# Topic 1

# Charge, Current, Voltage

Material discussed 1/15/19.

## 1.1 Charge

- SI unit is Coulombs (C).
- Fundamental unit is *magnitude* of charge on electron/proton:

$$e = 1.6 \times 10^{-19}\,\text{C}.$$

Note that the symbol $e$ refers to a *positive* quantity.

## 1.2 Current

- Current is a measure of the flow rate of charge past a point in a circuit:

$$I = \frac{Q}{\Delta t} \longrightarrow \frac{dQ}{dt}.$$

- SI unit is Coulombs/second (C/s), or Amperes (A).
- Current can be written in terms of microscopic quantities as

$$I = nAve,$$

where $n$ is the density of electrons, $A$ is the cross-sectional area of the wire, $v$ is the *drift velocity* of the electrons, and $e$ is the charge of the electron.

- Batteries are *not* sources of constant current.
  Bench-top power supplies can be sources of constant current when they are in constant current, or `CC`, mode.
- Ammeters measure current that flows through the meter. Ideal ammeters should have no resistance. Ammeters should be connected in series with current they they are being used to measure (so that they do not disturb the circuit under investigation).

## 1.3 Voltage

- Formal definition: The voltage *difference* between two points A and B in an electrical circuit is the negative of the work done *per unit charge* by electric fields in moving a charge from point A to point B:

$$W_{\mathrm{E}} = q\Delta V.$$

- SI unit for voltage/potential is Joules/Coulomb (J/C), or Volts (V).
- A voltage difference between the ends of a circuit element reflects the fact that electric fields exist within the element that will result in current through the element.
- The terms voltage, potential, voltage difference, potential difference, and emf, are often used interchangeably. Be careful — exact meaning can depend on context.
- Ideal batteries are sources of constant voltage difference.
  Bench-top power supplies can be sources of constant voltage difference (when they are in constant voltage, or `CV`, mode.)
- Ideal voltmeters have infinite resistance so that no current flows through them. Voltmeters should be connected in parallel with the circuit element across which the voltage difference is being measured (so that they do not disturb the circuit under investigation)..

## 1.4 Relationship between $I$ and $\Delta V$

We generate voltage differences by doing work on charges in things like batteries, generators, solar cells. Existence of a non-zero $\Delta V$ indicates that there are electrical forces acting on charges in a circuit. The name of the game is to make and use gadgets that have interesting/useful relationships between current and voltage difference. These relationships are sometimes characterized with graphs of current as a function of voltage difference, or $I$-$V$ curves.

### 1.4.1 Simple case

In some materials there is a direct proportionality between the potential difference between two points in a circuit and the current that flows between the two points. Such materials are said to obey Ohm's Law. (This is not really a law, but rather an observation about some materials.) In other words,

$$I = \frac{\Delta V}{R} \quad \text{or} \quad \Delta V = IR.$$

This is more commonly written $V = IR$, but I encourage you to think about potential *differences*.

For materials that obey Ohm's Law, the resistance of a wire can be written in terms of a material-dependent quantity $\rho$, and material-independent geometric factors:

$$R = \rho \frac{L}{A},$$

where $L$ is the length of the wire and $A$ is the cross-sectional area. The quantity $\rho$ is known as the *resistivity*. This same relationship can also be expressed in terms of the *conductivity* of the material, $\sigma$, which is just the inverse of the resistivity:

$$R = \frac{1}{\sigma}\frac{L}{A},$$

Values of $\rho$ and $\sigma$ for various materials are available in many books and in online sources.

### 1.4.2 More interesting cases

Resistors have boring, but useful, $I$-$V$ curves. The rest of the world of circuit elements have more interesting relationships between current and voltage difference, such as

- diodes (one-way devices you will meet in Lab 2),
- thermistors (temperature sensitive devices you will meet in Lab 3),
- strain gauges,

- photosensitive devices (you will meet in lab 8), and
- three-terminal devices like transistors (you will meet in lab 9).