Background Information

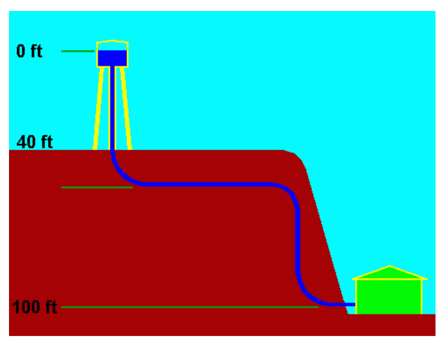
A REEL Power tm (Renewable Energy Education Lab) Lesson

The following can be used for any lesson. Please refer to it for background information on electricity and the components used in the lessons.

What is Voltage?

Voltage is to electricity as pressure is to water; both are forces that move things.

Voltage is the force that moves electrons through a circuit; the greater the voltage the greater the force of electron movement. Voltage is generated by creating a "potential difference" between positive and negative elements of the device generating it.



Like water, the higher the voltage, the more force it exerts. Water falling from a height uses gravity to create force; the higher the water falls (its potential difference), the more force or pressure it creates. Unlike water, however, voltage is not created by gravity but by chemical, optical, or magnetic forces.

Batteries use chemicals to generate voltage while common fuel cells use electrons in hydrogen gas to create voltage. Solar panels use optical means to capture the sun's photons to do the same and wind turbines use rotating magnets that are very close to coils of wire that generate voltage based on the magnetic fields created by the magnet's rotation.

Voltage is measured in units called volts.

What is Current?

Electrical current is to electricity as the volume of water is to water flow. A fire hose can carry more water at higher pressure compared with a clogged shower head. So too can lager wires carry more current as compared with smaller wires.

Electrical current carries electrons along a path (called a circuit) like water carries water molecules through a hose. More electrons mean more current flow.

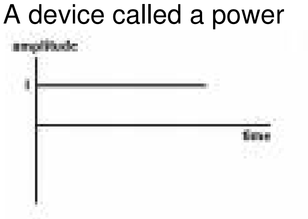
Water normally flows from upstream to downstream using gravity as a force. Electrical current normally flows from positive (+) to negative (-), which is called direct current or DC for short, but gravity is not involved.

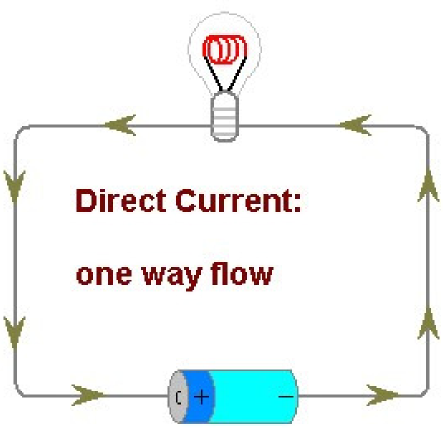
Unlike water, electrical current can flow in either direction – positive to negative and negative to positive. The latter is usually called alternating current, or AC, since the current switches (alternates) between positive and negative directions. Electrical current produced by batteries are DC while electrical current coming out of the wall socket is AC. Both have their applications in electronic circuits.

Current is measured in units called amperes or amps

What is Direct Current?

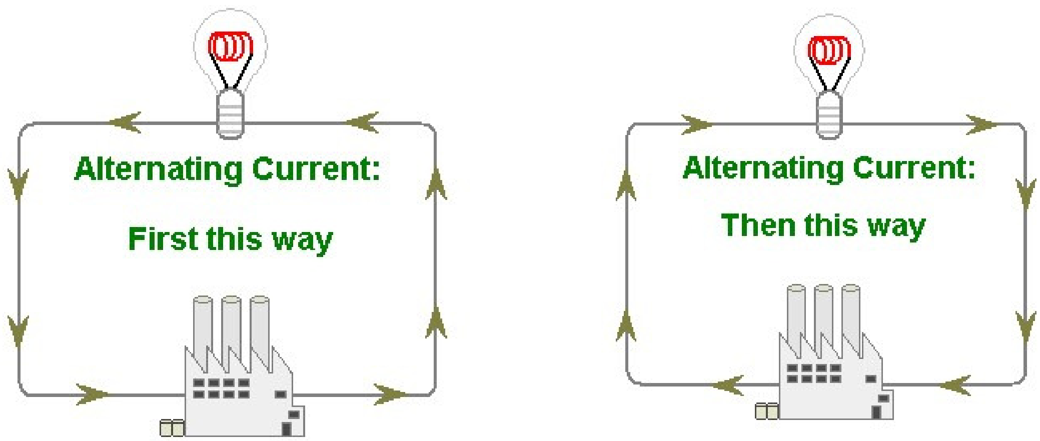
Direct current, or DC, is a continuous, non-changing, flow of charge through a circuit. Batteries, solar panels and fuel cells generate direct current at various voltages depending on their individual ratings. Even though most electronic appliances like televisions and computers run on DC they get their power from AC current by plugging a power cord into a wall outlet. A device called a power supply converts the AC to DC. On a computer plot direct current looks like a straight line going across the screen. Images courtesy green-planet-solar-energy.com.

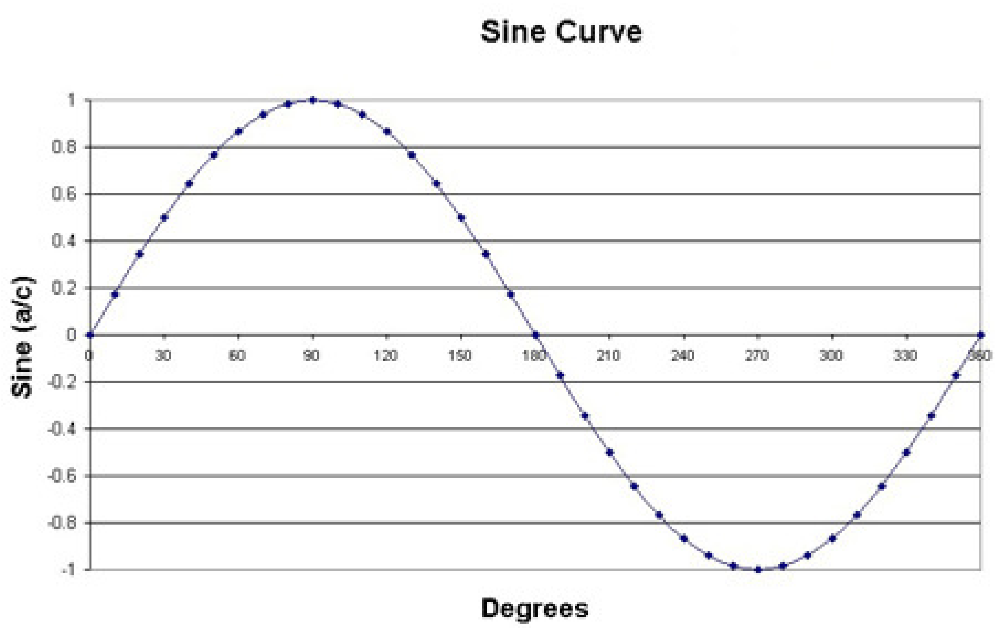




What is Alternating Current?

Alternating current, or AC, is a non-continuous flow of charge through a circuit. Certain wind turbines generate alternating current and all power coming from the local power plant into the home is AC that varies at 60 Hz or 60 cycles per second. Unlike direct current alternating current can be "scaled" up or down by a device called a transformer, which allows it to be efficiently distributed over long distances. On a computer plot alternating current looks like a wave with peaks and troughs. Images courtesy green-planet-solar-energy.com.

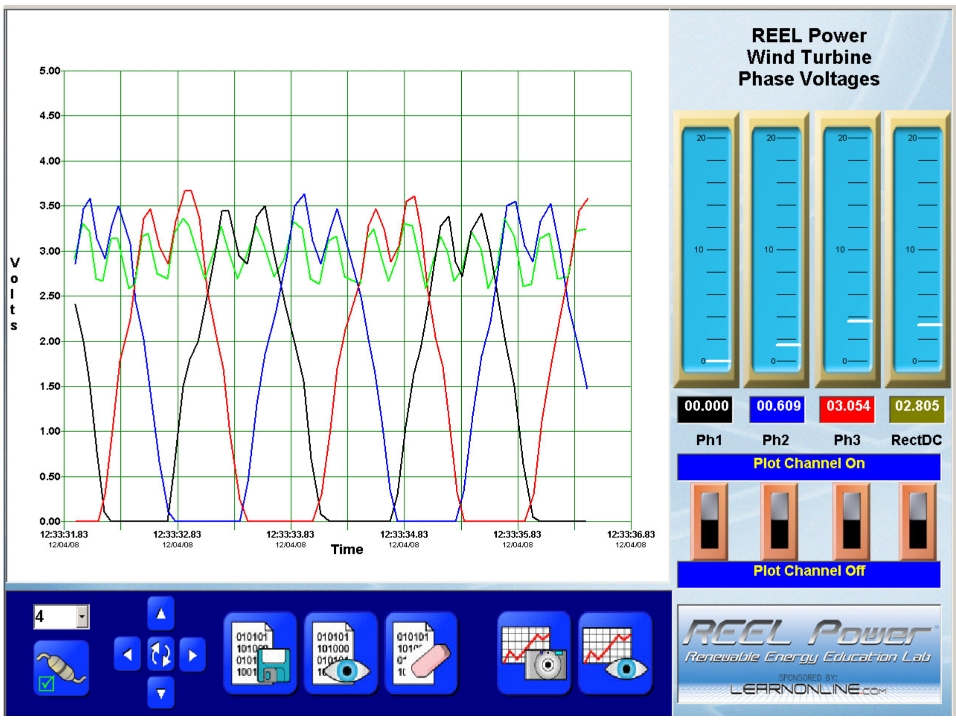




What are Alternating Voltage Phases?

Alternating current can have phases or waves of voltage that are displaced in time from one another. The AC coming into your house has a single voltage phase while most commercial AC motors operate on three phases that are spaced 120 angular degrees apart from one another. The advantage of multiple phases is that power never goes to zero as it does in a single-phase arrangement.

On a computer plot 3-phase AC looks like three waves that are meshed together. The red, blue and black lines represent the three phases while the green line is the voltage that never goes to zero volts due to the 3-phase arrangement.



What is Resistance?

Electrical resistance can be compared to a corroded water pipe. If the water pipe is wide and clear of corrosion the resistance is minimal because more water can flow unimpeded. If a water pipe is narrow and corroded, resistance is greater since water cannot flow because of the internal barriers to it. A soda straw has a higher resistance to water flow as compared with a garden hose since, for a given amount of water pressure (voltage in electrical terms), less water can flow through the straw as compared with a garden hose.

Larger wires can carry more electrical current as compared with smaller wires. In electrical circuit boards components called resistors are inserted in the circuit to limit current flow.

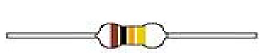
The resistance to the flow of electrons depends on the type and size of the materials used. While water flowing in a pipe does not generally produce heat by itself, electrical resistive materials produce varying degrees of heat created by the flow of electrons through the material. Heat is generally considered wasted energy (as in a light bulb) but not always, as in a toaster or hair dryer where heat from resistance is the desired quantity.

Resistance is measured in units called ohms.

What is a Resistor?

A resistor is a passive electrical device usually composed of a material like carbon that limits the flow of current from a power source. Resistors are normally considered as loads and are important components in any electrical circuit, since other components that are connected to the resistors depend on the limited current and voltage they produce to operate correctly.

The physical part and electrical symbol for a resistor are shown below:



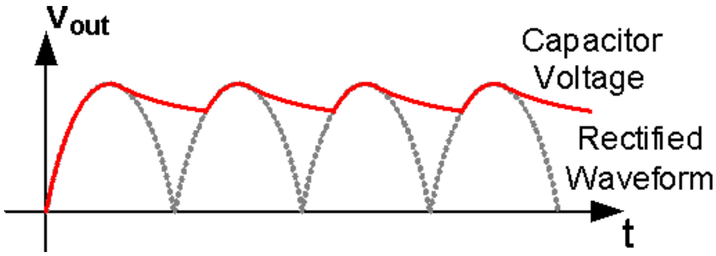
A resistor's value is specified in ohms.

What is a Capacitor?

A capacitor is a device that stores energy from a power source and then releases the stored energy when it is no longer available. Depending on the size of the capacitor (its value, in units called Farads), it can store and release energy many times faster as compared with a battery. The experiments will use the capacitor to "filter" or smooth out the voltage "ripples" produced by the wind turbine.

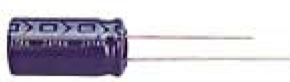
You can think of a capacitor as a water bucket with a small hole in the bottom, because like such a bucket a capacitor cannot hold a charge indefinitely – some of it leaks out. If water (the voltage or pressure) from a hose begins to fill the bucket with water at a fast rate, the bucket will begin to fill; however, a small amount of water (voltage) will trickle out of the hole in the bottom. If the water from the hose slows down the bucket will not fill as fast, but the water will still trickle out of the hole at the nearly the same rate. If this process is repeated over and over again the bucket will fill at varying rates depending on the water from the hose, but the trickle rate will be nearly constant – only changing by the overall amount of water (pressure) filling the bucket.

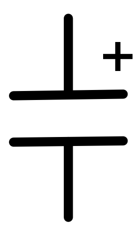
.



Capacitors come in two basic types – polarized and non-polarized. A polarized capacitor requires that you connect the positive lead to the red terminal on the circuit board and the negative lead to the black terminal. Non-polarized capacitors can have either lead connected to positive or negative. The experiments only use a polarized capacitor.

The physical part and electrical symbol for a polarized capacitor are shown below:



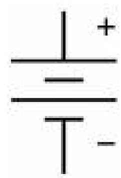


The longer lead of a polarized capacitor is positive (+) while the shorter lead is negative (-). The negative lead is also identified by a series of bar-and-arrow symbols on the part itself. In the experiments that follow, be sure to observe the positive and negative portions of the capacitor.

A capacitor's value is specified in farads, microfarads or picofarads

What is a Battery?

A battery is a device that stores chemical energy, which can be converted into electrical energy. Batteries are normally considered as power sources. The physical part and electrical symbol for a battery are shown below:



Primary batteries are ready to produce current as soon as they are manufactured. Primary batteries are generally used in flashlights and must be replaced when they go "dead".

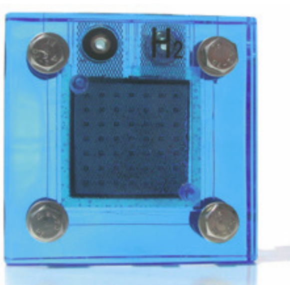
Secondary batteries can be recharged by applying an electrical current, which reverses the chemical reactions that occur during its use. All car batteries are secondary batteries that need constant recharging by the car's alternator.

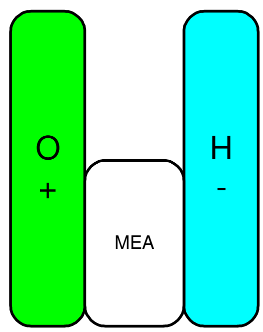
A battery value is specified in both volts and milliamp-hours

What is a "Reversible" Fuel Cell?

A "reversible" fuel cell splits water (H2O) into hydrogen and oxygen gases in electrolysis mode and then recombines the hydrogen and oxygen gasses to create electricity, which is why it is called "reversible". It doesn't take much voltage (about 1.5 volts) to split water into hydrogen and oxygen as one of the experiments will demonstrate.

The physical part and symbol for a reversible fuel cell are shown below:





What is an LED?

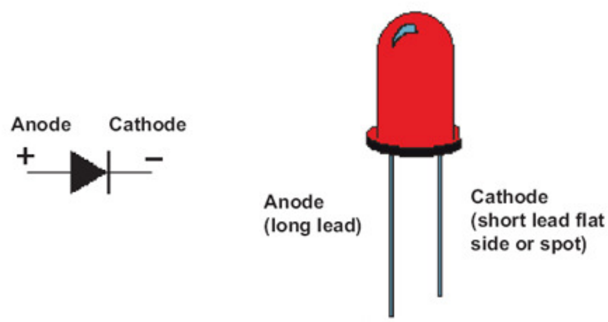
The term LED stands for Light Emitting Diode.

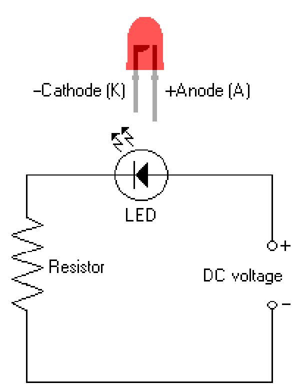
A diode is like a one-way valve that only lets electricity pass through it in one direction from positive to negative. The positive side is called the Anode and the negative side is called the Cathode. Normal diodes are used in electronic circuits to direct voltage and current in the desired direction.

A "light emitting" diode is really a diode that illuminates when electricity passes through it from positive to negative. Depending on the type of LED this illumination can be in various colors like red, green, yellow, blue and even white. The LED material creates the particular color.

Since LEDs are really diodes they are said to be "polarized" which means that they will only illuminate when the voltage source is properly attached with positive and negative connected correctly. Like batteries the positive and negative parts of an LED must be hooked up correctly.

The physical part and electrical symbol for an LED are shown below:





The longer lead of the LED is positive (+) while the shorter lead is negative (-).

Caution: Hooking up a battery directly to an LED will destroy it – even when the battery is hooked up correctly with the positive terminal to the Anode and the negative terminal to the Cathode. **This is because a battery will supply too much current to the LED causing it to heat up and burn out – VERY QUICKLY!** You must always use a resistor in series with the LED to limit the current. With a 1.5 volt battery a 470 ohm resistor will sufficiently limit the current.

Hooking up an LED to a small solar panel, fuel cell or wind turbine will (probably) not harm it, since these devices do not have the same high current capacity as a conventional battery.

Batteries are powerful devices and should be respected — especially when they are new.

What is Power?

Power is the combination of voltage and current. Voltage is the pressure component of power forcing electrons to move through a circuit, and current is the quantity component of power indicating the amount of electrons in the flow. Both voltage and current are required to produce the electrical force called power. Power is instantaneous and is not measured over time like energy. When you measure power, you measure voltage and current for a given instant of time.

This is an important distinction – time, or lack of it, is the essential difference between power and energy. Power is instantaneous while energy is power measured over time.

Electrical power is measured in units called watts.

What is Energy?

Energy is power over time. Energy is the power flowing through a circuit for a given time like one second, one minute or one hour. When we speak of energy we mean power times time. Energy is measured in units similar to power but with a time component as in watt-seconds, watt-minutes or watt-hours.

If a circuit generates 1 watt of power for 1 hour, it is said to generate 1 Watt-Hour of energy. Your electric meter measures power in Watt-Hours, but that can be converted to any other time frame by understanding how time is measured.

For example, there are 60 seconds in a minute and 60 minutes in an hour. With this in mind there is 3600 seconds in an hour (60 sec / min x 60 min / hr = 3600 sec / hr). So energy can be easily converted back and fourth between watt-hours and watt-seconds by the following equations:

Watt-Hrs = Watt-Sec / 3600

Watt-Sec = Watt-Hrs * 3600

Electrical energy is typically measured in watt-hours

What is a Power Source?

An electrical power source is a device that produces electrical voltage and current - in effect, power. Power sources can use chemical energy like a battery or fuel cell, solar energy like a solar panel or wind energy coupled with magnetic energy such as a wind turbine. Each of these power sources converts one kind of energy (chemical, light or mechanical) to electrical energy.

The equation for electrical power is shown below:

P = E*I

Where P = Power in watts
E = Voltage in volts
I = Current in amps

What is a Load?

A load is a device that absorbs the power coming from a power source and uses the power to do work, like spin a motor, or simply dissipate the power into heat like coils of wire in a toaster. In all cases, loads are used to both consume and regulate the power being produced.

Generally speaking, a load is measured as resistance in units called ohms.

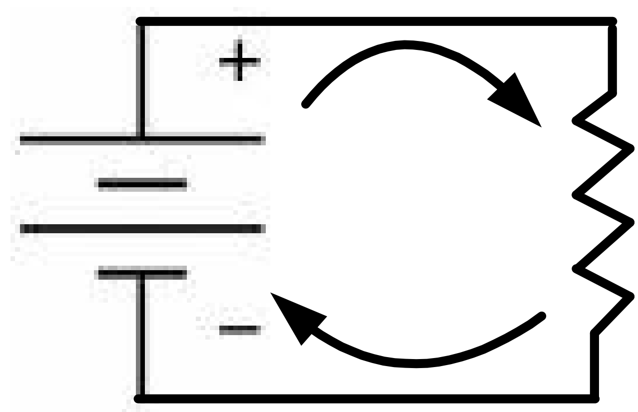
In relative terms, a “light” load has a “large” resistance and a “heavy” load has a “small” resistance. This may be counter intuitive, but it is the case, nevertheless. For example, a 100 ohm resistor presents a “lighter” load to a circuit as compared with a 10 ohm resistor.

The equation for computing the association among voltage, current and resistance (load) is known as Ohms Law and is stated as follows:

E = I*R

Where E = Voltage in volts
I = Current in amps
R = Resistance in ohms

What is a Circuit?



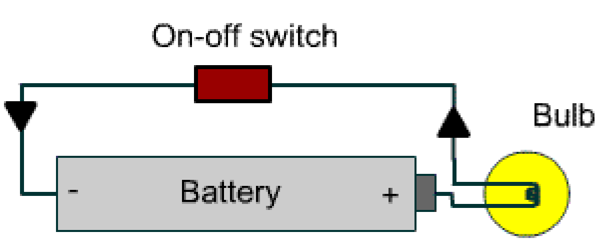
A circuit is any "unbroken" (closed) connection of electrical components that form a continuous conducting path for current to flow; if the circuit is "broken" (or open as in an open circuit) no current can flow and no power or energy can be delivered.

The most basic electrical circuit is made up of a power source (like a battery shown here) attached to a load (like a resistor shown here). The power source generates voltage and current that flows through the load and then back to the power source. The load is there to absorb the power (voltage and current) that is dissipated in work (like turning an electrical motor) or in heat like the coils in a toaster – or a combination of both. A load is always considered a resistance to the flow of current. This is a very simple circuit where voltage and current flow from the positive side of the battery through the resistor load then back to the negative side of the battery.

A Flashlight Can Be An Open or Closed Circuit?

A flashlight is really a simple circuit – an open circuit when it's off and a closed circuit when it's on. The battery, bulb and switch form a DC circuit.

If you take a continuous source of DC electricity, such as a battery, and connect wires from the positive and negative poles of the battery to an electrical device such as a light bulb, you have formed an electric circuit – a CLOSED circuit – that is, when the switch is ON.



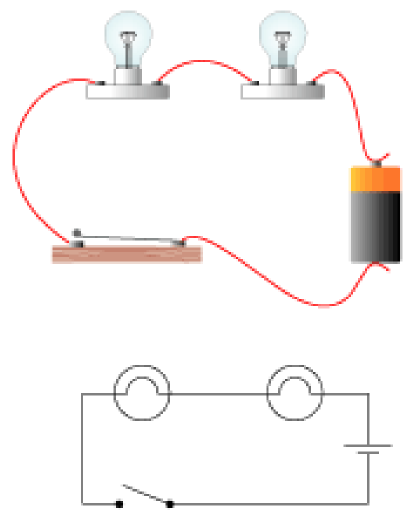
If the switch is OFF, the circuit is said to be OPEN because no electrons can flow out of the battery – the power source – into the light bulb – the load. The electrical symbols for an ON and OFF switch are shown below:

What is a Series Circuit?

In an electrical circuit several electrical devices such as light bulbs can be placed in a line - or in series in the circuit - between the positive and negative poles of the battery. This is called a series circuit.

A major problem is if one light bulb burns out, then it acts like a switch and turns off the whole circuit. On the other hand a major advantage of a series circuit is that it saves wires that are needed in a parallel circuit.

Image courtesy www.curriculum.edu



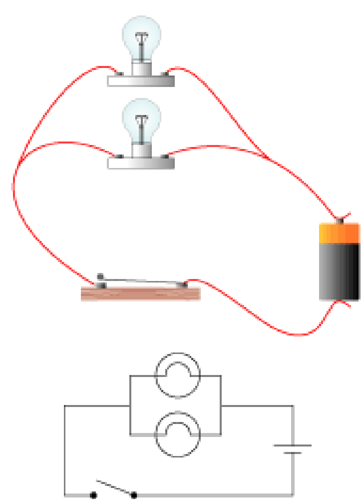
What is a Parallel Circuit?

Devices can also be arranged in a parallel circuit such that if any bulbs burn out the circuit is still intact.

Not only is a parallel circuit useful for holiday lighting, the electrical wiring in homes is also in parallel. In this way lights and appliances can be turned on and off at will. Otherwise if you turned one light off--or one burned out--all the other lights in the house would go off too.

Circuits can be wired in a combination of series and parallel arrangements like solar panels.

Image courtesy www.curriculum.edu



What is a Solar Panel?

A solar panel is made up of individual solar cells connected together in a series-parallel arrangement in order to create the desired voltage and current outputs. An individual solar cell generates only ½ volt no mater its physical size; however, an individual solar cell's current output is completely dependent on its physical size. The vertical and horizontal lines in the photo show the interconnections among the solar cells.

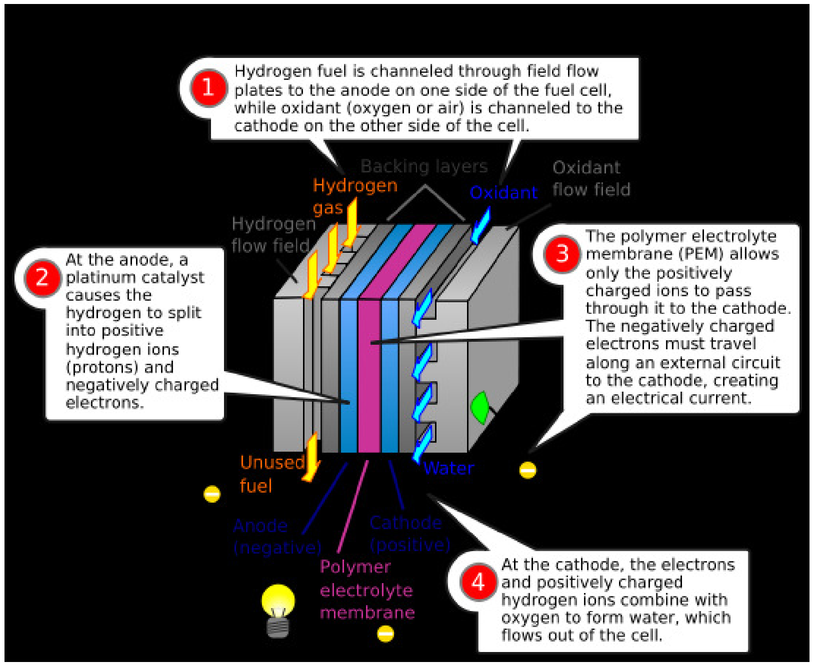
Solar panels are used to gather solar energy from the sun. After collecting sunlight, the panels convert the energy into electricity. Solar panels have no moving parts and are generally constructed of the same solid-state materials that go into making semiconductors. They are very reliable; however at the present time, they are not very efficient converting only 11% to 14% of the sun's energy received into electricity. Solar panel technology is constantly improving along with better materials and higher efficiency ratings.

Space satellites use solar panels to power their internal electronics and to run internal heaters to keep the electronics and motors from freezing in the ultra-cold space environment. Most importantly the solar panels are always kept pointed at the sun as the satellite orbits the Earth. This is a very complex endeavor since the solar panels must be constantly adjusted by on-board motors to keep them correctly aligned to produce maximum power as the satellite hurdles through space at thousands of miles per hour.

Modern solar panels on homes and buildings were originally developed by the space programs of the 1960's and 70's.

Images courtesy solarnavigator.net.

What is a Fuel Cell?



A fuel cell is an electrochemical conversion device like a rechargeable battery; however, it is both similar and different from a battery in several ways. Like a battery it produces electricity from fuel (on the anode side) and an oxidant (on the cathode side), which react in the presence of an electrolyte. The reactants flow into the cell, and the reaction products flow out of it, while the electrolyte remains within it. Fuel cells can operate virtually continuously as long as the necessary flows are maintained. Photo courtesy Wikipedia.

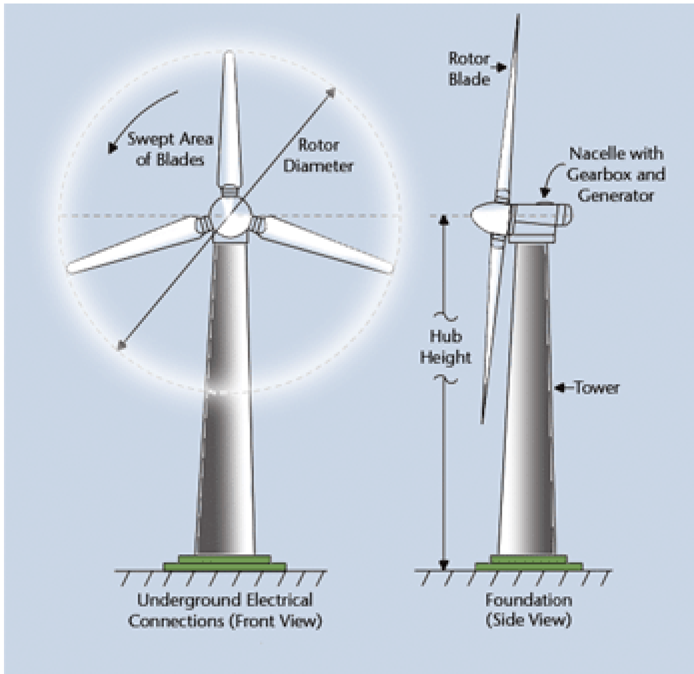
Fuel cells are different from electrochemical cell batteries in that they consume reactant from an external source, which must be replenished. By contrast batteries store electrical energy chemically internally, which is consumed when a load is applied.

Many combinations of fuel and oxidant are possible. A hydrogen fuel cell uses hydrogen as fuel and oxygen (usually from air) as oxidant. Other fuels include hydrocarbons and alcohols. Other oxidants include chlorine and chlorine dioxide.

What is a Wind Turbine?

A wind turbine is a rotating machine, usually with blades that attach to and rotate a central shaft that converts the wind's kinetic energy into mechanical energy. If the mechanical energy is used directly by machinery, such as a water pump or grinding stone, the machine is usually called a windmill. If the mechanical energy is converted into electricity using an alternator, the machine is called a wind turbine.

Wind turbines come in various sizes and configurations. Some are called Vertical Axis Wind Turbines because their rotating shaft is in a vertical position, which allows the rotating blades to capture wind from any direction. Others are called Horizontal Axis Wind Turbines like the one pictured here because their rotating shaft is horizontal to the ground with usually three large blades attached. Most commercial wind turbines are of the horizontal axis variety and must be pointed into the wind for optimum efficiency. Because this arrangement allows the rotating blades to be mounted higher off the ground the horizontal axis wind turbine is more efficient in terms of capturing wind at greater speeds with the resultant increase in power output.



Drawing of the rotor and blades of a wind turbine, courtesy of ESN

All commercial horizontal axis wind turbines generate 3-phase AC electricity which is then transferred to the power grid. Some smaller horizontal and vertical axis wind turbines deliver their 3-phase power directly to a site like a home or even a sailboat.

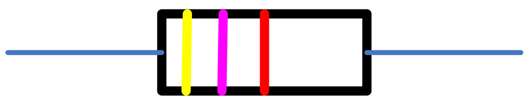
Understanding Resistor Color Codes

Since the value of the resistor is not stamped on the device, another method is used to identify its value. This method is called "color coding" and refers to the round bands that surround the resistor's cylindrical surface. The following is the number and corresponding color convention for identifying color codes.

0 – Black	5- Green
1 – Brown	6 - Blue
2 – Red	7- Violet
3 – Orange	8- Gray
4 – Yellow	9 - White

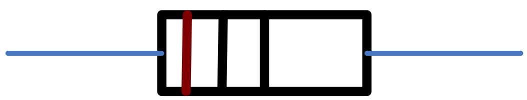
For example, a 4,700-ohm resistor would have the following color codes (stripes) beginning at the far end of the device.

4,700 ohms = Yellow (4) – Violet (7) – Red (2)

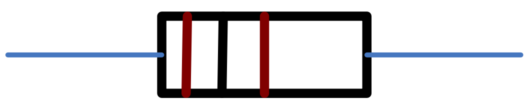


The last stripe (Red = 2) is a multiplier of 10 raised to the power of the stripe value, as in 10^2 which equals 100. Therefore, we get 47 x 100 = 4,700 ohms. Our two resistors have values of 10 ohms and 100 ohms with the corresponding color codes.

10 ohms = Brown (1) – Black (0) – Black (0) (A multiplier of $10^0 = 0$)



100 ohms = Brown (1) – Black (0) – Brown (1) (A multiplier of $10^1 = 10$)



There are other bands after these; however, they should be ignored. They are generally there to indicate the accuracy of the resistor (1%, 5%, 10%, etc.). The supplied resistors are within 5% of their rated value.

Understanding Data Logging

Data logging is a term used for sampling and storing data for later retrieval and analysis. In general, sampled data is "time tagged" with the date and time of the sample in order to determine when the sample was taken. In the context of these lessons data logging refers to sampling the following electrical data parameters plus date and time:

- Voltage
- Current
- Resistance
- Power
- Energy

Date MM / DD / YY
Time HH : MM : SS AM / PM

The ***Smart Meter – Data Logger*** tm instrument records (or data logs) samples of the above data in 1 second to 99 second intervals depending on how it is setup by the user. Each group of data is called a "sample" and there are a total of 2730 samples available for data storage. This translates to just over 45 minutes of samples at a 1 second rate and over 3 days, 7 hours and 41 minutes at a 99 second rate. Once again, the Sample Time is set by the user according to the type of experiment being performed.

Samples are stored in individual groups called "Tracks". A Track is akin to an audio recording where a group of samples can be stored for later playback and analysis. Tracks are intended to store data for individual experiments.

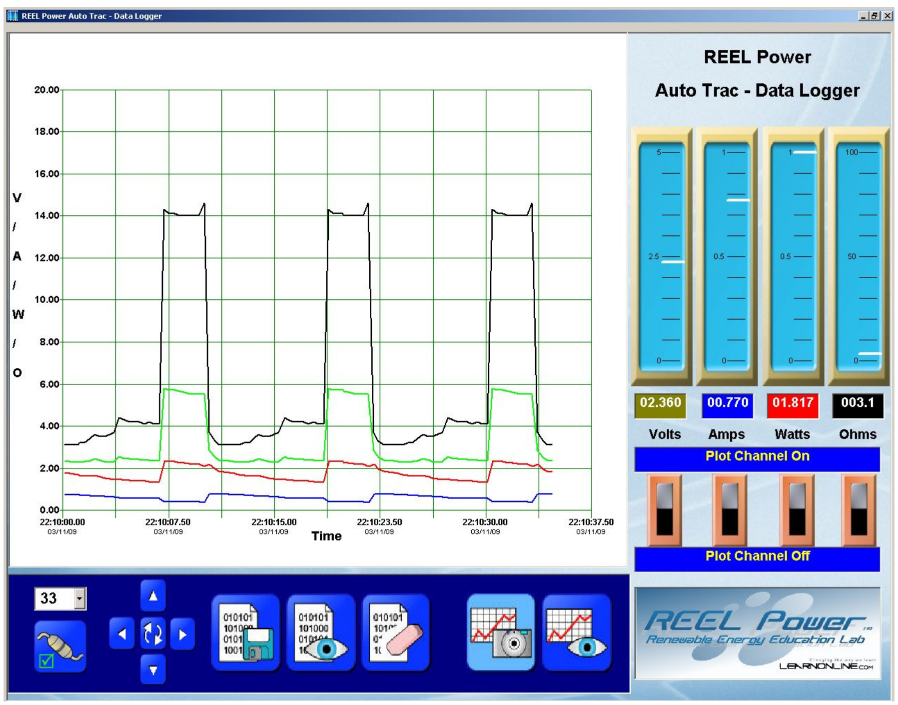
More information on data logging can be found in the ***Smart Meter – Data Logger*** tm **User Manual** which is available at www.learnonline.com.

Understand Computer Plots

The classroom computer is transformed into a laboratory instrument with the supplied graphic software. With it you can plot data from solar panels, fuel cells, wind turbines, batteries and a host of other renewable energy devices – both in real time in data log format.

The PC graphic software screen is divided into several regions that control how electrical quantities such as voltage, current, power and resistance readings are displayed. The large grid area continuously displays four plotted lines in four colors. The colors match the values displayed below the vertical meters.

- **Black – Resistance in ohms**
- **Blue – Current in amps**
- **Red – Power in watts**
- **Green – Voltage in volts**



Full details about setting up and using the graphical software can be found in the ***Smart Meter – Data Logger*** tm **User Manual** which is available at www.learnonline.com.