Circuits

MSJ Physics Club

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It should be noted that these handouts are concise and do not take the place of a full physics class.

4 Basic Circuit

We will first define the notion of current in a wire.

4.1 Current

Current in a wire/resistor/other object is defined as the amount of charge (in Coulombs) that passes through a certain point in the wire every per unit time. In equation form:

$$I = \frac{\Delta Q}{\Delta t}$$

The unit for current is amperes, also denoted $\mathrm{A} = \frac{\mathrm{C}}{\mathrm{s}}$.

4.2 Current in a wire

A conductor allows electrons to move freely within it. However, unless you have a superconductor, it always takes some effort (as in energy) to move the electrons through a material. We call materials that require large amounts of energy *resistors*. We define the resistance as the ratio of the electric potential applied (at two points) to the resulting current through an object.

$$R = \frac{\Delta V}{I}$$

Remember that the electric potential V is defined as the amount of electric potential energy per unit charge for an arbitrary test charge at a specified location. Resistance is measured in units of $\frac{\mathrm{J} \cdot \mathrm{s}}{\mathrm{C}^2}$. In most cases, R remains constant, regardless of changing electric potential or current.

4.3 Electromotive Force

The *electromotive force* (EMF) is a just a "battery" (usually). An EMF maintains a constant voltage (electric potential) between two points (the positive and negative ends of a battery). (Note that it is not necessary to mention absolute voltage; voltages, like potential energy are relative).

4.4 Power

The power (energy over time) released by an object is equal to the electric potential multiplied by the current flowing due to the electric potential. (because electric potential is energy over charge, and current is charge over time)

$$P = IV = I^2R$$

5 Circuit-Solving

Usually in circuits, one wants to find the voltage differentials or electrical currents at various points. To do this, we apply Kirchhoff's laws!

5.1 Junction Law

The current entering a junction is equivalent to the current leaving a junction. Basically, you can't deposit and build up charge in a junction.

5.2 Loop Law

The total changes in voltage as one goes around a loop is zero. Basically, a point has the same voltage as itself.

5.3 Advanced Laws

Take a look at these things to add into your toolbox!:
Y-Δ Transform
Equivalent circuits
Series and Parallel Resistors

6 Advanced Circuit Elements

This section requires calculus

6.1 Capacitors

Notice that all circuit elements are defined based on the relationship between the current that passes through them and the voltage that is applied to them. For a capacitor, this is:

$$I = C\frac{dV}{dt}$$

Where C is the *capacitance* of the capacitor (a constant).

6.2 Inductors

An inductor is similar:

$$V = L\frac{dI}{dt}$$

Where L is the *Inductance* of the inductor (a constant).

6.3 Methods for Solving Advanced Circuits

If the circuit is simple, you can just solve the differential equation(s) that you get from applying Kirchhoff's laws. In any other case, usually doing a Fourier transform and solving it in terms of cosine and sine waves does the trick; usually this is aided with a value called "impedance". This is relatively rare in contests.