Electric Current

The mechanical analogy: When electrons moves through a wire, think of it as water flowing through a pipe. I have a quantity of water flowing past a point in a given amount of time. The speed of the water in the pipe is the voltage (speed of the electrons in a wire) and the quantity of water flowing past that point is the current (quantity of the electrons in a wire).

How does a charge move through a wire?

The Facts:
1. Only electrons move through a metallic conductor. Think back to chemistry. Metals are substances that gain and lose electrons easily, thus conductors are metals.

2. Like charges repel and opposite charges attract.

Consider a battery (1.2V nicad battery, 1.5 – various A, C, D cells, 6V lantern battery, 9V transistor radio battery, 12V car battery). A battery maintains a potential energy difference across the terminals. A 1.5V "D" cell has the potential of delivering 1.5 Joules of energy for every coulomb that is moved from one terminal to the other terminal. A 12V car battery has the potential of delivering 12 Joules of energy for every coulomb that is moved from one terminal to the other terminal.

The components inside the battery (acids and dissimilar metals at the ends of the battery), through chemical reactions, produce an electric field that does work on a charge and that work produces a **deficiency** of electrons at one end of the battery (positively charged terminal) and an **excess** of electrons at the other end of the battery (negatively charged terminal). When an electrical device is connected to the battery, the electrons are repelled from the negative terminal, through the device, and attracted to the positive terminal.

This flow of electrons is a result of the negative charge pushing another negative charge in combination of the positive charge attracting the negative charge.

The **three primary components** of an electric current in a circuit:
1. Current – A progressive movement of free electrons along a wire or other conductor
2. Electromotive force – the electron moving force in a circuit that pushes and pulls electrons (current) through the circuit
3. Resistance – any opposing effect that hinders free-electron progress through wires when an electromotive force is attempting to produce a current in the circuit.

A simple electronic circuit consists of:
1. some sort of **electron-moving force** or source such as a battery, generator, or alternator
2. a **load** such as an electric light or motor
3. connecting wires
**4.** a **control device** such as a switch

There are two methods of illustrating a circuit:

1. Pictorial diagram – shows the actual physical placement of all components of the electrical device

2. Schematic diagram – shows the electrical connections and flow of the current in the electrical device. A schematic diagram is the electrical road map of an electronic device.

Below is illustrated a pictorial diagram and a schematic diagram of a battery, lamp, switch, and connecting wires.
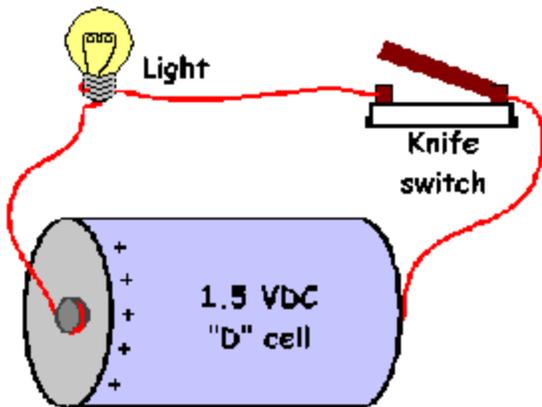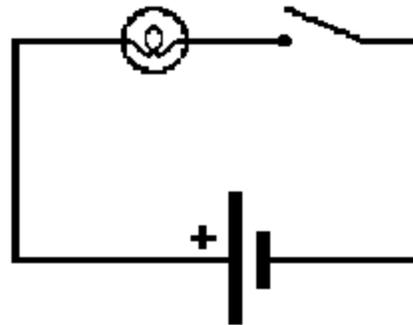
Pictorial Diagram   **Schematic Diagram**

For current to flow, the circuit must be closed. The function of the **control device** (switch) is to close the circuit for current flow and open the circuit to stop current flow. All circuits should have a **fuse** or other **circuit breaker,** these are safety devices that open the circuit if there is dangerously excessive current flow.

Electrical Pressure:

A mechanical analogy of electrical pressure – To open a door, you must push with a certain amount of force, say 5 N. An amount of force is required to obtain the desired movement of an object. To produce electrical motion (movement of electrons in a conductor), an electrical force is needed ($F_{electric}$). The electrical force causes the electrons in the outer energy level to leave their orbit and **"*surge*"** through the conductor as free electrons.

Electromotive force (emf) is the **electrical force** in the circuit and the units is the **volt** and the **potential difference** is called **voltage**.

Electric Current:

A current exists anytime there is a net movement of an electrical charge through a conductor. **Current** is the *rate* a charge moves through a cross section of wire. Current is expressed as the ratio of the charge passing by a given point (**?Q**) Current is the rate of charge movement and) to the time interval (**?t**).

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

I = current
?Q = charge passing past a point
?t = time interval

The **SI** unit for current is the **Ampere**, the unit symbol is **A** and the symbol in a formula is *I*. One ampere is equivalent to one coulomb of charge passing past a point in one second or more simply stated and coulombs per second.

1A = 1C/ 1s or **1A = 1C/s**

Drift Velocity:

I am going to turn off the lights. Can you get from your desk to the door before the lights go out? _____ Explain. _____
_____

The "*surge*" of electrons is not actually much of a surge. The free electrons cannot travel in a straight line from negative to positive because the electrons bounce around in the conductor, bouncing off of one stationary vibrating atom after another in some random direction towards the positive terminal. The electrons "**drift**" through the conductor occurs at a snails pace of **1 x 10^{-4} m/s**. It is the change or "signal" that propagates at a velocity that approaches the speed of light.

When the conductor is in electrostatic equilibrium, the electrons move randomly, bouncing off of other vibrating metal atoms in the conductor. Therefore the average drift speed, 10^{-4} m/s, is tiny compared to the internal electric field energy speed (**c**).

When I turn the lights on, why does it not take several hours for the light to come on after I flip the switch?

Source of electrical current:

Your laptop computer, cell phone, MP3 player, CD player, quartz watch uses batteries for their current source. A **battery** converts chemical energy into electrical potential energy. Batteries are either replaced or recharged. A device that can provide continuous power to our homes is a generator. **Generators** convert mechanical energy to electrical energy and produce either AC or DC current. Generators them selves need a power source that can be wind, water, steam, or a gas powered engine.

Current types – two:

Direct current (dc) – Current that flows only in one direction. Batteries can **only produce direct current** and the potential difference between the terminals of the battery is always fixed.

Alternating current (ac) – The motion of the charge continuously reverses its self. Generators produce AC as the armature turns, it crosses the "N" magnetic field of a permanent magnet and then the "S" magnetic field of the magnet. Therefore the current direction is constantly changing. This is the type of current that comes into our homes.

Electric Resistance:

Anytime electrical current flows through some device it will encounter resistance. When a light bulb is connected to a current source, as the current flows into the wire in the light bulb, the current encounters a resistance. As the **emf** is shoved/pulled through that wire in the bulb, the friction due to resistance causes the bulb to glow and give off heat. **Resistance** is the *opposition* to the flow of current in a conductor.

Resistance is defined as the **ratio of electromotive force to the current**. The **SI** unit for resistance is the **ohm** (**W**). Resistance is expressed with the following formula:

$$R = \frac{E}{I}$$

R = resistance in ohm's
E = electromotive force (emf) in volts
I = current in amperes

Note: My expressions in electronic formals and diagrams will follow the universally accepted conventions of the IEEE (Institute of Electrical and Electronics Engineers). Authors of physics books may use variations of this. When in doubt ask me and/or check www.ieee.org.

The above formula is also the **Ohm's Law** equation used to calculate voltage, resistance, amperage and power of an electrical circuit. Ohm's Law cannot be applied to all materials.
Ohmic materials – have a constant resistance over a wide range of voltages
        Examples – carbon, resistors for limiting current in a circuit
Non-ohmic materials – do not have a constant resistance over a wide range of voltages.
        Examples – semiconductors (diodes), light bulbs, heating elements

Factors that determine resistance:

Remember that electrons do not travel in a straight line in a conductor. Many factors can affect the number of collisions in the conductor. The primary factors are:
        1. Length   3. Material
        2. Cross-sectional area   4. Temperature

Resistor Uses - Resistors are used to **control the amount of current** in a conductor for a fixed voltage. When you build your electronic projects, some electronic components can be easily damaged buy excessive current. You will add a resistor to the circuit to limit the current and protect the sensitive components. You will learn more about this in chapter 20.

Resistors are **used in microphones**. The resistance changes with the mechanical pressure of your voice hitting the resistive carbon element, thus superimposing your voice or other sound onto the current.

Resistors are used with capacitors in time constant circuits. The time constant circuit will be the major focus of one of your projects. The time constant can control the rate those obnoxious coupon lamps in grocery stores flash. The time constant can also control an electronically produced tone as in an electric organ.

Capacitance – The property of a conductor that describes its ability to **store an electric charge**. In a way, a capacitor is like a battery because a capacitor can store a charge.

A **capacitor** is an electronic device designed to provide capacitance. The basic capacitor is constructed of two parallel metal plates with dielectric material in between the plates. The dielectric material can be air, paper, mica, or glass.

How a capacitor works (charging and discharging):
When an electric potential is connected across the plates of the capacitor, the **emf** forces electrons onto **one** plate giving that plate a negative charge. The electrons are pulled off of the other plate giving it a positive charge. Since the two parallel plates of a simple capacitor are separated by the dielectric from each other, a current cannot flow directly between the two plates. The energy is stored in the electrostatic force field that produced by the potential difference between the negative plate and positive plate of the capacitor. The capacitor is discharged when a wire or electrical component is connected across the terminals of the capacitor allowing electrons to move from the negative side and to the positive side allowing the capacitor to become electrostatic neutral.

Capacitance is defined as the ration of the net charge (Q) on each plate to the potential difference (voltage) created by the separated charges. The formula is:

$$C = \frac{Q}{\Delta V}$$

C = capacitance in Farads (F)
Q = charge in coulombs (C) on each plate
V = the potential difference in voltage (V)

The **SI** unit for capacitance is the **Farad** (**F**), named after Michael Faraday (1791 – 1867). If a charge of one coulomb is placed on each plate of the capacitor and the potential difference is one volt, the capacitance is defined as one Farad.   **1 F = 1 C / 1 V**

Factors that affect Capacitance:
1. The surface area of the plates
2. The spacing between the plates.
3. The dielectric constant of the insulating material between the plates.

Calculating Capacitance:
The three above factors are used to calculate capacitance of a capacitor. The formula is:

$$C = \frac{8.855\,KA}{d}$$

C = capacitance in pF
K = dielectric constant
A = surface area of one plate in m^2 (assuming a two plate capacitor)
d = spacing between plates in meters

Note that the answer is in **pF** – picofarads – 10^{-12}. Capacitance tends to be very small numbers. You will be working with these small values calculating the capacitance of the capacitors you build for your crystal radio.

The dielectric material in capacitors has two functions.
1. Increases the value of the capacitor.
2. Increases the voltage rating of the capacitor.

Capacitors are energy storage devices and the capacitor stores potential energy (Joules). Initially no work is done to charge a neutral capacitor. After the capacitor is charged, then other components are used to discharge the capacitor and the stored energy is now doing work to move electrons/charges through an electronic circuit at a specific rate. The formula to calculate the $PE_{electric}$ is:

$$PE_{electric} = \tfrac{1}{2}\,C(\Delta V)^2 \qquad \text{or} \qquad PE_{electric} = \frac{Q^2}{2C}$$

Uses of Capacitors:

Capacitors have many uses in electrical circuits.
1. Changing transmit or receive frequencies in radios (your xtal radios)
2. Filtering power supplies for pure DC during AC to DC conversions
3. Used to change tones in audio oscillators
4. Used with resistors in time constant circuits.
5. Used to bypass RF (radio frequency signals) from AF (audio frequency) circuits.
6. Increasing the power to strobe or camera lights

Superconductors - The first working superconductor was developed at our own University of Houston. The objective of a superconductor is to move current through a conductor that does not have resistance thereby reducing costs and increasing the efficiency of the conductor by avoiding wasted power. So far the primary usage superconductors is to build the express train in Japan that can travel at velocities in excess of 225 km/h.

Electric Power - Power describes how much work can be done in a given amount of time. Electric power is the rate as which charge carriers do work. Electric power is the rate at which charge carriers convert electrical energy into another form of energy. An example is when electrical energy is converted into heat energy (stove), into mechanical energy (motor), or into light energy (powering a flashlight or other type of light bulb).

The formula for electrical power is: **P = I x E**   or   **P = I²R**

> **P** = the **power** in **watts**   **E** = the **emf** in **volts**
> **I** = the **current** in **amps**   **R** = **resistance** in **ohms**

Look at most any light bulb. It will have a power rating in watts. Look at the power supply for your computer. You may not see the power used but you will see voltage and amperage and you can quickly calculate the power consumed by your computer.

The Kilowatt hour - When the bill from the power company arrives, the bill is for energy usage, the number of joules used, not the power. The term Kilowatt-hour is the energy delivered in one hour at a constant rate of 1000 watts. The following is a dimensional analysis to convert **one kilowatt-hour** to **Joules**.

$$1\text{kw?h} \times \frac{10^3 W}{1kw} \times \frac{60\min}{1h} \times \frac{60s}{1\min} = 3.6 \times 10^6 \text{ W?s}$$

The current flow from the electric plant, to your house, and back to the electric plant is a closed circuit. The power company charges you for the unrecoverable energy.

The energy in the current is converted into other forms, especially heat. Heat is sometimes referred to as **"waste energy,"** or **non-recoverable energy**. Refrigerators use energy to remove heat from an enclosed area. Put your hand near the vent of the refrigerator and notice the warm air that is expelled. As the electrons/charges are forced through a thin wire in a light bulb, the friction produced heat energy that is not recoverable. Some devices in our homes convert electrical energy into heat energy and the cost to use these devices is high. Hot water heaters, the central heating system for the house, electric stoves, and irons to name a few, use a lot of electrical energy to operate. Light from light bulbs is unrecoverable energy.

Moving energy to our homes - You have seen the power lines suspended high by power poles. The electrical companies must transfer a very large amount of energy from the power plants to the community it serves. Power plants produce AC. AC is easily stepped up and stepped down. Instead of transferring a low voltage at high current over the lines, the companies transfer a very high voltage at a low current to minimize energy loss. This can be proven by applying the equation **P = I²R** to the situation.

To further reduce cost, the power lines suspended by the power poles do not have insulating material on them. Why is it that if you touch the wire with a metal pole, you will get fried (electrocuted)? How can a bird sit on the wire and cackle at us the bird is not harmed?