SYNTHIAM

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Amps, Volts, Power Converters and Power Supplies.

This tutorial will explain what is needed for powering an EZ-B v4, any peripherals connected to it such as servos and sensors, and will talk about the different power requirements and hardware options that can be used to help avoid problems with your robotic projects.

Whether you are new to robotics, or have been involved in the field for years, hopefully this will help to confirm or deny a few misunderstandings, and set you on the road for having a safe and solid electrical system in your robotic projects. This tutorial will cover Amps, Volts, EZ-B v4 power specs, Batteries and Mains supplies. It will also go through what Series and Parallel means, how to use a multi-meter, Power regulation such as regulators and Buck converters, and electrical wire.

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Step1. Current/Amps.

To get the ball rolling, this step will explain one of the most important aspects to any electrical system, and something that can sometimes cause confusion or can be overlooked... "Amps" (also referred to as "Current" or "Amperage").

What are Amps and Current...

"Current", is a measurement of how much electrical charge flows through an electrical circuit. The more charge that flows, the bigger the current. Current is measured in units called amps. The symbol used to define amps is depicted with an "**A**". As an example, "10A" is a smaller current than 20A.

The definition of "Current" from the Oxford English Dictionary...

> **Quote:**
>
> **1.)** A body of water or air moving in a definite direction, especially through a surrounding body of water or air in which there is less movement:
>
> **2.)** A flow of electricity which results from the ordered directional movement of electrically charged particles:

You will see one thing in common in both of the above statements... direction. Current, only travels one way, which is from a power source to a device. A device will "suck" (referred to as "draw") only the amps it needs from a power source. It is very important to know that in any electrical system, amperage will present problems if you try to attach a device that will draw more then the circuit or power source can handle. This could be through the cables, connectors such as jacks and terminal blocks, or other devices that the same current passes through. Issues can also arise if the device in question draws current away from other devices connected to the same circuit.

One thing that gets overlooked quite often, is how important current is. EZ-Robot has this covered with their Revolution robots by supplying LiPo battery packs (more info about batteries in step 4). But when it comes to custom made robots, or indeed powering a revolution robot with something other than the supplied battery, problems can sometimes arise. Below are a few examples of questions that people ask quite regularly on the forum...

"Why won't my robot won't move."

"My EZ-B keeps cutting out. why?"

"Why does my EZ-B keep resetting?"

"Why does the EZ-B in my robot keep browning out?"

Sometimes, the reason maybe that the battery needs charging, an i2c cable is lose, or an initialization script has not been run. But the most common reason, is inadequate current. For example, someone will use a wall adapter with the correct voltage instead of a battery, and will try to move servos or motors connected to their EZ-B. The problem comes when they find out that the wall adapter is only supplying 2 amps, where as a single servo could need 3 amps and more for "servo inrush".

<u>Servo Inrush.</u>

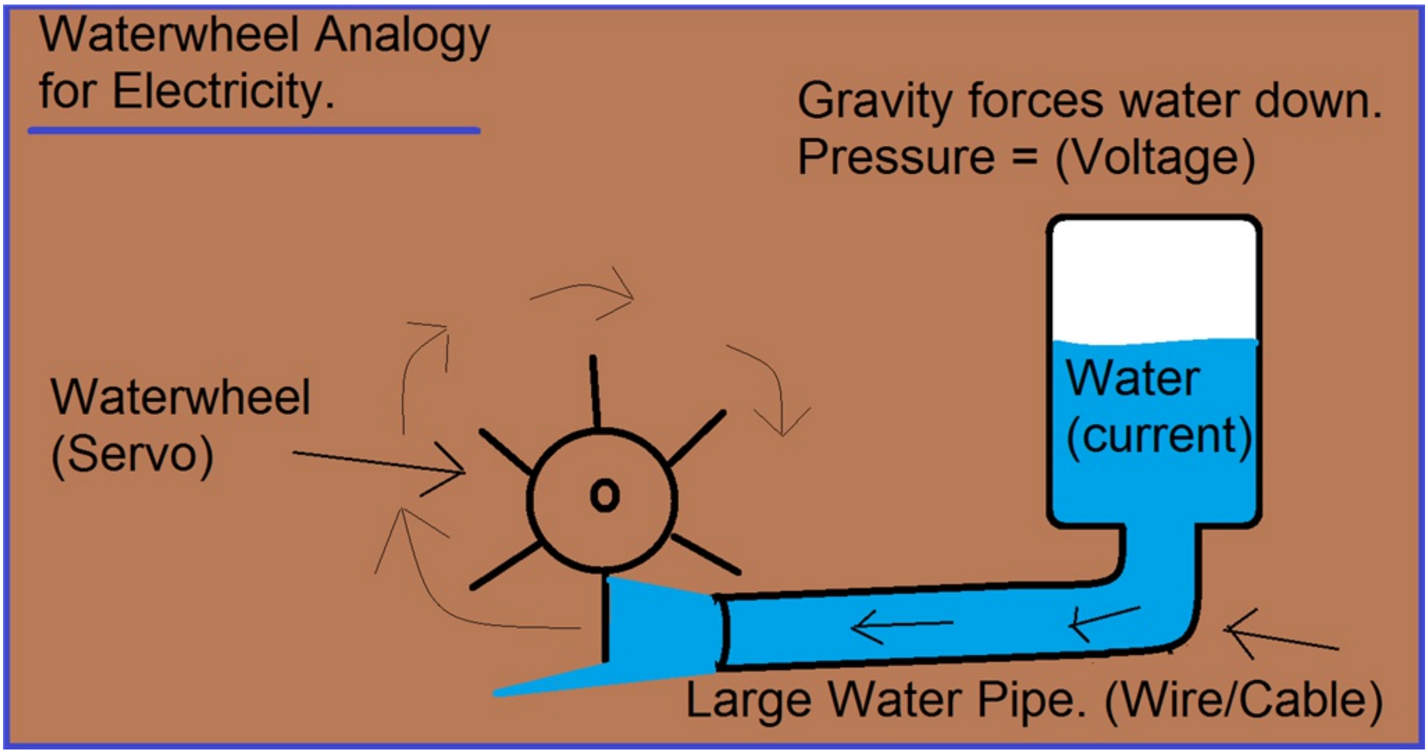
This term is used to describe the action of a servo, or indeed a DC motor, when it first begins to move. Lets use a single EZ-Robot HD Servo for example. When the servo begins to move, a very brief (few millisecond) surge of current is drawn which can be 3 Amps or more depending on the weight of what the servo is moving or lifting. The current then drops to its "running" current which is usually around 200mA (milliamps). So a 2 amp power supply will not be enough to handle the 3+

volts for the servo inrush.

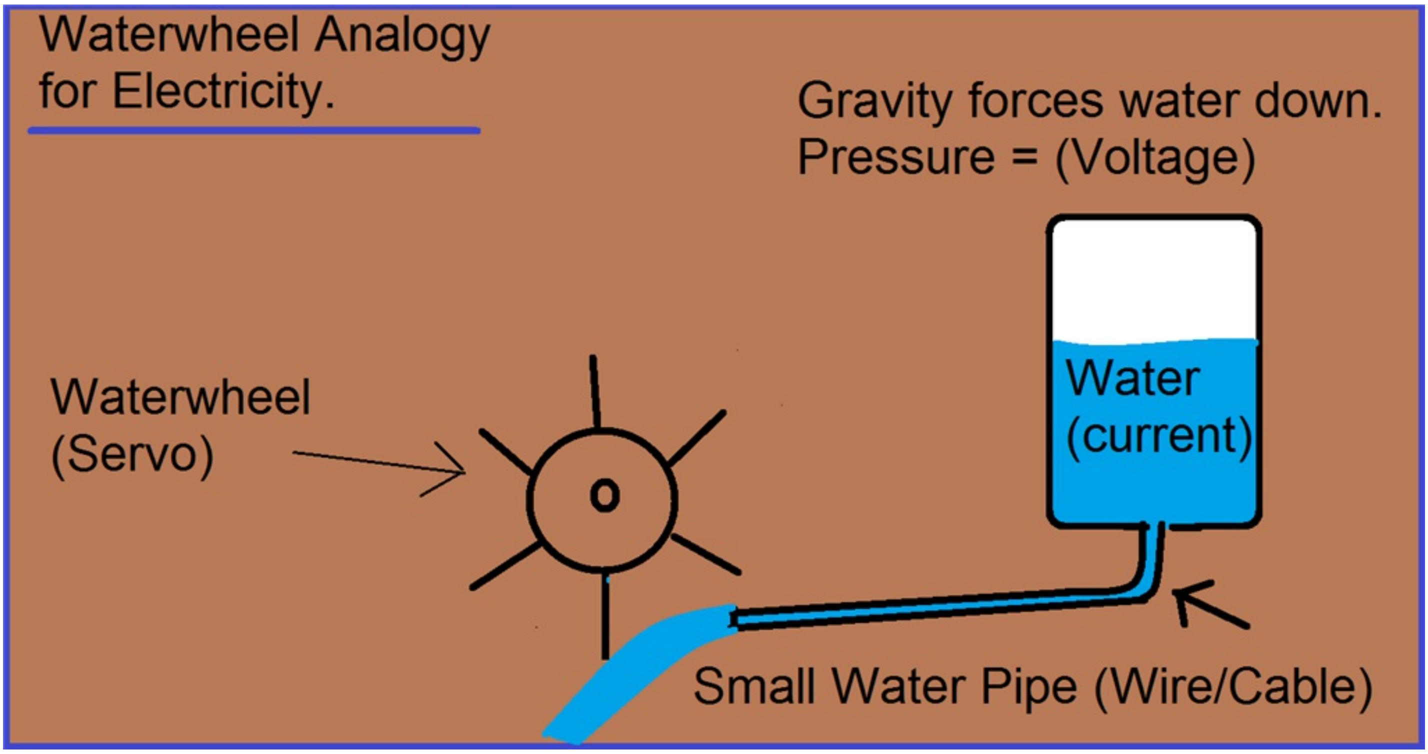
The following is a quote from one of EZ-Robots valued community members, Dave Schulpius, and gives a very good and simple analogy of an electrical circuit...

> **Quote:**
>
> A comparison I like to use for electrical theory is it's like water in a pipe: *The water is the current (amps). It does the work. *Pressure behind the water is the voltage. It pushes the water along. *The pipe is the conductor (wire, connectors or traces) and needs to be the proper size and type (resistance) . It carries the water along through the pipe that the pressure is pushing.

And if you like pictures...



With a large water pipe (large gauge wire or cable), the more the current can flow and deliver more amps. This turns the waterwheel (or servo).



With a narrow water pipe (small gauge wire or cable), far less current can flow, and delivers less amps which is not powerful enough to turn the waterwheel (or servo). Or to put it another way, you drink a glass of water.

The Math.

As the main culprit of current draw on a robot are motors and servos, you will need to work out the inrush current for every servo and/or motor that you are going to use, whether servos are connected to an EZ-B, or DC motors are connected to a motor controller with separate power supply.

From each servo or motor, you add up their "inrush current" figures, and that is the minimum current you need to supply. To do this, count up the number of servos, number of motors etc.

Multiply the number of servos and motors by their inrush current. Add everything together and that's the minimum amps to aim for.

Let's take a typical setup. Say you are running three servos with an inrush current of "3A", and two DC motors with an inrush current of "5A" and one DC motor with an inrush current of "3A" all at the same time...

2x 3A = 6A 2 x 5A = 10A 1 x 3A = 3A

The total inrush current works out at "19 amps". This would be your minimum current needed that your power source should deliver.

If the power supply you are using cannot provide the amount of current that is needed, it will cut out, or in the case of an EZ-B, brown out ("Brown Out" is the term used when the EZ-B becomes unresponsive. Turning the power off and on again ("Power Cycle") will put the EZ-B back on normal operating mode).

You may see the term "mAh" or "aH" mentioned a lot around the place. "mAh" means **m**illi**A**mp **h**ours, and "aH" is **a**mp **H**ours. This will mainly refer to a batteries capacity, meaning how long a battery can run a device at a certain amperage. For example a LiPo battery that is rated at "1000 mAh", would be completely discharged in one hour with a 1000 milliAmp load placed on it. Now if this very same battery had a 500 milliAmp load placed on it, it would take 2 hours to drain down. If the load was increased to around 15,000 milliAmps (15 amps), the time to drain the battery would be only about 4 minutes.

To Summarise Amps.

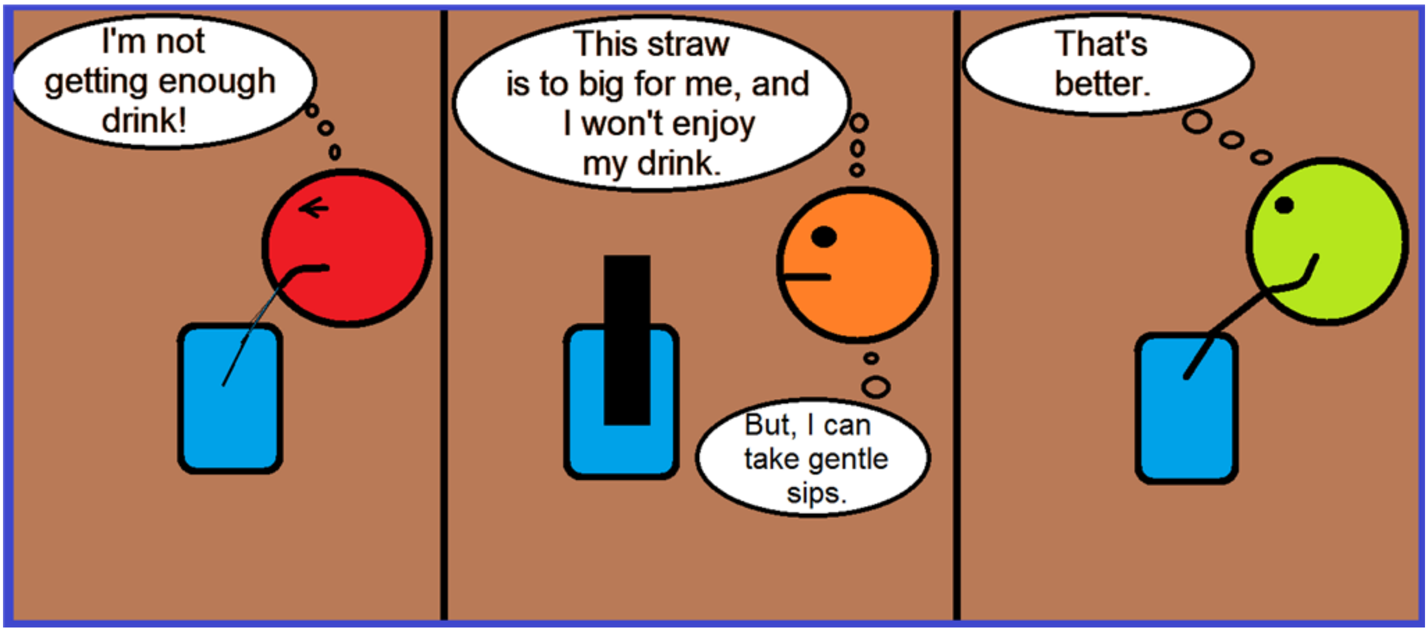
! Not supplying enough amps will cause problems, and the servo will not move.

! Supplying to many amps won't cause any damage as the servo will only take what it needs. To use another analogy, we will use three drinking straws... small, medium, and very large.

You take a drink of water with a small straw. You take a big suck, but you won't get very much drink and you may not be satisfied.

You take another drink of water with the large straw. You will probably get too much drink and won't be able to take it. But, your brain knows this, so if you know not to use the large straw, or suck gently and just what you need, much like a servo for example. The circuitry knows what how many amps it needs to operate, and wont take more than it can handle.

Finally, you take a drink of water with the medium straw. You get just the right amount of drink you want.



! Caution is needed though. Using "very" high amperage and encountering a short circuit can cause a lot of damage, so use correctly rated fuses or circuit breakers where possible.

The following is a quote from an 80's movie that best describes the power of amps when discussing touching the third rail of of a train track...

It's not the volts that will kill you... It's the amps! eek

Step 2. Voltage.

Just as important as current, "Voltage" is something that needs to be considered when powering electrical devices.

Voltage is measured in "volts", and as you may already know, the symbol for volts, is a "**V**". For example, "240V" is a bigger voltage than "12V".

Like "Current" is a measurement of "Amps", "Voltage" is a measurement of the difference in electrical energy between the two different parts of a circuit. The bigger this difference in energy is, the higher the voltage becomes. The best way to describe "volts", is that it is the pressure that causes a current to flow like was seen in the pictures in the previous step.

An example of this could be that you have a tank of pressurized water. This is connected to a hose. When you increase the pressure in the tank, this will make more water come out of the hose. It's that pressure that is the same as voltage. Increasing the voltage will make more current flow.

Planning and care needs to be taken when building a robots electrical system, as you may have different electrical components that require different voltages. Using the EZ-B v4 for example, using EZ-Robot HD Servos connected to the v4's digital ports can be powered with a 7.4v LiPo Battery. The black "Ground" and red "Vcc" pins helps deliver the **7.4 volts** to the servo.

Now you want to use an Ultrasonic Distance Sensor (ping sensor) on the digital ports next to your servo. The ping sensor is only rated for **5 volts**. You plug the sensor in and fire up your EZ-B. Chances are you will burn out the ping sensor as you are giving it "7.4 volts" which is too much power.

(Whatever voltage the battery is capable of delivering, will be the same voltage on ALL of the unregulated digital Vcc (red) pins.) on the EZ-B v4.

Possible ways around this, is to use another power source that is the correct 5v voltage, or use power converters, which will be explained in step 8.

A Voltage Summery.

Let's take a simple 4.8 to 7.4 volt servo.

! Giving it 12 volts will fry it.

! Giving it 2 volts will under power the servo and could damage it.

! Following the correct specifications for any electrical device is always advisable.

Step 3. EZ-B v4 Port Pins.

Electrical details for the EZ-B v4...

Parameter	Minimum	Maximum	Unit
Voltage input (Vin)	4.5	16	VDC
Vin Continuous Current Draw	0.008	5	A
Vin Current Spikes	-	20	A
Vcc Continuous Current Draw	-	1	A
Vcc Current Spikes	-	3	A
Vin Default Low Battery Warning	6	-	VDC
Current Draw with No Peripherals	-	80	mA
Current Draw with Camera		180	mA
Digital I/O TTL Voltage Level (input high)	1.6	5	VDC
Digital I/O TTL Voltage Level (input low)	0	1	VDC
Digital I/O TTL Voltage Level (output)	-	3.3	VDC
Digital I/O Power Pin Voltage	-	16	VDC (Vin)
ADC Voltage level	0	3.6	VDC (5V tolerant)
ADC Power Pin Voltage	3.3	3.3	VDC (Regulated)
I2C TTL Voltage Level (input/output)	3.3	5	VDC
I2C Power Pin Voltage	3.3	3.3	VDC (Regulated)
UART TTL Voltage Level (input/output)	3.3	5	VDC
UART Power Pin Voltage	3.3	3.3	VDC (Regulated)
Camera Voltage Level (input/output)	3.3	5	VDC
Camera Power Pin Voltage	3.3	3.3	VDC (Regulated)

A break down of the EZ-B v4 pin specifications.

Vin (Voltage input) = 4.5-16VDC Unregulated input voltage (Digital port section Red power pins)

Vcc (Voltage Common Collector) = 3.3VDC Regulated voltage (Analog port section Red power pins)

VDC: meaning "Volts of Direct Current".

The "minimum" input voltage from a power source that powers the EZ-B v4 is 4.5VDC.

The "maximum" input voltage from a power source that powers the EZ-B v4 is 16VDC.

The "maximum" continuous current draw through the EZ-B v4, is 5 amps. (limited by reverse polarity protection).

The "maximum" momentary power spike through the EZ-Bv4 is 20 amps (limited by 20A ATM Fuse in power base or power harness).

The "maximum" continuous current draw on the EZ-B v4 Vcc (3.3VDC) regulated supply (middle red power pins on analog ports), is 1 amp.

The "maximum" momentary power spike on the EZ-B v4 Vcc (3.3VDC) regulated supply (middle red power pins on analog ports), is 3 amps.

The EZ-B's current draw with no devices connected to it, is 80 milliamps. With the EZ-Robot camera connected, it's 180milliamps.

The digital I/O pin (white signal pin) voltage output "high" level, is 3.3VDC.

The digital I/O pin (white signal pin) voltage output "low" level, is 0VDC.

The digital I/O pin minimum voltage input "high" level is 1.6VDC.

The digital I/O pin maximum voltage input "high" level is 3.3VDC (5V tolerant).

The digital I/O pin minimum voltage input "low" level is 0VDC.

The digital I/O pin maximum voltage input "low" level is 1VDC .

The source/sink limitation from a single digital signal pin is 10milliamps. (up to 120mA total for all pins combined).

The ADC reads voltage levels from 0-3.6VDC but is 5V tolerant (voltage from 3.6V to 5V will likely show up as 3.6VDC).

The ADC signal pin "minimum" voltage level, is 0VDC.

The ADC signal pin "maximum" input voltage level, is 3.6VDC (5v tolerant).

The ADC power (centre) pin voltage, is 3.3VDC (regulated).

The i2c communication voltage level is 3.3VDC. (5V tolerant) The i2c power pin voltage, is 3.3VDC (regulated).

The UART (port 0) communication voltage level, is 3.3VDC (5V tolerant).

The UART (port 0) power pin voltage, is 3.3VDC (regulated)

The Camera TTL communication voltage is 3.3VDC. (5V tolerant)

The Camera power pin voltage, is 3.3VDC (regulated)

Where it is noted that the digital power pins can handle 5 amp per digital pin, this is combined constant amperage of 5A for all the digital power pins. The maximum amperage for each pin is 2 amps per pin. While you can have a spiked (pulsed) current up to 20A, the ez-bv4 is only rated for 5A of constant current.

Step 4. Batteries.

Where there are amps and volts, there are the things that deliver them. Batteries (also known as cells) come in lots of different flavours, so this step will go through some of the more popular choices available, along with some details so you can decide what would be the best for your robot project.

Batteries Types.

Alkaline:

These are the kind of batteries you will find in the back of your TV remote and various other everyday devices, and typically come in the form of 1.5 volt "AAA", "AA", "C" cell, "D" cell, and the "9v" brick, and cannot be (and not recommended to be) recharged. You won't normally find the discharge (mAh) rates so it can be difficult to work out how long they will last, unless you are willing to do some web surfing and find the manufacturers website where they may have the specifications listed.

Using a 12v alkaline (or dry) battery for this example, generally you would start with 12 volts but not enough amps. You could then use several alkaline batteries in parallel (more on "Series" and "Parallel" in step 6) to keep the same voltage, but increase the amps. But alkaline batteries will decrease in power as they drain.

Example.

Having four alkaline AA batteries connect in series, will power an EZ-B and some low powered sensors. Not recommended for servos.

Summary.

Alkaline's are cheap (sometimes), and readily available, but do a poor job of powering servos and high power motors due to not delivering enough current, and are not very environmentally friendly. Also, notice how more and more devices now have lithium rechargeable batteries installed.

NiCd:

Nickel-Cadmium batteries used to be used a lot in laptops and mobile/cell phones in the past (some still do), and come in various forms, including the more popular 1.2 volt "AA" and "AAA" single cell and 7.2 volt and 12 volt battery packs. A single cell AA batteries capacity can be between 500 and 1100mAh. NiCd's suffer from the "Memory Effect", meaning that they lose their charge faster when they are old compared to when they were brand new. NiCd's are being phased out of production and being replaced with better chemistry batteries.

Each cell on a NiCd cannot go below 1v before permanent damage occurs. Also the average life of a NiCd is about 500 recharges.

Example.

A 7.2v NiCd pack, will power an EZ-B and will handle the inrush of a few servos.

Summary.

Relatively cheap to buy, and can deliver enough current for powering DC motors and servos, but lose capacity each time they are charged and are being phased out. Not environmentally friendly due to highly toxic heavy metal in the batteries makeup.

NiMh:

Nickel Metal Hydride batteries are the sort of replacement for the NiCd's mentioned above. These also come in various forms, including the more popular 1.2 volt "AA" and "AAA" single cells, and 7.2 volt and 12 volt battery packs. NiMh battery packs have varying capacities ranging between 1300 and 13500mAh. The more popular choices of battery pack are the 7.2v and 12v NiMh packs which are available in varying mAh choices for longer or shorter run times. Have a look at the website link below for an idea of what is available...

www.componentshop.co.uk/batteries/radio-control/large-power-packs/72v-84v

www.maxamps.com/proddetail.php?prod=SLASH-RTRKIT-13500XL-74

On average, NiMh packs above 2100 mAh will have about 500 charge cycles. NiMH have some memory effect, but very little compared to NiCd cells. NiMH can benefit from the occasional deep discharge to regain some lost battery life. (This figure will depend on how you use and take care of the battery pack, and whether you use a fast charger which may give a shorter lifespan, or slow charger which may give a longer lifespan). NiMh packs can't be recharged as many times as a LiPo, and tend to die after about a year whether charging or not.

You can over-discharge NiMh batteries, so using battery ministers is advisable. You can set the LiPo Battery Warning" to warn you when your NiMh has reached its critical level to save over-discharge from happening., charge them any time you want. Each cell can't go below 0.8v for a Nimh, before permanent damage occurs so in this case the pack can't really go below 4.8v on a 7.2v battery pack.

Example. Can power an EZ-B for hours, and can handle servo inrush for multiple servos.

Summary.

Fairly inexpensive, although the price rises substantially for higher mAh packs. They deliver enough current to power servos and DC motors, but are slightly larger and heavier than LiPo batteries, also overall life expectancy is about half of an equivalent LiPo pack. (see below).

LiPo:

lithium-ion polymer batteries tend to be flat cells but can be made in almost any shape, and are usually found as multiple packs of 3.7 volt single cells. As with other batteries, they come in different flavours of voltage...

```
3.7 volt battery = 1 cell (1S)
7.4 volt battery = 2 cells (2S)
11.1 volt battery = 3 cells (3S)
14.8 volt battery = 4 cells (4S)
18.5 volt battery = 5 cells (5S)
22.2 volt battery = 6 (6S)
29.6 volt battery = 8 cells (8S)
37.0 volt battery = 10 cells (10S)
44.4 volt battery = 12 cells (12S)
```

They are also smaller than the NiCd and NiMh battery packs mentioned above, which makes them ideal for robotic projects of all sizes... large or small. These battery packs can deliver a huge amount of current which is great for powering multiple servos. These also come in various "mAh" and "aH" ratings for increased run times depending on what is being powered.

LiPo's have pretty much no battery memory effect, but you can damage them by over discharging them... You can however, charge them any time you want. EZ-Builders "LiPo Battery Warning" is set to 6.6v which saves the LiPo from over discharging. On a 7.4v 40000mAH pack, it's life cycle is around 700 recharge cycles. (This figure will depend on how you use and take care of the battery pack, and whether you use a fast charger which may give a shorter lifespan, or slow charger which may give a longer lifespan). LiPo battery packs should only be recharged by specific LiPo battery charges. A recommended type of charger is a "Balance Charger" which monitors the voltage of each individual cell in a pack, and then varies the charge on a per-cell basis to make sure that all cells are brought to the same voltage so the pack has a much better life cycle. EZ-Robot sells a LiPo Balance charger that can be found in the following link...

www.ez-robot.com/Shop/AccessoriesDetails.aspx?prevCat=9&productNumber=42

Example.

A 7.4v LiPo battery, can power an EZ-B, and can deliver enough current to move servos connected to all 24 digital ports. They are also capable of delivering enough current to power DC motors.

Summary.

LiPo batteries have become quite popular in the world of mobile robotics and in the R/C (radio controlled) fields, due to their smaller sizes and light weight design. They are a bit more expensive than NiMh batteries (not by much), but LiPo batteries CANNOT be recharged while connected to a device, as this will cause damage to the battery, or worst case burst into flames, so care must be taken. But don't be scared by that last statement, as long as you look after your LiPo battery packs, they are perfectly safe.

EZ-Robot 7.4v LiPo batteries are available from the following link...

www.ez-robot.com/Shop/AccessoriesDetails.aspx?prevCat=9&productNumber=41

LiFePo4:

Lithium iron phosphate batteries, have been around for a few years now, but only just becoming more widely used. In some respects, LiFe battery packs have some advantages over LiPo's in that they last longer, they are safer to recharge, about the same size and weight compared to similar spec LiPo's, longer overall battery life (apparently up to 10 times more charging cycles), they still pack a punch (current delivery), and they are more environmentally friendly.

As with other batteries, they have different options available. They come in "3.2v", "6.4v", "9.6v", "12.8v", "16v", and "25.6 volt with varying mAh choices. The minimum discharge voltage on a LiFePo4 cell is about 2.5v and maximum voltage is around 3.6v per cell.

Example.

A 6.4v LiFe pack will power an EZ-B, and move multiple HD servos at the same time, possible 24 connected to an EZ-B (Currently untested). They are also capable of delivering enough current to power DC motors.

Summary.

Just like LiPo battery packs, these have all of the advantages such as high current output, small form factor and can be made to almost any shape. They are currently quite expensive, but the lifespan of a LiFe can be many times more than a LiPo battery pack, so it may save money in the long run.

SLA / Lead Acid:

Sealed Lead Acid batteries are normally 6V, 12V and 24V although there are many other options are possible. You may know these kind of batteries as the type you would normally find in a car or motorbike. SLA batteries are usually measured in "aH" (amp hours) because of their larger size and capacity compared to their lithium counterparts.

A 6V SLA battery pack can normally provide enough current to power many servos, including the EZ-Robot HD servos, and also do well with heavy demand DC motors. You know them kiddie ride on cars... usually SLA powered. These batteries will be quite heavy so can really only be used in certain applications such as large robots. Because of their larger capacity, they require much longer charging times too, but you will get longer run times depending on your application.

<u>Example.</u>

Can power an EZ-B, and can produce enough current to move multiple servos. These are also great for powering DC motors hooked up to a motor controller connected to an EZ-B.

<u>Summary.</u>

Sometimes big and bulky, can be quite heavy, and take a long time to charge. But they are quite powerful (some are enough to start a car engine), and can have long run times. Prices are not to bad either, considering the amp hours they can have.

<u>NOTE:</u>

The amp hours, life cycles, and undercharge figures are gathered from various sources and are average figures. These will vary from battery to battery, manufacturer to manufacturer, and also how they are used and maintained. For more detailed information, do a web search for the particular battery you are interested in (Spec sheets/Datasheets are you friend here).

The next step will go through mains power supplies.

Step 7. Mains Electrical and Bench Power Supplies.

Sometimes, a battery pack will not be adequate for your robotic projects. There are various mains power supplies that plug in to the wall of you home or workshop, and can be the perfect solution for constant power for your static robot, or for bench testing. This step will go through a few different options that you can use.

DC: This is normally a low voltage continuous form of power which you will find in batteries. Power converters found in devices found in the home like your TV and refrigerator, convert AC in to the low power and safer DC to run the circuitry found inside of these devices.

AC: This is the high powered form of electricity that produces negative and positive alternating cycles. This is the more dangerous type of power, but is useful for delivering very high current across vast distances. This is the form of power that comes from your home power outlets.

Linear vs Switching.

Power Supply	Linear	Switching
Size	Big & Heavy	Small & Light
Internals	Simple	Complex
Unit Efficiency	30 to 50%	80 to 90%
EMI	Low Noise	Needs Filtering
££ Cost $$	High Due to materials used	Low

There are two basic power supply designs... linear, and switching-mode. Nowadays, computer power supplies are switch-mode power supply. "Linear" power supplies have a bulky transformer mode from steel or iron. This transformer provides a safety barrier for the low voltage output from the AC (usually mains power) input, and reduces and the input from typically 115V or 230VAC to a much lower voltage. This lower voltage AC output from the transformer is rectified by either two or four diodes, and converted into low voltage DC. This in turn is then regulated into the output voltage of choice.

"Switch-mode" or "Switching" supplies have much more going on inside of them. The same 115V or 230VAC voltage is rectified and leveled out using diodes and capacitors which produce a high voltage DC. That DC is then converted into a much safer, lower voltage. That voltage is then converted into the DC output voltage of choice by another set of diodes, capacitors.

The most common type of mains power supply takes in AC power from the mains, and delivers it as DC voltage to the device requiring power. The voltage and current that was mentioned in the previous steps, are the two most important considerations when choosing your power supply. These are quoted in "Volts", "Amps", and sometimes," Watts".

Linear power supplies are now replaced with switching supplies due to improvements such as size, weight, and cost. Some people have run in to problems using mains power supply's, so hopefully this guide will point people in the right direction.

Below are some examples of the various supply's available.

Adapters.

With various names such as "Wall Warts", "Power Bricks" and "Plug in Adapters", these are the external and portable supplies you find powering laptops, clock radios, and musical instruments which either run on batteries, or have no internal power source. These are also used as battery chargers to charge removable or sealed in rechargeable batteries in devices such as mobile/cell phones and laptops

AC Adapter:

These have built in transformers and can be quite bulky. There is no polarity because AC adapters are not polarized, as AC power oscillates between positive and negative voltages. There have been some people have used these adapters to run an EZ-B and control servos but run in to problems that was mentioned in step 1, the problem being lack of "current".

Summary.

These adapters come in a variety of different voltages, but the amp output can be relatively low and although they are not recommended for powering servos or DC motors, they are fine to power an EZ-B and a few sensors depending on the adapters "current" output. That being said, there are a few high current AC adapters available.

DC Adapters:

These have various choices of voltage and current output, and have transformers built in to them which are mainly (but not always) unregulated, meaning that the output is not guaranteed to be a specific value, but it will be at least what is says on its specifications. For example, with a 9v adapter drawing 300mA, the voltage is guaranteed to be higher than 9V.

Since the output is unregulated, the voltage supplied will reduce as more current is pulled from it, meaning that when nothing is connected to it, the measured output can be as high as 14V.

Summary.

These usually have a low "current" output which doesn't make them ideal to power multiple servos or DC motors, although there are some high current DC adapters available which can do the job. Working out the maximum servo or motor "inrush" current draw will help guide you in to choosing the correct DC adapter.

DC Switching Adapter:

"Switching" also known as "Switch mode" wall adapters are different from their DC counterparts, as switching adapters are regulated. This means that the output doesn't reduce when either a device is connected and powered by it or not. Due to this constant voltage, they can also be used with devices requiring less current.

Summary.

Like transformer adapters, switching adapters are also mainly low "current" output which again, are usually not recommended to power multiple servos or DC motors. But, there are some high current DC adapters available which can do the job. Low current adapters (depending on their actual output) are still capable of powering an EZ-B with sensors and camera connected to it with no issues.

The next two power supply types are great for static robots and for bench testing, as these tend to have the ability to deliver larger amounts of current. These are the type of supplies that power computers and found in medical equipment, and are either "open frame" or "enclosed", meaning these are mainly fitted internally inside a computers housing, but they can be used externally too. There are various power options available for output voltage (5V, 12V, 15V, 48V) or input voltage (85 to 132V, 85 to 256V, 100 to 250V, 100 to 264V), and there are many current output options available.

Linear Power Supplies.

Compared to the different type of power supply adapters mentioned so far, these are more recommended. A linear power supply uses simpler electronic designs than switching supplies, but need much more cooling that makes them less efficient. This is because they use bulky transformers to convert the power. Linear power supplies operate with only around 50% efficiency due to energy lost of heat which is lost using large heat sinks.

Switching Power Supplies:

Switching Power Supply

Much like their smaller adapter cousins, switching supplies work differently to linear as they diodes and capacitors resulting in DC high voltage. From there, power transistors convert this high voltage to a higher frequency AC. This is then reduced to a lower voltage using a small, lightweight transformer. Finally, the voltage is converted into the desired DC output voltage by another set of diodes, inductors, and capacitors. A lot more going on in a switching supply as you can see, but they are much more efficient and operate around 80% to 90%, much more efficient than linear supplies.

When you look for a switching power supply, it is highly recommended that you do some research. You will need to work out what your maximum amp draw will from the servos and motors you're using, as well as the correct voltage and type of voltage that is needed, whether it's AC or DC, and the same goes for what power source you are connecting the power supply to. Once you have worked out the maximum current you need, add a little extra on top as a safety margin so that you won't encounter brownouts.

A recommended option to have with these type of power supply's, is to have a power protection circuit. This way, if too much current is pulled from it, the supply will switch off with no damage caused. Simply cycle the power (switch it off and on again) and you'll be back in business. For running an EZ-B with multiple servos connected to it, the recommendation is to go with something that can supply 20 amps or more, along with the desired voltage (the EZ-B voltage minimum is 4.5v, and maximum input is 16v).

www.trcelectronics.com/View/Mean-Well/RSP-150-7.5.shtml

www.trcelectronics.com/View/Mean-Well/SE-350-7.5.shtml

www.amazon.com/gp/product/B007K2H0GI/ref=oh_aui_detailpage_o06_s00?ie=UTF8&psc=1

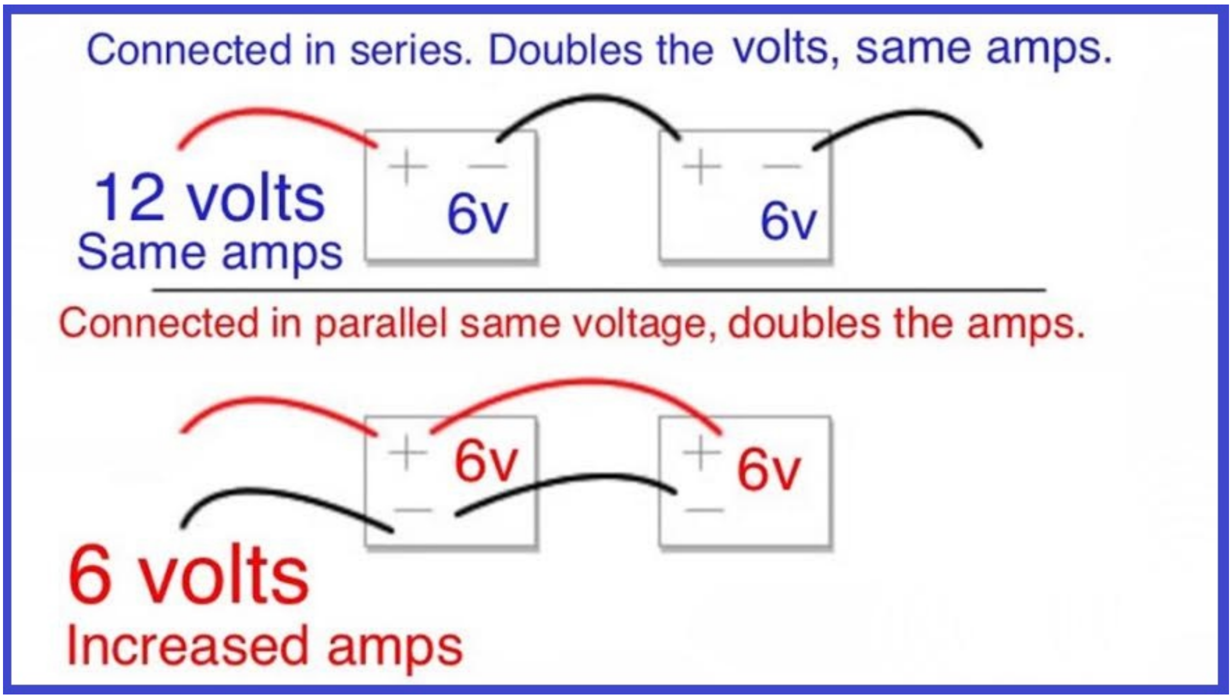
Of course, your set my up may not need that much current to run. The supply that is linked to below, is one option and is rated for 12 amp output, and may suit your requirements better...

www.amazon.com/gp/product/B007C7DWL8/ref=oh_aui_detailpage_o04_s00?ie=UTF8&psc=1

As with any power supply, be aware of cheap "knock off" supplies. They can be unreliable, and can possibly be dangerous.

Step 6. Series or Parallel.

Parallel increases current. Series increases voltage.



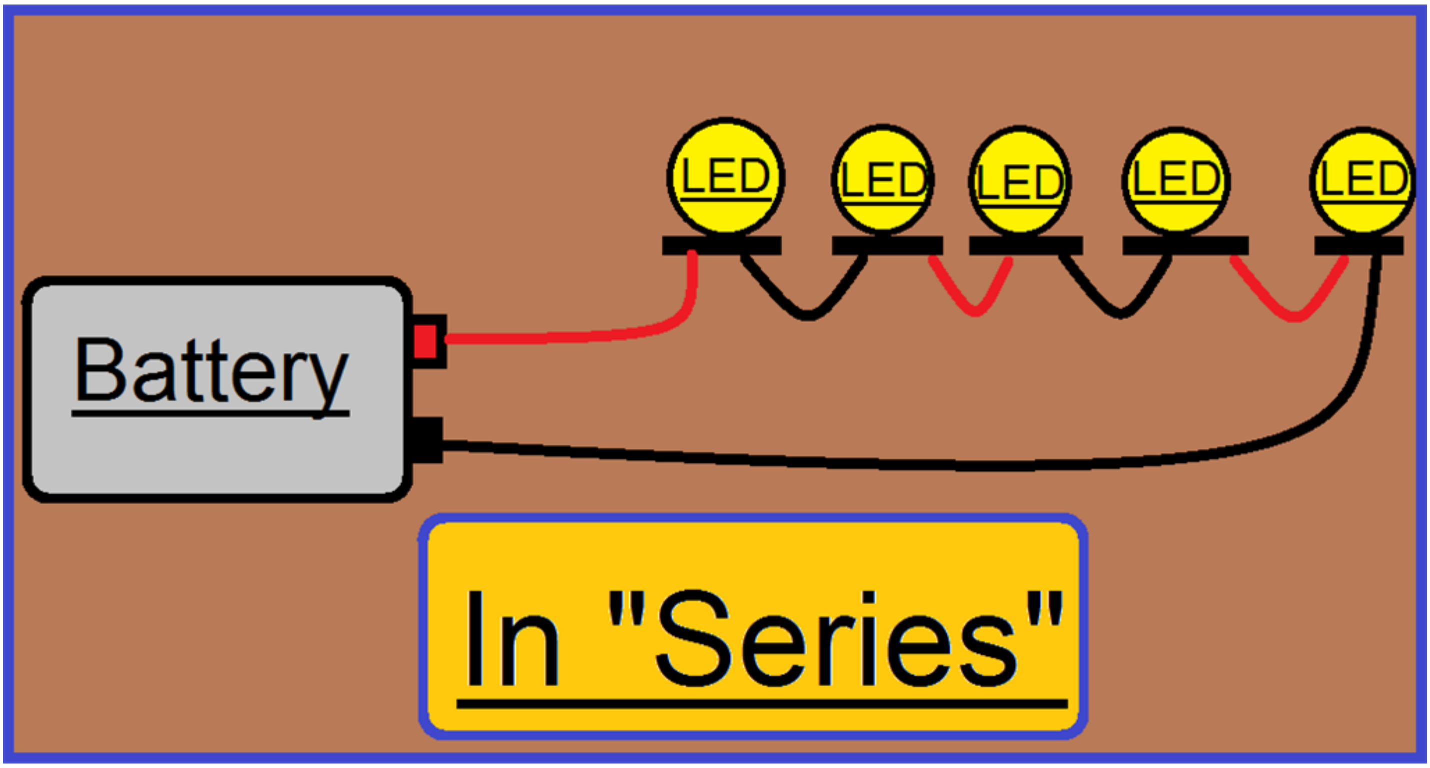
Something that can sometimes cause confusion, is the understanding of what "Parallel" and "Series" actually means. This step will explain exactly what they both mean, and what they do.

Series.

"Series", is where multiple devices are chained together, one after another. Think of when you watch your favorite TV show.

It has 24 episodes which play one after another. This makes a "series" of episodes.

In an electrical circuit, this could be a row of lights. Have a look at the image below for a visual example of these lights in "series"...



Battery packs that are made up of individual cells, and connected in series which adds each cells voltage together which increase the overall voltage.

Parallel.

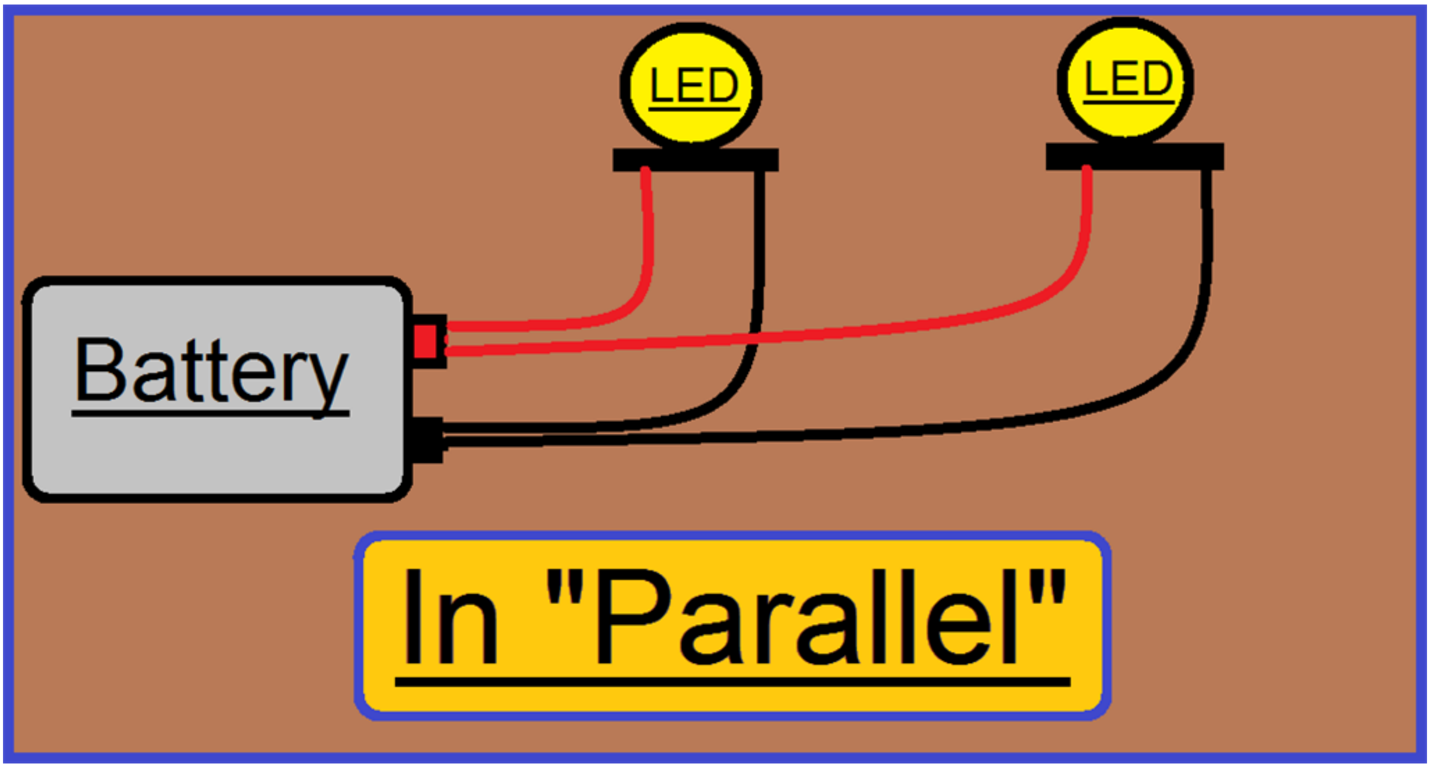
Unlike a "series"'circuit, where one device is connected to another, a "parallel" circuit is where two or more devices connect to the same power source with their own wires.

Back to the TV. You have a TV and a video recorder plugged in to one power outlet, so they are both using the same power supply.

You watch your favorite movie on channel 1 on your TV (maybe your favorite robot movie), and record another movie on channel 2 on the video recorder.

The TV movie finishes before the one being recorded does. You put the TV on to standby and leave the video recorder on to finish recording.

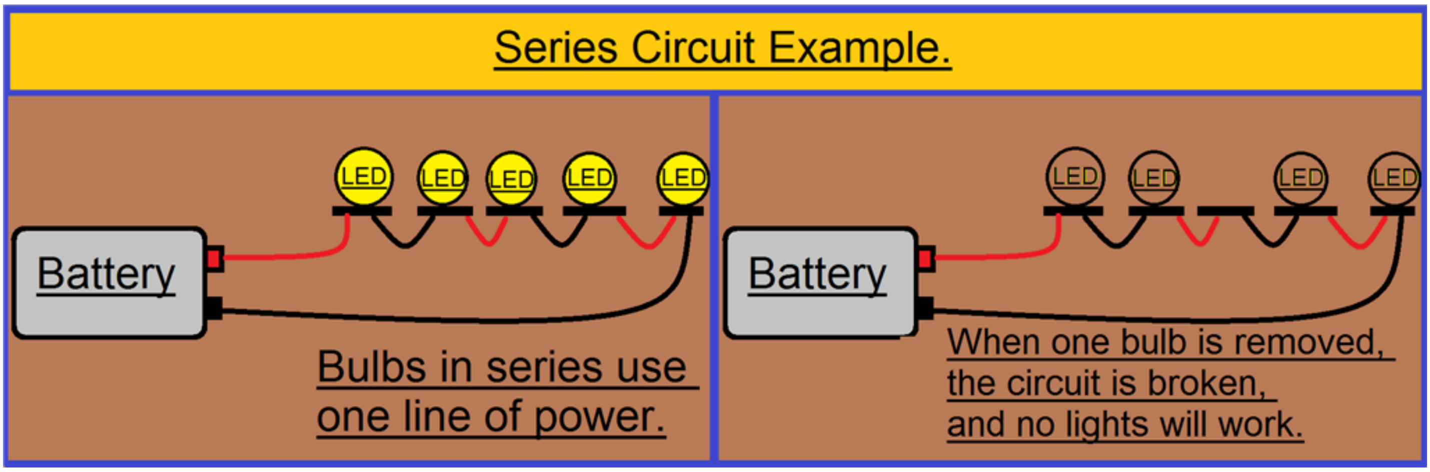
Although they are being powered from the same power outlet, one device is off, but the other one is still on.



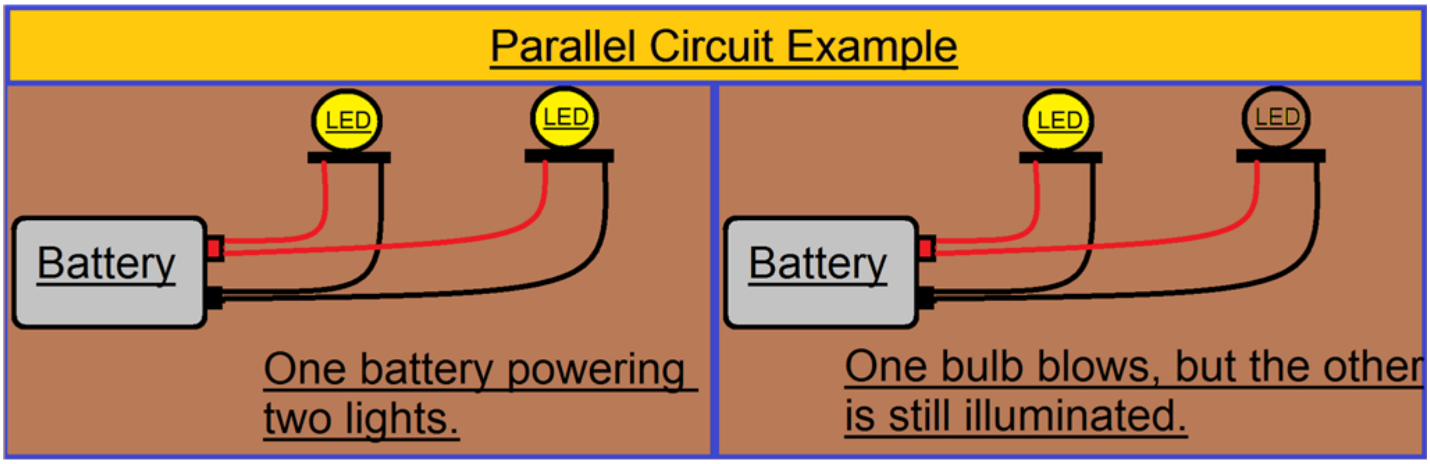
Connecting two batteries in parallel (both negative terminals connected together, both positive terminals connected together), to your robot, will not increase the overall voltage. What it will do though, is increase its run time (increasing the amp hours or milliamp hours). There will be more current on offer as well, but like was mentioned in step 1, an electrical device will only draw the current it needs.

A summery of "Series" & "Parallel".

A group of joggers run in single file (in series). The one in front falls over, and this effects the other joggers running behind. If one device fails, the others will stop operating. (Sorry, I can't draw joggers).



Another group of joggers run along side each other (in parallel). One falls over, but the others are not effected. If a device fails, the others will still operate.



Another reason to know the difference between "series" and "parallel", is when it comes to using a multi-meter to measure amps and voltage. That will be covered in the next step.

Step 7. Multimeters.

A Volt Meter.

Measures the potential difference, in Volts, between the two points being measured. The voltmeter gets connected in "parallel". It has a high resistance in order to divert the majority of current through the main circuit.

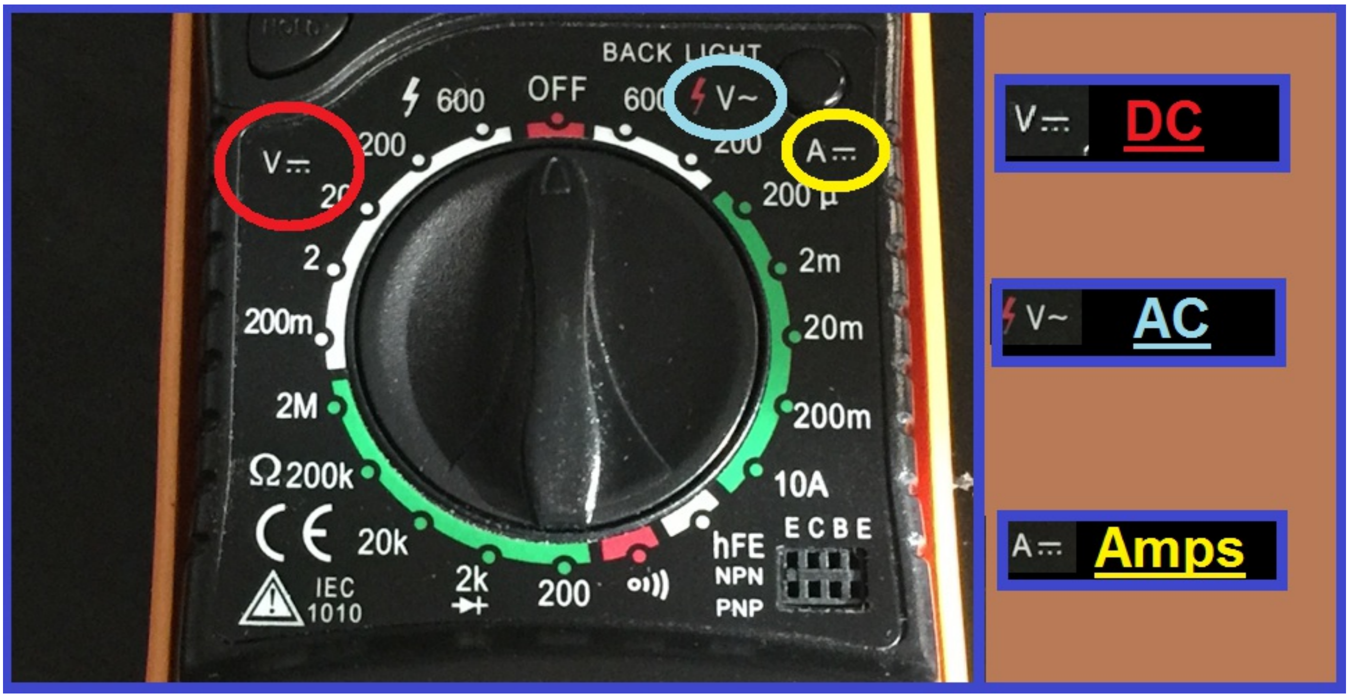
Ammeter.

Measure the current of the circuit in Amps. It essentially counts the electrons as they pass through the ammeter. The ammeter is connected in "series". It has a very low resistance so as not to disturb the functioning of the circuit too much.

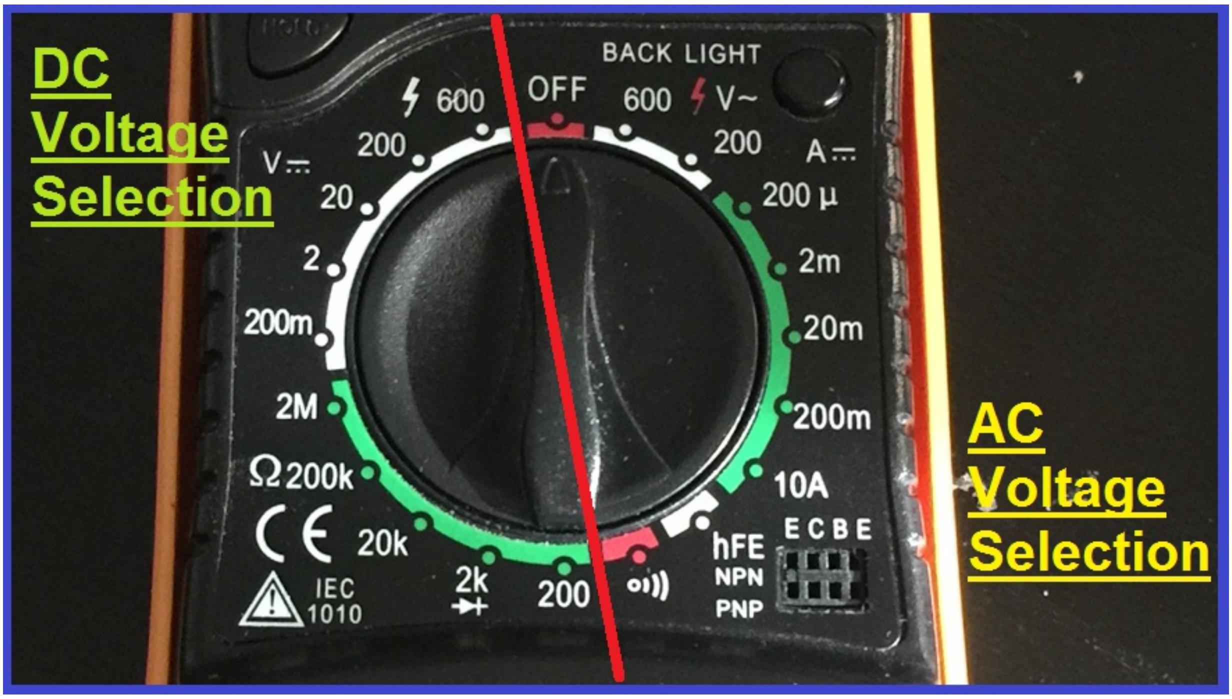
Multi-meter.

A device that has the options to measure both voltage, and amperage. Basically, the two meters mentioned above, in one unit. They can also measure resistance.

This step will explain how to measure voltage and amperage with a multi-meter. The thing to know before you start, is that there are usually 3 functions which will read DC (direct current), AC (alternating current), and A (amps). For reading voltage, the multi-meter used in this example has three different symbols for AC, DC and Amperage, which is seen in the picture below...



Some multi-meters are auto ranging, but this one is done manually, so it has different voltage ranges for DC on the left of the meter, and AC on the right...



The three terminals on the bottom of the multi-meter are as follows...

10 ADC Can measure up to 10 amps before the fuse between the "10ADC" and "COM" terminals blows if the 10 amp limit is exceeded.

COM Is the common terminal for the black probe.

V mA Can measure up to 200 milliamps before the fuse between the "V mA" and "COM" terminals blows before the 200 milliamp limit is exceeded.

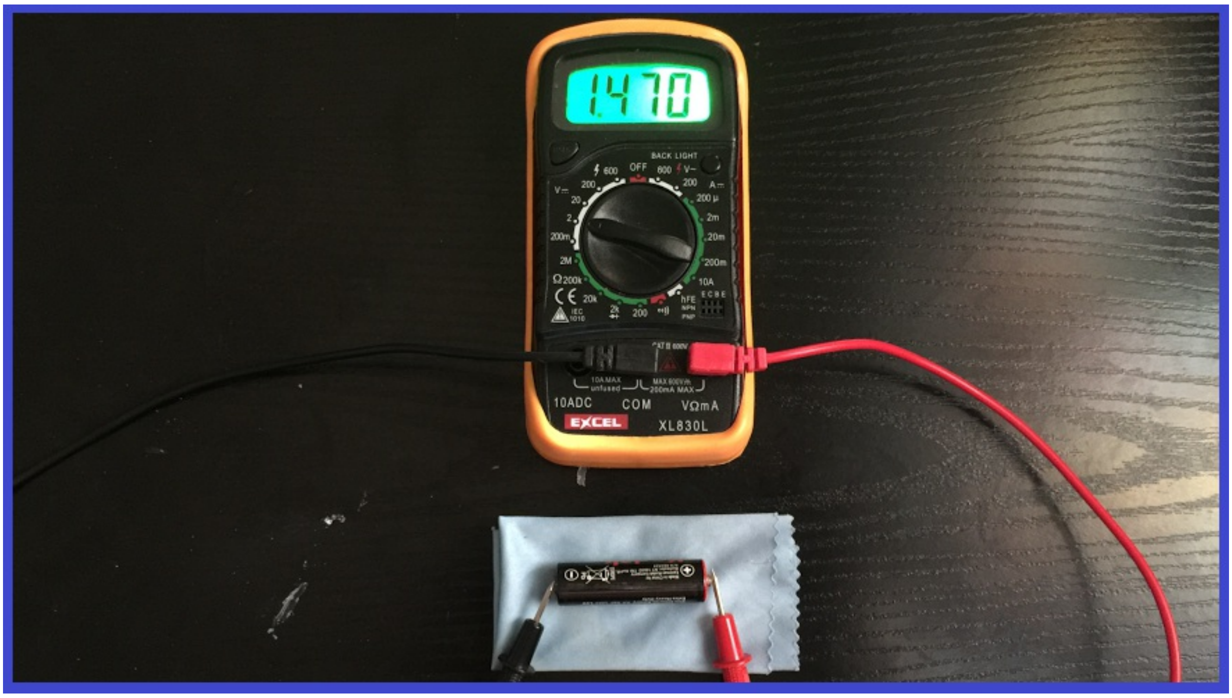
<u>Measuring "DC" Voltage.</u>

First, we will start by measuring the voltage of a 1.5v battery (DC power supply). This is essentially a "parallel" circuit we are creating... a power source powering one device directly.

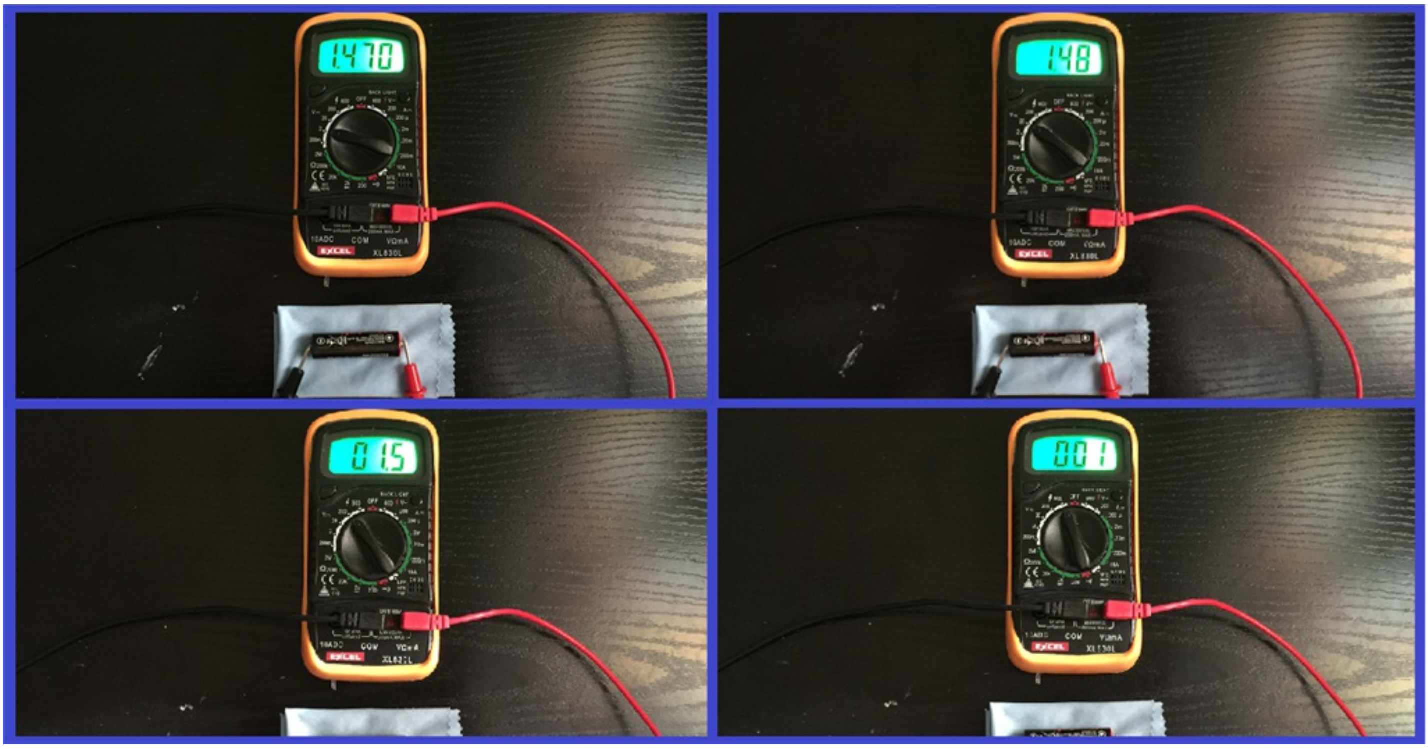
1.) Connect the black probe jack in to the "**COM**" terminal, and the red probe jack in to the "**V mA**" terminal.

2.) Move the multi-meters selector to the DC side of the meter, and select "**2V DC**" so we set the meters voltage reading to the next highest DC reading (we know the battery is 1.5v, as it says so on the battery).

3.) Touch the black probe to the negative "**-**" terminal, then the red probe to the positive "**+**" terminal of the battery. You should now get a reading from the battery...

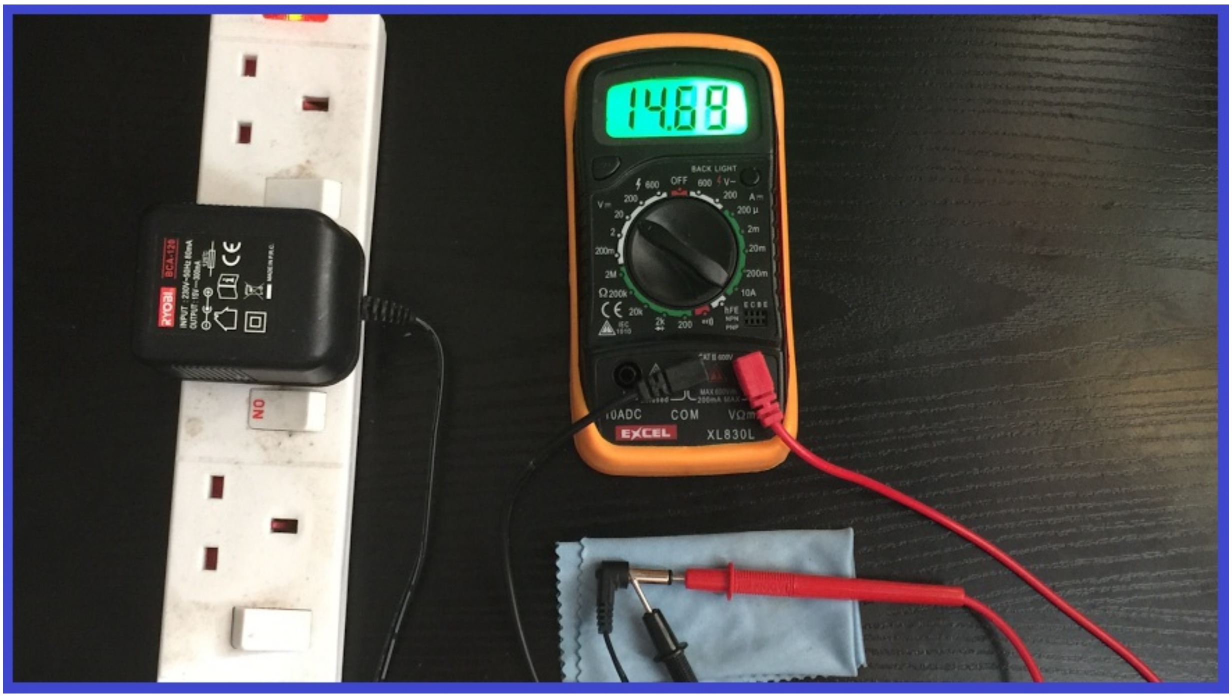


We get a reading of a little over 1.4 volts. What happens though, if you turn the selector to a higher voltage reading? Well have a look at the following images...



All that is happening here is the decimal place is decreasing, (1.470v, 1.48v, 1.5v, 1v), which as you can see, will also mean that the readings will lose accuracy.

Measuring the voltage of a DC wall adapter is no different. Set the voltage reading dial on the meter to the next highest setting than what the voltage output is from the adapter. Place the red probe in to the centre of the adapter jack, and touch the black probe to the outside of the jack...



you see a reading of 14.69v in the image above, that is reading the adapters output, which is 15V.

<u>Measuring "AC" Voltage.</u>

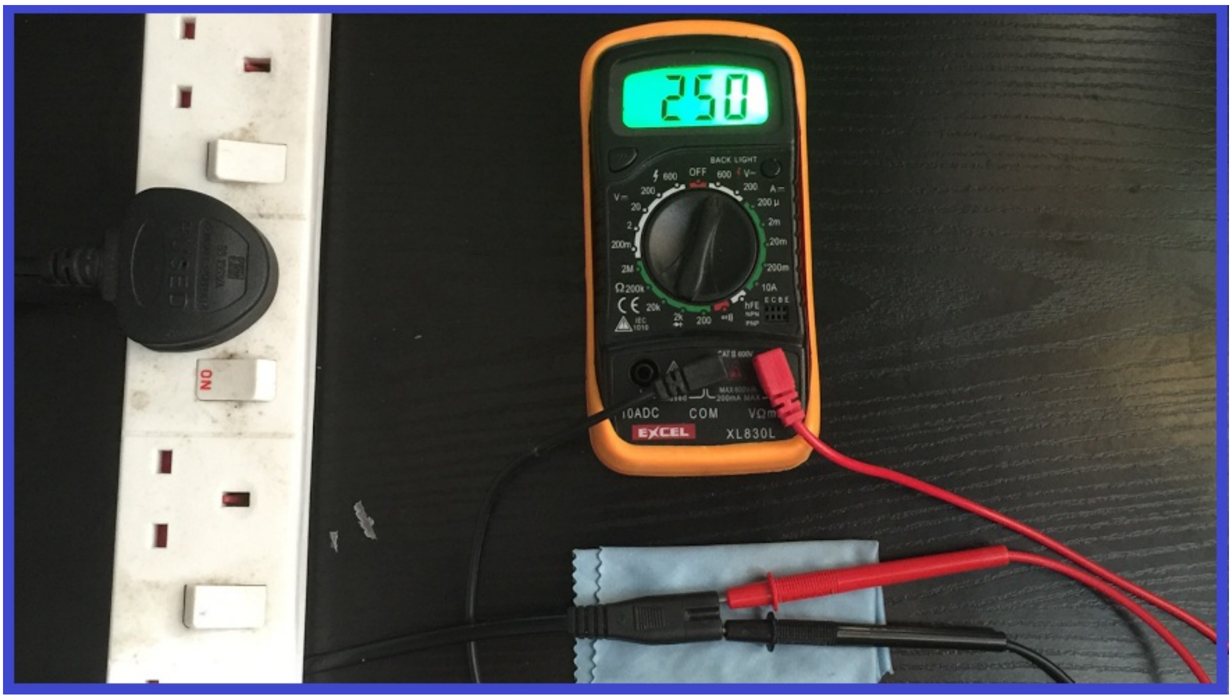
Now we will measure the voltage from a mains wall outlet (AC power supply).

This is just as easy as testing DC voltage, but much more care should be taken, as we are dealing with the higher power AC output. This example will be measuring a direct 240v mains output from a UK wall outlet.

1.) Turn off the wall outlet power.

2.) Move the meters dial to the AC side, and select the **600V AC** option (we know we are measuring 240V, so we go to the next highest AC meter read setting... in this case, 600V AC).

3.) Insert the probes in to the wall outlet (or cable in this example) and... "*Wait a minute, are you going to say turn the power on? what way do the red and black probes go?*" Well, it doesn't matter. AC by definition, is alternating current, so it is not polarized. So with that being said... turn on the power.



4.) In the image above, you will see a reading of 250V AC, not 240V AC as this is because AC is not regulated, so this reading is indeed, correct.

<u>Measuring Amperage.</u>

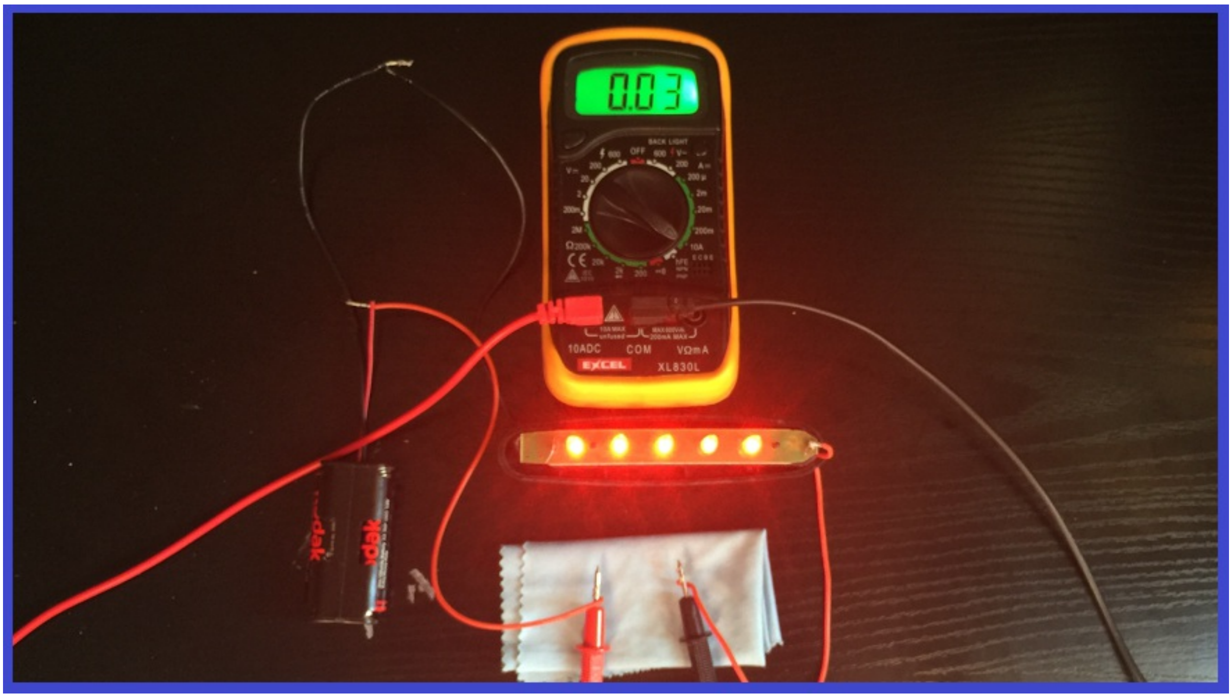
This is done differently to measuring voltage where we create a "parallel" circuit, as we will now create a "serial" circuit... one power source powering two devices chained together.

Here, we will measure the amp draw on an LED strip powered off two 1.5V batteries in series (=3 volts).

1.) On the multi-meter, plug the black probe jack in to the "**COM**" terminal, and the red probe in to the "**10ADC**" terminal.

2.) Move the dial to the "**10A**" option.

3.) On our LED circuit, we need to make a break in the positive wire so the meter can be chained to it (parallel). Cut the wire, strip the two ends, and wrap the striped wire coming from the battery around the red probe. The wrap the stripped wire going to the LED around the black probe (if this is reversed, you will still get a reading, but you will see a minus (**-**) symbol telling you that it is reversed.



4.) Once power is applied, we see that we get a reading of 0.03. As the dial is set to read 10A maximum, the 0.03 equals to 30mA (30 milliamps).

Reading current draw this way is great for deciding what fuse amperage to go for to protect your circuit, and your robot.

If you are unsure of what the voltage or amperage range of the device you are measuring is, start from the highest reading setting on the meter, then turn the dial to reduce the maximum reading. If it is set too low, you will more than likely get an "error" reading, or worse case, blow the fuse in the meter to protect it.

So with the basics covered with how to use a multi-meter to read amps and voltage, this will guide you away from supplying too little or not enough voltage and current to your motors, servos, sensors, and of course, LED lights.

NOTE: When measuring power with a meter, it must be remembered that you are measuring potentially dangerous power. For example, you could be worried about getting an electric shock from measuring an AC voltage or current from a wall outlet. The thing is, that is what these devices are made to do, but never the less, great care should be taken.

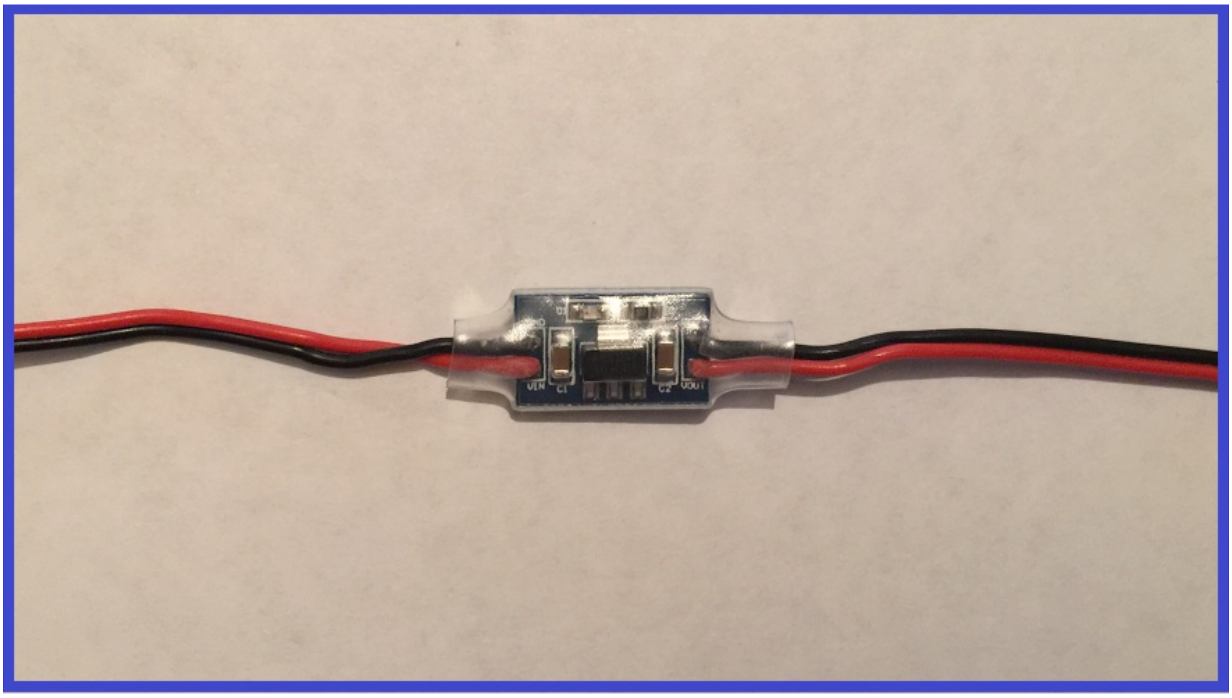
If you are not sure or nervous about using a multi-meter, or indeed working on any electrical system or device...PLEASE CONSULT AN EXPERT OR QUALIFIED ELECTRICIAN.

With that said, let's move on to power regulation options, in the next step.

Step 8. Power Regulation.

The three main types of power conversation units that we are going to talk about here, which are Buck converters, regulators, and inverters.

Voltage Regulators.



There are three popular types of voltage regulators...

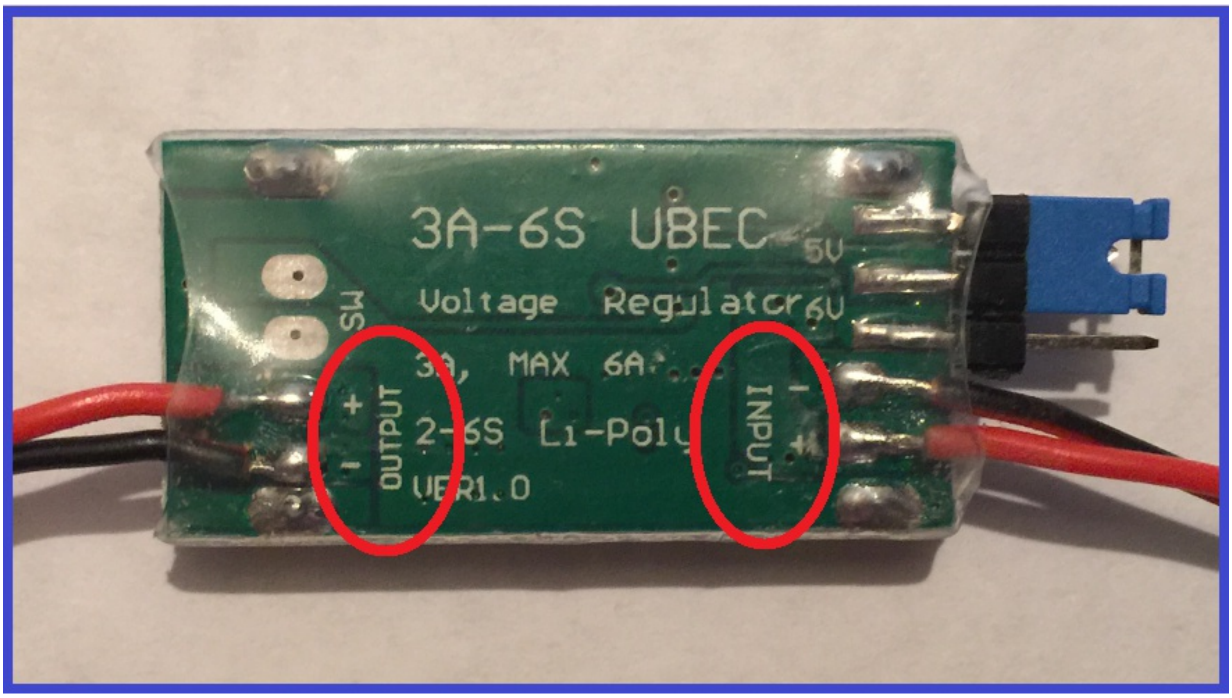
"Step Down" which reduces power,

"Step Up" which increases power,

and "Step Up / Step Down" which can both increase or reduce power.

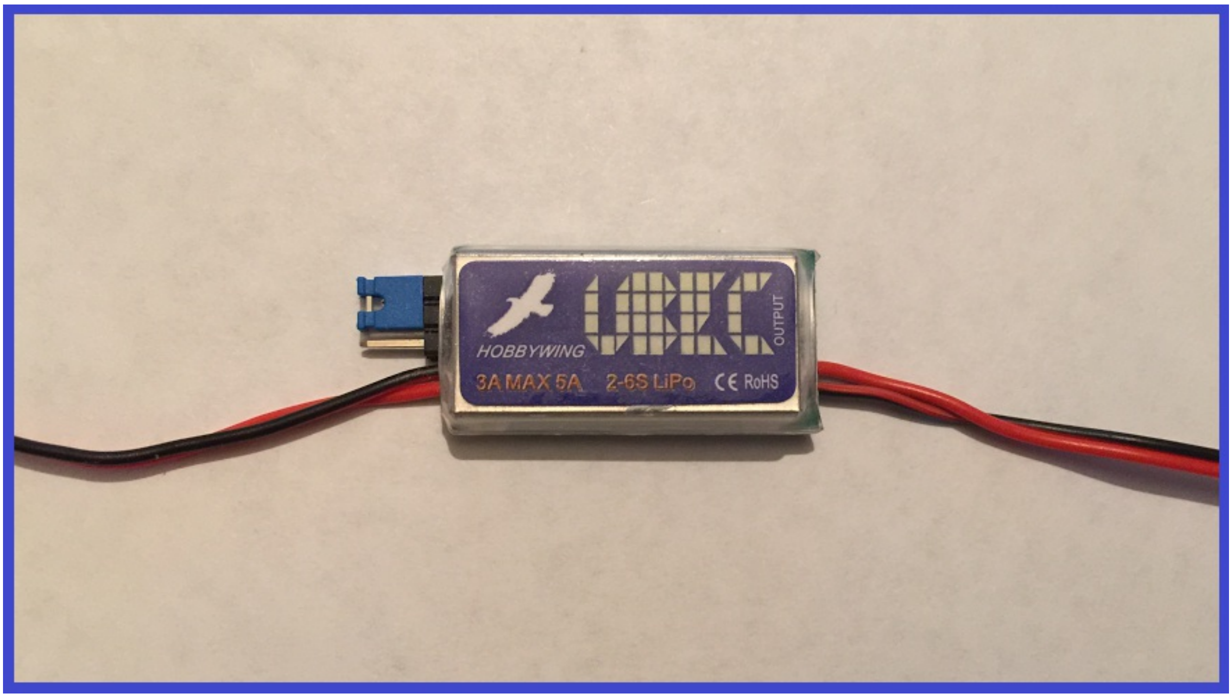
What these electronic devices do, is maintain the voltage of a power source within acceptable limits. Regulators can be found in many electronic devices, and their job is to maintain voltages within a set range that can be tolerated by the electronic device, using that set voltage. The EZ-B v4 has regulators built inside which reduces the incoming power down to 3.3v on the analog, UART, i2c, and camera power pins.

Voltage regulators have an "input" and an "output" which are usually marked on the regulator. The input, is where you would connect your power source to, where this power is then converted. The device that needs the power is connected to the output, and receives the adjusted power.



Keeping with the EZ-B, let's lay out a couple of real world examples.

You have a 7.5v 20 amp mains power supply that is powering your EZ-B, but you may want to connect an ultrasonic distance sensor to it. These connect to the digital ports, but the sensors are 5v, and your 7.5v power supply is going straight through to the power pins (unregulated). This is where an external 5v step down voltage regulator will come in (like the ones seen above and below)...



1.) You plug the "**Input**" leads in to the EZ-B digital pins, (power comes out of the EZ-B, and "**IN**" to the regulator).

2.) The sensor is connected to the "**Output**" leads, (power comes "**OUT**" of the regulator, to the sensor).

3.) You power up the EZ-B and 7.5 volts are fed to the regulator, where it reduces the voltage down to 5 volts, then feed the sensor with the correct 5 volts.

Now there is one thing to keep in mind when using regulators.

We use the same 5v regulator we used above, to reduce the power of the EZ-B itself, instead of *connecting it to the digital pins... no problem. Your mains power supply is feeding 7.5v to the 5v regulator, which now reduces 7.5 volts to 5 volts. 5 volts will now power the EZ-B. The EZ-B will power up okay as the voltage is over the minimum 4.5v requirements, and the sensor will receive the 5 volts (5v is now going in to the EZ-B, and 5v is coming out of the digital power pins).*

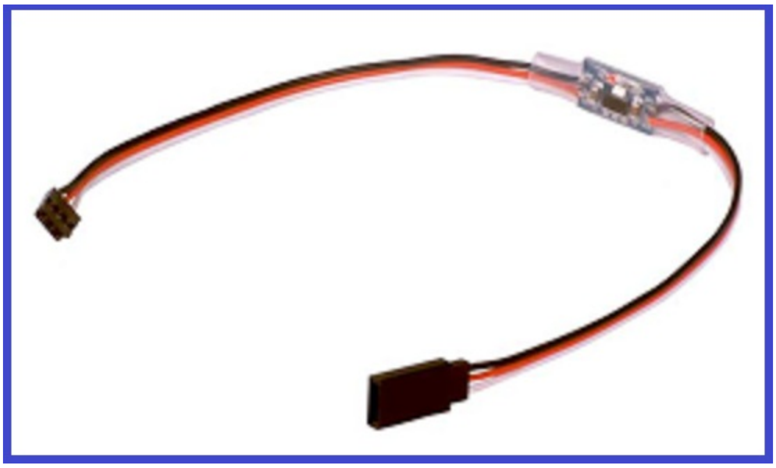
Now we connect 6 heavy duty servos to the EZ-B. The servos will work with 5 volts, so no problem there. We now move all of the servos at the same time... oops, what happened? The EZ-B has browned out. What happened?

Remember step 1? **AMPS!!!** The servo inrush current draw for all 6 servos moving at the same time is (for example) 18 amps.

It turns out that the 5v regulator is only rated to draw 5 amps, and will now only offer 5 amps maximum.

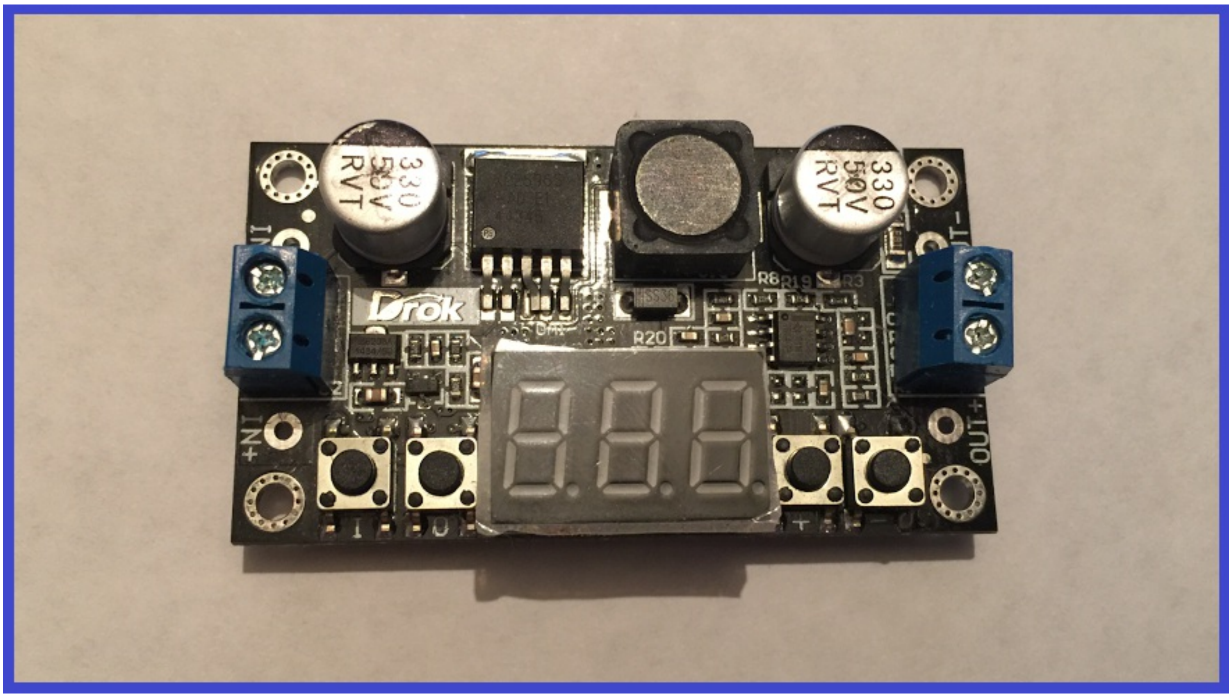
You are feeding the regulator 7.5v that it reduced to 5v output. But, you are also feeding 20 amps to the regulator that is only rated for 5 amps output. This is sometimes called a bottleneck. The regulator is restricting the amount of available current, and now not passing enough to the EZ-B and the servos.

So, voltage regulators are very useful when used with the correct application. They come in various sizes, some have connectors on them, some don't, and there are different input and output voltage and current options available. Below is a link for the EZ-Robot inline regulator that is rated for 16v input, 1 amp draw, and 5v output. It also has connectors on it which makes it a very easy "plug 'n' play" device.



www.ez-robot.com/Shop/AccessoriesDetails.aspx?prevCat=103&productNumber=98

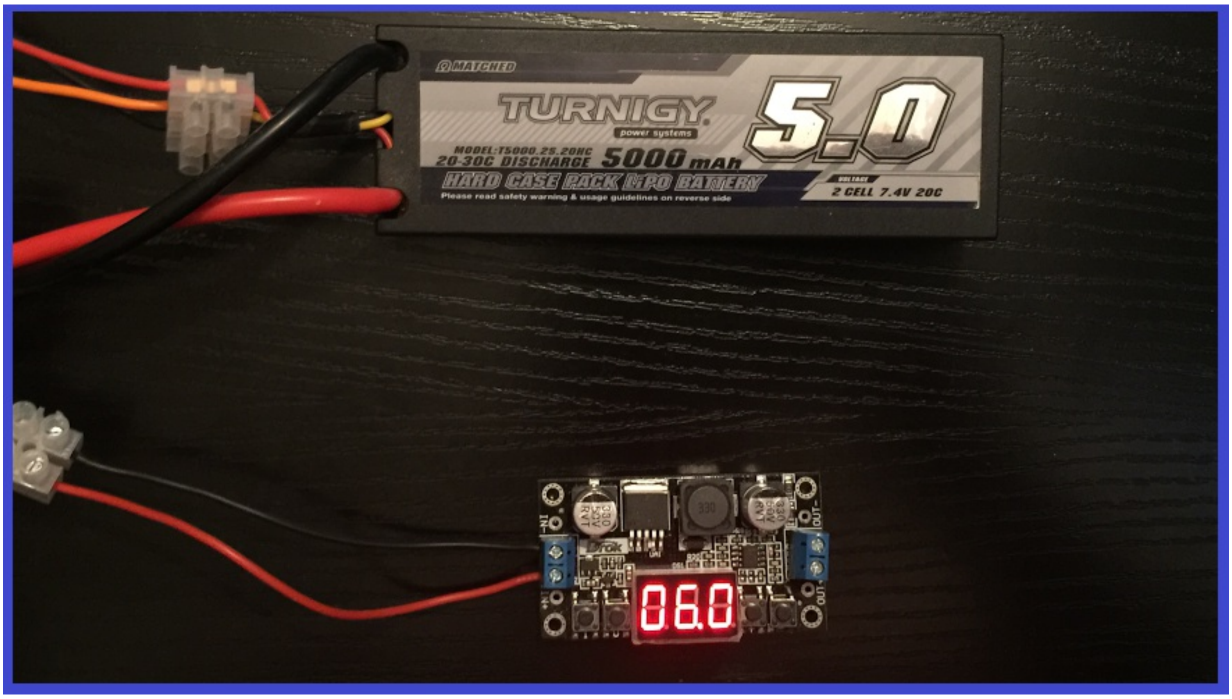
Buck Converters.



Buck converters are a form of switching regulator which means they are more efficient, but can cost slightly more. These are very similar to voltage regulators in that they can step up, or step down incoming power, but there are a few differences. Apart from their form factor and size, the output voltage from a Buck converter can be changed. Some have a momentary push buttons and others have potentiometers which, when pushed or adjusted, can change the voltage output. Many have a visual display so you can see what the input voltage is, and the output voltage so you can adjust it to your requirements.

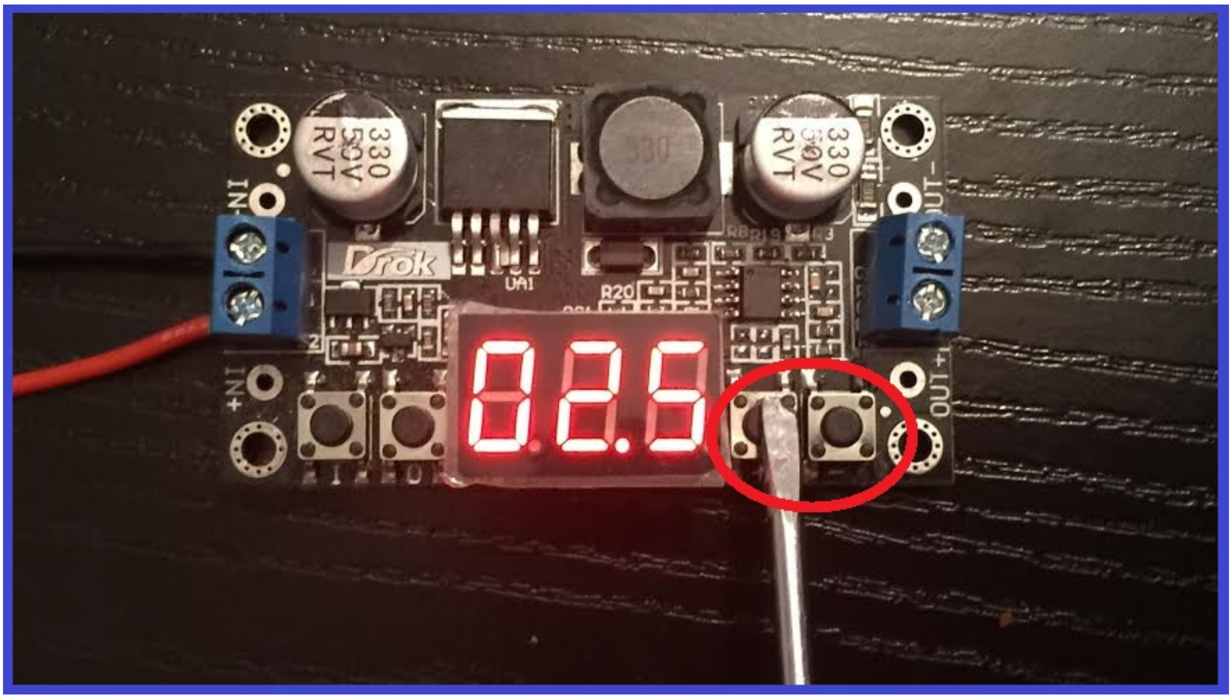
The following, is a short step by step guide for using a step down Buck converter with a momentary push button voltage selectors and an LED display, which using a battery will power a 3v LED strip.

1.) Connect the positive and negative wires from the battery to the correct "**Input**" terminals on the buck converter (do not connect the device at this point, as the buck converter my be set at a default voltage too high for your device to handle).



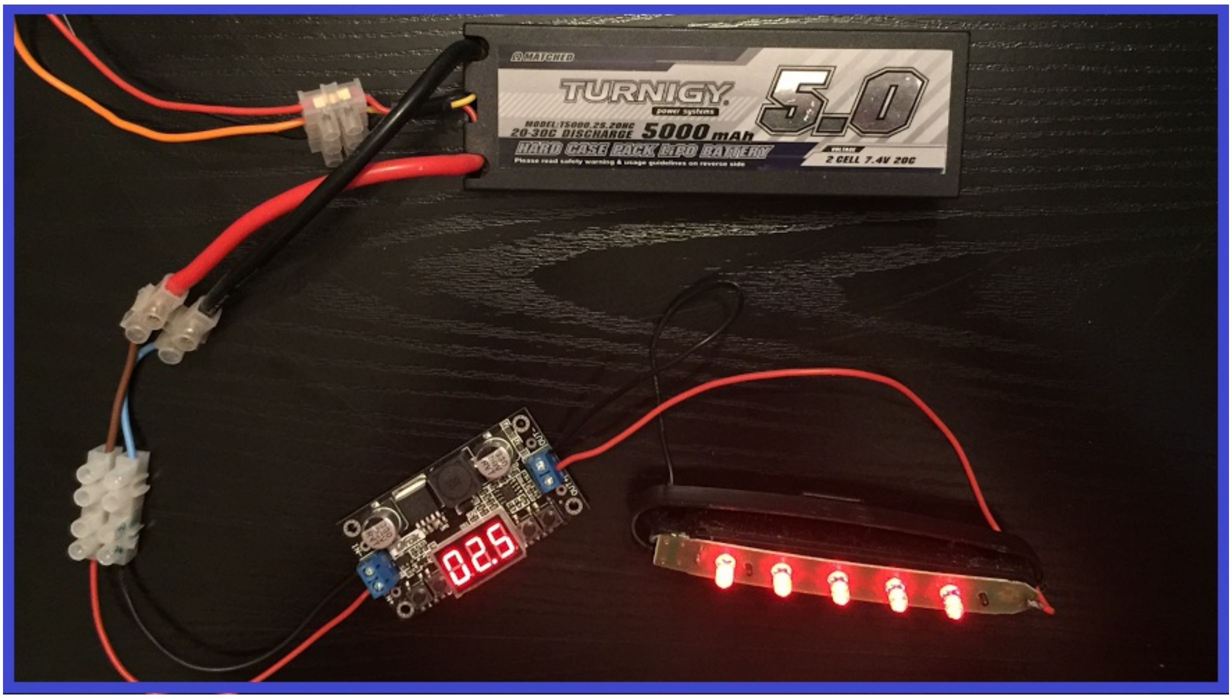
2.) You will now see the input voltage of the battery. Press the button to the right of the display to display the voltage output.

3.) With a small screwdriver, turn the screw on the potentiometer, or as seen below, press the "increase" or "decrease" voltage button. You should now see the display values change. If the buck converter has a screw and the numbers don't change when you turn it, turn the screw the other way (it may take a few turns). When your desired voltage is being displayed, stop turning the screw.



4.). Disconnect the battery, and connect the wires for the device that needs to be powered to the "**Output**" terminals, making sure the positive and negative wires are connected to the correct output terminals.

5.) Reconnect the battery, and the device will now receive the correct, regulated power.



In the image, the setting is an output for 2.5v which is fine for powering 3v LED's. If you think about it, LED's powered by two alkaline batteries in series will not always get the full 3 volts on offer, as the alkaline's slowly deplete as they are used.

As with voltage regulators, there are different options when choosing a buck converter, such as maximum and minimum voltage input, minimum and maximum output voltage, and maximum current draw. Some buck converters may have a small heat sink fitted and some will not, so you may need to fit one depending on the power requirements used.

Power Inverters.

A power inverter is designed to convert DC to AC. For example, the input power to the inverter would be a DC source from a battery. This is then converted to AC, so an AC powered device like a TV that is usually powered from the mains supply, can operate. The efficiency of many inverters is around the 80% mark and sometimes have built in low battery voltage protection.

The other part of a power inverters design, is to increase output voltage from a lower input power source. You may know that a taser weapon used to subdue bad guys can produce many volts, (around 50.000 volts and 133mA output), but it is only powered buy a 9 or 12VDC battery at 4.8 amps input. This is because a taser has a built in power inverter.

One final thing about inverters, is the current that gets drawn from the power source when powering an AC device. When you look at the specifications for inverters, the numbers given are usually Watts, and it's important to know that this in input, not output.

As an example, we need to run a 500 Watt AC device, but if you look at the table below, on the column to the right, you will not see a 500 watt value. However, on the next line, you will see a value of 520, and a current output of 2.17 amps. If you now go to the inverters rated wattage row, you will see a value of 650 watts which would a good place to start.

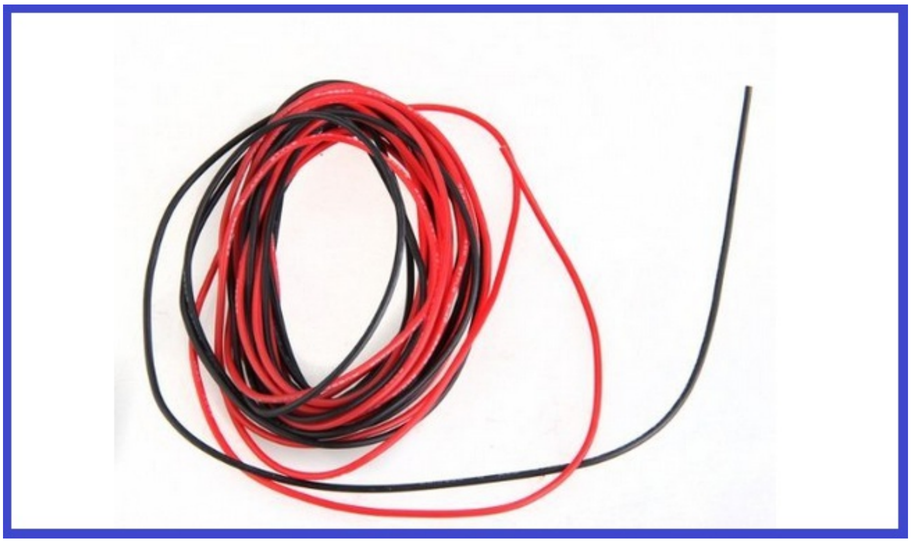
Inverter Rate (Watts)	Battery Voltage	Battery Current	Efficiency	Inverter Voltage Output	Inverter Current Output	Inverter Wattage Output
100	12	8.33	80	240	0.33	80
150	12	12.50	80	240	0.50	120
200	12	16.67	80	240	0.67	160
250	12	20.83	80	240	0.83	200
300	12	25.00	80	240	1.00	240
350	12	29.17	80	240	1.17	280
400	12	33.33	80	240	1.33	320
450	12	37.50	80	240	1.50	360
500	12	41.67	80	240	1.67	400
550	12	45.83	80	240	1.83	440
600	12	50.00	80	240	2.00	480
650	12	54.17	80	240	2.17	520
700	12	58.33	80	240	2.33	560
750	12	62.50	80	240	2.50	600
800	12	68.67	80	240	2.67	640
850	12	70.83	80	240	2.83	680
900	12	75.00	80	240	3.00	720
950	12	79.17	80	240	3.17	760
1000	12	83.33	80	240	3.33	800
1100	12	91.67	80	240	3.67	880
1200	12	100.00	80	240	400	950

That covers the basics for power regulators, and should have hopefully explained what these devices do, and how to use them.

Normally, where there is power, there is wire. The next step will go through how to choose the correct wire for your projects.

Step 9. Wire and cable.

Love it or hate it, wire and cables are an important aspect for any electrical system. Most electrical devices will use wire at some point in their makeup. Whether it's a mass of wire connecting different components together, a couple of wires connecting battery terminals to a circuit board, or a completely wire free device that needs to be recharged that will use a mains power charger.



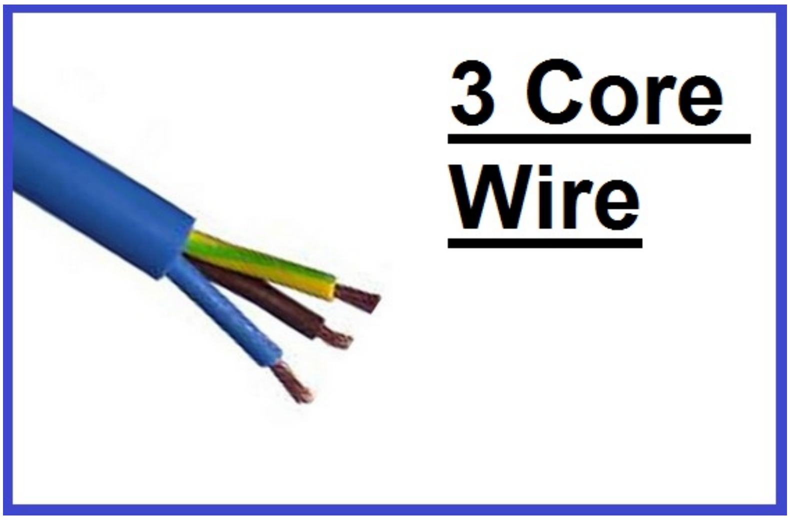
When building an electrical system, you will need to work out the power requirements for devices or peripherals used, such as the servos or DC motors that have been previously mentioned. Using an inadequate wire gauge connected to a DC motor for example, can cause the motor to not operate properly, and the wire can heat up excessively.

The difference between wire and cable is a simple one to remember.

A single or multiple metal wire strands that conduct electricity (normally copper or aluminum), make a wire.

A cable, is made up of multiple wires.

Take a three core cable for example. This is made up of three wires (cores) which are usually "*Earth* or *Ground*", "*Live* or *Positive*", and "*Neutral* or *Negative*" wires.



Wire comes in different thicknesses which is referred to as "Gauge". This is measured in millimeters and gauged in "**SWG**" (British **S**tandatd **w**ire **g**auge, and "**AWG**" **A**merican **w**ire **g**auge). Understanding this is important. When it comes to the actual wire sizes, AWG and SWG are not equivalent in size. In general, an SWG wire would be bigger than an AWG wire of the same gauge.

AWG is more widely used nowadays, although SWG measurements are used in some industries. So when working out your wire gauges, it's worth taking this in to consideration. Gauge measurements work out as a thin wire will be a high gauge number, and a thick wire will have a low gauge number. Much like the "waterwheel" analogy used to explain the flow of amps, the larger water pipe can deliver more current/amps, and the same is usually true for thicker wire.

Below is a wire gauge table that gives the maximum amp rating for different wire gauges...

	Copper Wire			Aluminum Wire	
AWG Wire gauge size	60°C (140°F)	75°C (167°F)	90°C (194°F)	75°C (167°F)	90°C (194°F)
	NM-B	THW	THWN-2	THW	XHHW-2
	UF-B	THWN	THHN	THWN	THHN
	---	SE	XHHW-2	SE	TWHN-2
	---	USE	---	USE	---
	---	XHHW	---	XHHW	---
14	15	15	15	---	---
12	20	20	20	15	15
10	30	30	30	25	25
8	40	50	55	40	45
6	55	65	75	50	55
4	70	85	95	65	75
3	85	100	115	75	85
2	95	115	130	90	100
1	---	130	145	100	115
1/0	---	150	170	120	135
2/0	---	175	195	135	150
3/0	---	200	225	155	175

<u>CAUTION:</u>

Pushing or drawing a higher amp rate than the wire is rated for, will cause the wire to heat up and possible melt the plastic, rubber, or silicone covering. This can cause short circuits and possibly burst in to flames.

The quality of wire varies as well, so make sure you get a good quality wire.

Final Thoughts.

Servos and DC motors have been used a lot in this tutorial, as most robots will have servos, motors, or both installed. There may be times that using many servos or very heavy duty ones directly off the EZ-B may not be feasible due to power requirements.

So putting a lot of what has been talked about in this tutorial together, such as "*current*", "*voltage*", "*power supplies*", and "*series/parallel*", we can find a more efficient of powering them. A good way to power these servos and DC motors, is to power them directly from the "*power source*". That could be the same source that's powering the EZ-B (*parallel*) providing the motors and devices connected to the EZ-B use the same "*voltage*". This way, depending on the power supply specifications, they will get all the "*current*" they need to operate at optimum efficiency. You could also use a separate power source and power the motors or servos from that.

So, we started with amps then voltage, then everything else that which these power variables are used with...

EZ-B pins that deliver the power,

Batteries and mains supplies that deliver the power,

Series/Parallel which is how this power is distributed,

Multi-meters to measure the power,

Regulation to reduce or increase the power,

and the Wire that transports the power.

Lots of subjects that all interconnect. Hopefully from reading through this tutorial, you will see that there is a lot information to take in for getting the right power requirements for your robotic projects. But if you take each of the above steps one at a time, you will soon be able to understand what is needed, and hopefully avoid any mishaps.

Isn't electricity a weird and wonderful thing!

Happy building.

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