Circuit Lab
Division B / C

Nov 2018

David Hein
dhein@lear.com

Event Description

- Tests knowledge of:
  - History, electricity, magnetism, electrical devices, electrical circuits
- 20-50% of score from practical portion (hands-on tasks)
- 50% to 75% of score from theoretical portion (written questions)
- Students bring:
  - Any calculators – up to 2
  - Reference material in 3-ring binder any size
  - Basic multimeters (optional- but recommended)
- 2 students per team allowed
- Points awarded for correct answers or techniques

Written Test Topics

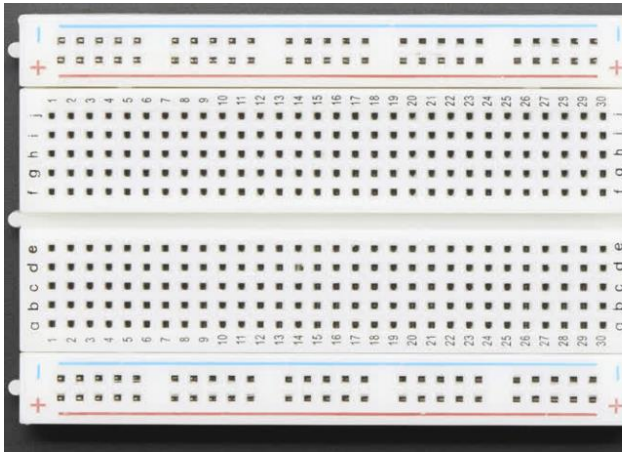
- Must have at least 1 task / question from each of these areas:
  - Historical perspective of the electricity discoveries made by Volta, Ohm, Tesla, Hertz, & Faraday
  - Properties of electric charge/fields, sources/hazards of static electricity, Coulomb's Law, capacitance
  - Direct current (DC) characteristics, sources, uses, simple circuit diagrams, DC hazards
  - Alternating current (AC) characteristics, sources, uses, AC hazards
  - Concepts and units of current, voltage, resistance, power, energy, and using Ohm's law
  - Magnetic poles/fields, electromagnets, transformers, motors/generators, right-hand rule
  - Electrical control devices including 3-way light switch circuits
  - Simple measurements, constructions, and configurations of a circuit and individual components
  - Fundamental characteristics and operation of a light emitting diode (LEDB)

Written Test Topics

- Division C only
  - Simple circuit analysis using Kirchhoff's Voltage & Current Laws
  - Basic digital logic and digital logic operations
  - Time constant of a RC circuits
  - Electrical characteristics of a silicon PN junction
  - Basics and application of Operational Amplifiers (OpAmps)

- Excluded topics:
  - Semiconductors
  - AC circuit theory / devices
  - Inductors
  - Advanced digital

Hands On Tasks



Examples include:

- Figure out the value of a mystery resistor
- Calculate the power supplied to a circuit
- Hooks up 2 LEDs to be equally bright
- Construct an electromagnet
- Where are the poles on a refrigerator magnet
- Find the spacing of the Halbacharray

Must be familiar with breadboards

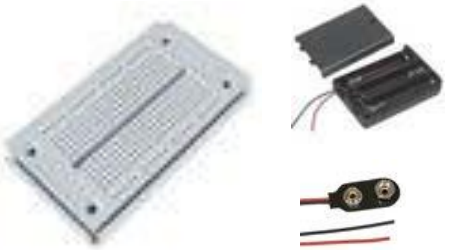
Must be familiar with usage of a multimeter for voltage, current and resistance measurements

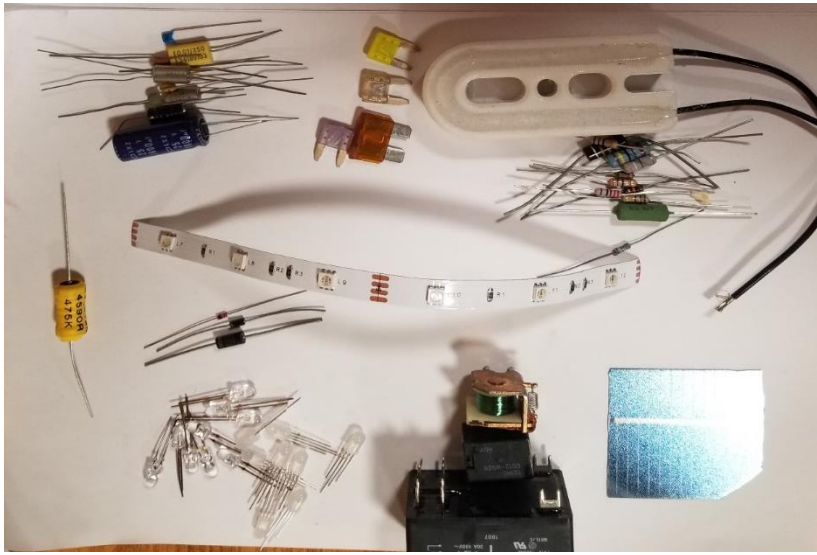
Binder

- 3 Ring Binder (nothing can fall out)
  - Must be attached in the rings of the binder
  - "Cheat Sheet" (2)
  - Constants
  - Equations
  - Detailed sections
  - History
  - Definitions and terminology
  - Graphs / tables / diagrams

Inspiring Future Scientists

- Circuit Lab kit Contents
  - Diode(3 pcs min)
  - LED's (25 pcs min)
    - Blue
    - Green
    - White
    - Full color (Red, Green, and Blue)
    - LED strip with full color LED's
  - Resistors (25 pcs min)
    - Variety of value, type, tolerance and power ratings
  - Variable resistor / potentiometer
  - Capacitor (10 pcs min)
    - Variety of value, type, tolerance and power ratings
  - Relay (2 pcs min) – electromagnet controlled switch
  - Solar Cell (1 pcs)
  - Inductor (2 min)
  - Switch (5 pcs min)
  - Fuse (3 min)
  - Breadboard (1pcs)
  - Wire (50 pcs min)
    - Assortment of alligator clip leads, breadboard wires and breadboard to clip leads
  - Battery clip 9 V (2)
  - Battery Holder AA (2)
  - Flash Drive
    - SO Training material including MI Region 7 Workshop
    - Overview of kit parts and usage of parts
    - Cautions for using LED's and kit parts
    - Experiments using kit parts
    - Sample tests – Quiz style example tests and past region and state tests

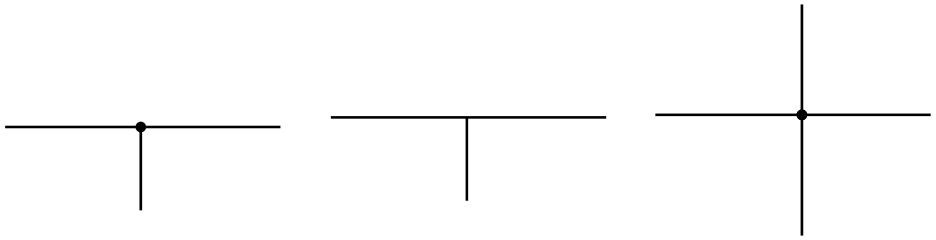




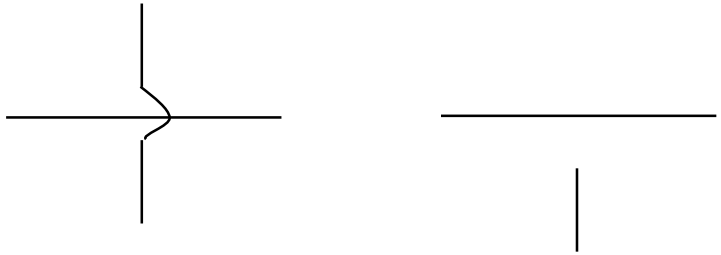
Kit Price $45

Basic Electrical Components And Symbols

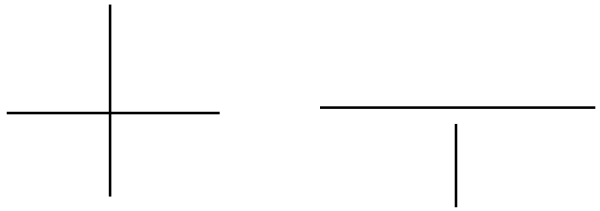
Wire / Connection



Wire / No Connection



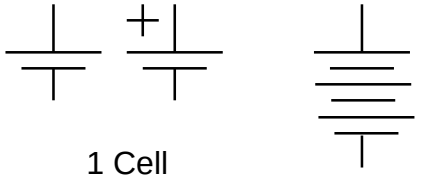
Normally means no connection
Unsure -> Ask



Basic Electrical Components And Symbols

Exploring the World of Science

Battery

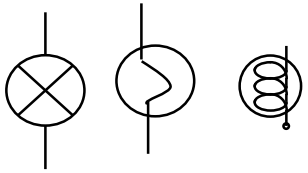


1 Cell

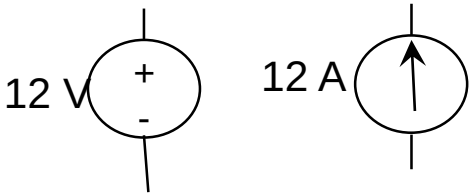
Light Bulb

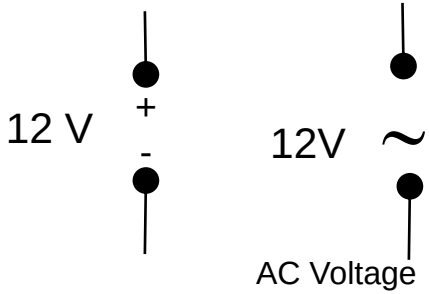
Picture Symbols

Schematic Symbols



Power Supply

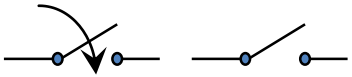




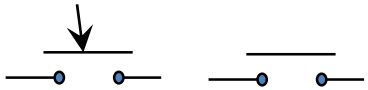
AC Voltage

Switch

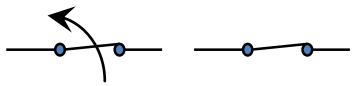
Normally Open or N.O.



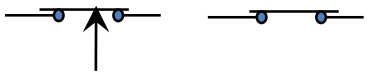
Preferred



Normally Closed or N.C.



Preferred



Basic Electrical Components And Symbols

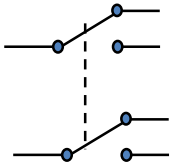
Single Pole Double Throw
SPDT

Switch - Complex

Normally Closed or N.C.

Normally Open or N.O.

Double Pole Double Throw
SPDT



Normally Closed or N.C.

Normally Open or N.O.

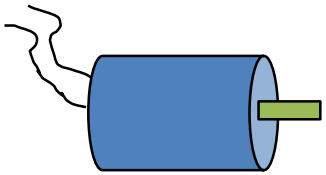
Normally Closed or N.C.

Normally Open or N.O.

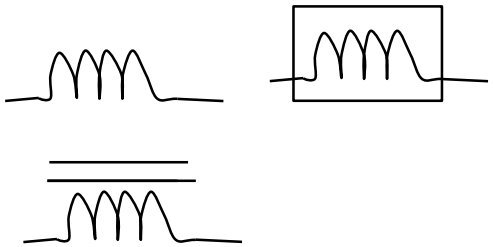
Ground

Indicates a zero voltage point or connected to the earth

Motor

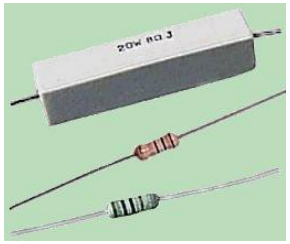


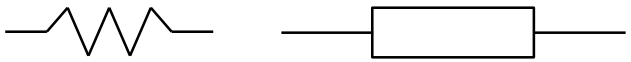
Electro Magnet

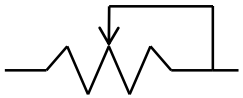


Basic Electrical Components And Symbols

Resistor



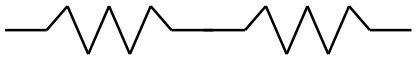




Variable resistor or potentiometer

Basic Electrical Concepts

Series Circuit

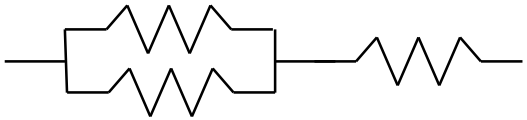


Electrons must flow through both components

Parallel Circuit

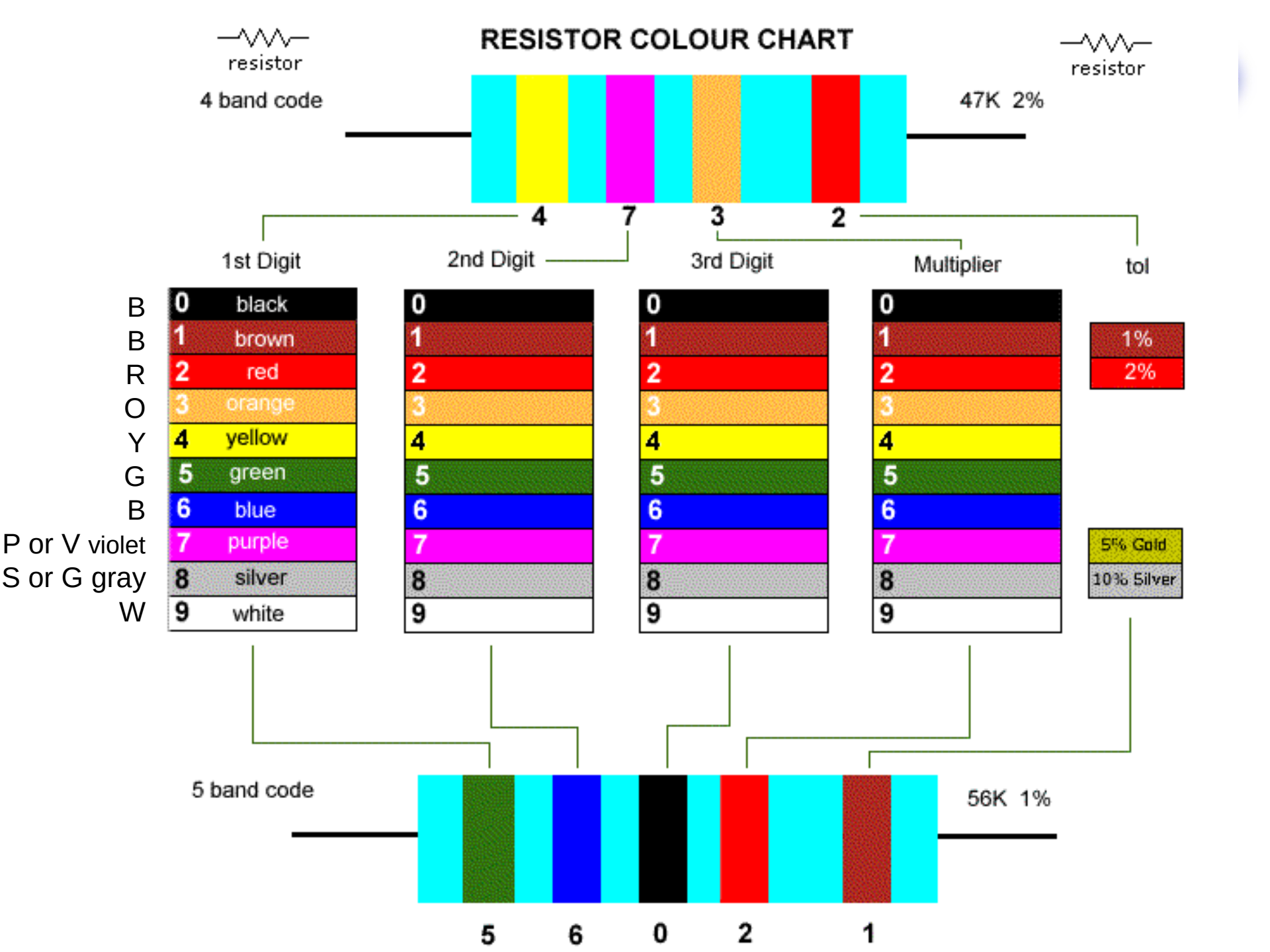
Electron will flow through one or the other component

Series Parallel Circuit



Combination of Series and Parallel
Many forms

RESISTOR COLOUR CHART



Basic Electrical Concepts

Voltage

Measured in Volts
Symbol for Volts = V
Potential to do work
Volt = Joule Per Coulomb
Higher Voltage => higher pressure to push electrons

Voltage (V) – electric potential
$V = \varepsilon \bullet d$ {Electric field, distance moved between 2 points}

Current

Measured in Amps
Symbol for Amps = A
Rate of flow of electrons
Amps = Coulomb per second
Higher Current => more electrons flowing

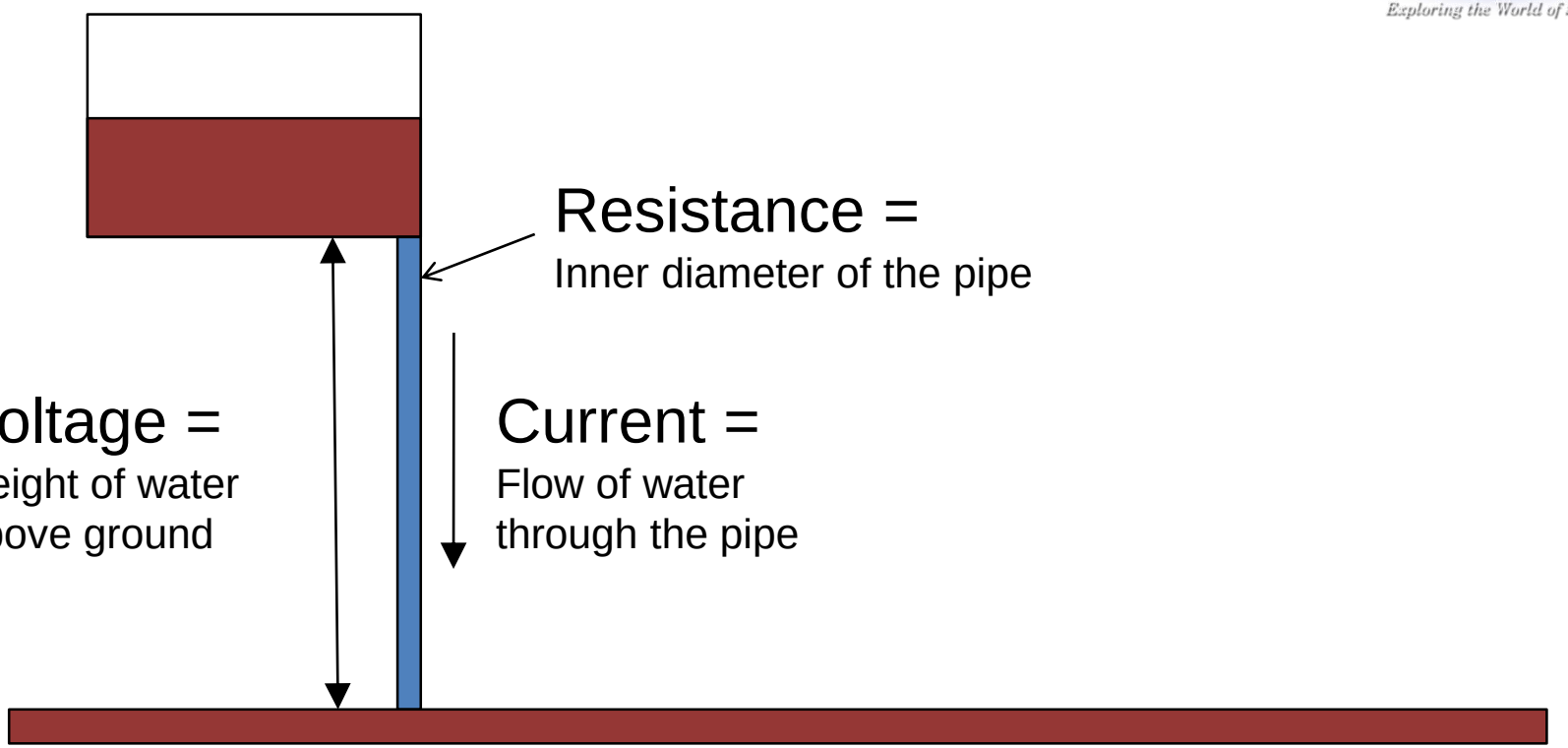
Current (A) – flow or movement of charge
$I = dQ / dt$

Resistance

Measured in Ohms
Symbol for Ohms = Ω
Limits / resists the flow of electrons
Resistance – opposition to flow of charge or electrons
Higher resistance => smaller current for a given voltage or larger voltage for a given current

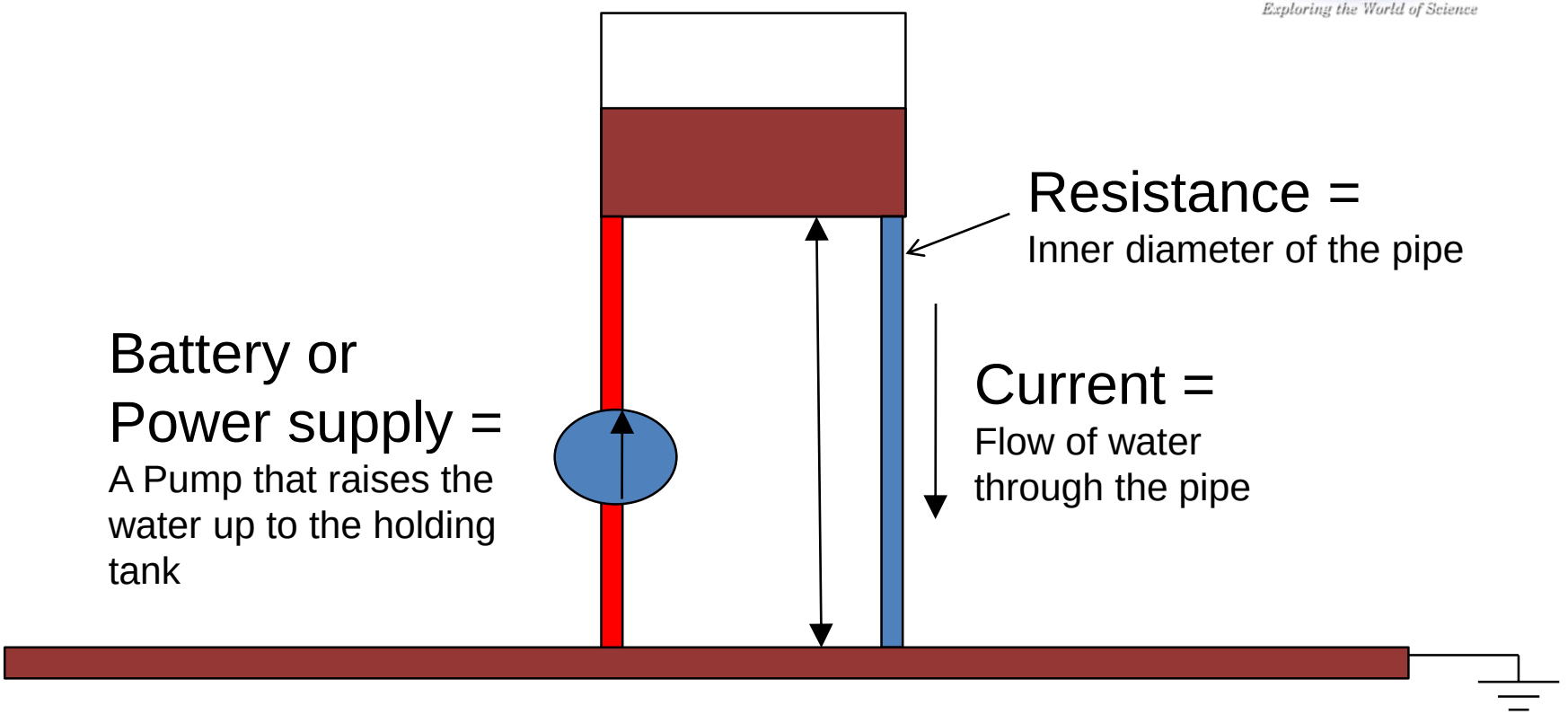
Resistance (Ω) – opposition to flow of charge
$R = \rho L / A$ {in a conductor}
$R_{series} = R_1 + R_2 + \ldots + R_n$
$R_{parallel} = (1/R_1 + 1/R_2 + \ldots + 1/R_n)^{-1}$

Basic Electrical Concepts – Water Analogy



In the water analogy – electrons are symbolized by water molecules. The height that the water molecules are above ground symbolizes the voltage. The higher the water is above ground the more potential energy the water has; or the more pressure that is exerted by the water.
The resistance is the size of pipe or hole that allows the water to flow out of the tank.
As the pressure increases (voltage increases), more water will flow through a give size of pipe.
As the size of pipe increases (resistance decreases) , more water will flow through a give size of pipe.

Basic Electrical Concepts – Water Analogy



A battery or power supply works like a pump to replenish the water (electrons) that flow out of the holding tank.
Under their own power, water molecules / electrons only flow from high to low.
It takes an external force to move them from Low to high (Pump; Battery or Power supply)

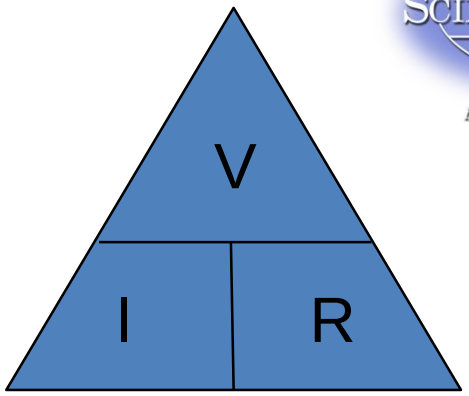
System only works in an equilibrium – if more water is pushed up than flows through the pipe, the water level in the holding tank increases and overflows. If the current flow out is too large, the tank drains and stops the current flow.

Basic Electrical Concepts – Ohms Law

V = I * R

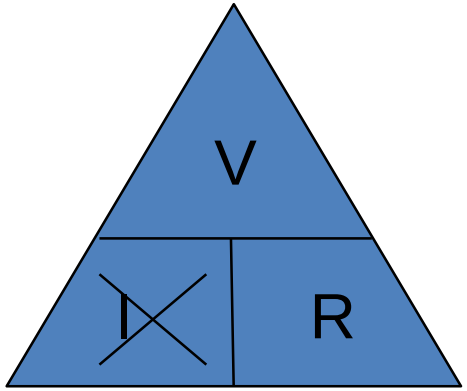
Voltage = Current * Resistance

Volts = Amps * Ohms



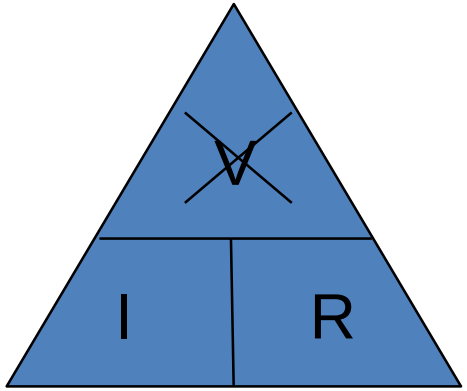
If you know any 2 you can find the other one

I =



= V / R

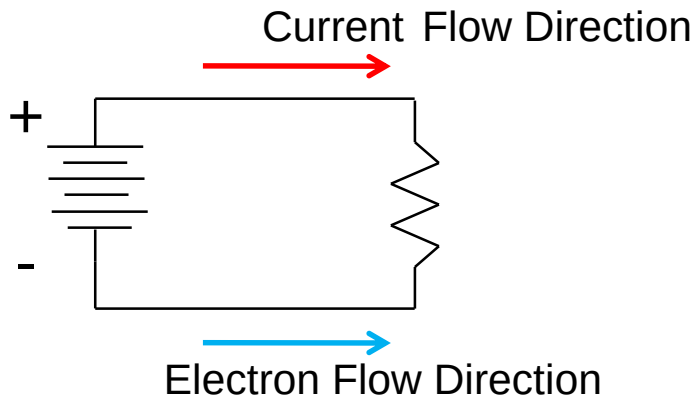
V =



= I * R

Basic Electrical Concepts – The Confusing Part

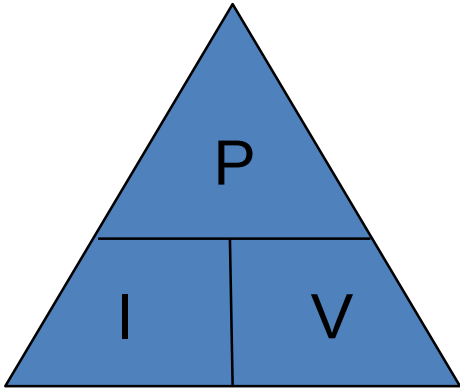
Electron Flow



Because Electrons are negative charged particles, the flow direction of electrons is in the opposite direction of the current flow.
A negative charge * Opposite direction (negative) = Positive current flow

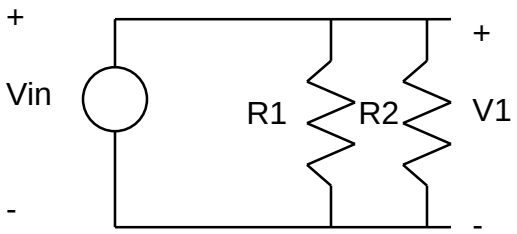
Basic Electrical Concepts – Power and Energy

Power = Voltage * Current
Measured in Watts
Symbol for Watts = W
Power is the rate that work is being performed
Higher Power => Higher rate of performing work



The Power Triangle

Energy = Power * Time = Voltage * Current * Time
Measured in Watts * Seconds or Joules
Symbol for Energy = J
Energy is the amount of work that is / was done
Higher Energy=> Higher amount of work



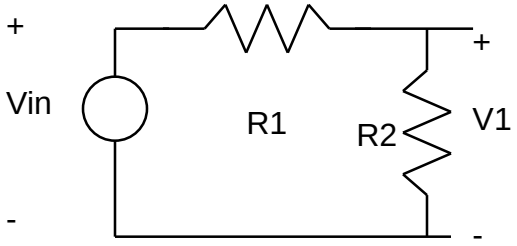
Simple Parallel Circuit

Vout = Vin - The voltage is the same across both resistors.

To find Req – Req = R1 * R2 / (R1 +R2)

To find current through one of the resistor, use Vin = I*R1 or I = Vin/R1

To find the current from the supply use Vin = I* Req or I = Vin / Req



Simple Series Circuit

$I_{R1} = I_{R2}$ - The current is the same through both resistors.

To find Req – Req = R1 + R2

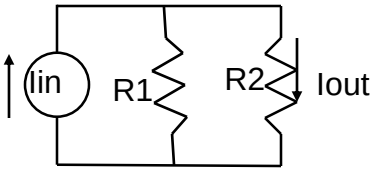
To find current through one of the resistor (either of the resistors since the current is the same), use Vin = I*Req or I = Vin/Req

To find the current from the supply use I = Vin / Req (Same current as the current through the resistors)

To find the voltage across a resistor use the voltage divider rule

$$V1 = \frac{Vin * R2}{R1+R2}$$

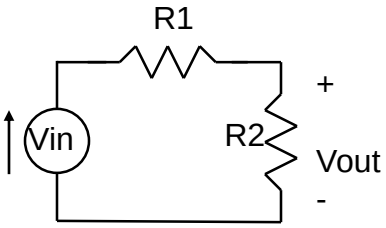
Current Divider Rule



$$Iout = \frac{Iin * R1}{R1+R2}$$

For example if R1 = 1K, R2 = 4 K, and Iin = 5 Amps
Iout = 5* 1 / (1+4) = 1 Amps

Voltage Divider Rule



$$Vout = \frac{Vin * R2}{R1+R2}$$

For example if R1 = 1K, R2 = 4 K, and Vin = 5 Amps
Vout = 5* 4 / (1+4) = 4 Volts

Resistor Equations

Resistors in Series

Req =R1 + R2 + R3 …..

Resistors in parallel

$$Req = \frac{1}{1/R1 + 1/R2 + 1/R3 \ldots\ldots}$$

For only 2 Resistors

$$Req = \frac{R1 * R2}{R1 + R2}$$

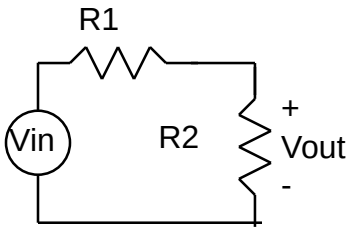
Ohms Law

V = I * R
I = V / R
R = V / I

Power

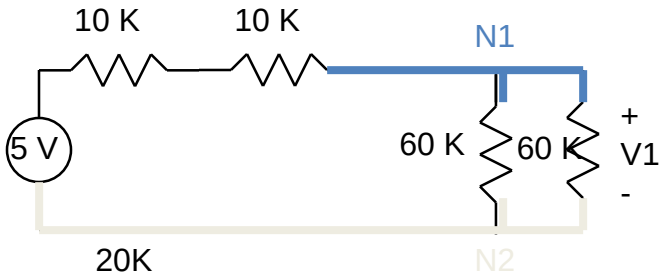
P = V * I
P = V* V / R
P = I * I * R

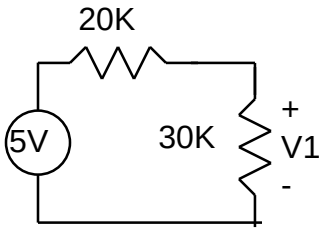
Voltage Divider Rule

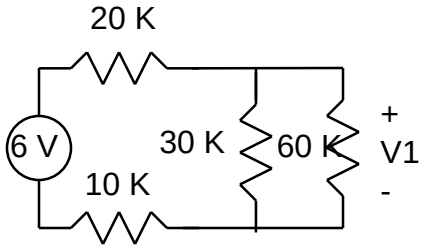


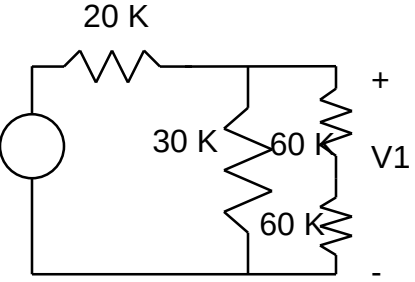
$$Vout = \frac{Vin * R2}{R1+R2}$$

For example if R1 = 1K, R2 = 4 K, and Vin = 5 Volts
Vout = 5* 4 / (1+4) = 4 Volts









Steps to find V1

Simplify resistor values using parallel and series rules.
The two series 10K's can be combined to a single 20K.
The two parallel 60K's can be combined to a single 30K

You can not combine the 60K's and the 10K's because you will change the value of V1

V1 is the voltage between the two wires N2 and N2.

Anything that is between the nodes can be combined together, and anything that is outside of the nodes can be combined together without changing the result.

For example you can combine the 20K and the 10K as series resistors (30K) in either leg of the power supply circuit without changing the value of V1.

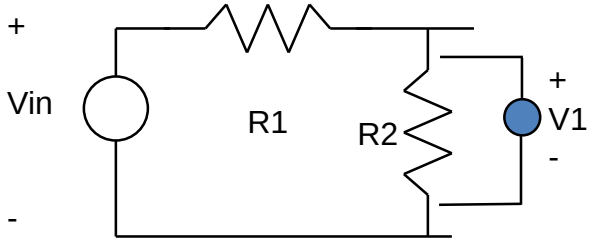
You can also combine the two 60K's and the 30K without changing V1

After simplification, the problem becomes an easy application of the voltage divider rule

Multimeter Basics

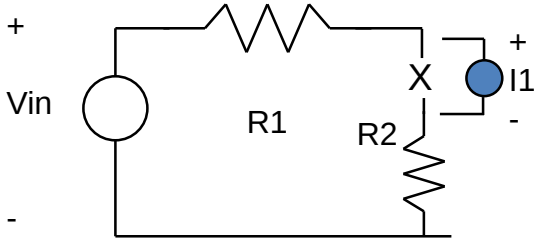
- A Multimeter is used to measure:
  - Voltage
  - Resistance
  - Continuity (level of resistance)
- When using a Multimeter, you must properly set it to either AC or DC, depending on the voltage you're trying to measure.

Using Meters



Measure Voltage

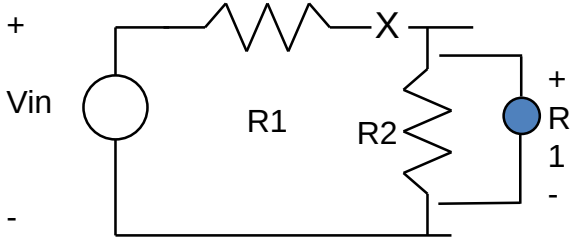
Voltage is measured across a component. Otherwise known as a voltage drop across the component. The meter is connected in parallel with the component to be measured.



Measure Current

Current is measured as a flow through a component. In order to measure current through a component, you will have to disconnect the circuit and hook the meter in series with the component to measure the current through.

Watch for Short Circuit



Measure Resistance

Resistance is measured across a component. The meter is connected in parallel with the component to be measured. In order to accurately measure the resistance, you should disconnect other components to prevent them from interfering with your reading.

Electron Info

- Electron Charge is -1.602×10^{-19} coulomb
- The force between two charged locations is
  - $F = 1/(4 * pi * e_o * e_r) * q1 * q2 / r^2$
  - Where e_o is the permittivity of free space= $8.854 * 10^{-12} c^2 / (N * m^2)$
  - Where e_r is the relative permittivity of the material
  - And r is the distance between the two charged bodys
  - The direction of the force is based on if they are like or opposite charges

- Power is the rate of change of the work
- Energy is the capacity to do work or amount of work done
- Work is force acting through a distance = F * d
- Electromotive force or voltage is the electron pressure to move back to a neutral / non charged state.
- V = W/Q = Work / Charge = J / coulombs
- Current = Q / t = Charge / time = coulombs / second
- P = V * I = W/Q* Q/t = W/t

- 1,000,000 electrons are pumped from one side to the other side of a 1mm thin insulator wall. The relative permittivity of the wall is 3000.
  - What is the force that is exerted by the electrons to the conductors on either side of the insulator
  - How much power was required to move the electrons
  - What is the voltage
  - If it took 0.5 seconds to move the electrons, what was the current
  - What would the voltage be if the insulator wall was thinned to 0.01mm with the same permittivity?

Capacitor

- A capacitor is made from two conductors separated by an insulator
- Capacitance = Area * e_o * e_r / distance
  - Where area is the area of the each of the conductors (the smallest one)
  - Distance is the distance between the conductors or thickness of the insulator barrier
  - Where * e_o is the permittivity of free space= 8.854 *10 $^{-12}$ c^2 / (N * m^2)
  - Where e_r is the relative permittivity of the material
  - Area is measured in square meters
- Capacitance is measured in Farads or F
- Capacitance can also be calculated by C = Q / V ; Q = C * V
- When discharging a capacitor the current I = change in Q / change in t
- I = dQ / dt = C * dV / dt

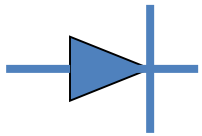
- For a capacitor that has plates that are 2 meters long, and 1cm wide with an insulator thickness of 1mm and a permittivity of 50,
  - What is the capacitance
  - If you charge it up to 10 volts, how much charge is stored in the capacitor?
  - If it took you 1 second to charge the capacitor, what was the current

  - Repeat the calculations if the insulator thickness was 0.1mm

DIODE

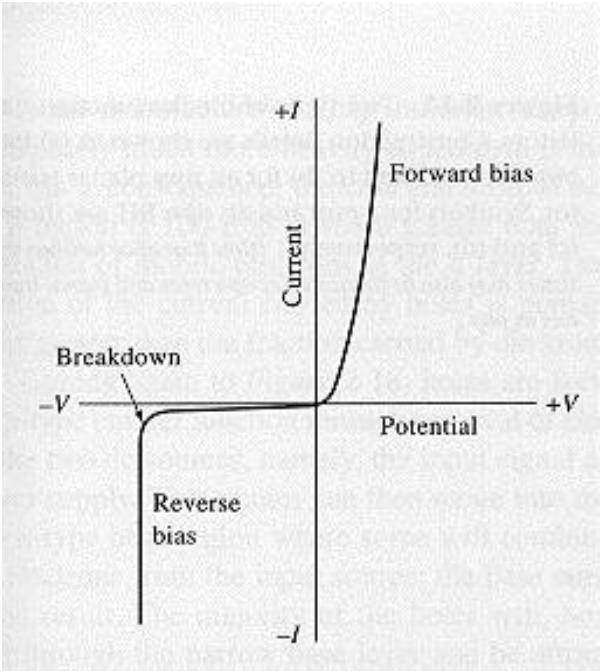
DIODE MEANS TO CONDUCT IN ONLY ONE DIRECTION

WILL CONDUCT ELECTRONS



WILL NOT CONDUCT ELECTRONS

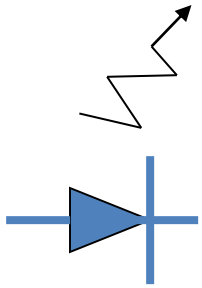
Ideal Diode



Real Diode

LIGHT EMITTING DIODE (LED)

- A DIODE THAT EMITS LIGHT WHEN CURRENT IS PRESENT.
- MOST LED'S REQUIRE ONLY A MILLIAMP TO BE SEEN.

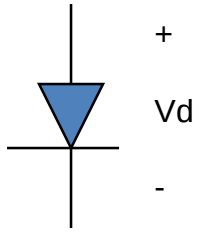


Working with ideal diodes

If the voltage across the diode (Vd) is positive, the diode will look like a short circuit or a wire.

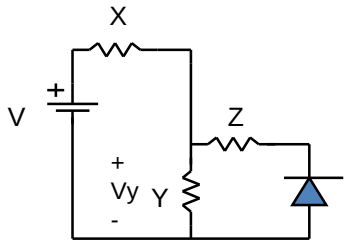
If the voltage across the diode (Vd) is negative, the diode will look like an open circuit or no connection.

When working with diodes, the first step is to look at the circuit to determine if the voltage across the diode is positive or negative. In order to determine if the voltage is positive or negative look at components that are in parallel to the diode. In the case on the left, the resistor Y is in parallel with Resistor Z and the diode. The voltage across resistor Y can be seen by inspection to be positive. Since the diode is reversed, Vd is negative.



If the voltage is positive, remove the diode and place a wire in it's place.

If the voltage is negative, remove the diode and leave the connections open. Any components that are in series with the diode can be ignored, or removed because no current can flow through them.



In complicated circuits, you may need to go back and check to see if your estimation was correct. The way you do that is to calculate Vy using the values you get from analyzing the circuit without the diode. If the voltage comes up the opposite way you assumed, you are going to have to do the analysis over again.

Remember – get the diodes out of the circuit, it takes away the confusion.

For non Ideal diodes similar rules apply, except

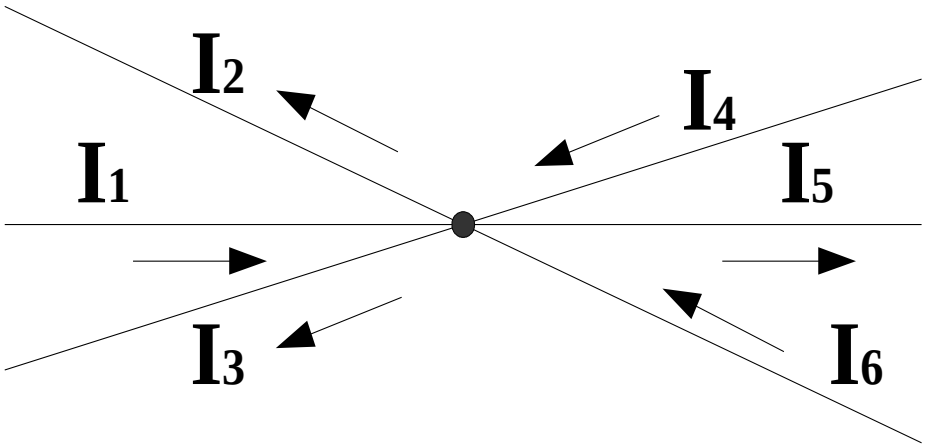
Vd has to be greater than a threshold voltage 0.3 or 0.7 volts depending on the type of diode.

The diode is replaced by a series resistor and a power supply that only can consume current, it can't generate current.

Kirchhoff's Law

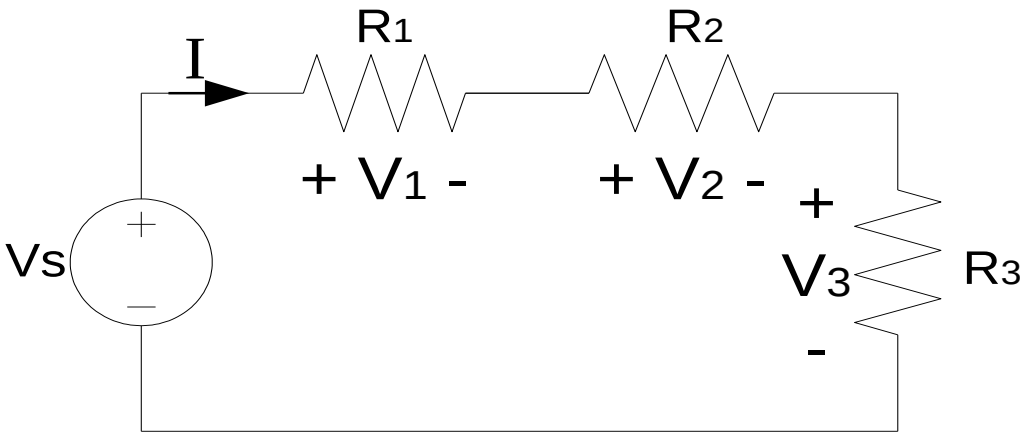
- There are TWO laws:
  - Kirchhoff's Current Law

- 1. Kirchhoff's Current Law (KCL) states that the net current entering a node is the same as the net current leaving that node. Therefore, the algebraic sum of all currents at any node in a circuit is equal to zero.
- **Σ I entering a node = Σ I leaving a node**



Kirchhoff's Law

- 2. Kirchhoff's Voltage Law (KVL) states that the algebraic sum of all the voltages around any closed path in a circuit is equal to zero. That is, the net sum of voltages across active components is the same as the net sum of voltages across passive components.



$$\Sigma V \text{ in a closed loop} = \mathbf{0}$$

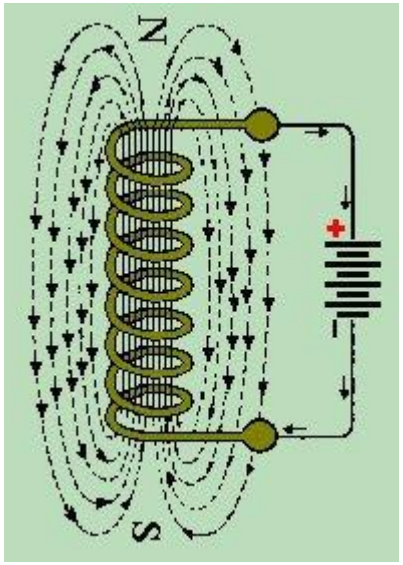
$$Vs - V_1 - V_2 - V_3 = \mathbf{0}$$

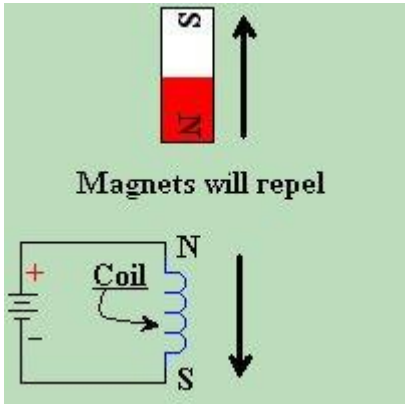
$$Vs = V_1 + V_2 + V_3$$

Basic Electrical Concepts – Electro Magnetism

Forcing electrons to travel in a circle causes a magnetic field.

North and south poles form because of the circulation of the electrons





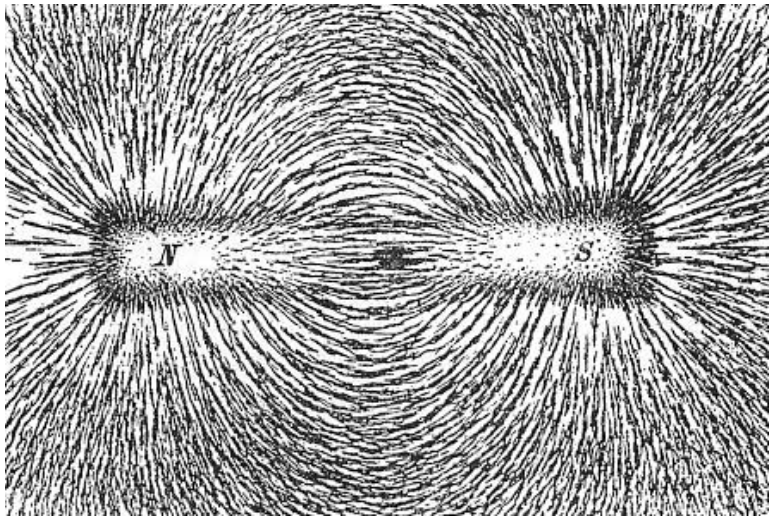
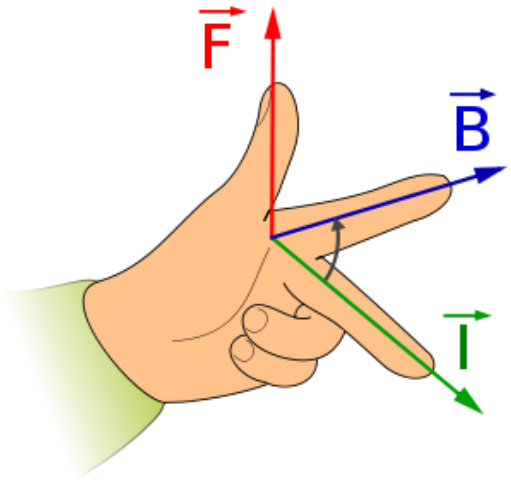
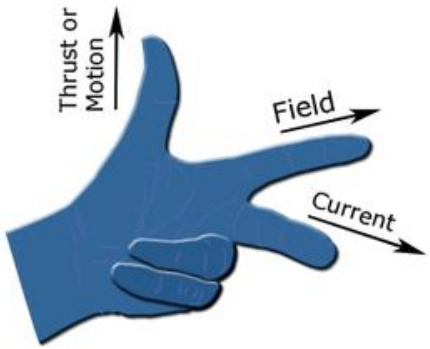
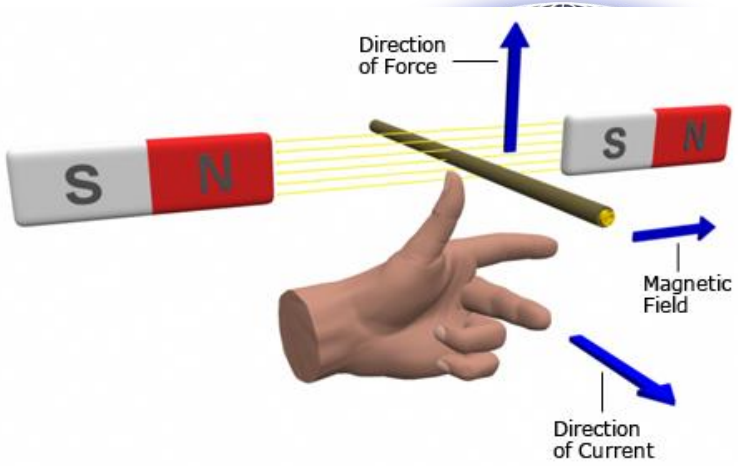


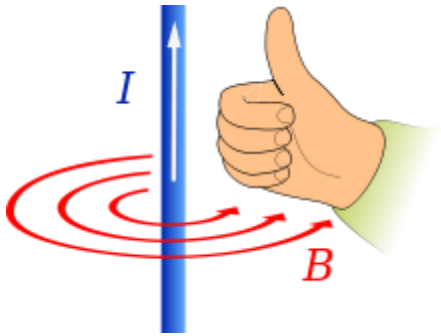
Table 12.1. Units for magnetic quantities

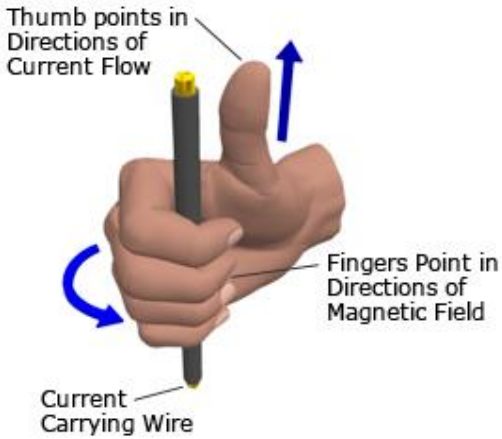
quantity	*MKS*	*unrationalized cgs*	*conversions*
core material equation	$B = \mu_0 \mu_r H$	$B = \mu_r H$	
B	Tesla	Gauss	$1T = 10^4 G$
H	Ampere / meter	Oersted	$1A/m = 4\pi \cdot 10^{-3}$ Oe
Φ	Weber	Maxwell	$1Wb = 10^8$ Mx $1T = 1Wb / m^2$


F
B
I


Thrust or Motion
Field
Current


Direction of Force
S
N
S
N
Magnetic Field
Direction of Current


I
B


Thumb points in Directions of Current Flow
Fingers Point in Directions of Magnetic Field
Current Carrying Wire

Suggested References

- Websites:
  - Soinc.org Shock Value / Circuit Lab Event pages
  - Scioly.org student forums / wiki / test exchange
  - Wikipedia (Electrical Circuit, Magnetism, etc.)
  - Ibiblio (Lessons in Electric Circuits, Volumes I,V and VI)
  - Youtube (Intro to electricity, Principles of Electricity)
  - http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc
  - http://www.khanacademy.org/#Physics
  - http://www.electronicstheory.com/html/e101-6.htm

- Books:
  - Science / Physics textbooks – most have chapters on this material
  - Electric Circuits, James W. Nilsson

Electricity Web Sites

- http://www.energyquest.ca.gov/story/chapter02.html
- http://www.exploratorium.edu/snacks/iconelectricity.html
- http://www.andythelwell.com/blobz/
- http://www.teachersfirst.com/tchr-keyword.cfm?keyword=electricity&lower=5&upper=8&Submit4=Search+by+keyword
- http://www.quia.com/jg/313986.html
- http://www.bbc.co.uk/schools/scienceclips/ages/10_11/changing_circuits.shtml
- http://ippex.pppl.gov/interactive/electricity/

Hands On / Fun Stuff

- Kits and parts
  - www.Sparkfun.com electronics kits, books
  - http://www.elenco.com/ electronics kits
  - http://www.kelvin.com/ Parts and kits – many subjects
  - https://www.digikey.com/ Parts, kits, training material

- YouTube 2000 V demonstration
  - http://www.youtube.com/watch?v=8hwLHdBTQ7s&feature=youtube_gdata_player

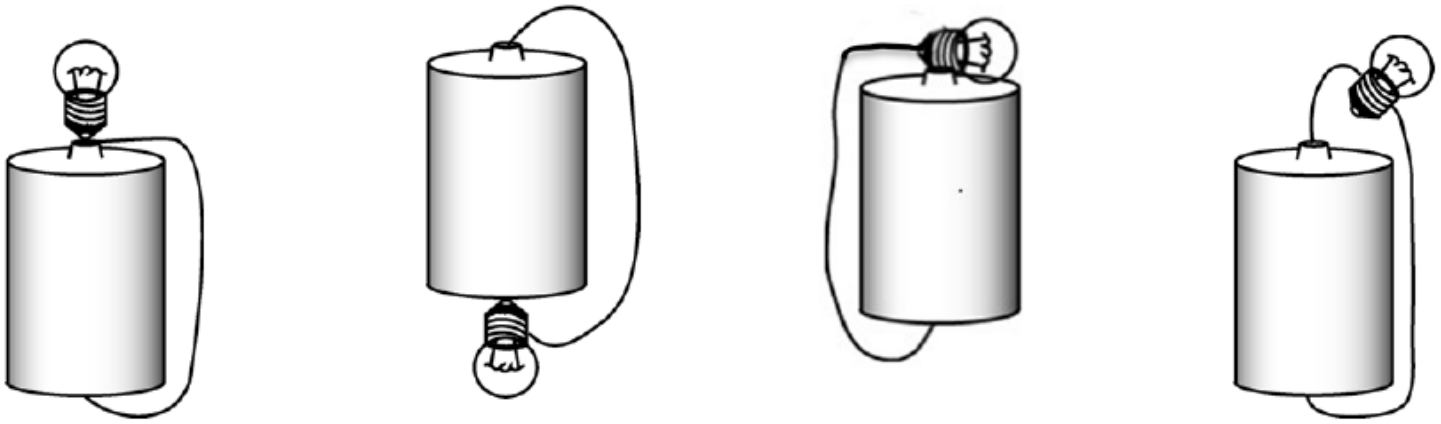
Final Random Thoughts

- Safety
  - Voltages greater than 60 Volts can be harmful
  - Incorrect connection can create sparks even in low voltage circuits
  - Objects can become hot
- Regularly check www.soinc.org
  - Clarifications
  - FAQs
  - Policies (Lasers, Safety, Building, etc)

Example Questions

1. Look at the picture of the bulb, battery and wire alignments below. Which bulb(s) are lit?

a. **b** **c** **d.**



2 Which of the following are insulators?

a) Copper b) Brass c) Aluminum d) Gold e) Rubber f) Glass
g) Sea Water

3. Given a 60-W light bulb and a 100-W light bulb, each in a lamp that is plugged into the wall. Which one will have more current passing through it?

a) 60-W light bulb b) 100-W light bulb c) Both are the same

4. Both 12 gage wire and 14 gage wire are used in the circuits in the home. Which wire is the better conductor?

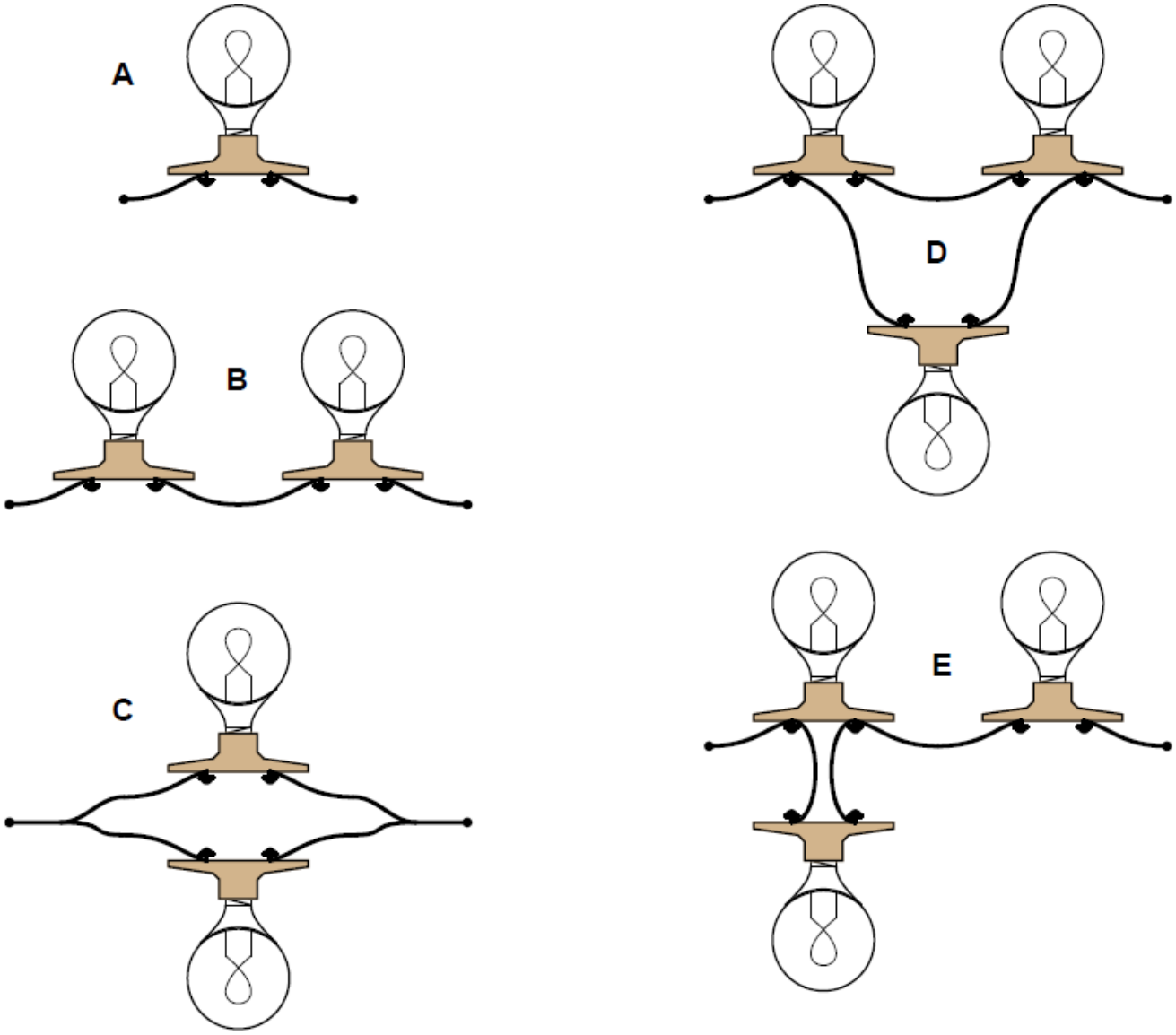
a) 12 gage wire b) 14 gage wire c) Both are the same

5. Two wires have the same length and diameter. One is made of aluminum and the other of copper. Which one has the greater resistance?

a) aluminum b) copper c) neither, they are both the same.

Question 10

Rank these five light bulb assemblies according to their *total* electrical resistance (in order of least to greatest), assuming that each of the bulbs is the same type and rating:



Explain how you determined the relative resistances of these light bulb networks.

Circuit Design

- Draw a schematic with the following circuits:
  - 3 resistors in series
  - 3 resistors in parallel
  - a series parallel combination of 3 resistors
- If all the resistors are 680 ohms, calculate the equivalent resistance of the three combinations.
- Measure the equivalent resistance of the 3 groups of resistors. how does the results compare to your measurements? If there are differences, explain the reason for the differences.

Draw the following circuit

1 - 9 volt power supply

A 1.0K resistor connected to the positive terminal of the power supply.

Two 2.2 K resistors connected in parallel, the two of resistors are in series with the 1.0K resistor.

One 5.1 K resistor connected between the parallel resistors and the negative terminal of the battery.

Draw the a schematic for the following circuit:

Four 1.5 V batteries in series

Connected in parallel to the batteries, two 100 ohm resistors in series with a switch that causes no power to be dissipated in the resistors.

Also connected in parallel to the batteries, two more 100 ohm resistors in connected in parallel that have current flowing through them.

And lastly connected in parallel to the batteries, two 100 ohm resistors in series that have current flowing through them.

After drawing the circuit, calculate the current and power for in each of the resistors.

Mystery Card - Continuity

- Use meter in the resistance measurement setting to determine what are the hidden connections.
- Note that more that multiple pins can all be connected together

Mystery Card – Resistor

- Use meter in the resistance measurement setting to determine the hidden resistor connections.
- Note that more that pins can connect to multiple resistors.
- Draw the hidden circuit.

Voltage and Current Measurement

- Both calculate and measure the voltages and currents in the below circuit
- Compare the results of your calculations and your measurements. What can explain the differences if any?

Resistor Color Code

LED Operation

- Measure the voltage and current in a LED
- Calculate the power used by the LED

Potentiometer

- Set a potentiometer to one end, measure and record the resistance and voltage across the potentiometer.
- Move the contact on the potentiometer about 1/3 of the way and repeat the measurement of resistance and voltage
- Move the contact to about 2/3 and the other end, making measurements at each point
- Create a graph of voltage versus resistance. What is the shape of the curve?

Error Circuit

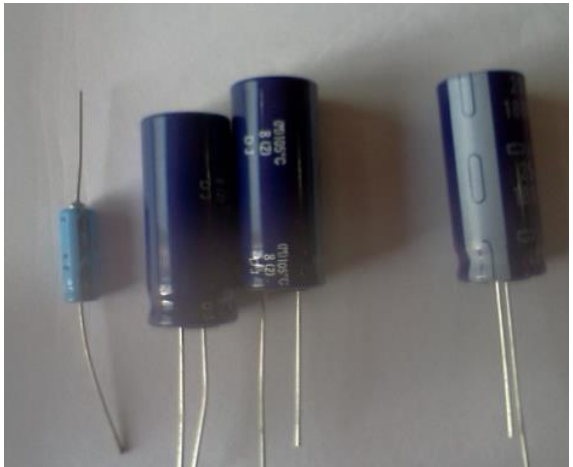
- There is an error in the circuit that is preventing the circuit from properly working.
- Use your multimeter to locate the error
- Once you locate the error note the location of the error, but do not fix the error.

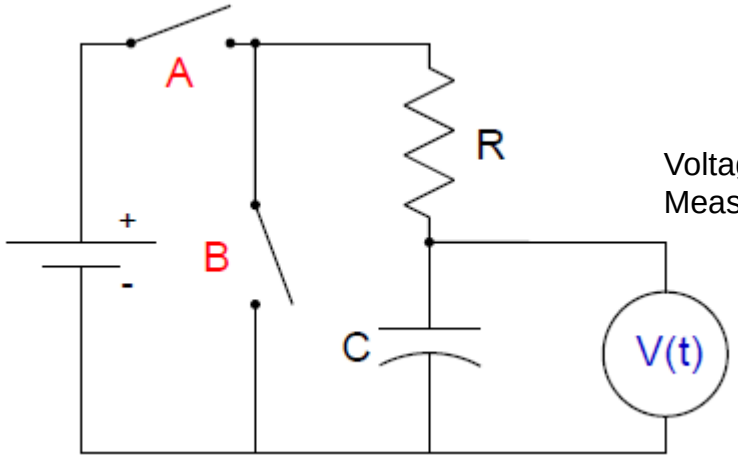
Magnet

- Use a Compass to locate the north pole on the bar magnet
- Next use the compass to locate the north pole on the electromagnet
- Reverse the electrical connections to the electromagnet
- What is the relationship between the location of the north pole and the current flow?

Capacitors

- Capacitors are devices in which electric charges can be stored. In fact, any object in which electrons can be stripped and separated acts as a capacitor. Practical capacitors are made of two conducting surfaces separated by an insulating layer, called a dielectric.
- Two primary types of capacitors exist – Polarized and non polarized.
  - Polarized capacitors will only work if they are connected in one direction (with the "+" terminal always higher or equal to the "-" terminal). If the "-" terminal is higher than the "+" terminal the capacitor will act as a bad resistor, and may permanently fail.
  - Non polar capacitors can be connected in either direction and function properly
- The symbol used to represent capacitors in schematics reflects their physical construction with electrolytic capacitor (which must be hooked up with the correct polarization) represented by a curved plate for its negative terminal.
- The negative terminal is indicated by "-" sign along the capacitor
- The blue capacitors below are polarized capacitors, while the yellow capacitor is a non polar capacitor
- Capacitors also have a maximum voltage rating. A capacitor should never have a voltage across it's terminals greater than it's maximum voltage rating
- The time constant is the time that it takes for a capacitor to reach 63% of the voltage in the RC Circuit in the below schematic. Time Constant = R*C
  - Capacitors are typically nanoFarads to microfarads.
  - If the Resistor is 100k ohms, and the Capacitors is 10 microFarad (uF), the time constant will be 1 second
  - This makes the measurement of the voltage on a capacitor difficult without special tools – one type of tool used to make these measurements is an oscilloscope
- Possible experiments
  - Open a capacitor to see the parallel plate construction of the capacitor
  - Place capacitors in parallel and series and measure the time constant
- http://www.coilgun.info/theorycapacitors/home.h





Voltage Measurement