Please read and re-read as many times needed in order to understand the inner workings of the solar car.

Definitions and Formulas

AC: Alternating current

DC: Direct current

Volt (V): The unit of measurement for the potential difference that causes a current to flow through a conductor.

Ampere (I): Often "amp", this is the unit of measurement of electric current.

Resistance (R): The unit of measurement of opposition of a component to the flow of electric current, measured in ohms.

Ohms Law: A formula used to calculate the relationship between voltage, current and resistance. It is expressed as V=IR. Also expressed as E= IR.

Diode: A component that conducts current in one direction only.

Watt: The metric unit for power is the **watt** (W). One watt = 1 joule/second. One **kilowatt** (kW) is 1,000 watts.

Watt-Hour: A unit of power; the expenditure of 1 watt for one hour, e.g. a one watt light bulb turned on for 1 hour, consumes one watt-hour of power.

Horsepower: A common imperial unit for power is the **horsepower** (Hp). One horsepower is defined as the amount of mechanical power required to lift 33,000 pounds 1 foot in 1 minute. 1 Hp = 746 W.

Wire: a long slender flexible strand of low-resistance material (usually copper) designed to carry electric current

Cable: two or more wires bundles together.

AWG: (American Wire Guage), the american standard for wire thickness

Grounding: A conductive connection to the earth (at zero volts) that acts as a protective measure.

Electrical Safety

- Remember that low voltage **does not** mean low hazard

- Electrical shock happens when current passes through the body. When a person receives a shock, electricity flows **between through the body to ground/negative.** Keep your body parts away from ground.
- Rubber gloves will act as an insulator, protecting your body from electrical shock
- Pure water is a poor conductor, but small amounts of impurities like salt and acid (both in perspiration), make it a ready conductor.
- Burns are the most common type of shock-related injuries. They occur when your body touches a live wire or electric current.

Power Systems

Energy refers to an amount of work that can be done, whereas power refers to how quickly that work can be done. In fact, power is defined as energy (converted between forms or used to do work) per unit time.

$$Power = \frac{Energy}{Time}$$

Electrical power is usually moved from one location to another through copper wires or other metal conductors.

Electricity on an atomic level

Charge is an electrical property associated with protons and electrons. Protons (usually found in an atom's nucleus) are said to have a positive (+) electric charge, whereas electrons (usually found orbiting the nucleus of an atom) are said to have a negative (-) electric charge. The term "electricity" refers to a host of related phenomena that happen when these charged particles move (or try to move) from one place to another. Often these movements happen (or try to happen) because opposite charges attract each other (so electrons and protons try to stick together) and identical charges repel (so two electrons or two protons attempt to move away from one another). Remember, electricity from positive to negative.

Electrical **current** is simply the flow of charged particles from one location to another. Anytime you separate positive charges from negative charges, you produce an electric field. An electron (negative) will be pulled toward the positive charges and away from negative charges (away from alike, towards different). The strength of this tendency for a charged particle to be pushed or pulled can be quantified in terms of a voltage. You can think of voltage as a kind of electrical pressure that can push electrical current through wires, just as water pressure can push water through pipes. It's important to remember that voltage is all relative. It's like altitude in which how high you are depends on whether you're measuring from sea level or the bottom of your ladder. **Thus, what matters in circuits is the *difference* in voltage between two points**, just as it's a difference in altitude that makes water flow down a stream, i.e. a potential difference. Accordingly, you should always speak of the voltage *across* a device (i.e., the voltage difference from one end of the device to the other). It is incorrect to talk about how voltage is flowing *through* a device. **Current flows through devices; voltage does not.**

Ohm's Law

Whenever electrical current flows through a wire, light bulb, or any other object, it encounters the electrical equivalent of friction, which converts some of the energy of the flowing electricity into heat and causes a drop in voltage from one end of the object to the other. This fricition-like property in electric wires and other components is called **resistance** (R) , which is quantified in units of ohms (Ω)

The resistance of an object (such as a length of wire) is defined in terms of the amount of voltage it takes to force a given amount of current through the object. Thus (Ohm's Law):

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

Basic Circuit Theory

Electric current typically flows in closed loops called circuits. A regular circuit will have at least three fundamental parts connected together to from the loop:

1. There will be some **voltage source** (such as a battery or a wall outlet), which provides the electrical “pressure” needed to push electrons or other charged particles around the loop.
2. There will be a **load**, which in this context refers to any device(s) and/ or process(es) being powered by the circuit. For example, in a flashlight circuit, the load would be the light bulb.
3. Almost all circuits include one or more **switches** to turn the load ON and OFF. When a switch is in the ON position, current can flow (closed circuit), and when it’s in the OFF position, current cannot flow (open circuit).

An **open** circuit occurs when a gap forms somewhere in the circuit, preventing current from flowing around the loop. An open circuit may be intentional (as when a switch is flipped to the OFF position) or it can be unintentional, as when a wire breaks or comes loose, or when a light bulb or some other component in the circuit burns out. Unintentional open circuits are a common cause of equipment problems.

A **short circuit**, or **short**, is a different type of error condition in which electric current finds some unauthorized “shortcut” through which it can bypass some or all of the usual load that it’s supposed to flow through. This can occur because of stray wires, poor soldering, or damage, like water damage, to the circuit. Under normal conditions, the load provides resistance that limits the amount of current flowing through the circuit; however, when a short occurs, electricity can bypass the usual current-limiting parts of the load, making it way too easy for the battery (or other power source) to push current through the circuit. **This can result in dangerously high current levels** capable of melting wires, damaging components, and starting fires. In addition, shorts can give high voltages a place where those high voltages are not normally present, and this can present a serious threat to human safety. Fuses, circuit breakers, and similar devices are used to minimize the risk to circuits, people and property when short circuits happen. Note that a closed circuit is used in situations where a circuit is closed intentionally, a short circuit is usually used when a circuit is closed unintentionally.

For convenience, one point in a circuit is typically defined to be at zero volts (just as sea level is commonly defined to be at an altitude of zero meters or feet). This point in a circuit is commonly called the **reference ground**, or simply **ground**. The point in the circuit with the lowest voltage is frequently, but not always, chosen as the reference ground. Any other part of the circuit connected directly to the reference ground point will also be at (or very nearly at) the same voltage and may also be considered "ground"

Power

The electrical power delivered to a device is equal to the current running through the device multiplied by the voltage difference across its input terminals:

Power (watts) = Current (amps) x Voltage (volts)

In a resistor, all that power is dissipated (i.e. released) as heat. All electronic devices act at least partly like resistors, even if they aren't designed to be resistors, so they also release heat when current is flowing through them. **When measuring power dissipated, measure the voltage across the component and then multiply it by the current flowing through the circuit.** There are two major reasons that the designer of a power system must be concerned about power:

1. The power source must be able to satisfy the combined power demands of all systems on the vehicle. It's crucial that the designer knows how much power each system requires and can estimate the peak power at the same time.
2. As mentioned, all devices produce heat at some rate when electric current is flowing through them. If too much heat is produced too quickly, the device (or something else near it) may overheat. The technical specifications on most electrical components specify the maximum power the device can handle without overheating.

ACDC

AC power sources, AC appliances, and AC circuits produce or use electricity in which the currents in the circuit (and the voltages that drive those currents) alternate back and forth, usually between positive and negative values, and usually many times each second. For example, a standard household wall outlet in US/CAN crosses back and forth between positive and negative values 60 times, (60Hz).

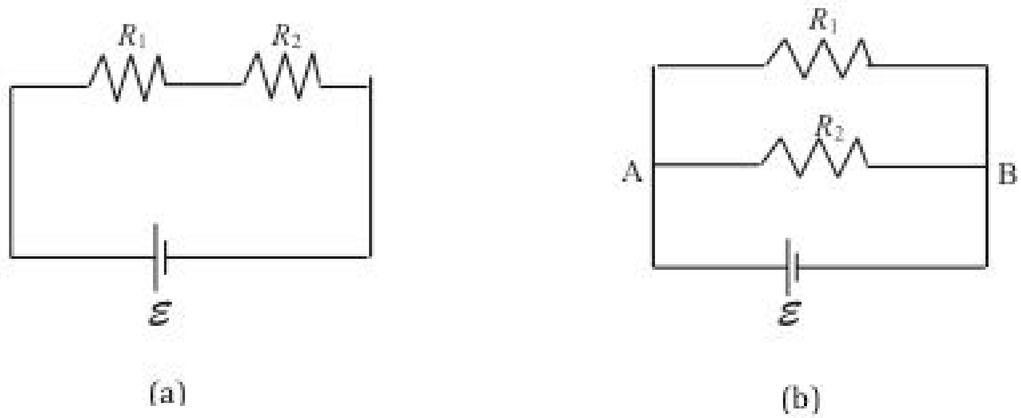
DC power sources, DC appliances, and DC circuits are characterized by voltages and currents that are more or less constant in time, like the voltage at the terminals of a freshly charged battery. Currents in DC devices may be switched ON or OFF, but when they are ON, they maintain fairly steady, constant values.

Series and Parallel

A) Components are said to be arranged in **series** when two or more components are connected end to end so that all the current flowing through one component must also flow through each of the other components. The amount of current flowing is equal throughout the circuit.The voltage difference from one end of the series to the other will be equal to the sum of the voltage difference across each of the individual components. **Solar cells** are connected in series. **(Current equal, Voltage adds up)**

B) The alternative is called a **parallel** arrangement. In this parallel arrangement, two or more components are exposed to exactly the same voltage: however, the current flowing into the parallel arrangement splits up, so that some fraction of the total current flows through each of the separate components, proportional to the resistance of each component. **Zones** are connected in parallel, connect positive to negative/ negative to positive.

(Voltage equal, current adds up)



Wires

Objects or materials that offer high resistance to electric current are called **insulators**. Objects that have low resistance conduct electricity easily and are called **conductors**. The materials with adjustable conductivity (and circuit devices made from them) are called **semiconductors**

Individual wires may have a solid conductor core or a stranded conductor core **(conductor)**. A stranded core is manufactured by twisting many thin strands of metal together, giving the wire greater flexibility than solid core wire.

Most wires are coated with a colored layer of flexible plastic or other non-conductive material called **insulation**. The insulation allows wires to cross one another or be bundles together into a cable without creating a short circuit, and in high-voltage circuits, it protects people from shocks. For the solar car, the color codes for wires are as follows: Red is positive, Black or Blue is negative, and Ground is gray.

Joining Wires/Connectors

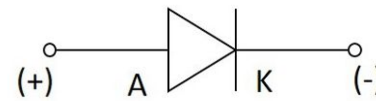
A wide variety of **connectors** (electrical connectors controls power to the vehicle's external components)are available to join

different wires or other parts of electrical circuits (e.g. extension cord plug and wall outlet). **Always** check the manufacturer's specifications to make sure the wires and connectors you use are rated for your expected current and voltage. When joining two wires together, always use either butt connectors, or a solder joint with shrink wrap.

There are many types of electrical connectors. Each have their respective pros and cons. **The ones most widely used on the Solar Car are Anderson Connectors (right top) and crimp terminals (right bottom).**

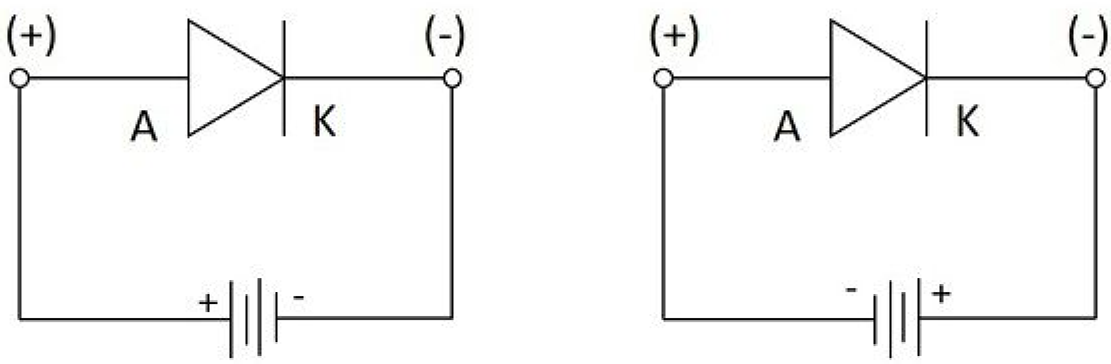
Diodes

A diode is an electrical component, represented by the symbol to the right, that only allows electrical current to flow one way. This is known as forward biasing, or reverse biasing.



Symbol of a Diode

- When a diode is connected with its anode to the positive terminal and the cathode to the negative terminal, it is said to be **forward biased and current flows**
- When a diode is connected with its anode to the negative terminal and the cathode to the positive terminal, the diode is said to be **reverse biased and current cannot flow**.

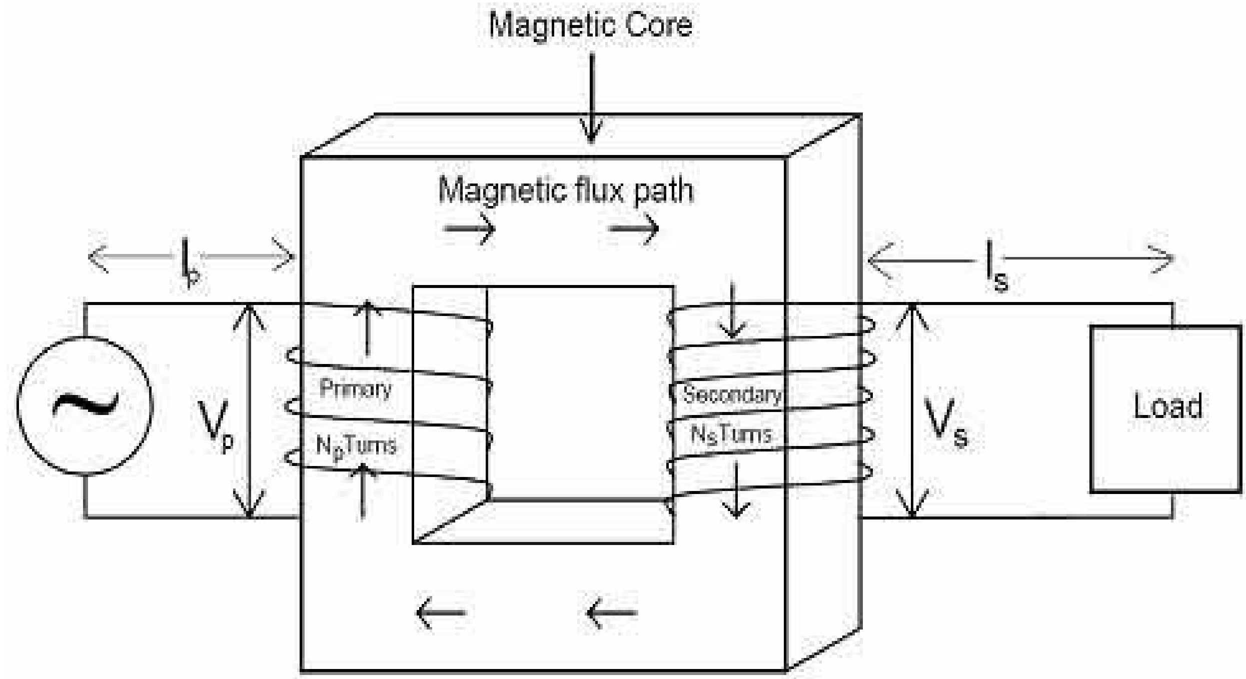


Forward biased Connection

Reverse biased Connection

Transformers

A transformer is an electrical component that converts AC voltage to another AC voltage.



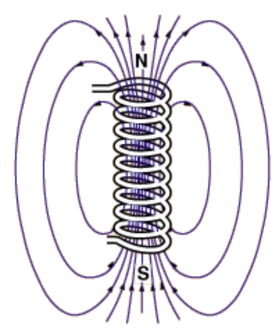
An alternating voltage (Vp) applied to the PRIMARY creates and alternating current (Ip) through the primary.

This current produces an alternating magnetic flux in the magnetic core, following the right hand rule.

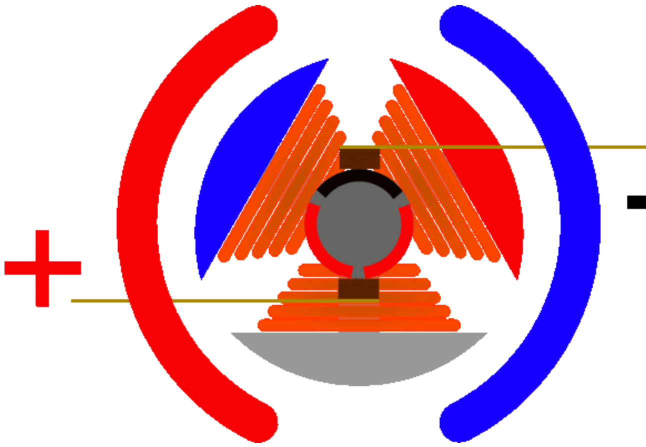
This alternating magnetic flux induces a voltage in each turn of the primary and ni each turn of the SECONDARY.

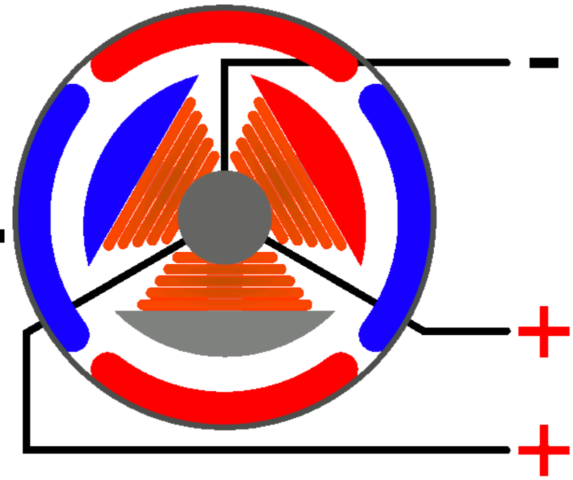
A transformer can be used to step up or step down an AC voltage by controlling the ratio of primary to secondary turns.

Motors



The working principle behind a motor is magnetism. Electric current running through a wire will produce a magnetic field, and motors are built in such a way that this phenomenon is used to create rotational motion. The picture to the right shows an energized electromagnet producing a magnetic field, research right hand rule.





The animation on the left depicts the anatomy of a DC brushed motor, and the animation on the right shows the anatomy of a brushless motor (the kind on the solar car.

- The theory behind a DC brushed motor is as the windings are energized, they are attracted to permanent magnets around the motor, which rotates the motor (the inside part) until the brushes make contact with a new set of contact windings. This means that a DC brushed motor can on DC power only, without the need of an alternating current
- The theory behind a brushless motor is as each individual winding is energized, it creates a magnetic field that attracts the magnets which rotate the rotor (the outside part this time). Brushless motors are more efficient, require less maintenance and can run at a higher speed than brushed motors. However, they require a special controller that creates a sine wave for the motor, sometimes a three-wave sine wave like the motor controller on the solar car.

Fuses

Fuses are designed to protect circuits from short circuits. Since the load normally limits the amount of current allowed to flow from the battery or other source, a short can cause a huge surge in current. This surge can quickly heat wires or other components and start a fire.

A conventional fuse is, essentially, a thin piece of wire designed to be the failure point in a circuit. A fuse is normally placed between the positive terminal of the battery and the rest of the circuit, so that all current leaving the battery must pass through the fuse.
If a short develops, the excessive current flowing through the circuit will melt the fuse wire in two, cutting off current to the rest of the circuit before anything else in the circuit has enough time to overheat. When a fuse melts like this, it is said to have “blown”. A blown fuse acts like a switch in the open (OFF) position; it cuts off power to the rest of the circuit, preventing further damage and reducing the likelihood of electrical shock. Usually the fuse’s thin section of wire is encased in a protective glass or plastic covering, so that the fuse itself won’t damage anything when it gets hot and melts in two.

Before a fuse is replaced, the cause of the excess current must be diagnosed and repaired, or the replacement fuse will blow, too. When you replace a fuse, make certain you are replacing it with a fuse having suitable voltage and current ratings.
The voltage rating of the fuse needs to be higher than the expected voltage in your circuit, but beyond that, it doesn’t really matter. Make sure the current rating is somewhat (but not a lot) more than the expected maximum current under normal operating conditions. A short circuit will usually draw at least 10 times as much current as a properly functioning circuit (and sometimes thousands of times more current), so a fuse rated for 1.5 or 2 times the normal current should allow routine operations, yet blow reliably in the event of a short.
A fuse should be placed as close as practicable to the positive terminal of the battery, even before the power switch, so that all current flowing out of the battery must go through the fuse before it can go anywhere else. The closer the fuse is to the battery, the greater the range of possible short-circuit situations it can guard against.

Master Switch

Most electrical systems have a master switch (**a set of motor and array disconnect switches are located on the outside and inside of the solar car)** located between the fuse and the rest of the circuitry to turn the entire electrical system ON or OFF. Unless there's a mechanism for cutting off the power, the load will eventually deplete a battery and potentially damage it, even if the vehicle is sitting in storage. You can effectively turn off the system by simply disconnecting the battery or unplugging the fuse.

How to use a Multimeter

Multimeters can be used to test voltage, amperage, resistance, and continuity.
**When switching to testing amperage, remember to change the ports that the leads are plugged into- theres a difference!*

Voltage- set the dial to the proper voltage setting (AC or DC) and then estimate the approximate voltage that you expect and set the multimeter to the next highest setting.
Amperage- remember to switch the ports, and then switch it back after you're finished. Estimate the approximate amperage that you expect and set the multimeter to the next highest setting.
Resistance- Estimate the approximate resistance that you expect and set the multimeter to the next highest setting.
Continuity- Continuity is the testing of whether there is a connection between two points. YOu can use this to test for a short, or you can use it to see if two spots in a circuit are connected. Switch the multimeter to the diode symbol with propagation waves around it (like sound waves from a speaker) and then use the leads to test for continuity. The multimeter will beep when it detects continuity. **Beep=conected No Beep=not connected**

How to Solder

Safety

1. Solder in a well ventilated area. The smoke from the flux is generally nontoxic, but it may bother some people and may carry trace amounts of lead. Try to arrange your work area so that the smoke from the solder flux blows away from you and your helper. Use a fan placed well behind you to generate a slight breeze. Do not let it blow on the iron or your work as this can cause bad solder joints.
2. Pay attention to the job at hand. Do not solder if you can't devote full attention to the job. Have a helper hold the objects you are solder and hand you things as needed. You'll have the iron in one hand and the solder in the other.

Soldering Basics

Video-Website

Solder is an alloy, usually made up of some combination of tin and lead (e.g. 60/40 solder). A soldering iron is used to melt the solder onto an electrical joint to provide a physical and electrical connection.

Steps:

1. Clean your solder joint before doing any soldering- if they are dirty or corroded, the soldering may not be as effective.
2. Flux is used when soldering to remove any oxidized metals from the surface of the joint which provides a better solder joint. The flux should be applied to your solder joint before soldering, when needed.
3. The soldering iron should be around 370 degrees
4. The soldering iron must be HOT. When you touch the solder to the tip of the iron, it should liquefy immediately.
5. Strip only enough insulation off the wire necessary to 'sit' on the terminal. On the final solder joint, the insulation should be about 1/16" from the terminal. If more bare wire is exposed, it may flex and short. The insulation should not be in the solder joint.
6. The solder joint should look smooth and shiny after soldering.