Let's develop an understanding of electrical systems that are NOT in electrostatic equilibrium. In these systems, charges move, under the influence of externally imposed electric fields. Such systems provide us with the useful electricity we get out of flashlight batteries and rechargeable devices.

**Electrical Current**

Electrical Current is simply the flow of electrical charges.

The average current over the time interval \( \Delta t \) is the number of charges of one sign flowing through a surface \( A \) per unit time.

\[
I = \frac{\Delta Q}{\Delta t}
\]

By convention, we say that the direction of the current is the direction in which the positive charge carriers would move.

Note: for most problems we examine, it's really the negative charge carriers that move. Nevertheless, we say that electrons move in a direction opposite to the electrical current.

Leftover from Ben Franklin!
The average current over some time interval $(t_1, t_2)$ is given by the slope of the line joining those two points in the $Q$ vs $t$ plot.

\[ \bar{I} = \frac{\Delta Q}{\Delta t} \]

The instantaneous current is the slope of the tangent line at a specific instant in time $(t^*)$.

\[ I = \frac{dQ}{dt} \]

Why do charges move?

Well, what happens when you put an electric field across a conductor?

- electrical force on the charges in the conductor
- charges can move freely in conductors.

A current flows!
If there are \( n \) charge carriers per volume in the conductor, then the total charge passing through a surface \( A \) in a time interval \( \Delta t \) is given by

\[ I = \frac{\Delta Q}{\Delta t} = nqAv_d \]

The current density is the combination of variables:

\[ \vec{J} = nq\vec{v}_d \]

The magnitude of the current density is related to the current:

\[ |\vec{J}| = \frac{I}{A} \]

\[ \text{Units!} \]

\[ |I| = \left[ n \right] \left[ q \right] \left[ A \right] \left[ v_d \right] \]

\[ = \text{1 ampere} = 1 \text{ A} \]

\[ \vec{J} = nq\vec{v}_d \]

\[ \text{A} \]

\[ \text{m}^2 \]

We refer to the Concept Quiz for additional notes and problems.
Electric fields exert an electrical force on charges given by
\[ \vec{F} = q \vec{E} \]
And remember from last semester, Newton’s 2nd Law
\[ \vec{F} = m \vec{a} \]
So shouldn’t the charges be accelerating instead of moving with an average velocity \( v_d \)?

Let’s follow the path of one of the charge carriers to see what’s really going on...

The thermal motion of the charges in the conductor keep the charges bouncing around all over the places, “hitting” the fixed atoms in the conductor.

You are probably asking yourself, “So, just how long does it take the average electron to traverse a 1m length of 14 gauge copper wire if the current in the wire is 1 amp?”

Let’s try to guess first: 1) years 2) weeks 3) days 4) hours 5) minutes 6) seconds 7) microseconds 8) nanoseconds