

## Electron Drift Velocity

When we turn on a light switch, the lights go on almost instantly. Do the electrons in the switch actually travel from the switch to the light bulb that fast? How fast do electrons actually move in a wire? The answer is easy to calculate, and a bit surprising.

Let's imagine we have a copper wire of cross-sectional area  $A$ .



*Wire with cross-sectional area  $A$ .*



*After time  $\Delta t$ , electrons have filled a volume  $V$  (shaded region.)*

As electrons flow past a cross section, we can imagine the electrons filling up a volume of wire. (See diagram above.) This volume ( $V$ ) depends on the cross-sectional area ( $A$ ), the average speed of the electrons ( $\bar{v}$ ), and the amount of time the current is flowing ( $\Delta t$ ).

$$V = A\bar{v}\Delta t \quad \text{eqn. 1}$$

It is easy to calculate the number of atoms in the volume of wire, if we know the density and atomic weight of the wire. Most of the electrons in the wire are "locked" in place to a particular atomic nucleus. We will assume that each atom in the wire has one loosely held electron, or one *free electron*. It is the free electrons that are moving in the wire when there is an electric current. Therefore, if we know the number of atoms in the volume of wire, we know the number of free electrons in the wire.

The free electron density, ( $\rho_e$ ), is the number of free electrons per unit volume in the wire, and simply depends on the material of the wire. (That calculation for copper appears at the end of the handout.) Therefore, the number of free electrons ( $\Delta q$ ) in the volume of wire is simply the volume of the wire multiplied by the free electron density:

$$\Delta q = V\rho_e = A\bar{v}\Delta t\rho_e \quad \text{eqn. 2}$$

The current,  $I$ , in the wire is the amount of charge passing through a cross section per time,  $I = \Delta q/\Delta t$ . Therefore, the number of electrons in the volume of wire after a time  $\Delta t$  must be

$$\Delta q = I\Delta t \quad \text{eqn. 3}$$

Equation 2 must equal equation 3. Equating these and solving for  $\bar{v}$  gives

$$\bar{v} = \frac{I}{A\rho_e} \quad \text{eqn. 4}$$

where  $I$  is the current in the wire, (measured in electrons per second),  $A$  is the cross-sectional area of the wire, and  $\rho_e$  is the density of free electrons (which is identical to the density of atoms in the wire).

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*Calculating the Free Electron Density for Copper:*

From the *CRC Handbook* (or any Periodic Table,) we find the density of copper and the atomic weight of copper. From this, we calculate the volume density of copper atoms.

$$\rho = 8.9 \text{ gm/cm}^3$$

$$A_w = 63.5 \text{ gm/mole}$$

$$\text{Avogadro's number} = 6.02 \times 10^{23} \text{ atoms/mole}$$

So, the number of atoms per unit volume in copper is:

$$\rho_e \cong \frac{\# \text{ atoms}}{\text{cm}^3} = \frac{\left(6.02 \times 10^{23} \frac{\text{atoms}}{\text{mole}}\right) \left(8.9 \frac{\text{grams}}{\text{cm}^3}\right)}{\left(63.5 \frac{\text{grams}}{\text{mole}}\right)}$$

We will assume that each atom "gives up" one electron to the metal, so the free electron density ( $\rho_e$ ) is simply

$$\rho_e = 8.4 \times 10^{22} \text{ electrons/cm}^3$$

*Converting Amps to Electrons per Second*

There are  $6.2 \times 10^{18}$  electrons in one coulomb of charge. Simply multiply the measured current by this constant to convert from amps to electrons/second.

### Questions:

1. Calculate the average speed of electrons in a copper house wire of diameter 1 mm, and carrying a current of 5 amps. (These are typical numbers for the wiring in a house.)
  
2. What is meant by the term *free electron* and why is there only one per atom?
  
3. Why would *free electrons* sometimes be called *conduction electrons*?
  
4. Electrons take considerable time to travel from the light switch to the light bulb in your room, yet the lights turn on almost instantaneously. How do you explain this?