* 18–8 Microscopic View of Electric Current

It can be useful to analyze a simple model of electric current at the microscopic level of atoms and electrons. In a conducting wire, for example, we can imagine the free electrons as moving about randomly at high speeds, bouncing off the atoms of the wire (somewhat like the molecules of a gas—Sections 13–9 to 13–11). When an electric field exists in the wire (Fig. 18–24) due to a potential difference applied between its ends, the electrons feel a force and initially begin to accelerate. But they soon reach a more or less steady average speed (due to collisions with atoms in the wire), known as their **drift speed**, v_{d}. The drift speed is normally very much smaller than the electrons' average random speed.

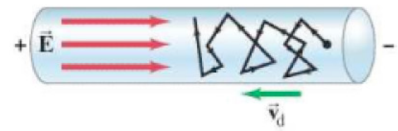
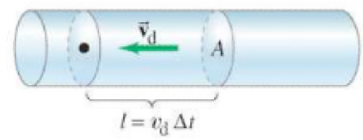


FIGURE 18–24 Electric field $\vec{\mathbf{E}}$ in a wire gives electrons in random motion a drift speed v_{d}.

Drift speed

We can relate v_{d} to the macroscopic current I in the wire. In a time Δt, the electrons will travel a distance $l = v_{\mathrm{d}}\,\Delta t$ on average. Suppose the wire has cross-sectional area A. Then in time Δt, all electrons in a volume $V = Al = Av_{\mathrm{d}}\,\Delta t$ will pass through the cross section A of wire, as shown in Fig. 18–25. If there are n free electrons (each of charge e) per unit volume, then the total number of electrons is $N = nV$ (V is volume, not voltage) and the total charge ΔQ that passes through the area A in a time Δt is

FIGURE 18–25 Electrons in the volume Al will all pass through the cross section indicated in a time Δt, where $l = v_{\mathrm{d}}\,\Delta t$.



$$\begin{aligned}\Delta Q &= (\text{number of charges, } N) \times (\text{charge per particle})\\ &= (nV)(e) = (nAv_{\mathrm{d}}\,\Delta t)(e).\end{aligned}$$

The current I in the wire is thus

$$I = \frac{\Delta Q}{\Delta t} = neAv_{\mathrm{d}}. \tag{18–10}$$

Current (microscopic variables)

EXAMPLE 18–14 **Electron speeds in a wire.** A copper wire, 3.2 mm in diameter, carries a 5.0-A current. Determine the drift speed of the free electrons. Assume that one electron per Cu atom is free to move (the others remain bound to the atom).

APPROACH We can apply Eq. 18–10 to find the drift speed if we can determine the number n of free electrons per unit volume. Since we assume there is one free electron per atom, the density of free electrons, n, is the same as the density of Cu atoms. The atomic mass of Cu is 63.5 u (see Periodic Table inside the back cover), so 63.5 g of Cu contains one mole or 6.02×10^{23} free electrons. We then use the mass density of copper (Table 10–1), $\rho_{\mathrm{D}} = 8.9 \times 10^3\,\mathrm{kg/m^3}$, to find the volume of this amount of copper, and then $n = N/V$. (We use ρ_{D} to distinguish it here from ρ for resistivity.)

SOLUTION The mass density $\rho_{\mathrm{D}} = m/V$ is related to the number of free electrons per unit volume, $n = N/V$, by

$$\begin{aligned}n = \frac{N}{V} = \frac{N}{m/\rho_{\mathrm{D}}} &= \frac{N\,(1\text{ mole})}{m\,(1\text{ mole})}\rho_{\mathrm{D}}\\ &= \left(\frac{6.02 \times 10^{23}\text{ electrons}}{63.5 \times 10^{-3}\,\mathrm{kg}}\right)(8.9 \times 10^3\,\mathrm{kg/m^3})\\ &= 8.4 \times 10^{28}\,\mathrm{m^{-3}}.\end{aligned}$$

The cross-sectional area of the wire is

$$A = \pi r^2 = (3.14)(1.6 \times 10^{-3}\,\mathrm{m})^2 = 8.0 \times 10^{-6}\,\mathrm{m^2}.$$

Then, by Eq. 18–10, the drift speed is

$$\begin{aligned}v_{\mathrm{d}} = \frac{I}{neA} &= \frac{5.0\,\mathrm{A}}{(8.4 \times 10^{28}\,\mathrm{m^{-3}})(1.6 \times 10^{-19}\,\mathrm{C})(8.0 \times 10^{-6}\,\mathrm{m^2})}\\ &= 4.7 \times 10^{-5}\,\mathrm{m/s},\end{aligned}$$

which is only about 0.05 mm/s.

NOTE We can compare this drift speed to the actual speed of free electrons bouncing around inside the metal like molecules in a gas, calculated to be about 1.6×10^6 m/s at 20°C.