Answer on Question #48961, Physics, Electrodynamics

A copper wire has a square cross section 2.9mm on a side. The wire is 3.8m long and carries a current of 4.0A . The density of free electrons is $8.5\times10^{28}\text{m}^{-3}$.

a) Find the magnitude of the current density in the wire.

b) Find the magnitude of the electric field in the wire.

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

Solution:

a) The current density is

$$J = \frac{I}{A}$$

where A is cross section area.

$$A = a^2 = (2.9 * 10^{-3})^2 = 8.41 * 10^{-6}\ \text{m}^2$$

Hence,

$$J = \frac{4.0}{8.41 * 10^{-6}} = 4.76 * 10^5\ \text{A/m}^2$$

b) The magnitude of the electric field is

$$E = \rho J$$

where ρ= 1.72 * 10^{-8} Ω·m is the resistivity of copper.

Hence,

$$E = 1.72 * 10^{-8} * 4.76 * 10^5 = 0.0081872 \approx 0.0082\ \text{V/m}$$

c) The current in a conductor is the product of the concentration of moving charged particles, the magnitude of charge of each such particle, the magnitude of the drift velocity, and the cross-sectional area of the conductor.

$$I = n|q|v_d A$$

Thus, the time is

$$t = \frac{L}{v_d}$$

The drift velocity is

$$v_d = \frac{I}{n|q|A} = \frac{4.0}{8.5 * 10^{28} * 1.6 * 10^{-19} * 8.41 * 10^{-6}} = 0.00003497\ \text{m/s}$$

Hence

$$t = \frac{3.8}{0.00003497} = 108664.5\ \text{s} = 30.185\ \text{hours}$$

The currents propagate very quickly along the wire but the individual electrons travel very slowly.