Basic Electricity for Computer Scientists

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Electric Current

Electricity is usually described as the flow of electrons through a conductor. This is not quite accurate. Electric current is the **movement of electrical charge**, and the charge can be carried by electrons, ions, or even "holes' (places where an electron is missing from a crystal structure).

Arbitrarily, we say that **current flows from positive to negative**. That is, when we draw an arrow to show the direction of current flow, we always draw it from positive to negative (the opposite of the way the electrons actually move). This is a convention that dates from the time of Benjamin Franklin, and now we're stuck with it. Anyhow, it's desirable to always show the current moving the same way whether carried by positive or negative particles.

Current can be carried by…

Electrons moving from source to destination – as in a vacuum tube or CRT;

Electrons moving railroad-car style, which means that an electron enters at one end, pushes all the other electrons along a short distance, and a different electron comes out at the other end – as in a metal;

Holes moving railroad-car style, where a "hole" is a place where an electron is missing from the crystal structure – as in a P-type semiconductor;

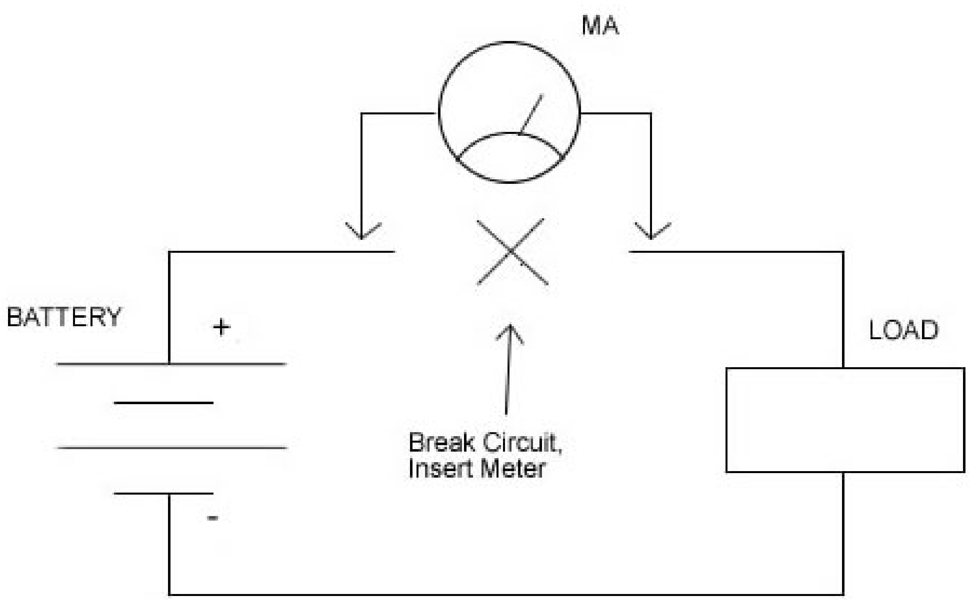
Or **positive or negative ions**, as in a battery.

Units of current

A flow of 6.25×10^{18} electrons per second – or the same charge carried by other particles – is called **one ampere**. By today's standards this is a lot of current, enough to light a bright light bulb or power a few dozen digital ICs. We usually deal in **milliamperes** (10^{-3} ampere) or occasionally **microamperes** (10^{-6} ampere).

Measuring current

To measure the current flowing through a circuit, you have to break the circuit at some point to insert the meter into it:



SAFETY: Remember, **a current meter conducts electricity!** Don't connect it anywhere you wouldn't connect a piece of wire.

Resistance and voltage

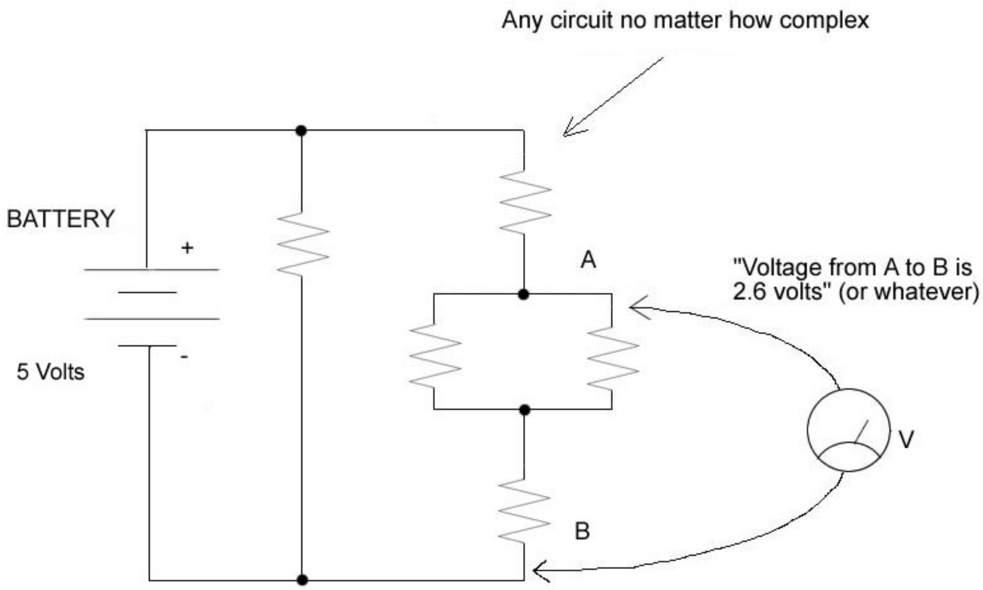
Current flows more easily through some materials than through others. Resistance is measured in **ohms** (Ω), **kilohms** (kΩ), and **megohms** (MΩ).

The resistance of a piece of wire is less than 0.01 Ω. Some of the most useful electronic components are **resistors** with specific resistances anywhere from 1 Ω to 10 MΩ.

The force that drives a current through a resistance is called **voltage** (or, by real purists, "electromotive force").

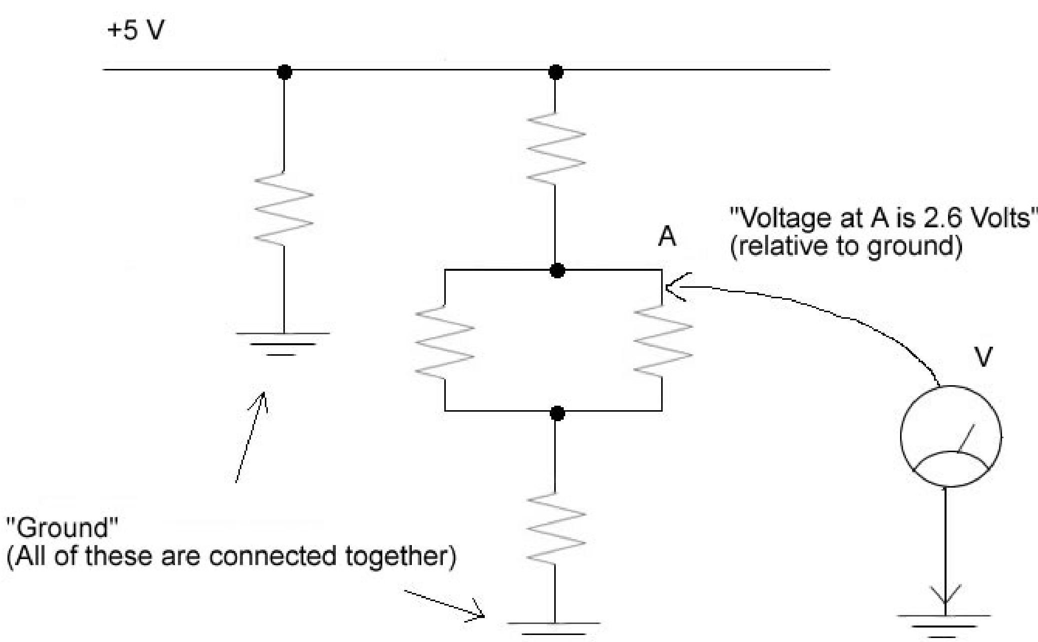
We measure voltage with a **voltmeter**.

The voltmeter conducts only a tiny current, and you can connect it anywhere. It tells you how much voltage *would* drive a current from point A to point B if there were a path for it.



Ground

To simplify matters, we often pick a particular point in the circuit, call it ground, and refer all other voltages to it. Ground is generally something to which a lot of things are connected, usually including the negative side of the power supply. When we say the voltage at point X is 5 volts, we mean the voltage between point X and ground.



SAFETY: **A voltage of 25 V is sufficient to drive a dangerous current through your body**. Watch what you grab!

The term "ground" goes back to the early days of radio. One side of a large antenna circuit actually is connected to the ground, in order to use the earth as a huge reflector.

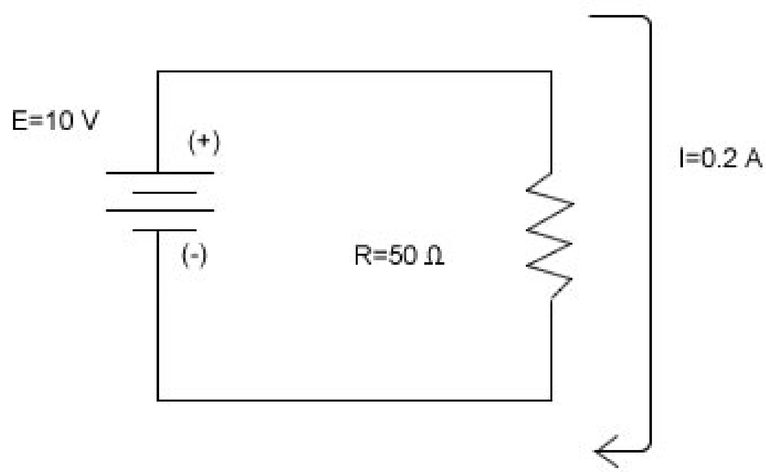
Also, for reasons of safety, one side of the 120-volt AC line is connected to the earth, to ensure that there is no large voltage difference between it and the ground on which you are standing when you use electrical appliances.

Ohm's law

We said voltage is the force that drives current through a resistance. Specifically,

Current = Voltage / Resistance or $I = E / R$

For example, 10 volts will drive a current of 0.2 ampere through a 50Ω resistance.



It's handy to memorize all three forms of Ohm's Law too:

$I = E / R$ $E = I R$ $R = E / I$

It's even more important to **build the intuitive understanding that…**

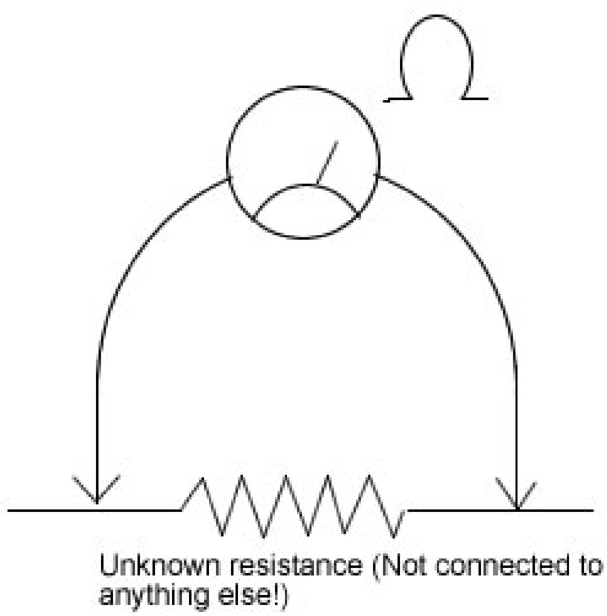
More voltage → more current

More resistance → less current

Measuring resistance

We measure resistance with an **ohmmeter** (what else?), which drives a known current through the unknown resistance and measures the voltage necessary to do so.

SAFETY: **Never connect an ohmmeter to a circuit with power applied. Never connect an ohmmeter to a transistor or IC unless you know it's OK to do so.**

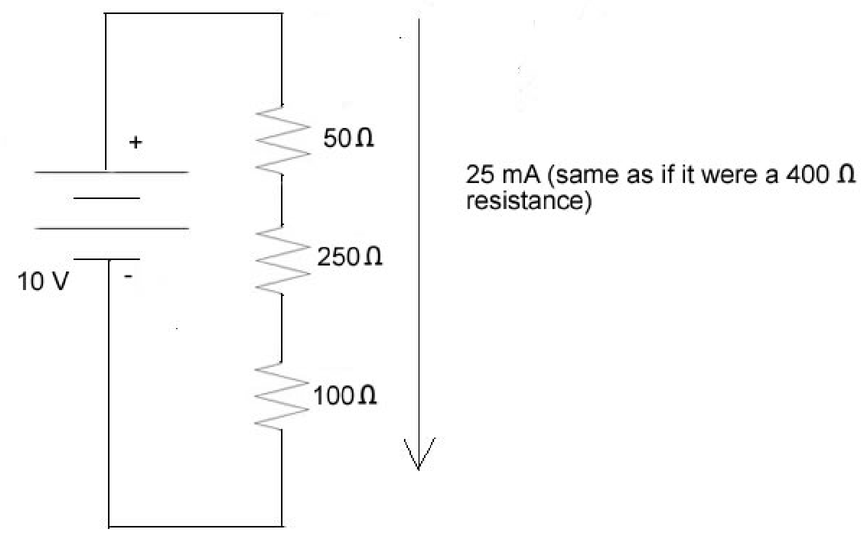


Resistance in series

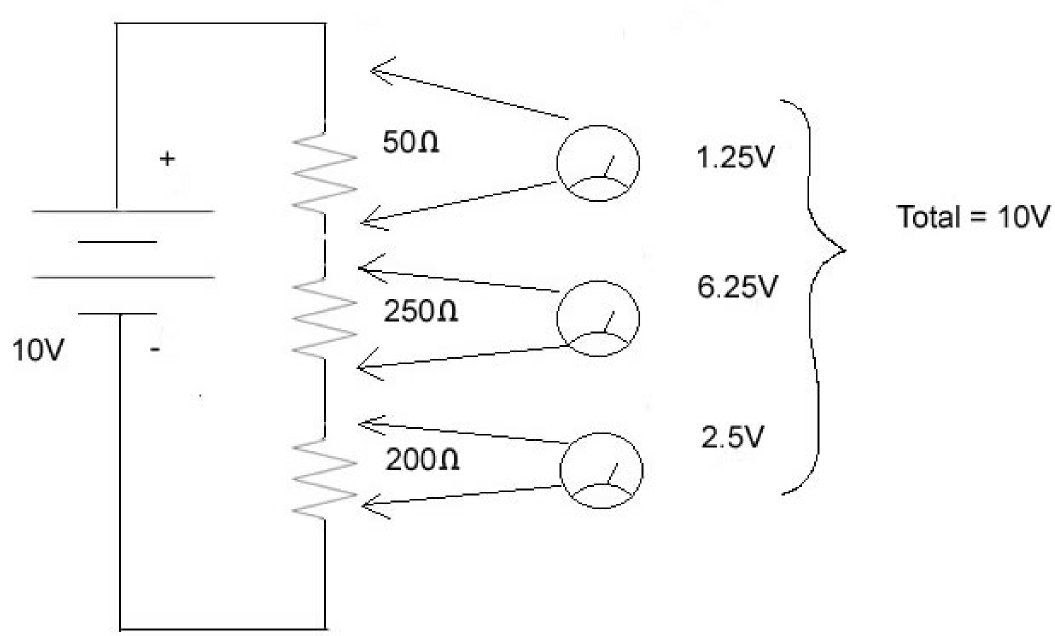
One of Kirchhoff's laws states that **if several electronic components are connected in series, the current** (= rate of electron flow) **through all of them is the same.**

This entails, among other things, that **it doesn't matter what order you connect them in.**

If you have several **resistances in series**, the total resistance is the sum of the individual resistances.

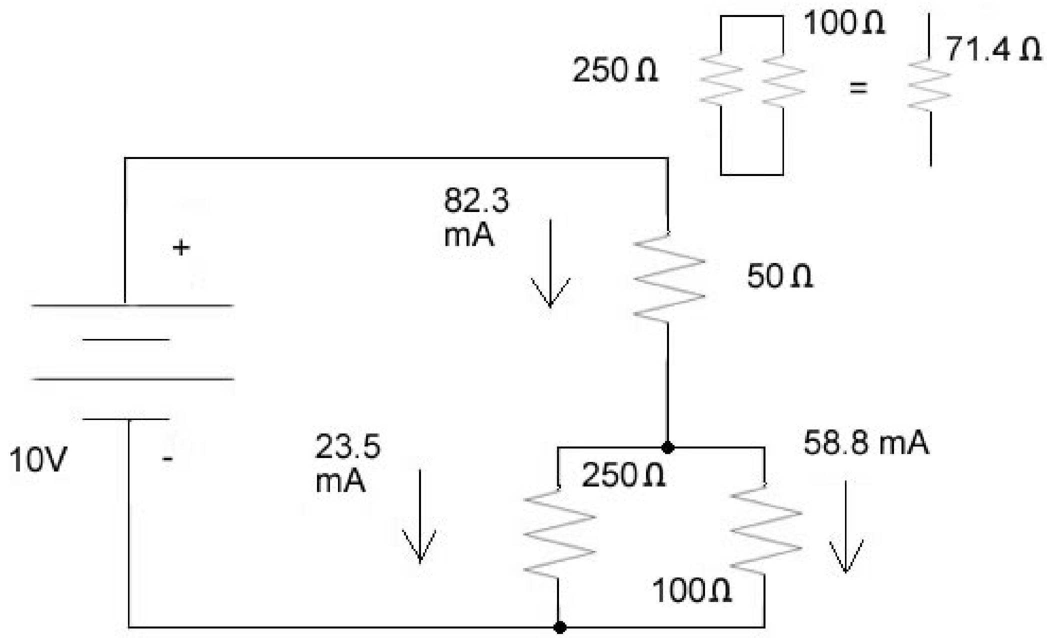


Since each resistor conducts the total current, it follows that each resistor does not experience the total voltage. (If it did, Ohm's law would be violated.) Instead, the **voltage is divided among the resistors**.



Resistances in parallel

If you have several resistances in parallel, the voltage across them is the same (it has to be – their endpoints are the same points!), but the **current gets divided up** among them.



The total resistance is the **reciprocal of the sum of the reciprocals** of the individual resistances.

$$R_{total} = 1/\left(1/R_1 + 1/R_2 + \ldots \right)$$

Memorize this if you want to, or derive it from Ohm's and Kirchhoff's laws.

Non-ohmic components

Many electric components, including all of the really interesting ones, **violate Ohm's law**. For example…

A **diode** conducts in one direction, but not in the other; further, instead of a resistance, it has a constant voltage drop;

A **transistor** conducts only up to a specific maximum current, which depends on the current flowing into one of its other terminals;

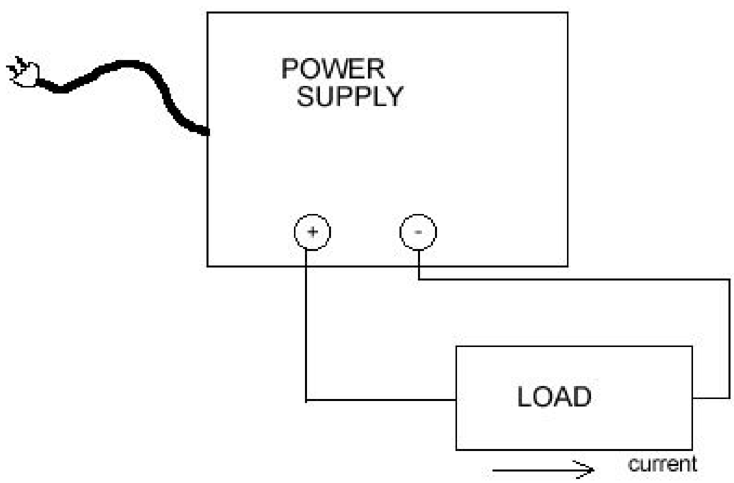
A **capacitor** stores charge, and "conducts" only temporarily while changing the voltage it is charged to;

Thermistors and photocells have a resistance that varies with temperature or exposure to light.

Even a **light bulb** has a different resistance when hot (lit up) than when cold.

Power supplies

We usually get electric power from devices that **deliver a constant voltage, while the amount of current flow depends on the resistance of the thing being powered** (the "load"). In this we are following the tradition of Alessandro Volta, who got his electricity from electrochemical reactions (batteries).



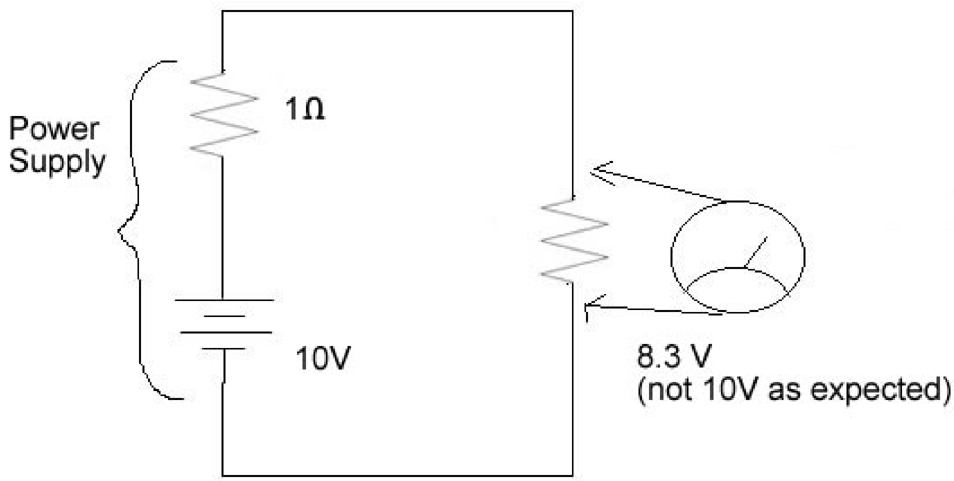
SAFETY: **Never allow electricity to flow from + to – without going through a suitable load!** If you do, you'll have a *short circuit* and things may burn up.

Many lab-type power supplies have **current limiters** that keep you from exceeding a preset maximum. However, even if this is set as low as 100 mA, it can destroy things that aren't supposed to carry heavy currents.

Internal resistance of voltage sources

An ideal power supply would be a **perfect voltage source** – it would always deliver exactly the same voltage regardless of the amount of current flowing into ("drawn by") the load.

In real life, the voltage drops a little if the current becomes large. We can model this by saying that the power supply has nonzero **internal resistance (source resistance)**.



The internal resistance of a lab-type power supply is about 0.1Ω. That of a 9-volt battery can be as high as 100 Ω.

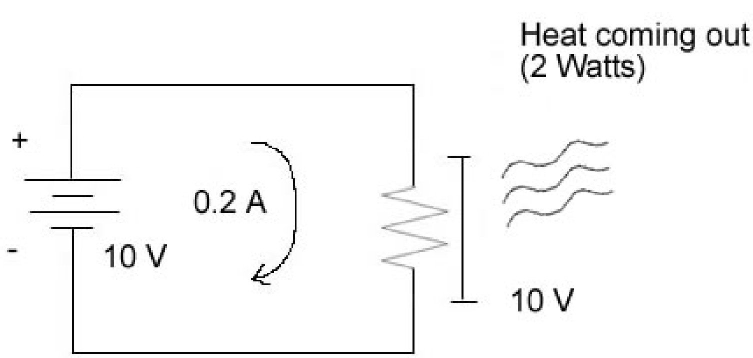
It's worth remembering that **any source of voltage** (that isn't full of non-ohmic effects) can be modeled as a perfect voltage source plus a source resistance. This is known as a **Thevenin equivalent circuit.**

Further notes:

A resistance turns electrical energy into heat. (The energy has to go somewhere!) The rate of energy consumption is called power and is measured in watts:

$$P = E\,I \quad \text{or} \quad \text{Watts} = \text{Volts X Amps}$$

Anything dissipating > 1/8 watt will be warm to the touch; anything > 1 watt will be hot.

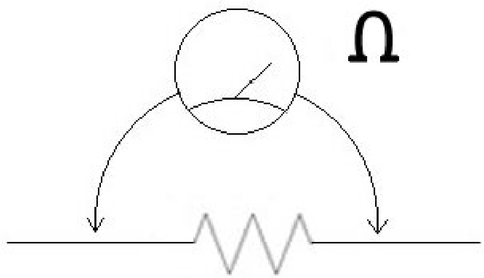


Resistors are rated for the maximum wattage they can carry without harm (usually 1/8 W).

Experiment 1 - Resistors and ohmmeter

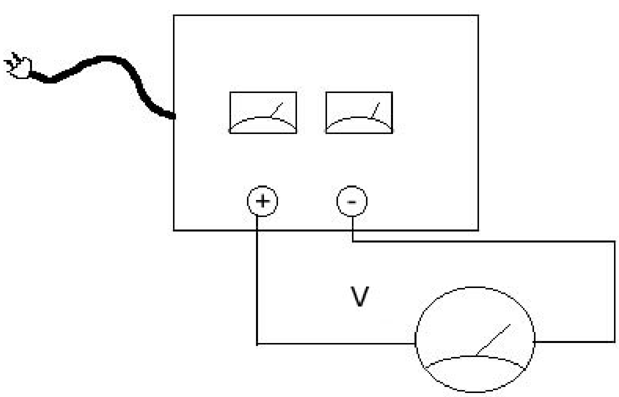
Choose 3 resistors at random. Using the color code, determine their rated resistance.

Then use an ohmmeter to determine the actual resistance of each.



Experiment 2 -Power supply and voltmeter

Use a voltmeter to measure the output of a power supply. Adjust it to 5.0 V and leave it there.



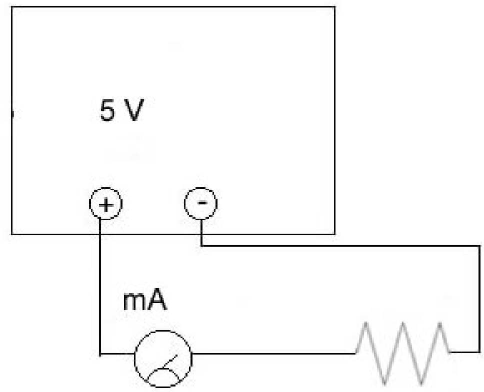
METER MUST be set to measure voltage BEFORE you connect it to the circuit.

HINT:

Red is +
Black is -

Experiment 3 - Ohm's Law

Choose 2 resistors each > 200 Ω. Calculate the current that would be driven through each by a voltage of 5 volts. Then measure it.



Experiment 4 - Voltage Divider

Connect the same 2 resistors in series. Measure the voltage across each. Before measuring it, calculate it.