Name:
Date:

// Parts of a Multimeter

Often you will have to use a multimeter for troubleshooting a circuit, testing components, materials or the occasional worksheet. This section will cover how to use a digital multimeter, specifically a SparkFun VC830L. We will discuss how to use this multimeter to measure voltage, current, resistance and continuity on the circuits in the S.I.K.

Display: Where values are displayed.

Knob/Setting: Used to select what is being measured and the upper limit of how much is being measured.

Positive Port 1: Where the positive port connector is plugged in if you are measuring less than 100mA of current.

Common/Ground: Where the negative port connector is plugged in no matter what.

Positive Port 2: Where the positive port connector is plugged in if you are measuring more than 100mA of current.

Probes: The points of contact for measuring electrical signals. Place the positive probe closer to the energy source and the negative probe closer to ground.

Port connectors: Plug them into multimeter.

Important: Sometimes the reading will not remain steady or will display a value that you believe is wrong. If this happens make sure your probes are making firm, constant contact with your circuit on a conductive material.

Name:
Date:

// Settings

There are many different settings depending on how much of a signal the multimeter is being used to measure. This is a good opportunity to talk about unit conversion.

Changing com ports:
Use the first positive com port if you are measuring a signal with less than 100mA of current. Switch to the second positive com port if you are using more. With the Arduino you will usually be using the first positive com port.

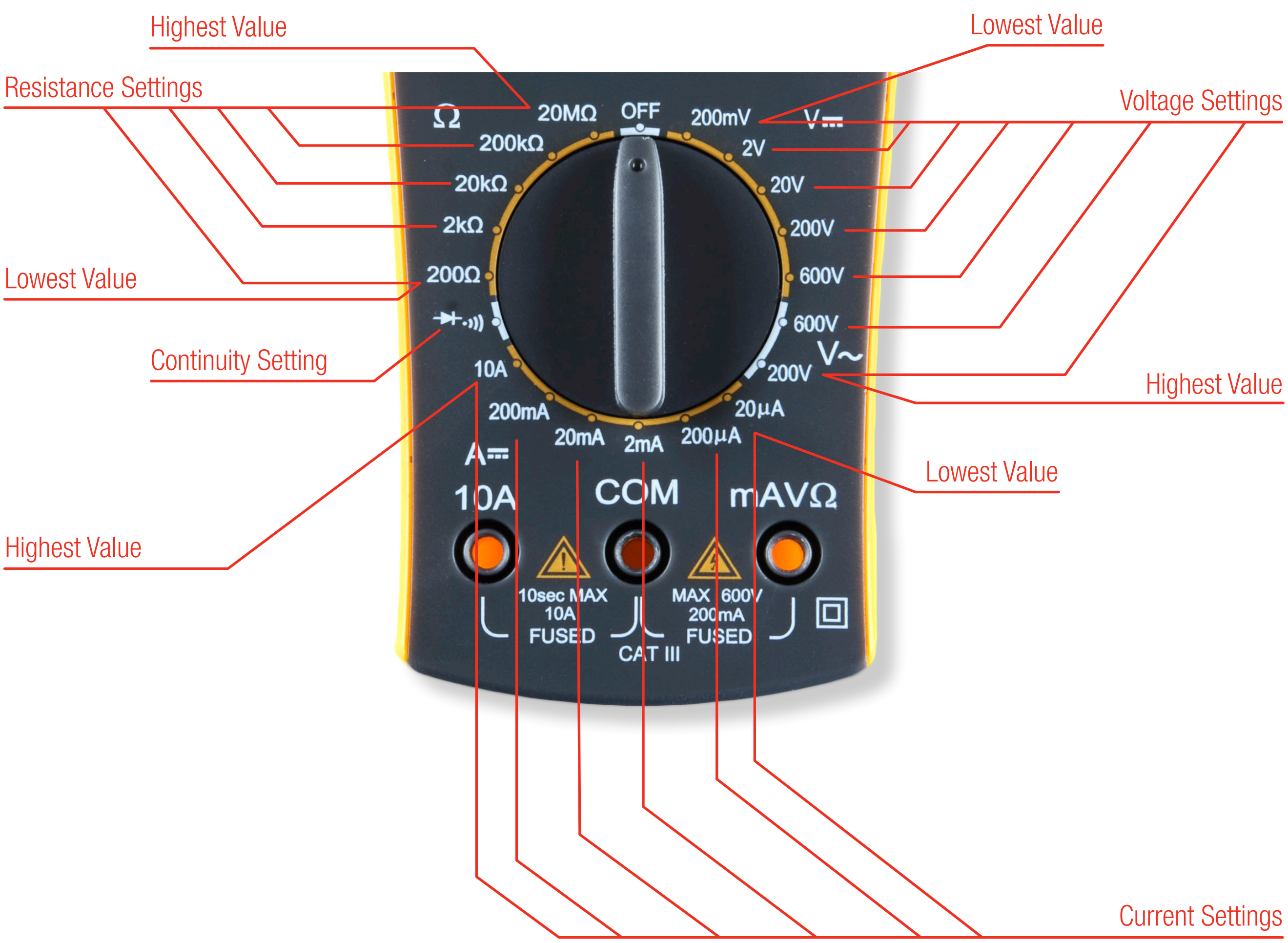
Replacing fuses:
If you try to measure more than 100mA of current through the first positive com port you will most likely blow the fuse in your multimeter. Don't worry, the multimeter isn't broken, it simply needs a new fuse. Replacing fuses is easy, this tutorial explains it: http://www.sparkfun.com/tutorials/202

Voltage: The options for measuring voltage range from 200mV all the way up to 600 Volts.

Current: The options for measuring current range from 20µA all the way up to 10 Amps.

Resistance: The options for measuring resistance range from 200Ω to 20MΩ.

Continuity: This option is for testing to see if there is an electrical connection between two points.



Name:
Date:

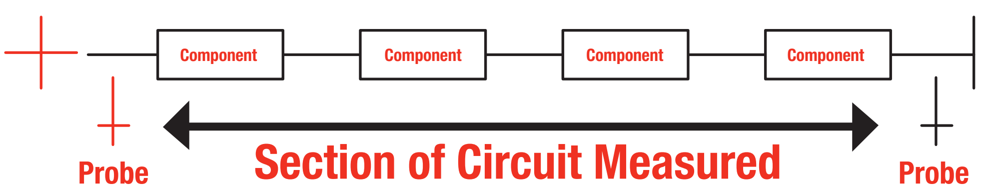
// Measuring Voltage

To start with something simple, let's measure voltage on an AA battery. Pull out your multimeter and plug the black probe into COM ('common') jack and the red probe into mAVΩ. Set the multimeter to "2V". Squeeze the probes with a little pressure against the positive and negative terminals of the AA battery. The black probe is customarily connected to ground or '-' and red goes to power or '+'. If you've got a fresh battery, you should see around 1.5V on the display!

What happens if you switch the red and black probes? Nothing bad happens! The reading on the multimeter is simply negative - so don't worry too much about getting the red or black probe in the right place.

For most RedBoard uses you will be measuring voltages that are 9V or less. Knowing this allows you to start your voltage measurement setting at 20V and workyour way down.

On a circuit use the multimeter to measure voltage from one point in the circuit to another point somewhere along the same circuit. The multimeter can be used to measure the voltage of the whole circuit (if it's going from 5V to GND this will usually read 4.8 to 5V) or just a portion. If you want to measure the voltage of just a portion of your circuit, you have to pay attention to where you place your probes. Find the portion of the circuit you want to measure, and place one probe on the edge of that portion nearest to the energy source. Place the other probe on the edge of that portion nearest to ground. Voila - you have found the voltage of just that section between your probes! Confused? See the schematic images below. Still confused? For more on this see voltage drop.



If your multimeter reads **1.** the multimeter voltage setting you are using is too low. Try a larger voltage setting, if you still encounter the same problem try an even higher setting.

If your multimeter reads **0** the multimeter voltage setting you are using is too high. Try a smaller voltage setting, if you still encounter the same problem try an even smaller setting.

Name:
Date:

// Measuring Resistance

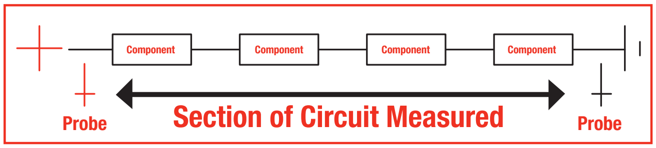
To start with something simple, let's measure the resistance of a resistor. Pull out your multimeter and plug the black probe into COM ('common') jack and the red probe into mAVΩ. Set the multimeter to "2kΩ". Squeeze the probes with a little pressure against the wires on either end of the resistor. The black probe is customarily connected to ground or '-' and red goes to power or '+'. The multimeter will measure the resistance of all the components between the two probes.

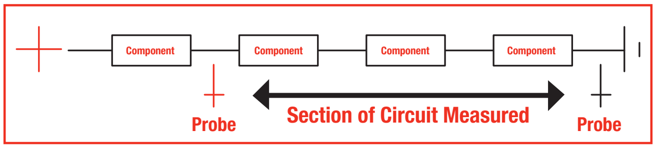
It is important to remember to turn off the power of a circuit before measuring resistance. Measuring resistance is one of the few times you will use a multimeter on a circuit with no power.

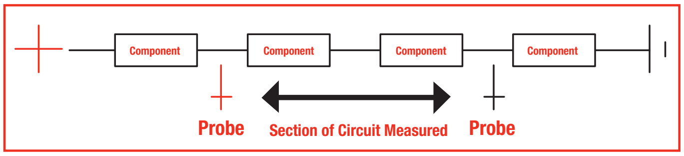
The example below is a 330Ω resistor. Notice the multimeter does not read exactly .330, often there is some margin of error.

When measuring resistance first make sure that the circuit or component(s) you are measuring do not have any electricity running through them.

On a circuit use the multimeter to measure resistance from one point in the circuit to another point somewhere along the same circuit. The multimeter can be used to measure the resistance of the whole circuit or just a portion. If you want to measure the resistance of just a portion of your circuit, you have to pay attention to where you place your probes. Find the portion of the circuit you want to measure, and place one probe on the edge of that portion nearest to the energy source. Place the other probe on the edge of that portion nearest to ground. Voila - you have found the resistance of just that section between your probes! Confused? See the schematic images below. Still confused? For more on this see **Resistance** (Page 48).







If your multimeter reads **1.** the multimeter resistance setting you are using is too low. Try a larger resistance setting, if you still encounter the same problem try an even higher setting.

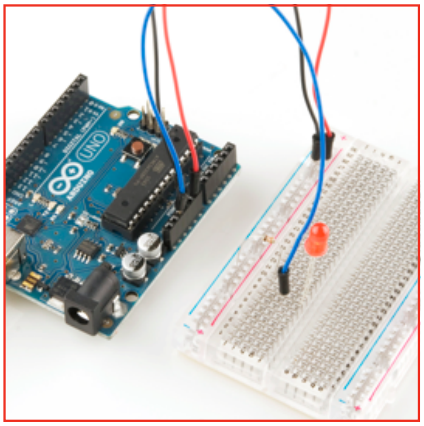
If your multimeter reads **0** the multimeter resistance setting you are using is too high. Try a smaller resistance setting, if you still encounter the same problem try an even smaller setting.

You can measure the resistance of any conductive material whether it is in a circuit or not. Depending on how conductive the material is you may need to change your resistance multimeter setting, or even use a multimeter with a larger range, but if the material is conductive you can measure the resistance of it. This is an easy way to get students to wander around getting comfortable with measuring resistance. Maybe start them off measuring the resistance of some of the S.I.K. circuits, then move to a penny and finally just set them loose to measure anything and everything.

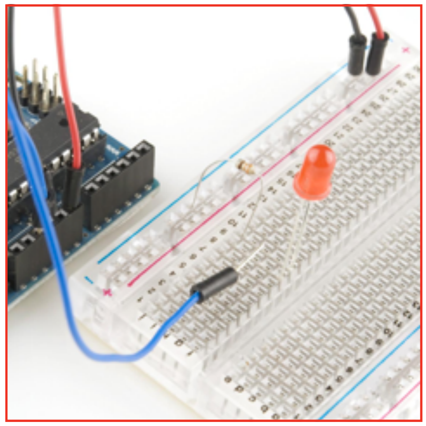
Name:
Date:

// Measuring Current

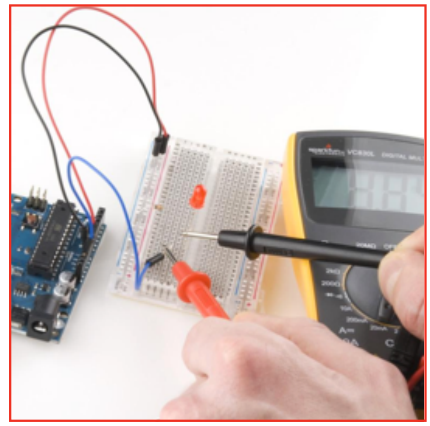
Ok, we're done with simple. Measuring current is a little more complicated than measuring voltage or resistance. In order to measure current you will need to "break" your circuit and insert the multimeter in series as if the multimeter and it's two probes were a wire. The pictures below are an example of how to measure the current of the first S.I.K. circuit.



Unbroken circuit



Circuit broken by unplugging wire connected to power



Multimeter probes touching wire connected to power and positive lead of LED, putting multimeter in series

It doesn't matter where in the circuit you insert your multimeter. The important thing is that the electricity has no choice but to travel through your multimeter in order to get through the rest of the circuit.

So, pull out your multimeter and plug the black probe into COM ('common') jack and the red probe into mAVΩ. Set the multimeter to "20mA". Squeeze the probes with a little pressure against the two wires you used to "break" your circuit. The black probe is customarily connected closer to ground or '-' and red goes closer to power or '+'. The multimeter will measure the total current running through the circuit.

When you are measuring current the multimeter measures the current that is present at that very instant. If your circuit or RedBoard is changing the amount of current you will see that change happen instantly on your multimeter. In order to get a good reading make sure you keep the multimeter connected for at least a couple seconds. (You may also get two readings, a high and a low.)

If your multimeter reads **1.** the multimeter resistance setting you are using is too low. Try a larger resistance setting, if you still encounter the same problem try an even higher setting.

If your multimeter reads **0** the multimeter resistance setting you are using is too high. Try a smaller resistance setting, if you still encounter the same problem try an even smaller setting.

Name:
Date:

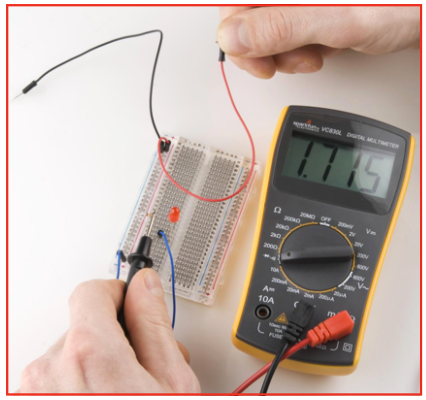
// Measuring Continuity

Continuity is how you check to see if two pieces of a circuit are actually connected. The multimeter does this by sending a very small current from the positive probe to the negative, when there is electricity present the multimeter beeps. This is useful when you have a circuit that you think should work but doesn't. Make sure to turn power off when checking continuity.

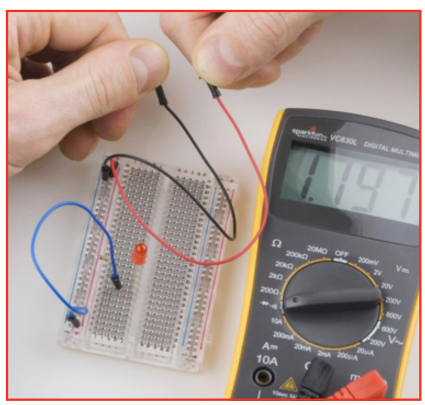
Set the multimeter to the continuity setting as shown to the right. Touch your probes together and you should hear a beep. This means that electricity is free to travel between the two probes without too much resistance.

If your circuit is plugged in incorrectly, or if it is broken somewhere (maybe your breadboard or a wire is broken) when you touch the probes to the wire providing power and the wire connected to ground the multimeter will not beep. If it were hooked up correctly you would hear a beep and you wouldn't be using the continuity setting!

In order to figure out where the circuit is broken move one of the probes along the circuit towards the other probe. Do this component by component. When the multimeter beeps you know that the probes now detect electricity passing between them so the break must be between where the probe you are moving is now, and where it was the last time the multimeter didn't beep.



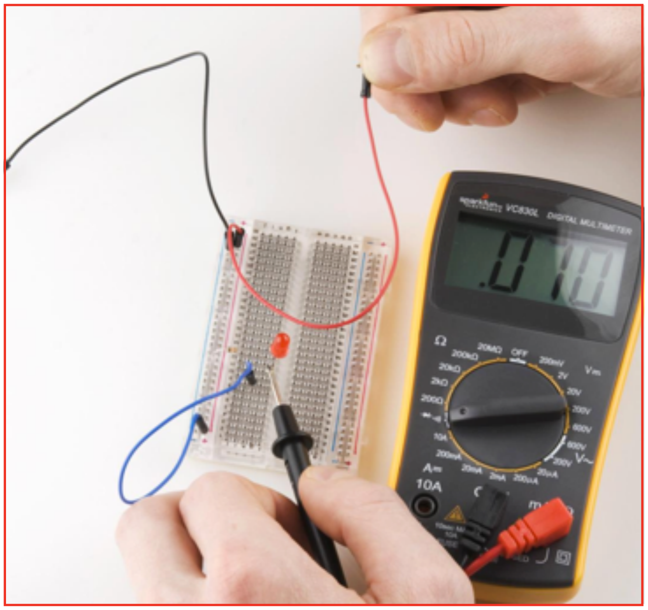
Measuring continuity of the circuit excluding wire connected to ground and resistor. Measured continuity includes LED and two wires connected to breadboard power rail and power. Probes are touching resistor wire and power.



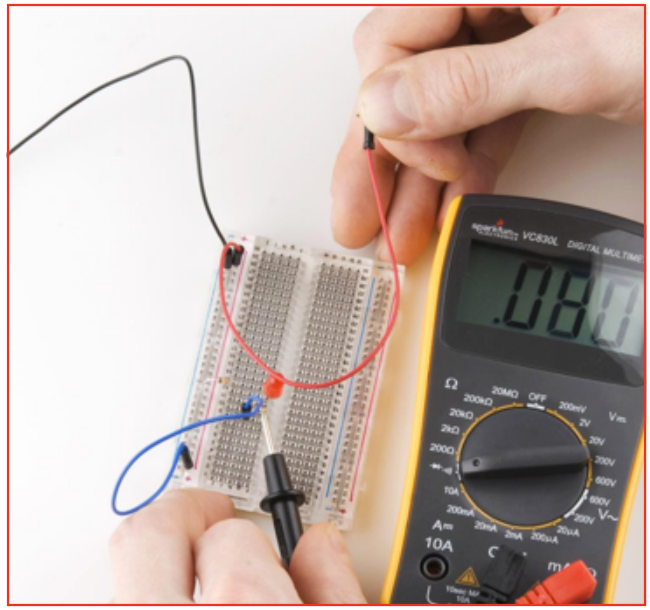
Measuring continuity of the whole circuit from power to ground. Probes are touching wires normally plugged into power and ground.

Name:
Date:

// Measuring Continuity

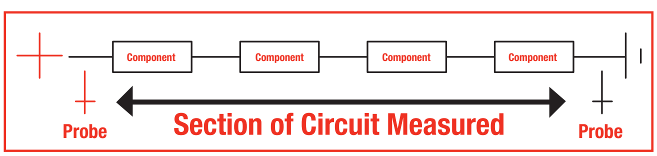


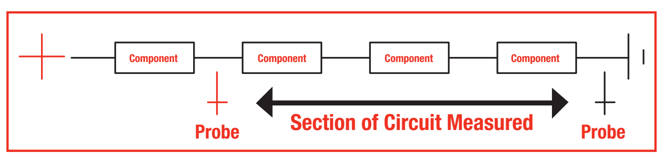
Measuring continuity of the circuit excluding wire connected to ground, resistor and LED. Measured continuity includes two wires connected to breadboard power rail and power. Probes are touching negative LED wire and power.

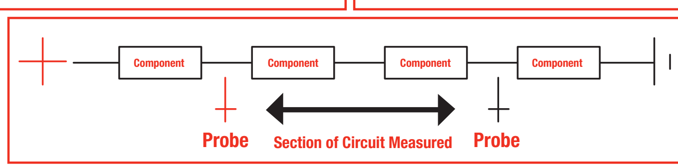


Measuring continuity of the circuit excluding wire connected to ground, resistor and LED. Measured continuity includes two wires connected to breadboard power rail and power. This image looks similar to the image on the left, but the black probe is touching the blue wire, not the negative LED wire. Probes are touching blue wire and power.

The multimeter can be used to measure the continuity of the whole circuit or just a portion. If you want to measure the continuity of just a portion of your circuit, you have to pay attention to where you place your probes. Find the portion of the circuit you want to measure, and place one probe on the edge of that portion nearest to the energy source. Place the other probe on the edge of that portion nearest to ground. Voila - you are testing the continuity of just that section between your probes! Confused? See the schematic images below.







Continuity is one of the most useful settings on a multimeter and you will most likely use it constantly simply to check for connections that aren't quite connected. Breadboards sometimes break so if your multimeter tells you there is no continuity but you know everything is plugged in correctly try switching breadboards.

The beep of the multimeter only tells you that there is very little resistance between the two probes. If there is a resistor in the circuit you will not hear a beep but the display will show a number indicating there is continuity between the two probes.

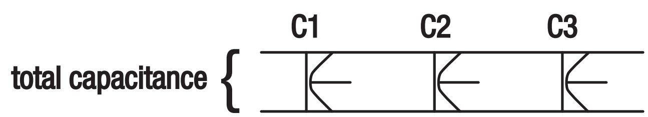
Name:
Date:

One of the most important concepts in circuit building is the difference between components in series and components in parallel. Basically you can think of components in series as being one after another, like in a chain, while parallel components are hooked up next to each other. It's important to know how certain components affect your circuit when hooked up in these two ways. There are a few things to remember, mostly that resistors and inductors work in the opposite way from capacitors:

Resistors and Inductors **in series** can simply be added together:

R1 + R2 + R3 = total resistance

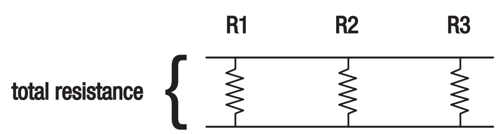
As can capacitors that are **in parallel**:



C1 + C2 + C3 = total capacitance

However, for resistors and inductors **in parallel**, as well as capacitors in series, the equation is a bit more complex. Basically the values between any two elements in these setups equal the product of the values divided by the sum of the values. For three elements or more, solve for two and repeat until done. For example (the // indicates that the elements are in parallel):

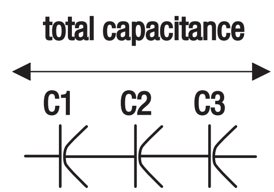
Resistors:



R1 // R2 =(R1 * R2) / (R1 + R2)
total resistance = (R1 // R2) * R3 / (R1 // R2) + R3

Capacitors:

It seems quite dry, but you never know when basic knowledge like this will come in handy. (Hint: read the next section on powering your projects)



C1 // C2 = (C1 * C2) / (C1 + C2)
total capacitance = (C1 // C2) * C3 / (C1 // C2) + C3

Name:
Date:

When dealing with electronics, it is always a good idea to know how much power you need and how you're going to get it. If you want your project to be portable, or run separately from a computer, you'll need an alternate power source. Plus, not all RedBoard's projects can be run off 5V from the USB port. Fortunately there are a lot of options, one or more of which should suit your purposes perfectly.

Understanding Battery Ratings

One popular way to get power to your project is through batteries. There are tons of different kinds of batteries (AA, AAA, C, D, Coin Cell, Lithium Polymer, etc). In fact, there are too many to go over here-however, they all have a few things in common which can help you choose which ones to use. Each battery has a positive (+) and negative terminal (-) that you can think of as your power and ground. Batteries also have ratings in volts and milliamp hours (written mAh). Given this info along with how much current your circuit will draw, you can figure out how long a battery will last. For example, if I have a battery rated at 1.2v for 2500 mAh, and my circuit requires 100mA (milliamps) current, my battery will last around 17.5 hours. Wait, what? Why not 25 hours you say? Well, you shouldn't drain your battery completely, and other factors such as temperature and humidity can affect battery life, so typically the equation for determining battery life is:

(Capacity rating of battery (in mAh) ÷ Current Consumption of Circuit) x 0.7

Note that we could still use our 2500 mAh battery in a 500mA circuit, but then our battery life would only be 3.5 hours. Make sense? There's a lot to understand about powering circuits, so don't worry if it's not all clicking. Just take an educated guess, be safe, use your multimeter, and make adjustments. It is also worth mentioning that batteries are not the only potential source of power for your project. If your project will be outside or near a window, consider using solar power. There's plenty of good documentation online, but basically, solar cells have the same kinds of voltage and current ratings that any power source might have; the only difference is that the percentage you get from your solar panel depends on how much sunlight it's getting. (Check out http://www.solarbotics.com/) for some good products and documentation using solar power.

So, what if your circuit needs 12v, and all you have are a bunch of 1.5v batteries? Or what if you need your project to be powered for longer, but you don't want to give it too much power? This is where your knowledge of series and parallel may actually come in handy.

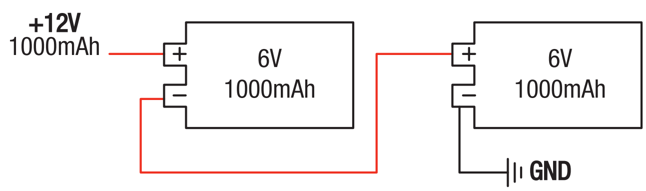
Here's the rule:

Connecting batteries in series increases the voltage but maintains the capacity (mAh) - this what you want to do if you need more power.

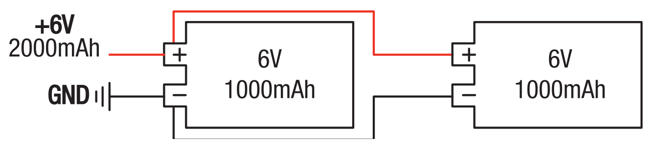
Connecting batteries in parallel maintains the voltage but increases the capacity. This is what you want to do if you need your power supply to last longer.

Here's how to hook them up:

Batteries in Series



Batteries in Parallel



As always, use caution. Batteries of the same kind (same voltage and capacitance) work best in these kinds of situations. Using different kinds of batteries may also work but it is not recommended, as the results are not as predictable.

Name:
Date:

Resistance is an important concept when you are creating circuits. Resistance is the difficulty a current encounters when it passes through a component. Everything that electricity passes through provides some measure of resistance: wires, motors, sensors, even the human body!

Measuring voltage, current and resistance are all done in different ways. **To measure resistance you disconnect (turn off) your circuit and place both multimeter leads on either side of the portion of the circuit you wish to measure.** For example: for measuring just a component you would place your leads on the power and ground leads of the component. To measure the resistance of multiple components you leave them connected and place the positive (red) multimeter lead closer to the disconnected power source and the negative (black) multimeter lead closer to the ground. Sometimes you will want to measure the resistance of input and output leads, but more often you will find yourself measuring resistance along the power to ground circuit. It is important to know how much resistance is present in components and circuits for many reasons. Too much resistance and the current will never travel through the whole circuit, too little and the current may fry some of your components! But most importantly you can use resistance to choose the path the current takes through your circuit.

Hook up the circuit below using red LEDs. (Don't hook up the power yet.)

Measure the resistance of each of the possible paths the current can take from power (5v) to ground. There are three possible paths. You will have to measure each component separately and then add the resistance up for the total. You will can add the components' resistance together because the components are in series, if they were parallel it would require more math. Record the total resistance for each circuit below. (Hint: you won't be able to measure the LED)

Circuit 1: ___Ω Circuit 2: ___Ω Circuit 3: ___Ω

Now connect the power and, one at a time, press the two buttons. Which circuit makes the LED the dimmest? Circuit # _______
If you press both buttons which path does the current take? Circuit # _______
If the voltage is staying at 5v in this circuit no matter which paths are closed, there is a way to calculate the current given the resistance. **Write the name of the law and the equation that solves for resistance below. Label all variables.**

____

Now measure the resistance of a potentiometer when it is dialed all the way up and down. Record the highest and lowest values you get.

Highest:________________________ Ω

Lowest:________________________ Ω

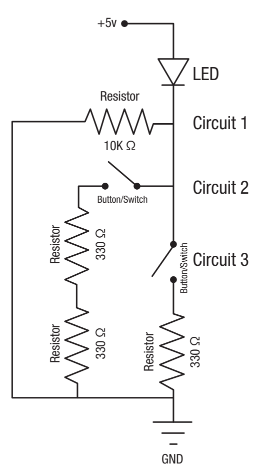
Redraw the schematic below, but use a potentiometer to control the LED brightness instead of the buttons and various resistors. Remember that you must have at least 330Ω of total resistance, otherwise you'll burn out your LED!

Since a circuit or component does not need a current running through it in order to measure the resistance you can take your multimeter and measure the resistance of anything you can think of. Wander around and measure the resistance of various objects. Start with a penny. **Record the most interesting things that have resistance and the value of their resistance below. List at least three.**

____

____

____



Draw Your Schematic

Name:
Date:

Voltage drop is an important concept when you are creating circuits. Voltage drop is the amount that the voltage drops when it passes through a component. The following exercises will show how to measure voltage drop in real life. This is essential when you are fixing your remote control car, electric guitar or even a cell phone.

Measuring voltage, current and resistance are all done in different ways. To measure voltage you connect your positive (red) multimeter lead to the side of the circuit that is closer to your power source and the negative (black) multimeter lead to the side of the circuit that is closer to the ground. It is important to know how much voltage is going through a circuit for many reasons. The most important reasons being that too much voltage can damage your components and too little voltage may not allow electricity to flow all the way through to ground.

Hook up the 5v circuit below using red LEDs.

Close the circuit so only one LED is grounded with the 300 resistor. Insert the end of the resistor not plugged into the ground into a hole on the same row as the first LED's negative lead. The other LEDs don't light up, why is this?

____

____

____

____

Measure the voltage drop across just the LED and record.
_______________v

Measure the voltage drop across the LED and the resistor.
_______________v

Close the circuit so two LEDs light up.

Voltage drop across one LED = _____v
Voltage drop across two LEDs = _____v

Measure the voltage drop across the whole circuit and record.
____________v

Close the circuit so three LEDs light up.

Voltage drop across one LED = _____v
Voltage drop across two LEDs = _____v

Voltage drop for three LEDs = _____v
Voltage drop for whole circuit = _____v

What happened to the LEDs with the last question?

____

____

Now hook up the same circuit to the 3.3V power source without the resistor.
Why don't you need the resistor?

____

____

____

____

Measure the voltage drop across all the LEDs and record.
____________v

Close the circuit so only two LEDs light up.

Voltage drop across one LED = _____v

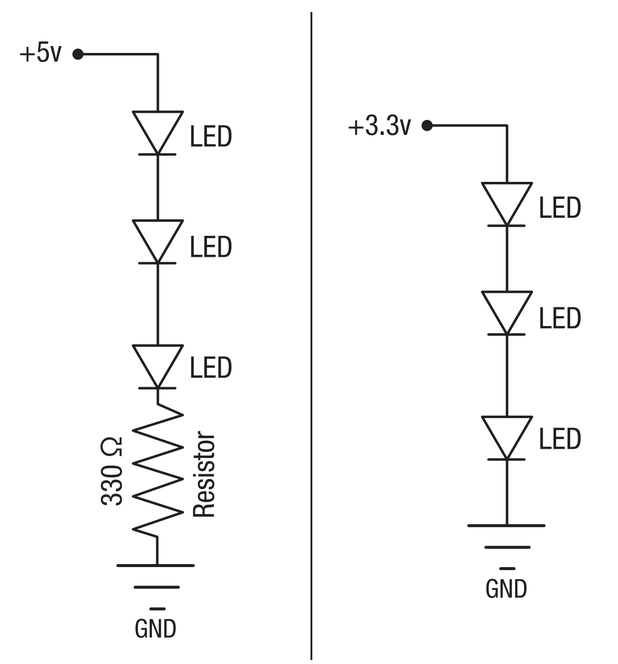
Voltage drop across two LEDs = _____v
Hook up the circuit above to the 5V power source but use the 3.3v as ground.
Wait a second! You can't use a power source as a ground! Or can you?

What is the voltage available and how many LEDs can you light up with it?

Voltage available = ________v

# of LEDs you can light up = __________

Many people think of Gnd as the ONLY place to connect a 'negative' pin, but all you need is a voltage drop from the beginning of a circuit to the end. This difference in voltage is what draws the current in the correct direction.



Name:
Date:

What is a transistor?

Transistors are semiconductors used to amplify an electrical signal or switch an electrical signal on and off.

Why is a transistor useful?

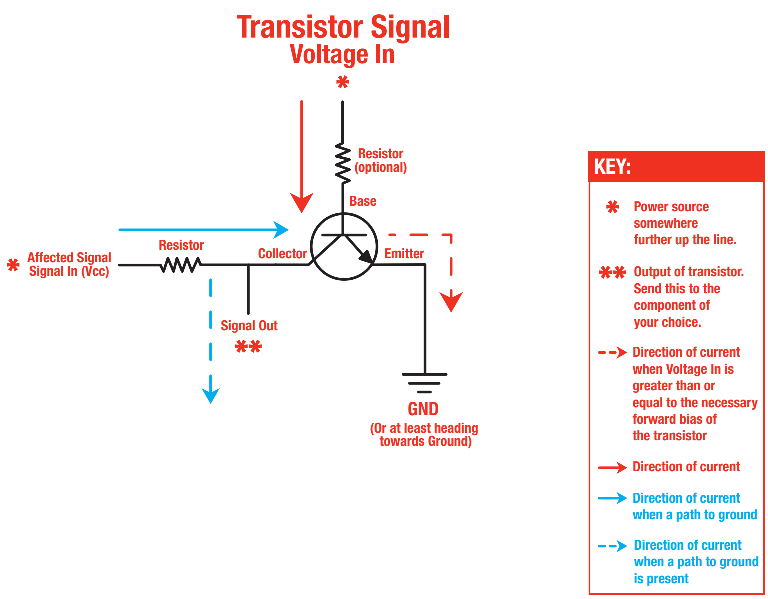
Often you will need more power to run a component than your Arduino can provide. A transistor allows you to control the higher power signal by breaking or closing a circuit to ground. Combining this higher power allows you to amplify the electrical signal in your circuit.

What is in a transistor?

A transistor circuit has four parts; a signal power source (connects to transistor base), an affected power source (connects to transistor collector), voltage out (connects to transistor collector), and ground (connected to transistor emitter).

How do you put together a transistor?

It's really pretty easy. Here is a schematic and explanation detailing how:



The transistor voltage in signal is the signal that is used to control the transistor's base.

Signal in is the power source for the signal out which is controlled by the transistor's action.

Signal out is the output of the signal originating from signal in, it is controlled by the collector.

The amount of electrical current allowed through the transistor and out of the emitter to ground is what closes the entire circuit, allowing electrical current to flow through signal out.

Ok, how is this transistor information used?

It depends on what you want to do with it really. There are two different purposes outlined above for the transistor, we will go over both.

If you wish to use the transistor as a switch the signal in and voltage in signal are connected to the same power source with a switch between them. When the switch is moved to the closed position an electrical signal is provided to the transistor base creating forward bias and allowing the **electrical signal** to travel from the **signal in** to the **transistor's collector** to the **emitter** and finally to **ground**. When the circuit is completed in this way the **signal out** is provided with an electrical current from **signal in**.

The signal amplifier use of the transistor works the same way only **Signal In** and **Voltage In** are not connected. This disconnection allows the user to send differing values to the base of the transistor. The closer the **voltage in** value is to the saturation voltage of the transistor the more electrical current that is allowed through the emitter to ground. By changing the amount of electrical current allowed through to ground you change the signal value of signal out. For examples of transistor uses see S.I.K. circuits # 12 and # 13.

Name:
Date:

What is a voltage divider?

Voltage dividers are a way to produce a voltage that is a fraction of the original voltage.

Why is a voltage divider useful?

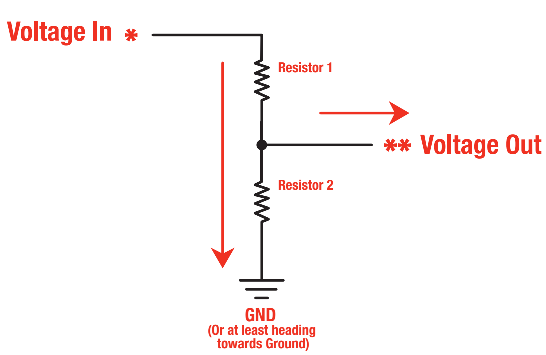
One of the ways a voltage divider is useful is when you want to take readings from a circuit that has a voltage beyond the limits of your input pins. By creating a voltage divider you can be sure that you are getting an accurate reading of a voltage from a circuit. Voltage dividers are also used to provide an analog reference signal.

What is in a voltage divider?

A voltage divider has three parts; two resistors and a way to read voltage between the two resistors.

How do you put together a voltage divider?

It's really pretty easy. Here is a schematic and explanation detailing how:



KEY:

- * Power source somewhere further up the line.
- ** Output of voltage divider. Send this to input pins or a circuit that needs a lower voltage than the original voltage source.
- → Direction of current

Often resistor # 1 is a resistor with a value that changes, possibly a sensor or a potentiometer.

Resistor # 2 has whatever value is needed to create the ratio the user decides is acceptable for the voltage divider output.

The Voltage In and Ground portions are just there to establish which way the electrical current is heading, there can be any number of circuits before and after the voltage divider.

Here is the equation that represents how a voltage divider works:

$$V_{out} = V_{in} \frac{R_2}{(R_1 + R_2)}$$

If both resistors have the same value then Voltage Out is equal to ½ Voltage In.

Ok, how is this voltage divider information used?

It depends on what you want to do with it really. There are two different purposes outlined above for the voltage divider, we will go over both.

If you wish to use the voltage divider as a sensor reading device you first need to know the maximum voltage allowed by the analog inputs you are using to read the signal. On an Arduino this is 5V. So, already we know the maximum value we need for **Vout**. The **Vin** is simply the amount of voltage already present on the circuit before it reaches the first resistor. You should be able to find the maximum voltage your sensor outputs by looking on the datasheet. This is the maximum amount of voltage your sensor will let through given the voltage in of your circuit. Now we have exactly one variable left, the value of the second resistor. Solve for R2 and you will have all the components of your voltage divider figured out! We solve for R1's highest value because a smaller resistor will simply give us a smaller signal which will be readable by our analog inputs.

Powering an **analog Reference** is exactly the same as reading a sensor except you have to calculate for the Voltage Out value you want to use as the analog Reference.

Given three of these values you can always solve for the missing value using a little algebra, making it pretty easy to put together your own voltage divider. The S.I.K. has many voltage dividers in the example circuits. These include: Circuits # 2, 5, 6, 9 and 10.