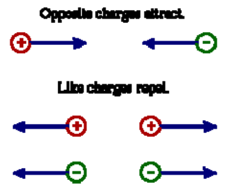
Static Electricity

When you get 'shocked', or see a 'spark', you are experiencing the same electrical effect that makes lightning. Most objects have the same number of positive (**proton**) and negative (**electron**) charges. This makes them **neutral** (no charge). Static electricity happens when there is an imbalance of electrons (which have negative charges).

The Laws of Electrical Charges



Van de Graaff Generators (VDG) build up an excess of static charge using friction. A rubber belt rubs a piece of metal and transfers the charge to a sphere. When you touch the sphere the charge builds up on you.

Charge separation occurs, when a charged object is brought close to a neutral object. The charged electrons repel the electrons in the neutral object and the charged object is then attracted to the protons of the neutral object.

Electrical Discharge is the movement of charges whenever an imbalance of charges occurs. The action results in neutralizing the objects. The over-charged electrons repel the electrons in the object and the positive protons attract the charged electrons causing a discharge or 'miniature lightning bolt'. Certain animals like an electric eel, can produce electric shock, to kill or stun prey. They have a special organ that contains specialized muscle cells called **electroplaques**. Each cell produces a small amount of electricity. When all the cells work together, a large amount of electricity is produce and used to help the eel survive. This type of electricity is like static electricity, which builds up and then discharges. **It does not flow continuously.**

Current Electricity

Electrical devices need a steady flow of electricity. The steady flow of charged particles is called electrical current. The flow continues until the energy source is used up, or disconnected.
Amperes - The rate at which an electrical current flows is measured in amperes (A). This flow varies from a fraction of an ampere to many thousands of amperes, depending on the device. Conductors are used to allow the flow of electrical charges from where they are produced to where they are needed. These conductors are materials (often wires), which allow the flow of electrical charges easily. Circuits - A circuit is a pathway that allows the flow of electricity. Most electrical circuits use wires (as conductors), although others may use gases, other fluids or materials. A circuit consists of a conductor, an energy source, a load and often a switch (to control the flow).

Electrical Energy and Voltage

Electrical energy is the energy carried by charged particles. Voltage is a measure of how much electrical energy each charged particle carries. The higher the energy of each charged particle, the greater the potential energy. Also called **'potential difference',** the energy delivered by a flow of charged particles is equal to the voltage times the number of particles. Voltage units are volts (V), and for safety purposes, the voltage of most everyday devices we commonly use is relatively low, while industries and transmission lines are **relatively high.** The simplest way to measure voltage is with a **voltmeter**. Some voltmeters can measure a wide range of voltages. **Multi-meters** should be used with caution, so that the sensitive needle is not damaged (by testing a low range with high voltage).

Measuring Voltage with Computers
A voltmeter can also be hooked up to a computer. Hook-up the red and black lead in the same way as you would for a voltmeter.

Electrical Safety

Coming in contact with a power transmission line can be deadly. By touching it, a short circuit can occur, because the electricity is trying to find a path to the ground - you can complete the circuit. Amperage is more important to consider. 0.001A will likely not be felt at all, 0.015A to 0.020A will cause a painful shock and loss of muscle control (which means you will not be able to let go of the line). Current as low as 0.1A can be fatal. When current can flow easily, it is more dangerous. Insulators (such as wood, rubber and air) hamper the flow of electricity.

The Danger of Lightning - A lightning strike can have 30,000A - more than enough to kill you. Lightning can also do a lot of damage to a building. Metal lightning rods that are connected to the ground with a grounding wire are fixed on the roof of many buildings to prevent damage to the building during an electrical storm.

Canadian Standards Association

issues labels to identify the amount of voltage required to operate electrical devices and the maximum current they use.

Plugs, Fuses and Breakers

The third prong of a 3 prong plug is a ground wire, connected to the ground wire of the building, in case of a short circuit. Fuses and circuit breakers interrupt a circuit when there is too much current flowing through it. Fuses contain a thin piece of metal designed to melt if the current is too high. Circuit breakers, on the other hand, trip a spring mechanism, which shuts off the flow of electricity through the circuit, when there is too much current. It can be reused over and over (provided the cause of the increased flow is corrected).

Electrical Safety Actions

-Never handle electrical devices if you are wet or near water
-Don't use devices that have a frayed or exposed power cord
-Always unplug an electrical device before disassembling it
-Don't put anything into an electrical outlet - except a proper plug for an electrical device
-Don't overload an electrical circuit, by trying to operate too many devices at once
-Avoid power lines
-Don't bypass safety precautions when you are in a hurry
-Pull on the plug, not the wire
-Never remove the third prong from a 3 prong plug
- Avoid being the target of a lightning strike, by staying low to the ground (horizon) and away from trees.
-Moisture is a good conductor of electricity, so avoid water when working with electricity.

Cells and Batteries

Electrochemical cells produce small amounts of electricity from chemical reactions within the cell.

Dry Cells - The electricity-producing cells, which are referred to as 'batteries', are called dry cells. They are 'dry' because the chemicals used are in a paste. The chemical reaction in a cell releases free electrons, which travel from the negative terminal of the cell, through the device, which uses the electricity, and back to the positive terminal of the cell. The dry cell is made up of two different metals, called electrodes in an electrolyte. An electrolyte is a paste or liquid that conducts electricity because it contains chemicals that form ions. An ion is an atom or group of atoms that has become electrically charged through the loss or gain of electrons from one atom to another. The electrolyte reacts with the electrodes, making one electrode positive and the other negative. These electrodes are connected to the terminals

Wet Cells
Wet cells are 'wet' because the electrolyte is a liquid (usually an acid). Each electrode (zinc and copper) reacts differently in the electrolyte. The acidic electrolyte eats away the zinc electrode, leaving behind electrons that give it a negative charge. The copper electrode is positive, but it is not eaten away. Electrons travel from the negative terminal (attached to the zinc electrode) through the device and on to the positive terminal (attached to the copper electrode).

A car battery is made up of wet cells. Each battery has 6 lead-acid wet cells containing alternating positive and negative metal plated (electrodes) in a sulfuric acid electrolyte.

Types of Batteries

Connecting 2 or more cells together creates a battery, which is a sealed case with only two terminals. Rechargeable Cells Dry cells and wet cells are called **primary cells**. The chemical reactions, which produced the electricity, cannot be reversed. Using an external electrical source to rejuvenate the cell however can reverse the chemical reactions in a rechargeable battery. The reversed flow of electrons restores the reactants in the cell. Rechargeable cells are **secondary cells**, because they store electricity that is supplied by an external source. The most common reactions that are efficient enough to be used for these types of cells are Nickel Oxide and Cadmium (Ni-Cad). The reactants are restored, but the electrodes wear out over time. Pacemaker cells can last from 5-12 years. **Fuel Cells** combine hydrogen and oxygen without combustion. Electricity, heat and pure water are the only by-products of the fuel cell's reaction. They are 50-85% efficient.

Processes & Applications

Electrochemistry - Allesandro Volta made the first practical battery around 1800, by piling zinc and copper plates on top of each other, separating them with electrolyte-soaked paper discs. Humphrey Davy filled an entire room with 2000 cells to make one massive battery.

His work led to a whole new field of science called **electrochemistry**, the study of chemical reactions involving electricity.

Electrolysis – using electricity to split molecules into their elements is called electrolysis. Industries use electrolysis to separate useful elements from solutions; like chlorine to make drinking water safe, and fuel for the Space Shuttle.

Electroplating - Silver and Gold plating can make jewelry and other attractive items look very expensive. The thin coating (which is usually stronger than the original element) is produced through a process called electroplating. This process is often used to protect the metal from corrosion.

Anodizing is a process that coats aluminum parts with a layer of aluminum oxide, which is much harder than aluminum. It is used in products such as screen doors, airplanes, car parts, kitchenware and jewelry.

Electro-refining is used to remove impurities from metal. Another process used by automobile companies bonds special paints onto car parts.

Energy Forms

The scientific definition of energy is 'the ability to do work'. Energy is found in many forms. The four most common forms of energy are:

Chemical - potential or stored energy stored in chemicals, released when the chemicals react.

Electrical - energy of charged particles, transferred when they travel from place to place.

Mechanical - energy possessed by an object because of its motion or its potential to move.

Thermal - kinetic energy of a substance

Measuring energy inputs and energy outputs allows you to calculate the efficiency of devices and systems.

Energy Conversions

Light to Electricity - photovoltaic (PV) cells, are made of semiconductor materials, such as silicon. When light is present, the material, breaks electrons loose – allowing them to flow freely. This current is drawn off by metal contacts on the top and bottom of the cell and then used in devices such as calculators, heater, or emergency telephones. Individual solar cells combined in modules form **arrays** producing more electric current.
Electricity to Motion - The ***piezoelectric effect*** produces sound by converting electricity into motion (vibrations). When a piezoelectric crystal, such as quartz, or Rochelle salt is connected to a potential difference, the crystal expands or contracts slightly.
Electricity to Light - An incandescent resistance filament (load) glows white-hot when electricity is passed through it. In fluorescent tubes a gas glows brightly. **LED**'s (light-emitting diodes) are solid–state components that use a fraction of the power.

Motion to Electricity - A barbeque spark lighter uses the **piezoelectric effect** in reverse. When a crystal or Rochelle salt is compressed or pulled, a potential difference is built up on the opposite sides of the crystal. Conductors then take this through a circuit to produce electric energy (a spark).
Electricity to Heat - Ovens convert electrical energy into thermal energy. A thermo-electric generator is a device based on a thermocouple that converts heat directly into electricity without moving parts. Several thermocouples connected in a series is called a **thermopile**. Thermopiles are extremely reliable, low-maintenance devices and are often used in remote locations for emergency power.
Heat to Electricity - A **thermocouple** is a device that can convert thermal energy into electrical energy - the '***Seebeck Effect***.' It consists of two different metals (bimetal) joined together that conduct heat at slightly different rates. When heated, the difference in conduction results in electricity flowing from one metal to the other.

Conductors and Insulators

In **insulators** - electrons are bonded closely to the nuclei (allowing little movement), while in **conductors**, the electrons are free. When electricity is added, the electrons move toward the positive terminal.

Semiconductors are almost perfect conductors - they have almost no resistance to electron flow. The largest obstacle is to get the semiconductor to work at reasonable temperatures for practical applications.

A gas can also act in the same way as a wire. It conducts the flow of charged electrons from the negative terminal to the positive terminal. Gases usually insulate, but 'some' gas atoms can be excited by electricity.

Resistance

Resistance is a measure of how difficult it is for electrons to flow through a conductor. It is measured in **ohms**. A special type of conductor, called a **resistor**, allows electrons to flow, but provides some resistance. The more resistance a substance has, the greater the energy gain it receives from the electrons that pass through it. The energy gain is evident in heat and light energy (light bulb filament, wire in a toaster). Solutions can also be resistors.

A **switch** is a device that allows the flow of electrons or stops the flow. When the switch is open, the is no flow, because there is a gap in the conductor. When the switch is closed, the switch becomes the 'gap replacement' and allows the flow of electrons to continue. To change the electron flow gradually, a **variable resistor**, or **rheostat** is used (a dimmer switch, volume control knob).

Ohm's Law

Georg Simon Ohm, a mathematician, proved a link between voltage (V), current (I) and resistance (R). The unit of resistance was named after him, the **ohm** Ω

Ohm's Law states that:

as long as temperature stays the same the resistance of a conductor stays constant, and the current is directly proportional to the voltage applied

$$R=V/I$$

Applying Ohm's Law
If the temperature of a resistor changes, the resistance changes as well (resistance is usually low when the resistor is cool, and as the temperature increases, so does resistance).

Modeling Voltage

A waterfall is used, as a model, to demonstrate voltage. Water flows when there is a change in the **gravitational potential energy** (elevation). Electricity will not flow unless there is a change in **electrical potential** (voltage).

Voltmeters measure voltage difference (**voltage drop**).

Ammeters measure current (rate of flow) in amperes. Small currents are measured using **galvanometers**.

Multimeters can measure voltage, current and resistance in a circuit.

Modeling Resistance and Current

Flow of water in pipes is used, as a model, to demonstrate resistance. The size of pipe determines the volume of water allowed through it. The amount of resistance, in a circuit, determines the size of the current.

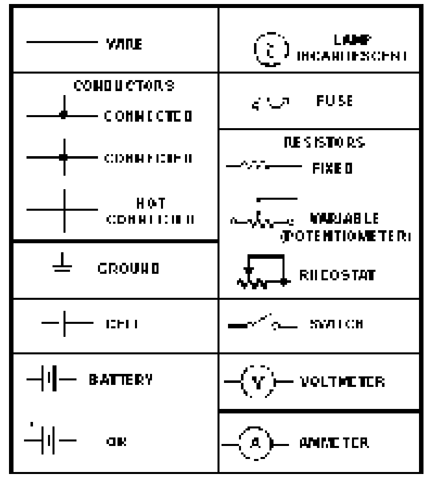
Analyzing and Building Circuits

Engineers and designers of electrical circuits use symbols to identify components and connections. A drawing made with these symbols is called a schematic or schematic diagram.

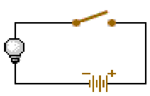
All circuit diagrams have four basic parts:

- **sources** - provides energy and a supply of electrons for the circuit
- **conductors** - provides a path for the current
- **switching mechanisms** - controls the current flow, turning it off and on, or directing it to different parts of the circuit
- **loads** - converts electrical energy into another form of energy

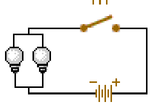
Basic Electrical Circuit Symbols



Series and Parallel Circuits

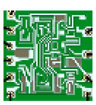


A **series circuit** provides only one path for the current to flow,



A **parallel circuit** has multiple pathways.

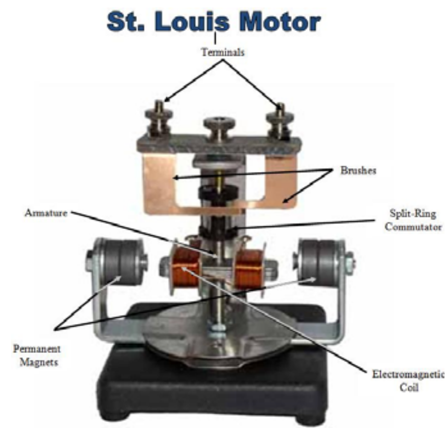
Microcircuits (Integrated Circuits) - transistors are used with three layers of specially treated silicon, with the middle layer (receiving a small voltage, allowing it to control the voltage in the outer layers, allowing them to act as switches. Microcircuits are made up of transistors and resistors and are built on an extremely small scale.



Integrated circuits put all of the components in one chip, reducing the size of the circuit.

Electric Motors

Oersted found that an electric current created a magnetic field by the deflection of a compass needle - demonstrating that electricity and magnetism are related. **Faraday** constructed the first motor. By coiling (copper) wire around a (iron) metal core a strong **electromagnet** can be made. When attached to an electrical source it will produce a strong magnetic field. To keep this electromagnet spinning in a magnetic field, the direction that the current is traveling through the coil must be switched. This is accomplished by with a gap, which allows the polarity of the electromagnet to change just before it aligns with the permanent magnet. Many electric motors use a **split ring commutator** that breaks the flow of electricity for a moment and then reverses the flow in the coil, when the contact is broken and **brushes** (contact points) to reverse the flow of electricity through the magnetic field. The **armature** (the rotating shaft with the coil wrapped around it) continues to spin because of momentum, allowing the brushes to come into contact once again with the commutator.



Direct and Alternating Current

Some motors run on direct current (DC). It is 'direct', because the electricity flows in only one direction. Alternating current (AC) flows back and forth 60 times per second.

Generating Electricity

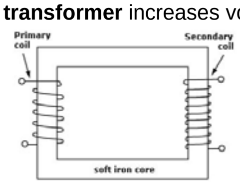
Michael Faraday discovered **electromagnetic induction** in 1831. He demonstrated that moving a conducting wire through a magnetic field by moving it back and forth through the field, Faraday created the first electricity-producing generator, which could generate electrical current. Massive coils of wire rotating in huge generators can produce enough electricity to power an entire city.

Generating DC and AC

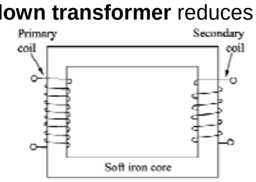
A **DC generator** is much the same as a DC motor. The spinning armature produces the electricity (if electricity is passed through a DC generator, it will spin like a motor). The central axle of an **AC generator** has a loop of wire attached to two slip rings. The current is switched as the loops move up and down alternatively through the magnetic field. The slip rings conduct the alternating current to the circuit through the brushes (the brush and ring assembly allows the whole loop to spin freely). In large AC generators many loops of wire are wrapped around an iron core.

Transformers are used to change the amount of voltage with hardly any energy loss. Voltage change is necessary because the most efficient way to transmit current over long distances is at high voltage and then reduced when it reaches its destination, where it will be used.

A **step-up transformer** increases voltage,



A **step-down transformer** reduces voltage.



Power *is the rate at which a device converts energy*. The unit of power is the **watt** (**W**), which is equal to 1 **joule** per second. For an electrical device the power is the current multiplied by the voltage.

(**P**) Power in watts (**I**) current in amperes
(**V**) voltage in volts

$P = I \times V$ $I = P / V$ $V = P / I$

Shortcut $\frac{P}{I\,V}$

(**E**) Energy in joules (**P**) Power in watts (J/s)
(**t**) time in seconds

$E = P \times t$ $P = E / t$ $t = E / P$

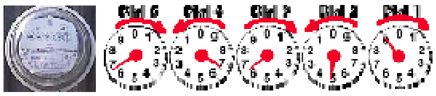
Shortcut $\frac{E}{P\,t}$

Energy

The power rating of a device can be used to determine the amount of energy the device uses. Multiply the power rating by the time the device is operating.

Kilowatt Hours is used as a unit for energy. The energy calculation is the same, except that hours are substituted for seconds and kilowatts (**kW**) are substituted for watts.

Electricity meters measure the energy used in kilowatt hours and then bills you for every kilowatt hour used.



Law of Conservation of Energy

Energy is neither created nor destroyed. It doesn't appear and then disappear, but transformed from one form to another. **No device is able to be 100% efficient in transforming energy**.

Most often, the energy is lost, or dissipated as **heat**. Mechanical systems also dissipate energy to their surroundings, but not as obvious as the heat loss. Much of the dissipated energy is **sound**.

Understanding Efficiency

The **efficiency** of a device is the ratio of the useful energy that comes out of a device to the total energy that went in. The more input energy converted to output energy, the more efficient the device is.

$$\textbf{Efficiency} = \frac{\textbf{Joules of useful output}}{\textbf{Joules of input energy}} \times 100\%$$

Most of the energy transformed in a light bulb is waste heat. (5% is **light** , while 95% is **heat**)
Florescent lights are about 4x more efficient than incandescent lights.
Arc-discharge lights are even more efficient (streetlights)

Comparing Efficiencies

Comparing efficiencies of devices the energy cost and their environmental impact can be determined. **Hybrid gasoline-electric** vehicles are more efficient than gas-powered vehicles.

Reducing Energy Waste

Devices, which have an **energy-efficient design**, are an important consideration for the consumer, because these devices use less electricity.

Limits to Efficiency - Electric heater come very close to being 100% efficient, but devices, which convert electricity to other forms, can never be 100% efficient. Some energy is lost, or dissipated in a form that is not useful output. Friction causes thermal energy to be lost, or dissipated in many devices.

Increasing Efficiency - of a device depends on its purpose. The easiest way to increase efficiency in many devices is to **reduce friction**, as much as possible. **Insulating** a device from heat loss is also another practical way to increase efficiency. Using **capacitors** in electrical circuits is also another way to increase efficiency.

Energy Sources and Alternatives

Burning **fossil fuels** generates 65% of electric power.

Renewable & Nonrenewable Energy

Coal is a **non-renewable** resource (it cannot be replaced, as it is used up). Other **fossil fuels** are non-renewable as well. **Renewable resources** can be replenished over and over again. These types of resources include; **wind energy**, **solar energy**, **tidal energy**, **biomass energy**, **geothermal energy**. **Tree harvesting** can also be renewed, but it takes a much longer period of time to renew this resource.

Using Water to Generate Electricity

Hydro-electric power plants generate 20% of the world's electricity. **Gravitational energy** is transformed into electrical energy.

Coal is mined, crushed into a powder, blown into a combustion chamber and burned to release heat. This heat boils water and superheats the resulting steam to a high temperature and pressure, which then turns a **turbine**. The turbine shaft rotates large electromagnetic coils in the **generator** to produce electricity. In a **nuclear reactor**, atoms of a heavy element, usually uranium, are split (**nuclear fission**) in a chain reaction, which releases an enormous amount of energy. Heat from the Earth's core - **geothermal energy** (hot water and steam) is channeled through pipes to drive turbines - connected to generators, which produce the electricity. **Biomass** is another type of fuel used to generate electricity. The gases produced from the decomposition of garbage in landfills can be used as fuel for stem-driven generators. Waste heat from many industrial processes is used to produce steam generated electrical power. This process is called **cogeneration**.

Alternative Energy Sources

Tides - moving water can power turbines, which then run generators. When the tide comes in, the water is trapped in large reservoirs and then allowed to flow out past turbines.

Wind - this energy is harnessed by large propeller-type blades, which turn a shaft - connected to a generator.

Sunlight - **Solar cells** (made from silicon) enable the energy from the sun to be transformed (**photoelectric effect**) into electricity.

Batteries - from small portable batteries to rechargeable and most recently to the **fuel cells** all provide an electrical source by using chemical reactions within the cells.

Electricity and the Environment

The burning of fossil fuels to generate electricity releases: **Fly ash**, from the burning of coal, is carried up the smokestack and released into the atmosphere.
Sulfur Dioxide (SO_2) - causes acid rain
Nitrogen oxides (NO) - causes air pollution
Carbon dioxide (CO_2) - is the cause of global warming.

Other Environmental Effects

Strip-mining techniques removes all plants and animals from large areas of land - habitat and species destruction.
Oil and Gas wells can often give off poisonous gases.
Steam turbines often release warm water into nearby lakes and rivers – thermal pollution
Mines and refineries produce nuclear fuel and radioactive waste.
Dams, **wind farms** and **solar cell arrays** destroy large areas of ecological habitat.
Tidal power plants disrupt fish habitat and other marine life.

Fossil fuel reserves are decreasing, but with less reliance on these fuels we will be able to see a decrease in pollution. Conserving energy can be accomplished a little at a time.
Sustainability means using resources at a rate that can be maintained indefinitely. If sustainability is not achieved, future generations will suffer. A sustainable approach often means a different way of getting what you want. Personal decisions can affect sustainability, even if it seems like it's only on a small scale. More technology means more resources are needed to manufacture and operate them, making sustainability more difficult to achieve. Electrical signals from computer to computer throughout the world, makes the storage and transmission of information compact, easy and cheap. Concerns include; access, privacy, safety, misleading or false information and the 'information explosion' has created other storage, handling and access problems. Search engines may locate some of the information, but they cannot access everything.

Electrical Technology and Society

Benefits - improved our standard of living. Most improvements have come as a result of a desire to improve speed, efficiency or convenience.
Drawbacks - obsolete devices become waste, adding to our problems of waste disposal. Some technologies are too expensive for some countries to adopt, leading to isolation and exclusion.
Computers and Information - revolutionized the way we accomplish many tasks, including writing, calculations and communications, leading to the digital technology era.
Electricity and Computers - Lasers, photo-detectors, and electrical pulses all enable electronic devices to complete the tasks they are made to do. A computer hard drive - uses electrical pulses to record and transmit information, sent to an arm with read and write heads, which are magnetic coils that magnetize spots on the spinning disk.