49 \times 10^{28} \text{ m}^{-3}$. What is the drift speed of the conduction electrons in section 1?

**Sol**

The number density of conduction electrons in copper is $n = 8.49 \times 10^{28} / \text{m}^3$. The electric field in section 2 is $10.0 \text{ μV}/(1.75 \text{ m}) = 5.71 \text{ μV/m}$. Since $\rho = 1.69 \times 10^{-8} \Omega \cdot \text{m}$ for copper (see Table 26-1) then Eq. 26-10 leads to a current density vector of magnitude $J_2 = (5.71 \text{ μV/m})/(1.69 \times 10^{-8} \Omega \cdot \text{m}) = 338 \text{ A/m}^2$ in section 2. Conservation of electric current from section 1 into section 2 implies

$$J_1A_1 = J_2A_2 \quad \Rightarrow \quad J_1 (4\pi R_1^2) = J_2 (\pi R_2^2)$$

(see Eq. 26-5). This leads to $J_1 = 84.5 \text{ A/m}^2$. Now, for the drift speed of conduction-electrons in section 1, Eq. 26-7 immediately yields

$$v_d = \frac{J}{ne} = 6.22 \times 10^{-9} \text{ m/s}$$

3. Earth’s lower atmosphere contains negative and positive ions that are produced by radioactive elements in the soil and cosmic rays from space. In a certain region, the atmospheric electric field strength is 120 V/m and the field is directed vertically down. This field causes singly charged positive ions, at a density of 620 cm³, to drift downward and singly charged negative ions, at a density of 550 cm³, to drift upward (Fig. 26-27). The measured conductivity of the air in that region is $2.70 \times 10^{-14} (\Omega \cdot \text{m})^{-1}$. Calculate (a) the magnitude of the current density and (b) the ion drift speed, assumed to be the same for positive and negative ions.
We use $J = \sigma E = (n_+ + n_-)ev_d$, which combines Eq. 26-13 and Eq. 26-7.

(a) The magnitude of the current density is

$$J = \sigma E = (2.70 \times 10^{-14} / \Omega \cdot m) (120 \text{ V/m}) = 3.24 \times 10^{-12} \text{ A/m}^2.$$

(b) The drift velocity is

$$v_d = \frac{\sigma E}{(n_+ + n_-)e} = \frac{(2.70 \times 10^{-14} / \Omega \cdot m)(120 \text{ V/m})}{(640 + 550) / \text{cm}^3 (1.60 \times 10^{-19} \text{ C})} = 1.70 \text{ cm/s}.$$

4. **Swimming during a storm.** Figure 26-30 shows a swimmer at distance $D = 35.0$ m from a lightning strike to the water, with current $I = 78$ kA. The water has resistivity $30 \Omega \cdot m$, the width of the swimmer along a radial line from the strike is 0.70 m, and his resistance across that width is $4.00 \text{ k}\Omega$. Assume that the current spreads through the water over a hemisphere centered on the strike point. What is the current through the swimmer?

Sol

Since the current spreads uniformly over the hemisphere, the current density at any given radius $r$ from the striking point is $J = I / 2\pi r^2$. From Eq. 26-10, the magnitude of the electric field at a radial distance $r$ is

$$E = \rho_w J = \frac{\rho_w I}{2\pi r^2},$$

where $\rho_w = 30 \Omega \cdot m$ is the resistivity of water. The potential difference between a point at
radial distance $D$ and a point at $D + \Delta r$ is

$$
\Delta V = -\int_{D}^{D+\Delta r} Edr = -\int_{D}^{D+\Delta r} \frac{\rho_s I}{2\pi r^2} dr = \frac{\rho_s I}{2\pi} \left( -\frac{1}{D + \Delta r} - \frac{1}{D} \right) = -\frac{\rho_s I}{2\pi} \frac{\Delta r}{D(D + \Delta r)},
$$

which implies that the current across the swimmer is

$$
i = \frac{\Delta V}{R} = \frac{\rho_s I}{2\pi R} \frac{\Delta r}{D(D + \Delta r)}. \tag{5}
$$

Substituting the values given, we obtain

$$
i = \frac{(30.0 \, \Omega \cdot m)(7.80 \times 10^4 \, A)}{2\pi(4.00 \times 10^3 \, \Omega)} \frac{0.70 \, m}{(38.0 \, m)(38.0 \, m + 0.70 \, m)} = 4.43 \times 10^{-2} \, A.
$$