

Training L1

Electric Circuits

Objectives

Understand:

- Understand the electrical Language
- Understand the basic components of electric circuits
- Understand ohms law
- Understand power
- Understand wire within FIRST
- Understand magnetism with respect to motion

Ingredients we need to make electricity

- **Matter** is made of atoms, with closely-spaced protons (positive charged particle) and electrons(negative charged particle). They are close together, so their effects cancel out.
- **Atoms** of conductive materials have electrons that are held loosely. A source of electric potential (**Voltage**), will push electrons from a point of low potential energy to higher potential energy.
- The definition of electricity is the flow of charge(**Current**).
- A closed (**Circuit**) of conductive material provides a path for electrons to continuously flow.
- The measure of how well something conducts electricity is called its *conductivity*, and the reciprocal of conductivity is called the (**Resistance**).

Electricity Component Definitions

- **Voltage (V)**

- This is the force, or “potential” of an electrical source. **Electrical Potential** is the energy stored ready to do work.
- Measured in **Volts**
- A Battery provides potential energy chemically

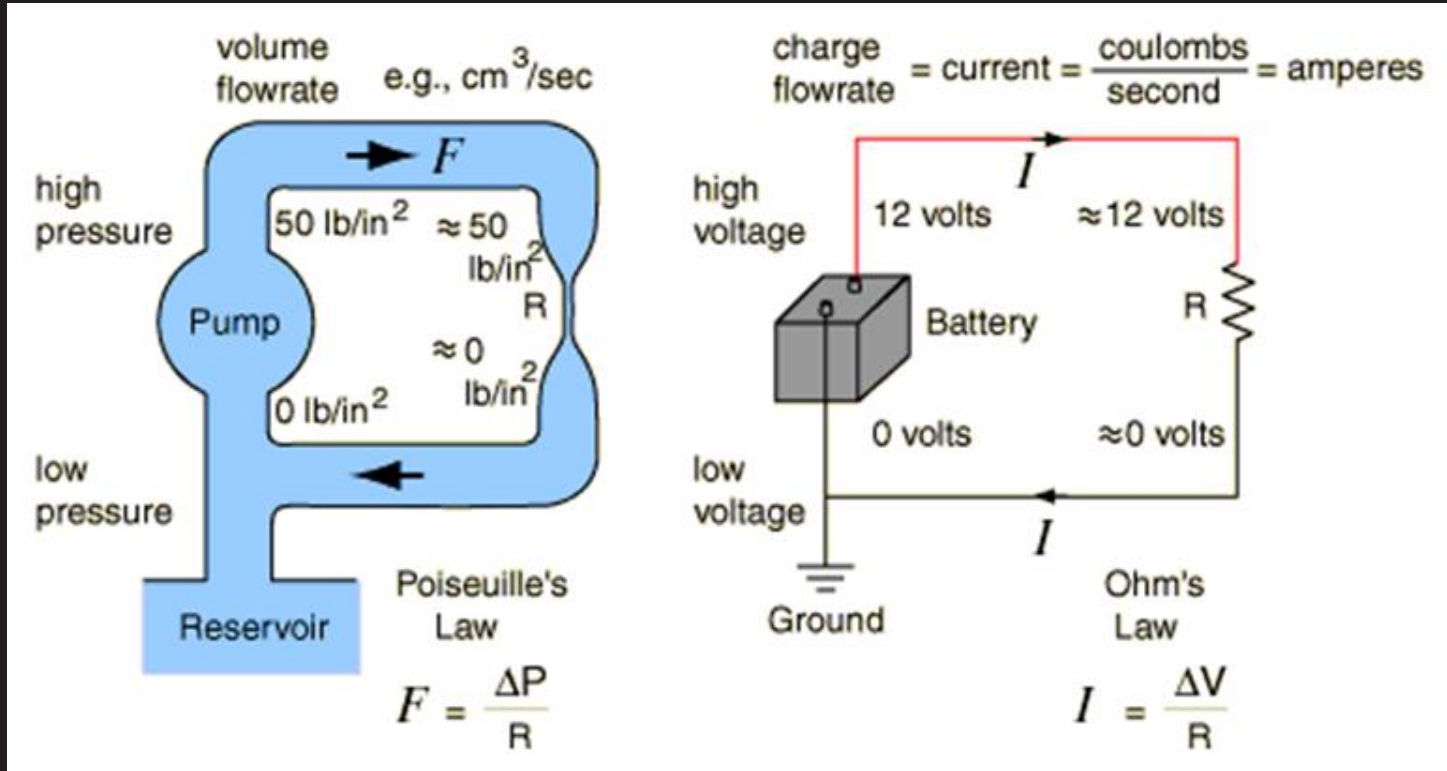
- **Current (I)**

- The flow of electric charge through a circuit
- Measured in **Amps**
(1 amp = movement of 1 coulomb(electric charge) or 6.25×10^{18} electrons /sec)

- **Resistance (R)**

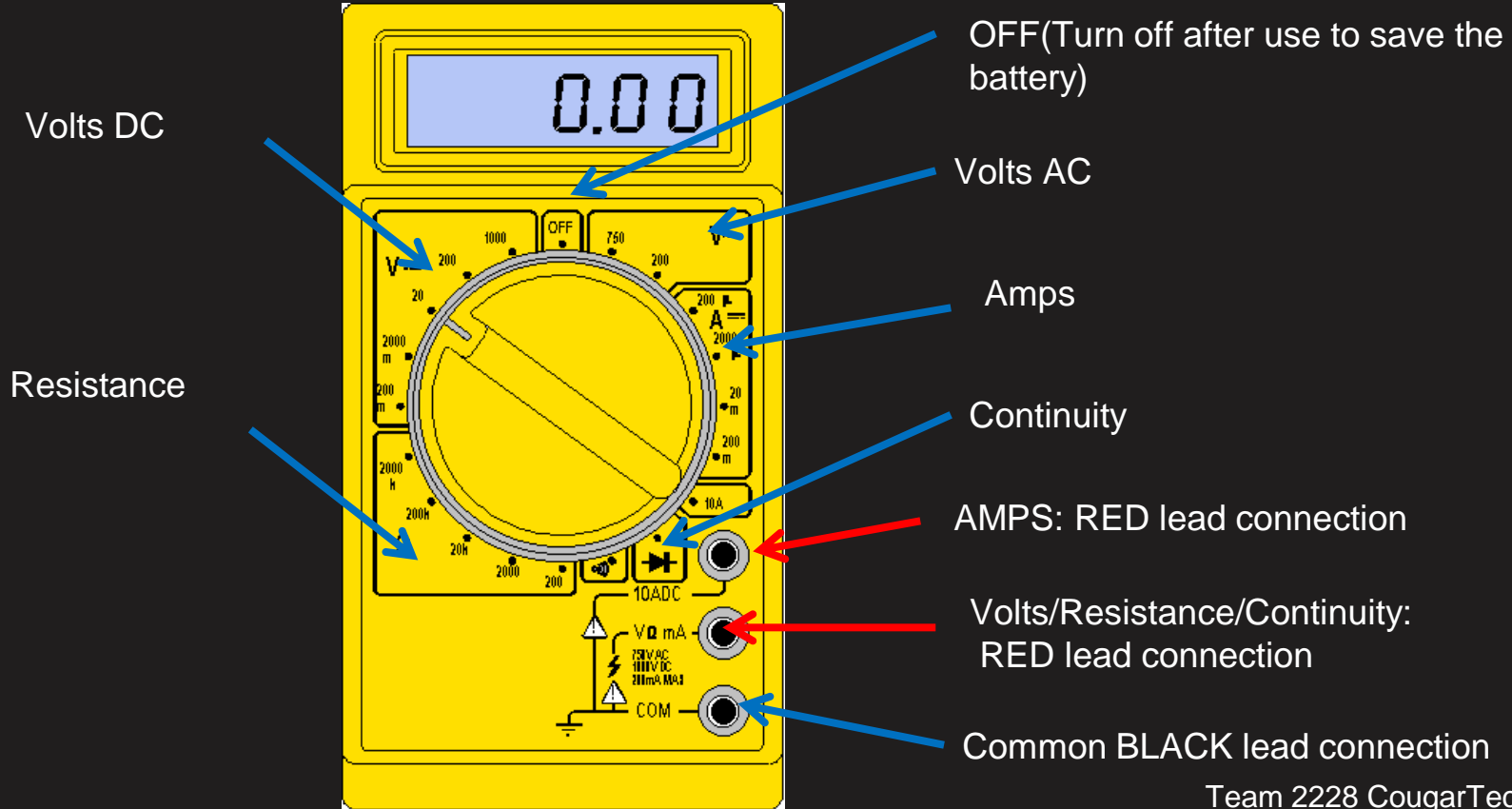
- The degree to which an object opposes the flow of current
- Measured in **Ohms**

Water-Electrical Analogy



Measurement: Volts/Amps/Resistance

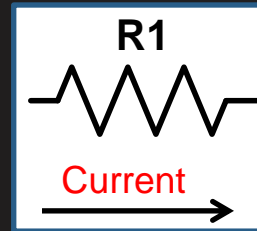
Digital Multi-Meter Typical Layout



Conventional Current-Voltage Polarity

Conventional current was proposed by Ben Franklin in the 1700's and is defined as moving from the Positive side of the voltage source to the Negative side of the voltage source. This convention still holds today.

Polarity of voltage drops across resistors is important in circuit analysis
Drop is + to – in the direction of conventional current.



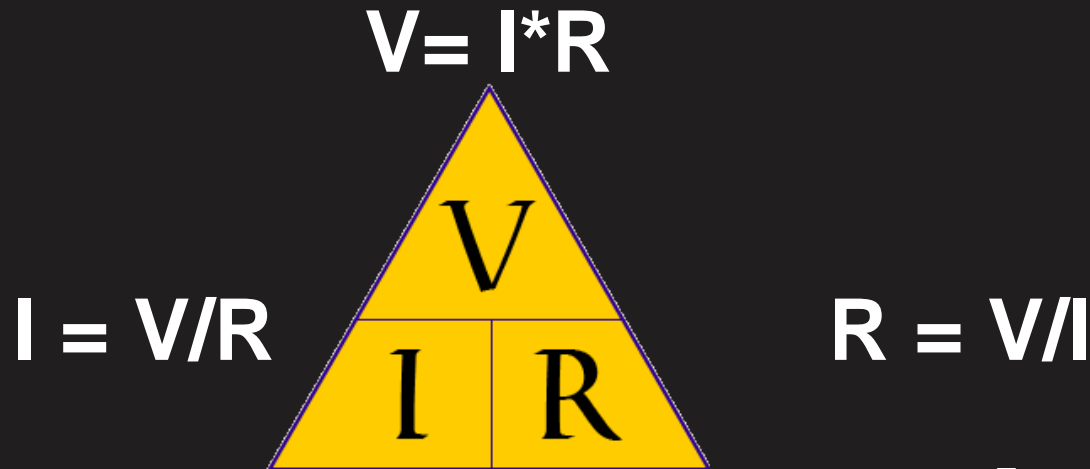
+ Meter Voltage -

Ohm's Law

German physicist George Ohm, experimentally determined that the if the voltage across a resistor is increased, the current through the resistor will increase.

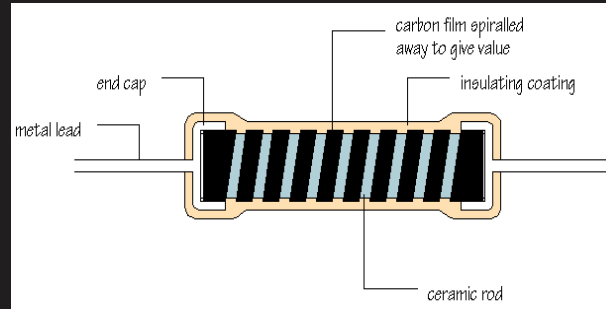
Ohm's Law ($V = I \cdot R$) was published in 1827 and was rejected by his peers.

Ohm's Law Triangle



Resistance

Resistance is the opposition to the flow of current. When electrons enter at one end of a resistor, some of the electrons collide with atoms within the resistor. These atoms start vibrating and transfer their energy to neighboring air molecules. In this way, a resistor dissipates electrical energy into heat energy. It is analogous to the viscous friction element of mechanical system.



Resistors can be made of:

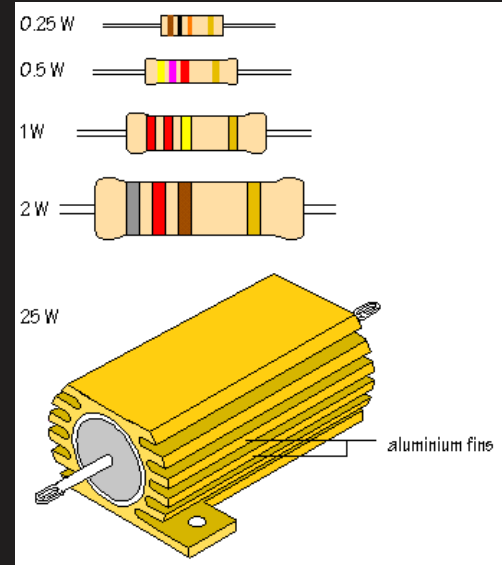
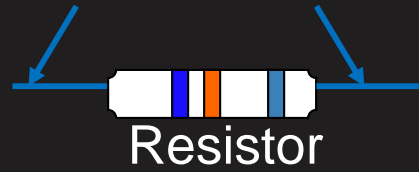
- Carbon composition (carbon powder and glue-like binder).
- Carbon film (decomposition of carbon film on a ceramic core).
- Metal oxide (ceramic core coated with metal oxide).
- Precision metal film.
- High power wire wound.

Resistor Examples

Symbol for resistor



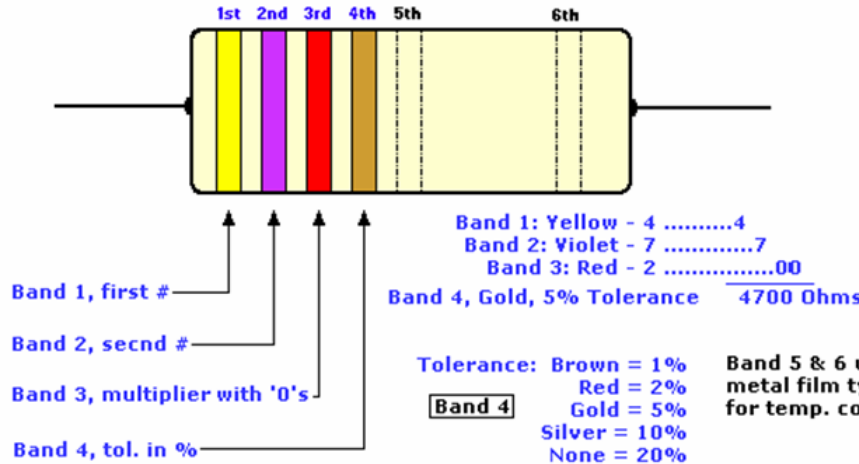
Contact leads



Resistor Color Code

Resistor Colour Code

Example: 4K7 or 4700 ohms (Carbon)

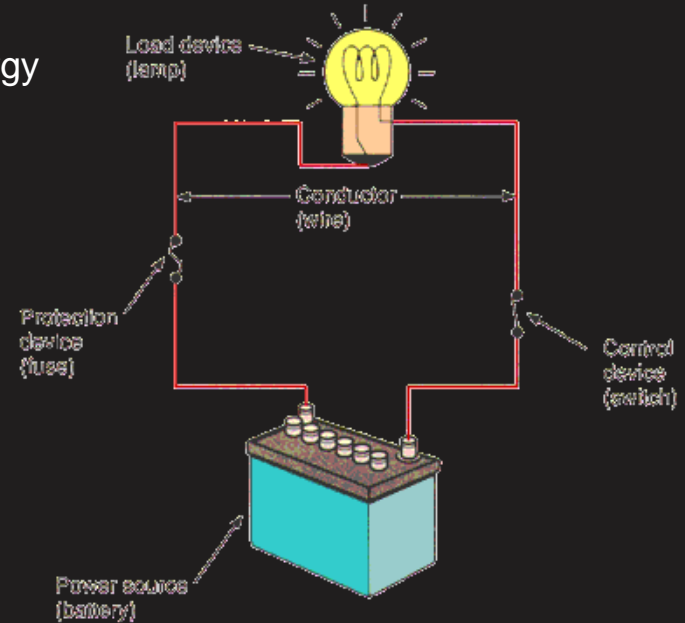


- Band 1, 2, 3
Black = 0
Brown = 1
Red = 2
Orange = 3
Yellow = 4
Green = 5
Blue = 6
Violet = 7
Gray = 8
White = 9
Gold = 0.1

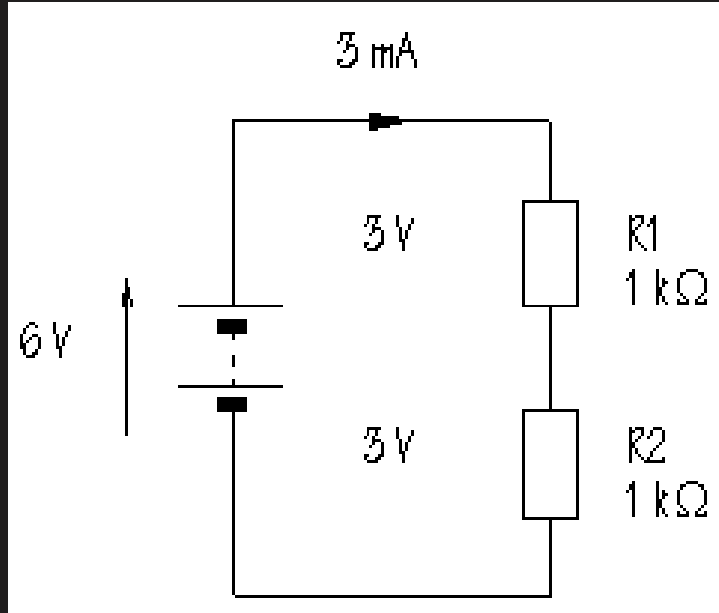
Band 5 & 6 usually for 1% metal film types. Band 6 for temp. coefficient.

Electric Circuit

- **Electric Circuit:** closed-loop path of conduction through which an electric current flows
- The **load** is the part of the circuit that converts the electrical energy into another form. (light bulbs, motors, heaters, etc.)
- **Two types of conduction paths:**
 - Series** – Components connected in series
 - Parallel** – Components connected in parallel
- **Two types of current:**
 - DC** – Direct Current (e.g. Battery current)
 - AC** – Alternating Current (e.g. House current)



Series Resistors in a Circuit



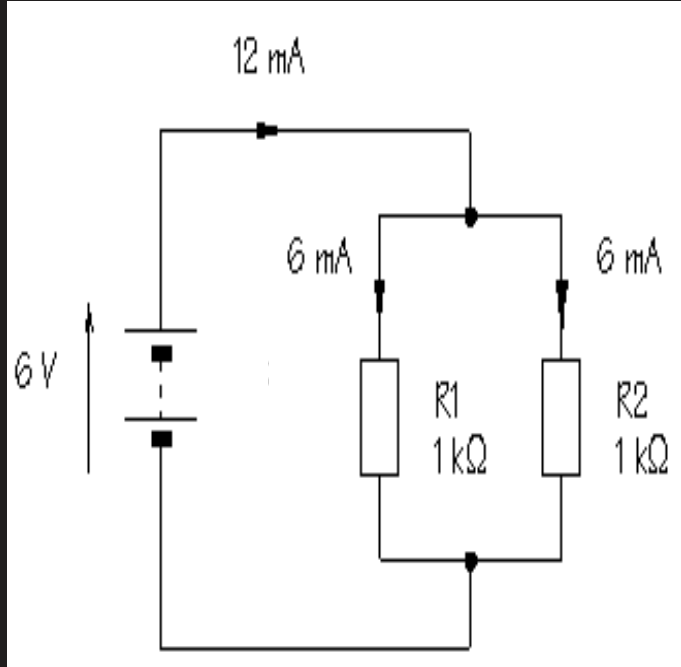
$$R_{total} = R_1 + R_2$$

$$R_{total} = 1 + 1 = 2k\Omega$$

$$I = V/R = 6/2000 = .003Amps = 3ma$$

$$V = I * R = .003 * 1000 = 3Volts$$

Parallel Resistors in a Circuit



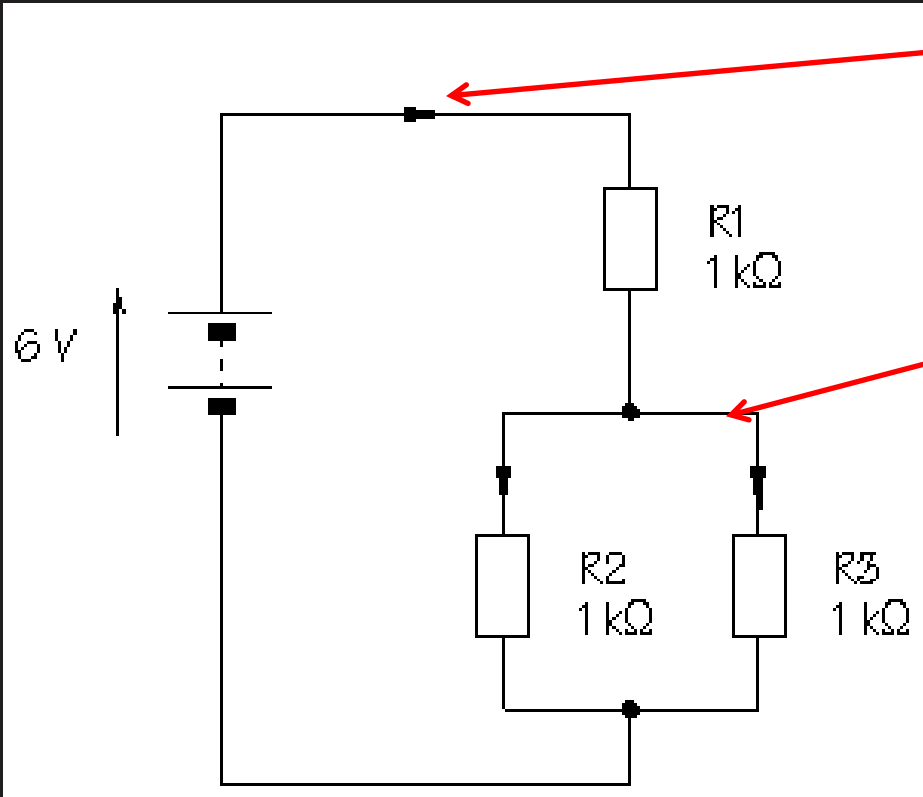
$$R_{total} = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_{total} = \frac{1 \times 1}{1 + 1} = \frac{1}{2} = 0.5k\Omega$$

$$I = V/R = 6/500 = 0.012Amps = 12ma$$

$$I = V/R = 6/1000 = .006Amps = 6ma$$

Resistor Exercise



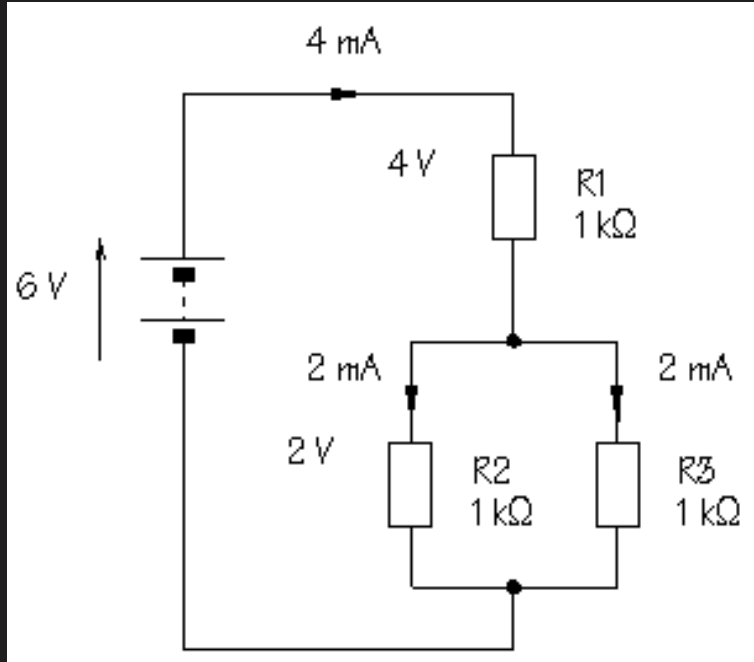
What is the total current?

What is the Voltage?

What is the parallel resistance?

What is the total Resistance?

Resistor Exercise



$$R_{total} = R_1 + \frac{R_2 \times R_3}{R_2 + R_3}$$

$$R_{total} = 1 + \frac{1 \times 1}{1 + 1} = \frac{3}{2} = 1.5k\Omega$$

$$I = V/R = 6/1500 = .004Amps = 4ma$$

$$V = I * R = .004 * 1000 = 4Volts$$

Variable Resistor: Other Examples



Potentiometer:
Rotation changes resistance



Force Resistor:
Pressure changes resistance

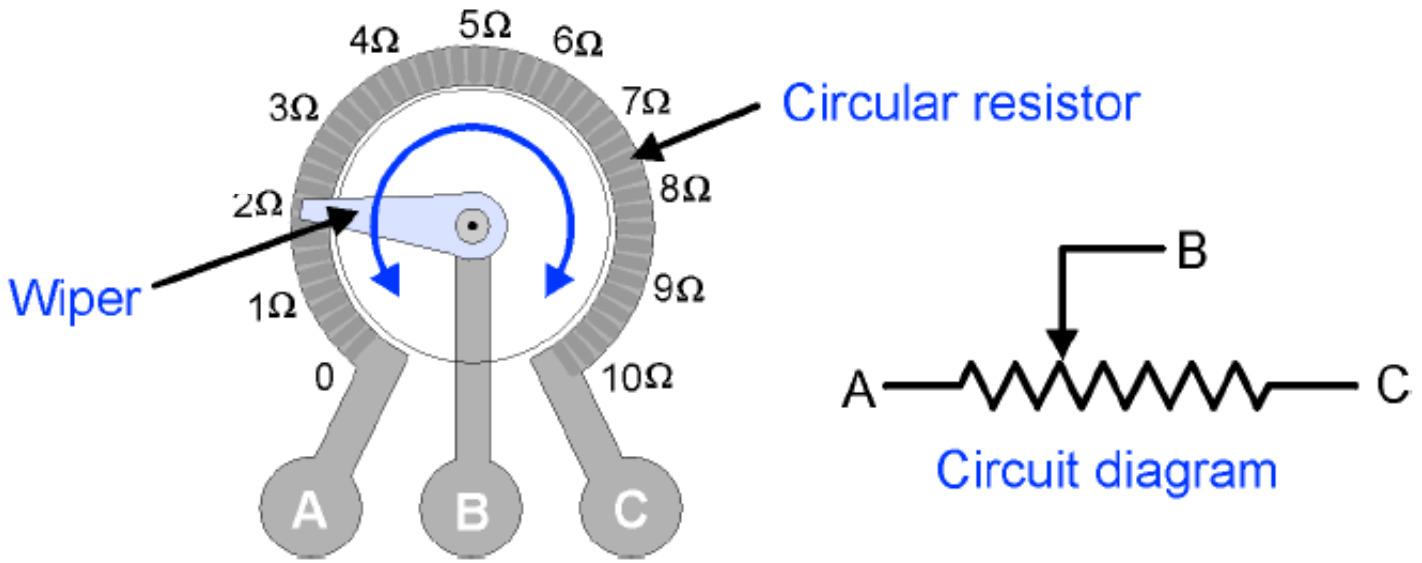


Photoresistor:
Light changes resistance



Thermistor:
Temperature changes resistance

Inside a Potentiometer



Power

- In addition to voltage and current, there is another measure of free electron activity in a circuit:

power

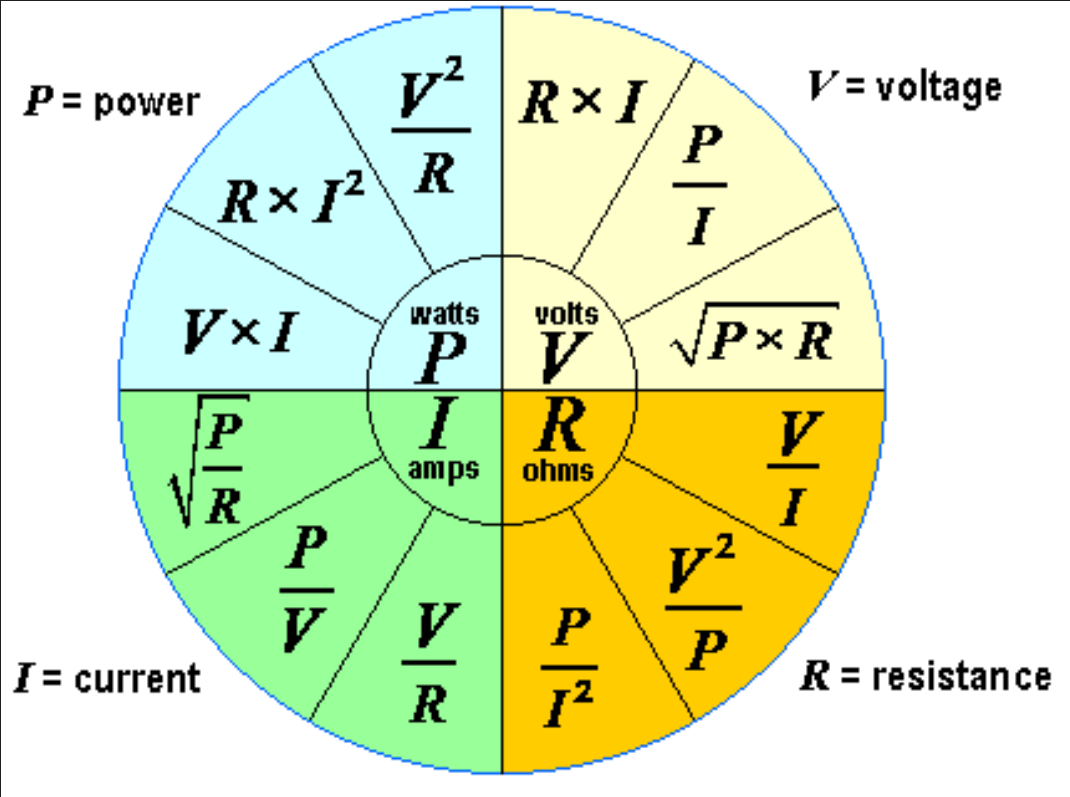
- **Power** is the measure of how much energy is used over a period of time.
 - It is the rate at which energy is converted from the electrical energy of the moving charges to some other form [work/time] (ie. heat, mechanical energy, or energy stored in electric or magnetic fields).
- **Power** is measured in Watts (W) where as energy is measured in **joules (J)**

One **Watt(W)** = **Joule(J)** / Second

Power

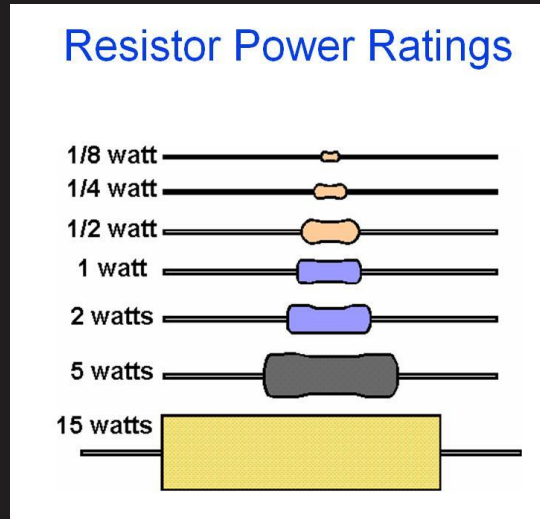
- In an electrical circuit, the
Electrical voltage: V (volts) = Joules (J) / Electric charge Q in coulombs (C)
Current: I (Amps) = Electric charge Q in coulombs (C) / Second.
- Thus: Power (P) = $J/C * C/sec = V*I$
- Using ohms law $P = I^2R$
- Since power is measured in watts (or joules per second) and time in seconds, the unit of energy is the *wattsecond* (Ws) or *joule* (J).
- The watt-second is too small a quantity for most practical purposes, so the *watt-hour* (Wh)

Ohm's Law and Power Wheel



Resistor Power Ratings

- When electrons enter at one end of a resistor, some of the electrons collide with atoms within the resistor. In this way, a resistor dissipates electrical energy into heat energy. This Kinetic Energy is turned into thermal energy (heat).
- Resistors must be able to safely dissipate their heat without damage



Wire

- Components in a circuit are connected with wire that is conductive.
- The amount of current that can safely pass through a wire is determined by the wire diameter.
- Thus large diameter wires can carry large currents.
- The diameter of the wire is defined by a gauge number, the larger the wire diameter the smaller the gauge.
- Typical wire gauges in FIRST include: #6, #10, #12, #14, #20, #24

Fuse – Circuit Breaker

A **FUSE** is a safety device consisting of a strip of wire that melts and breaks an electric circuit if the current exceeds a safe level.

A **CIRCUIT BREAKER** is a thermal switch that interrupts current in an electric circuit. A self resetting breaker will allow current to flow after the switch cools

Note: It takes some amount of time to heat the fuse and circuit breaker before the circuit is broke

Don't Waste Valuable Time Replacing Fuses When We Can Take The Trips For You

Maxi Fuse

ATO or ATC Fuse

Mini Fuse

AT2 Breaker
Mini Fuse Replacement

VB3 Breaker
ATO & ATC Fuse Replacement

MX5 Breaker
Maxi Fuse Replacement

SNAP ACTION INC.

Miniature Circuit Breakers

MADE IN USA

Directly Replace Automotive Fuses

The advertisement features a collection of automotive fuses and circuit breakers. On the left, there are Maxi fuses in yellow, green, and red, with ratings of 30, 50, and 60 AMP. In the center, there are Mini fuses in red and black, with ratings of 10 and 20 AMP. On the right, there are ATO or ATC fuses in yellow and green, with ratings of 10 and 30 AMP. Below the fuses, there are three circuit breakers: a 40 AMP MX5 Maxi Fuse Replacement, a 60 AMP MX5 Maxi Fuse Replacement, and a 30 AMP VB3 ATO & ATC Fuse Replacement. The company logo 'SNAP ACTION INC.' is prominently displayed in the center, with 'MADE IN USA' below it. The text 'Miniature Circuit Breakers' is on the left and 'Directly Replace Automotive Fuses' is on the right.

Power Wiring Current Ratings

FIRST uses the following wire gauges/current ratings that should not be exceeded:

- **#6** up to 120Amps; used from the battery to the robot power switch and PDP
- **#12** up to 40Amps; used from the PDP to speed Controllers used with CIM motors
- **#14** up to 30Amps; used from PDP to speed controllers used with car window motors

Typical First Robotics Wiring Rules

- F. Each primary power connection between the battery and Power Distribution Board must be made with 6 AWG red and black wire or larger.
 - A. **12 AWG or larger** diameter wire must be used for all circuits protected by a 40A circuit breaker.
 - B. **14 AWG or larger** diameter wire must be used for all circuits protected by a 30A circuit breaker.
 - C. **18 AWG or larger** diameter wire must be used for all circuits protected by a 20A circuit breaker.
 - D. **20 AWG or larger** diameter wire must be used for the power connection between the Power Distribution Board and the cRIO Mobile Device Controller.
 - E. **20 AWG or larger** diameter wire must be used for the power connection between the Power Distribution Board and the Linksys Wireless Bridge
 - F. **20 AWG or larger** diameter wire must be used for the power connections between the Power Distribution Board and the Analog Breakouts and/or Solenoid Breakout if individual power feeds are used. **18 AWG or larger** diameter wire must be used if a common power feed is used for multiple breakouts.
 - G. **24 AWG or larger** diameter wire must be used for providing power to pneumatic valves.

Wire Has Resistance

Size		Resistance ohm/1000'	6 feet Resistance (Ohms)	Voltage Drop (Volts)	Maximum Current Capacity
AWG	Diameter inch				
20	0.0369	10.360	0.0622	6.22	5 A
18	0.0465	6.520	0.0391	3.91	7 A
16	0.0587	4.080	0.0245	2.45	12 A
14	0.0740	2.580	0.0155	1.55	20 A
12	0.0933	1.620	0.0097	0.97	30 A
10	0.1177	1.020	0.0061	0.61	50 A
8	0.1484	0.640	0.0038	0.38	80 A
6	0.1871	0.402	0.0024	0.24	125 A
4	0.2360	0.253	0.0015	0.15	200 A

*Calculation shown for 6 feet of wire @ 100 Amps @ 12Vdc
Max Current rating based on allowable 2.5% voltage drop*

Typical FIRST Circuit

Resistances:

8ft of #6 = 0.0032 ohms

6ft of #10 = 0.0060 ohms

Rtotal = 0.0092 ohms

CIM motor stall current 114Amps

Voltage drop = $I \cdot R = 114A \cdot 0.0092\text{Ohms} = 1.05\text{Volts}$

Thus max voltage at **Load** = $12\text{Volts} - 1.058\text{Volts} = 10.95\text{Volts}$

Wire Color Codes

Power wires:

12Volts/5Volts: Typically **RED**, brown

Return: Typically **BLACK**, **blue**

Signal wires:

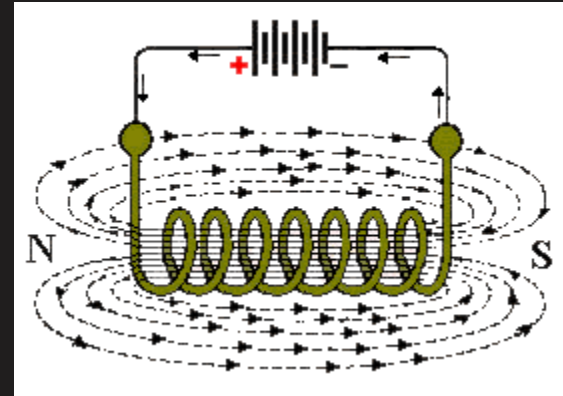
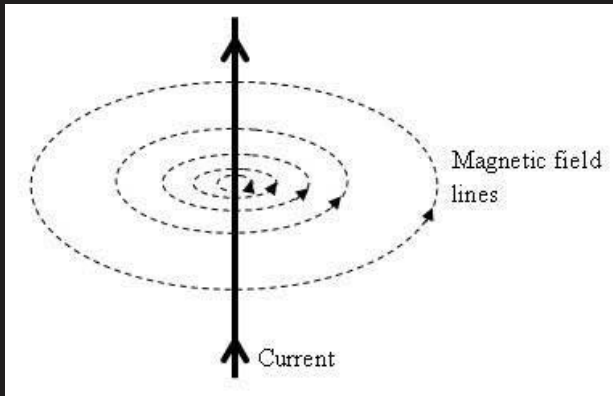
PWM cables: Typically **WHITE**

CAN High **YELLOW**

CAN Low **GREEN**

Magnetism - Electromagnet

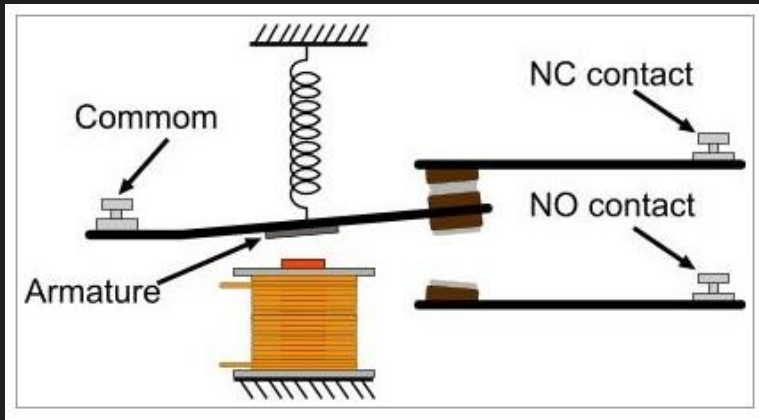
When an electric current is run through a wire, an electromagnetic field is generated



- By winding the wire in a coil, the electromagnetic field is made stronger.
- Adding ferromagnetic material (iron, nickel, cobalt) to the core also increases the electromagnetic field.

RELAY

A Relay Is an Electromagnetic Switch that is used to isolate one electrical circuit from another.



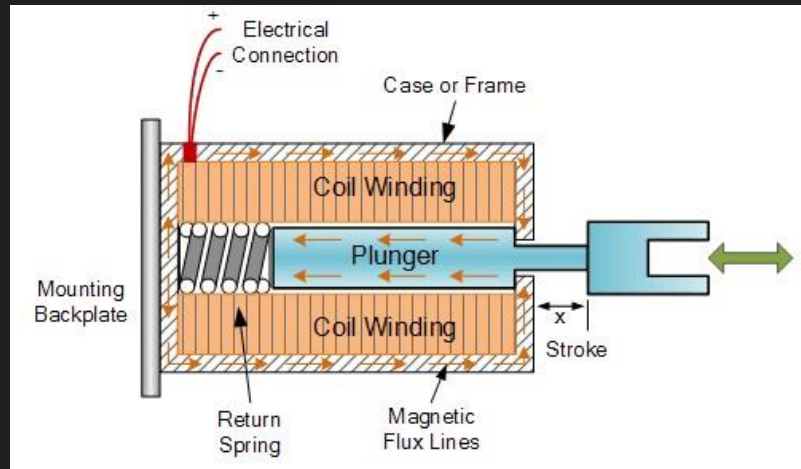
FIRST "SPIKE" Relay



Solenoid

A **solenoid** is simply a specially designed electromagnet that provides linear motion.

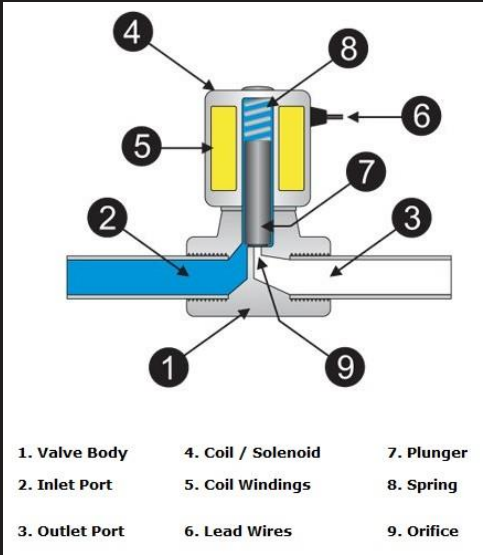
A **solenoid** usually consists of a coil and a movable iron core (plunger) called the *armature*. The movable core is usually spring-loaded to allow the core to retract when the current is switched off.



Solenoid – Solenoid Valve

Solenoids are primarily limited to on-off applications such as latching, locking, and triggering.

Solenoid valve is use to open and close a fluid port.

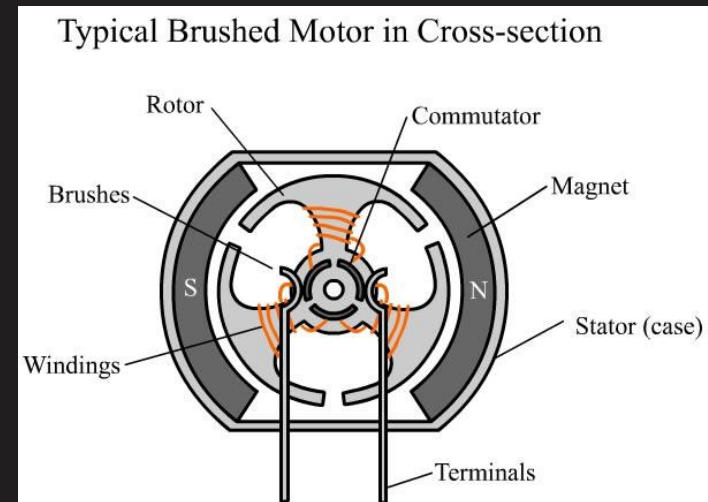
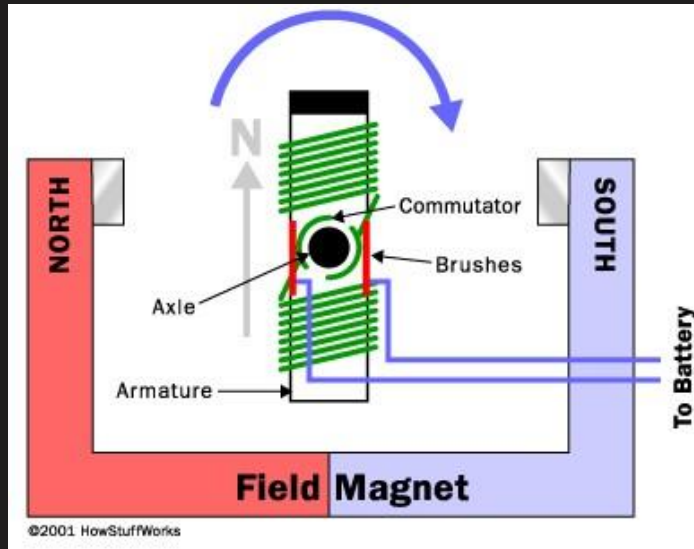


Solenoid Heat

- One of the main disadvantages of solenoids and especially the **linear solenoid** is that they are “inductive devices”. This means that their solenoid coil converts some of the electrical energy used to operate them into “HEAT”.
- In other words when connected for long periods of time to an electrical supply they get hot!
- However, Solenoid valve is designed such that it can be on for a long time and not overheat.

Motor

A **motor** is a special electromagnet that changes **electrical** energy to rotary **mechanical** energy that can do **work**



Electrical History

William Gilbert 1544; known as the 'father of electricity', began his career as a successful physician. Gilbert conducted extensive research on magnets and magnetism

In 1792 **Alessandro Volta** showed that when moisture comes between two different metals, electricity is created. This led him to invent the first electric battery, the voltaic pile,.

George Simon Ohm(1787-1854), a German mathematician and physicist, was a college teacher in Cologne when in 1827 he published, "The Galvanic Circuit Investigated Mathematically". His theories were coldly received by German scientists.

Electrical History

In 1831, **Michael Faraday** discovered that an electrical current could be induced in a copper wire by a moving magnetic field. This led to two crucial inventions: the dynamo (electric current developed by the motion of coils of wire in a magnetic field) and the electric motor.

James Clerk Maxwell (1831 - 1879) developed the laws of electromagnetism in the form we know them today: Maxwell's Equations. Maxwell's Equations are to electromagnetism what Newton's Laws are to gravity

In 1860, the British physicist **Joseph Swan** invented the electric light bulb.

In the late 1800's, the American inventor **Thomas Edison** perfected the light bulb and wanted to use DC current to provide power for lights in houses. This, however, would have meant placing generators at frequent intervals, as a lot of power was lost through the resistance of the cables.

Electrical History

Nikola Tesla(1856-1943) a Serbian-born engineer and inventor who worked with Edison for a time, developed a new kind of generator that produced a current that switched direction many times a second, known as alternating current (AC) . Tesla died a broke and lonely man in New York City.

This had the advantage that the voltage and current could be varied using a transformer. Power loss could be minimized by transmitting the electricity at low current and high voltage, then reducing the voltage and increasing the current for domestic use.

George Westinghouse (1846-1914)[invented in 1869 the air brake system to stop trains.] was awarded the contract in 1893 to build the first AC generators invented by Nikola Tesla at Niagara Falls(1886). He used his money to buy up patents in the electric field. One of the inventions he bought was the transformer from William Stanley.

Revisions

V160611 – RJV – Updated to Team 2228 format
V150829 – RJV - Original