ELECTRICITY

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Electrical Engineering – SS 2019 – Duke TIP

FOUR FUNDAMENTAL FORCES OF NATURE

Four Fundamental Forces Of Nature

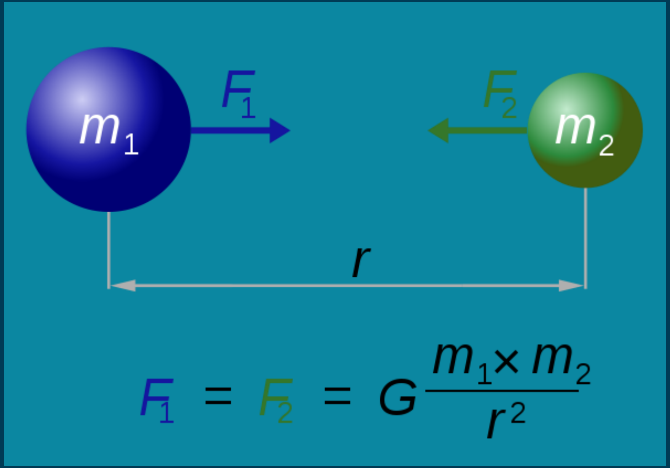
- Gravity
- Strong Nuclear Force
- Weak Nuclear Force
- Electromagnetism

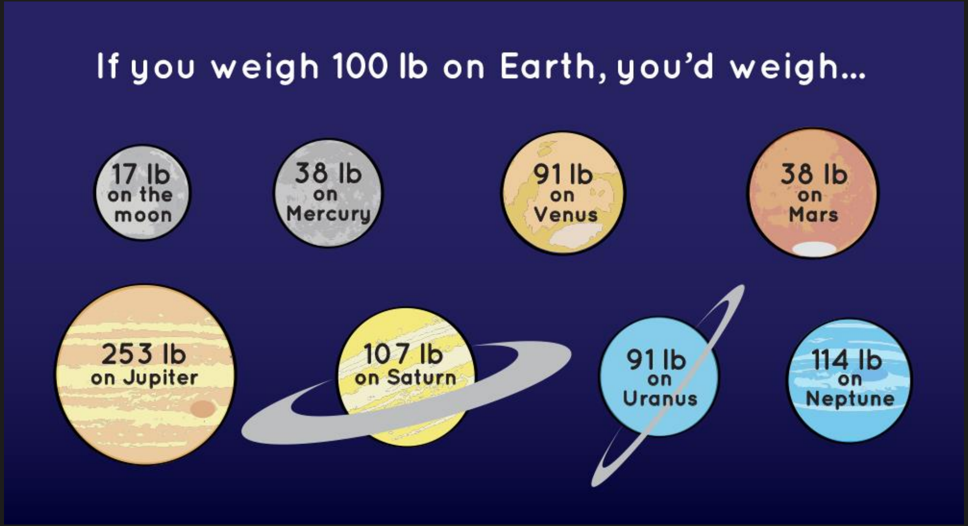
- Responsible for everything in the universe!!

What is gravity?

Gravity

- An attractive force between all things with mass or energy.
- $F = G\frac{m_1 m_2}{r^2}; G = 6.674 \times 10^{-11}\frac{m^3}{kg * s^2}$
- Weakest of the four fundamental forces.
- Infinite range.

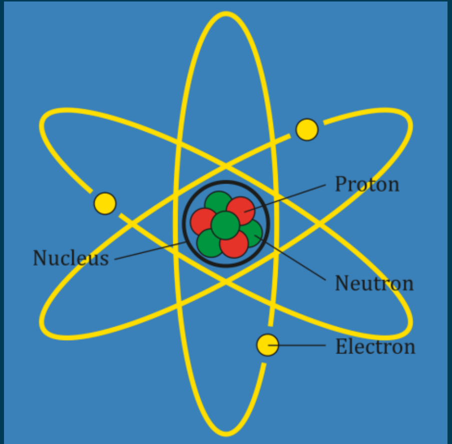



If you weigh 100 lb on Earth, you'd weigh...
17 lb on the moon
38 lb on Mercury
91 lb on Venus
38 lb on Mars
253 lb on Jupiter
107 lb on Saturn
91 lb on Uranus
114 lb on Neptune

ATOMS

Atoms

- An atom is the smallest constituent unit of ordinary matter that has the properties of a chemical element.
- An atom is comprised of a three subatomic particles
  - Protons – resides in the nucleus, has positive charge
  - Neutrons – resides in the nucleus, has no charge
  - Electrons – orbits the nucleus, has negative charge



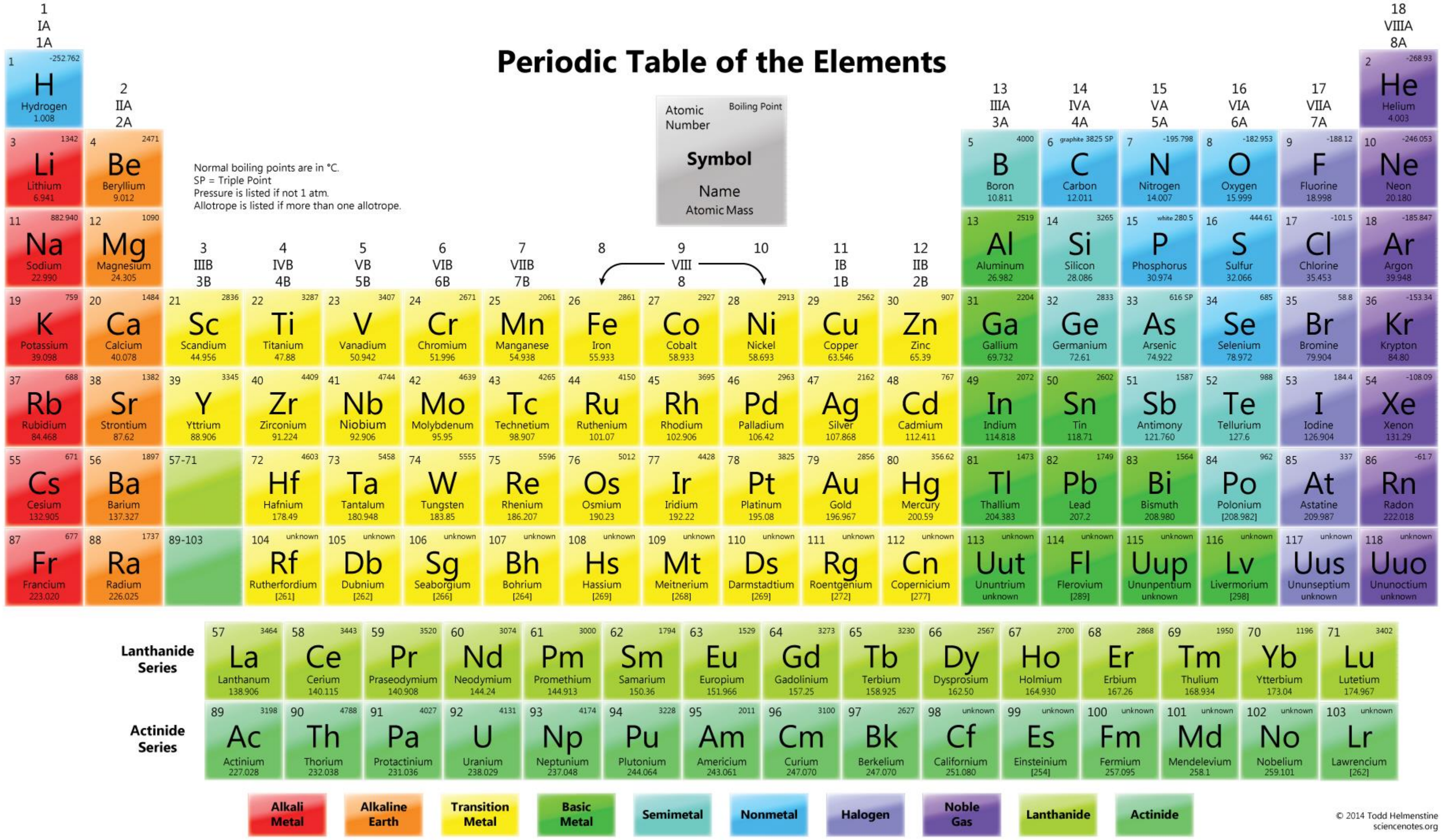
Nucleus

- Contains over 99.9% of an atom’s mass.
- Has an overall positive charge.
- Typically same number of protons as neutrons.
- Provides an attractive force towards the negatively-charged electrons that orbit the nucleus.

Electrons (e^-)

- The smallest subatomic particle.
- Orbit the nucleus in shells.
- Each shell seeks a specific number of electrons.
- The outer shell of electrons is called the valence shell
  - Wants to fully fill or empty it’s outer shell.
  - Responsible for bonding properties.
  - Electrons in valence shell are considered free electrons because they can move freely and form bonds with other atoms.

Periodic Table of the Elements



Normal boiling points are in °C.
SP = Triple Point
Pressure is listed if not 1 atm.
Allotrope is listed if more than one allotrope.

Atomic Number	Boiling Point
Symbol	
Name	
Atomic Mass	

1 IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 VIII 8	10	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 -252.762 H Hydrogen 1.008																	2 -268.93 He Helium 4.003
3 1342 Li Lithium 6.941	4 2471 Be Beryllium 9.012											5 4000 B Boron 10.811	6 graphite 3825 SP C Carbon 12.011	7 -195.798 N Nitrogen 14.007	8 -182.953 O Oxygen 15.999	9 -188.12 F Fluorine 18.998	10 -246.053 Ne Neon 20.180
11 882.940 Na Sodium 22.990	12 1090 Mg Magnesium 24.305											13 2519 Al Aluminum 26.982	14 3265 Si Silicon 28.086	15 white 280.5 P Phosphorus 30.974	16 444.61 S Sulfur 32.066	17 -101.5 Cl Chlorine 35.453	18 -185.847 Ar Argon 39.948
19 759 K Potassium 39.098	20 1484 Ca Calcium 40.078	21 2836 Sc Scandium 44.956	22 3287 Ti Titanium 47.88	23 3407 V Vanadium 50.942	24 2671 Cr Chromium 51.996	25 2061 Mn Manganese 54.938	26 2861 Fe Iron 55.933	27 2927 Co Cobalt 58.933	28 2913 Ni Nickel 58.693	29 2562 Cu Copper 63.546	30 907 Zn Zinc 65.39	31 2204 Ga Gallium 69.732	32 2833 Ge Germanium 72.61	33 616 SP As Arsenic 74.922	34 685 Se Selenium 78.972	35 58.8 Br Bromine 79.904	36 -153.34 Kr Krypton 84.80
37 688 Rb Rubidium 84.468	38 1382 Sr Strontium 87.62	39 3345 Y Yttrium 88.906	40 4409 Zr Zirconium 91.224	41 4744 Nb Niobium 92.906	42 4639 Mo Molybdenum 95.95	43 4265 Tc Technetium 98.907	44 4150 Ru Ruthenium 101.07	45 3695 Rh Rhodium 102.906	46 2963 Pd Palladium 106.42	47 2162 Ag Silver 107.868	48 767 Cd Cadmium 112.411	49 2072 In Indium 114.818	50 2602 Sn Tin 118.71	51 1587 Sb Antimony 121.760	52 988 Te Tellurium 127.6	53 184.4 I Iodine 126.904	54 -108.09 Xe Xenon 131.29
55 671 Cs Cesium 132.905	56 1897 Ba Barium 137.327	57-71	72 4603 Hf Hafnium 178.49	73 5458 Ta Tantalum 180.948	74 5555 W Tungsten 183.85	75 5596 Re Rhenium 186.207	76 5012 Os Osmium 190.23	77 4428 Ir Iridium 192.22	78 3825 Pt Platinum 195.08	79 2856 Au Gold 196.967	80 356.62 Hg Mercury 200.59	81 1473 Tl Thallium 204.383	82 1749 Pb Lead 207.2	83 1564 Bi Bismuth 208.980	84 962 Po Polonium [208.982]	85 337 At Astatine 209.987	86 -61.7 Rn Radon 222.018
87 677 Fr Francium 223.020	88 1737 Ra Radium 226.025	89-103	104 unknown Rf Rutherfordium [261]	105 unknown Db Dubnium [262]	106 unknown Sg Seaborgium [266]	107 unknown Bh Bohrium [264]	108 unknown Hs Hassium [269]	109 unknown Mt Meitnerium [268]	110 unknown Ds Darmstadtium [269]	111 unknown Rg Roentgenium [272]	112 unknown Cn Copernicium [277]	113 unknown Uut Ununtrium unknown	114 unknown Fl Flerovium [289]	115 unknown Uup Ununpentium unknown	116 unknown Lv Livermorium [298]	117 unknown Uus Ununseptium unknown	118 unknown Uuo Ununoctium unknown

Lanthanide Series	57 3464 La Lanthanum 138.906	58 3443 Ce Cerium 140.115	59 3520 Pr Praseodymium 140.908	60 3074 Nd Neodymium 144.24	61 3000 Pm Promethium 144.913	62 1794 Sm Samarium 150.36	63 1529 Eu Europium 151.966	64 3273 Gd Gadolinium 157.25	65 3230 Tb Terbium 158.925	66 2567 Dy Dysprosium 162.50	67 2700 Ho Holmium 164.930	68 2868 Er Erbium 167.26	69 1950 Tm Thulium 168.934	70 1196 Yb Ytterbium 173.04	71 3402 Lu Lutetium 174.967
Actinide Series	89 3198 Ac Actinium 227.028	90 4788 Th Thorium 232.038	91 4027 Pa Protactinium 231.036	92 4131 U Uranium 238.029	93 4174 Np Neptunium 237.048	94 3228 Pu Plutonium 244.064	95 2011 Am Americium 243.061	96 3100 Cm Curium 247.070	97 2627 Bk Berkelium 247.070	98 unknown Cf Californium 251.080	99 unknown Es Einsteinium [254]	100 unknown Fm Fermium 257.095	101 unknown Md Mendelevium 258.1	102 unknown No Nobelium 259.101	103 unknown Lr Lawrencium [262]

Alkali Metal **Alkaline Earth** **Transition Metal** **Basic Metal** **Semimetal** **Nonmetal** **Halogen** **Noble Gas** **Lanthanide** **Actinide**

Periodic Table

- For our purposes, it is important to be able to determine the atomic number and the number of valence electrons for each element.
- This helps us characterize the elements to understand their electrical properties as:
    - Conductors
    - Insulators
    - Semiconductors

FOUR FUNDAMENTAL FORCES OF NATURE

Resumed

Strong Nuclear Force

- The force which holds the nucleus together.
- Stronger than all of the other fundamental forces.
- Protons and Neutrons are comprised of quarks.
- “Color” force is what holds quarks together.
- Force only acts within a small range (diameter of nucleus).
- Protons are positive
- Neutrons are neutral

Weak Nuclear Force

- The force that deals with radioactive decay.
- Causes quarks to change their “flavor”.
- Responsible for things like carbon dating & fusion.
- Works over even smaller range (0.1% size of proton).

Strong and Weak Nuclear Forces

- To fully understand these, we would have to dive deep into quantum physics.
- It is important to just recognize that these forces are at work at the subatomic level and are responsible for many phenomenon.
- For our purposes, we will focus on the electrons and how it relates to a difference in charge that creates the electromagnetic force.

Electromagnetism

- The force that acts between electrically charged particles.
    - Opposite charges attract. Like charges repel.
    - Why? Everything wants to be neutral or balanced.
    - Keeps electrons orbiting nucleus.
- This phenomenon includes the electrostatic force acting between charged particles at rest, and the combined effect of electric and magnetic forces acting between charged particles moving relative to each other.
- Works over an infinite range like gravity.
- Stronger than gravity and weak nuclear force.

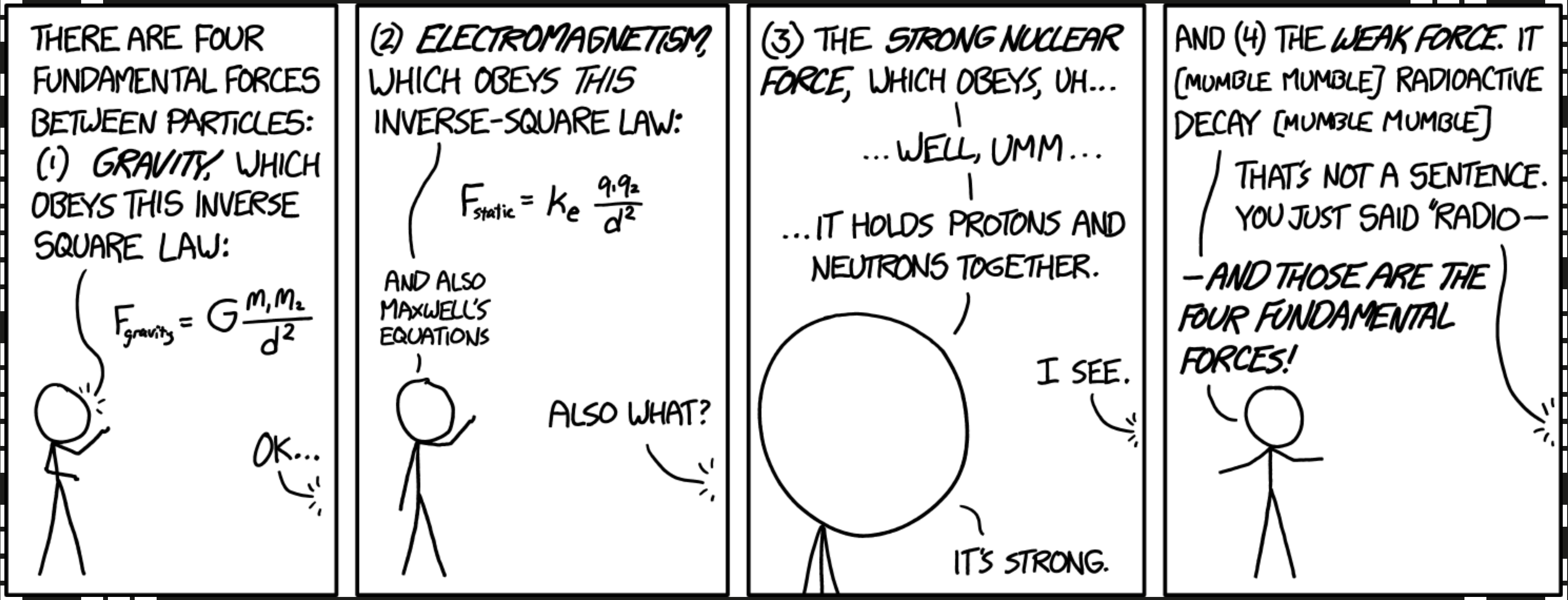
Electricity and Magnetism

- They were originally thought to be separate forces.
- Now we recognize them as two different manifestations of the same force: electromagnetism.
- The presence of an electric charge, which can be either positive or negative, produces an electric field.
- The movement of electric charges is an electric current and produces a magnetic field.

- We will circle back around to this later.

Activity: Build an Electromagnet

Activity: Build a Generator


THERE ARE FOUR FUNDAMENTAL FORCES BETWEEN PARTICLES: (1) *GRAVITY,* WHICH OBEYS THIS INVERSE SQUARE LAW:
$F_{gravity} = G\frac{m_1 m_2}{d^2}$
OK...
(2) *ELECTROMAGNETISM,* WHICH OBEYS *THIS* INVERSE-SQUARE LAW:
$F_{static} = k_e \frac{q_1 q_2}{d^2}$
AND ALSO MAXWELL'S EQUATIONS
ALSO WHAT?
(3) THE *STRONG NUCLEAR FORCE,* WHICH OBEYS, UH...
...WELL, UMM...
...IT HOLDS PROTONS AND NEUTRONS TOGETHER.
I SEE.
IT'S STRONG.
AND (4) THE *WEAK FORCE.* IT [MUMBLE MUMBLE] RADIOACTIVE DECAY [MUMBLE MUMBLE]
THAT'S NOT A SENTENCE. YOU JUST SAID "RADIO—
—AND THOSE ARE THE FOUR FUNDAMENTAL FORCES!

STATIC ELECTRICITY

What is static electricity?

- Have you ever rubbed a balloon against your shirt?
- What happened? Why? -> Static Electricity!
- https://phet.colorado.edu/en/simulation/balloons-and-static-electricity

How does this happen?

- When you rub certain materials together (typically 2 insulators), they can swap electrons.
- Electrons are easily dislodged.
- Rubbing puts the atoms in close proximity causing certain materials to lose electrons and causing others to gain electrons.
  - Materials like rubber, silk tend to gain electrons.
    - Negative
  - Materials like wool, glass tend to lose electrons.
    - Positive

Static Electricity

- Static electricity is an imbalance of electric charges within or on the surface of a material.
- The charge remains until it is able to move away by means of an electric current or electrical discharge.
- *Static Electricity* is named in contrast with *Current Electricity*, which flows through wires or other conductors and transmits energy.

Activity: Static Electricity

CONSERVATION OF CHARGE

Conservation of Charge

- The total quantity of charge in the universe is constant.
- It is assumed to be zero.
- The total charge in a given isolated volume does not become positive or negative, it can only be redistributed.
- Charges want to spread out and become neutral, so a force must be applied to redistribute.

ELECTRIC CHARGE

What is electric charge?

- The presence of electric charge causes an electrostatic force.
- A charge can be:
  - Positive: fewer electrons than protons
  - Negative: more electrons than protons
- In 1785, Charles-Augustin de Coulomb discovered the forces caused by opposite and like charges.
- He did this by rubbing glass and amber rods with a cloth and finding that they would attract each other.

- *The term electricity comes from the Greek word for Amber!

Coulomb's Law

- Electric charge is abbreviated with an uppercase "Q".
- Units are in Coulombs (C).
- $F = k_e \frac{Q_1 Q_2}{r^2};\ k_e \approx 9 \times 10^9 \frac{N * m^2}{C^2}$
    - If charges are opposite, F is negative -> attractive.
    - If charges are the same, F is positive -> repulsive.

- As the charges increase, the force increases.
- As the distance increases, the force decreases.

Charge of an Electron

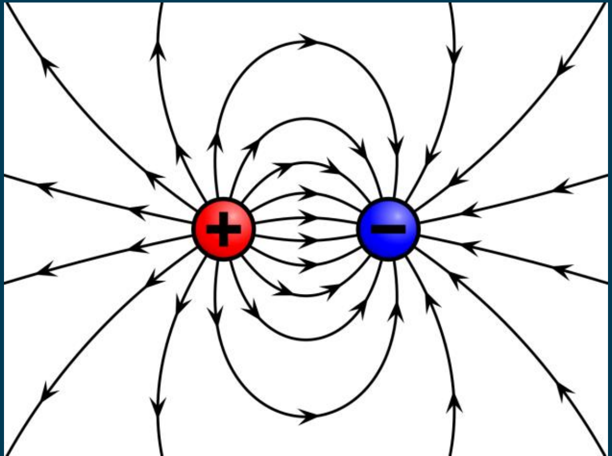
- An electron has a charge of $q_e = -1.6022 \times 10^{-19}$ C
- Known as the elementary charge.

- How do we carry a charge?

ELECTRIC FIELDS

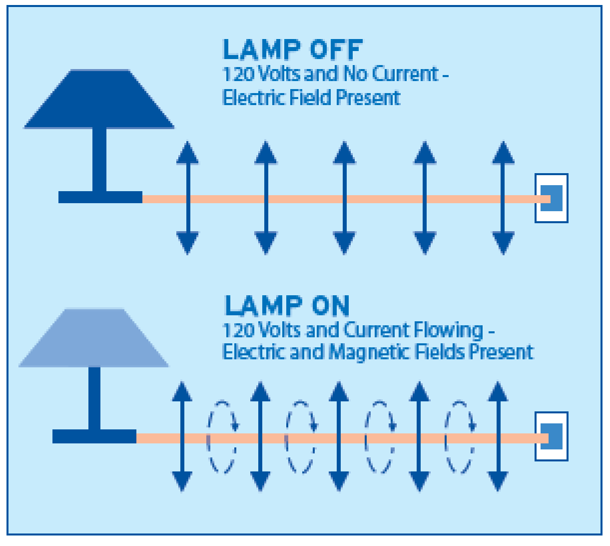
Electric Fields

- An electric field surrounds an electric charge, and exerts force on other charges in the field, attracting or repelling them.
- Units are $\frac{Newtons}{Coulomb}\left(\frac{N}{C}\right)$ or $\frac{Volts}{Meter}\left(\frac{V}{m}\right)$



Electric Fields

- We will return to this concept later to learn more about Electric Fields.
- Just know that every charged particle exerts a force outward.



CONDUCTORS & INSULATORS

Conductivity

- Some materials have electrons that move more easily.
- *Free electrons* – electrons with a high mobility.
- *Conductivity* is the property that describes how freely the electrons can move. High conductivity means electrons are more free.
- We can classify materials as two types:
  - Conductors – high conductivity, more free e^-
  - Insulators – low conductivity, less free e^-

Conductors

- Materials with high conductivity or more free electrons.
- Useful for carrying electric charge.
- We use conductors to transmit electricity!
- Examples: silver, copper, gold, aluminum, iron, steel, brass, bronze, mercury, graphite, dirty water.

Insulators

- Materials with low conductivity or less free electrons.
- Useful for preventing the carriage of electric charge.
- We use insulators to stop the flow of or shield us from electricity!
- Examples: glass, rubber, plastic, wood/paper, cotton, fiberglass, porcelain, air, diamond, clean water.

CURRENT ELECTRICITY

Current Electricity

- Current Electricity or Dynamic Electricity is contrasted with Static Electricity.
- Static Electricity - an imbalance of electric charges.
    - No energy transmitted. Potential Energy
- Current Electricity – charges flow through conductors and transmit energy.
    - Energy is transmitted. Kinetic Energy

CURRENT

Electric Current

- Electric Current - the rate of flow of electric charge.
- Abbreviated with an uppercase “I”.
- Units are in Amperes or Amps (A)
- $I = \frac{Q}{t}$
- 1 Amp is equivalent to 1 Coulomb of charge crossing a specific point in 1 second.
- Named after André-Marie Ampère who worked in electromagnetics writing Ampere’s Law in 1825.

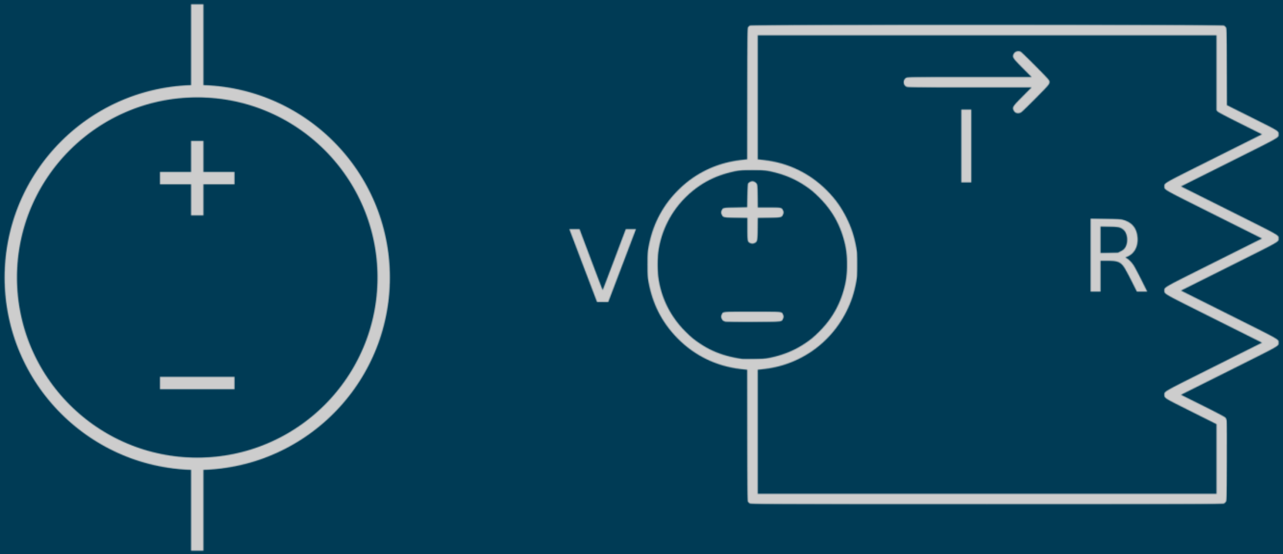
VOLTAGE

Electric Potential or Voltage

- Voltage is the difference in electric potential between two points.
- Unit is volts (V). Abbreviation is uppercase “V”.
- $Voltage\ (volts) = \frac{Energy\ (joules)}{Charge\ (coulombs)}$
- Voltage is the amount of work to be done (or potential energy) per unit charge.
- Named after Alessandro Volta who developed the voltaic pile (early battery) in 1799.

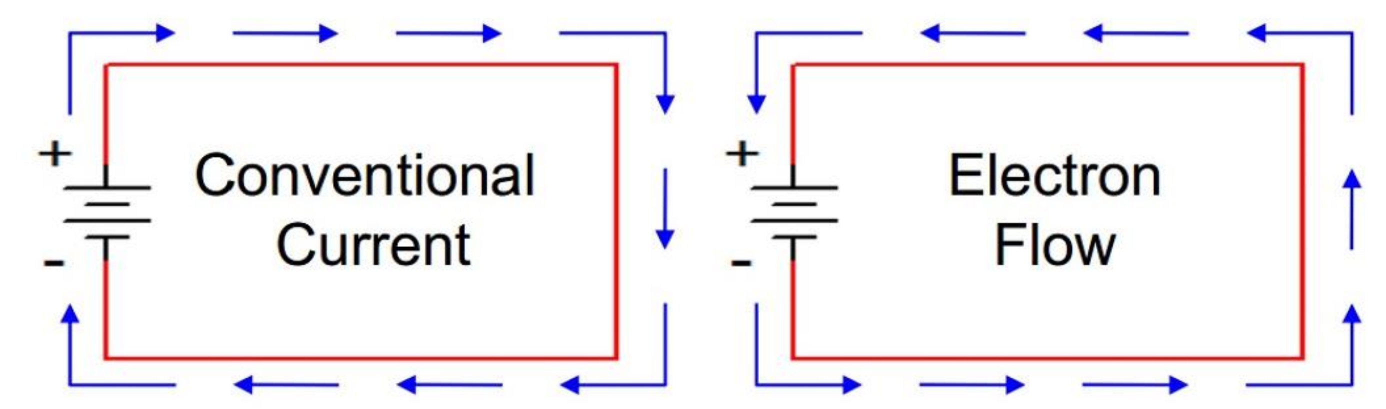
Voltage Sources

- Provide a specified voltage level to a circuit.
- Can be lab power supply, batteries, generator, etc.

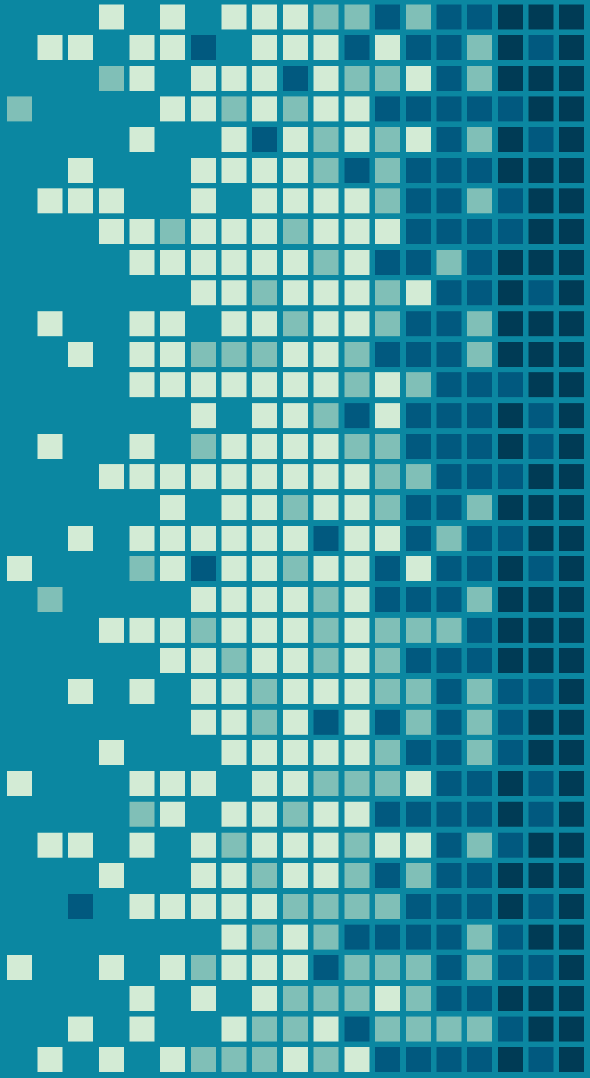


Current Convention

- In electrical engineering, we standardized on current flowing from higher voltage to lower voltage.
- This is the opposite direction of electron flow.
- Think about it as flow of positive charge.



RESISTANCE

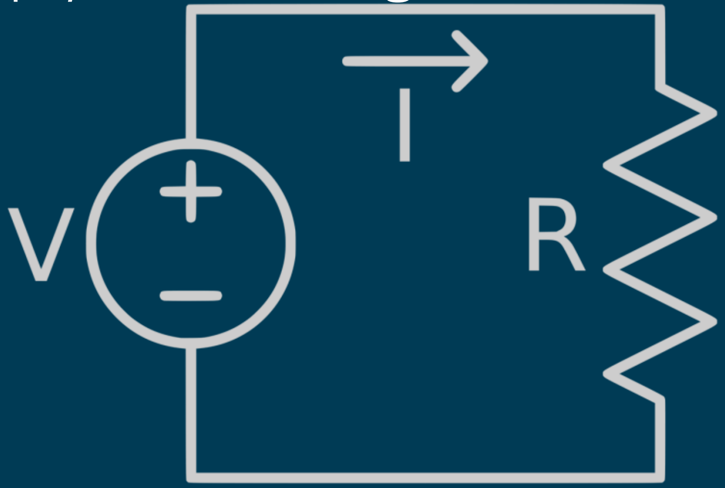


Resistance

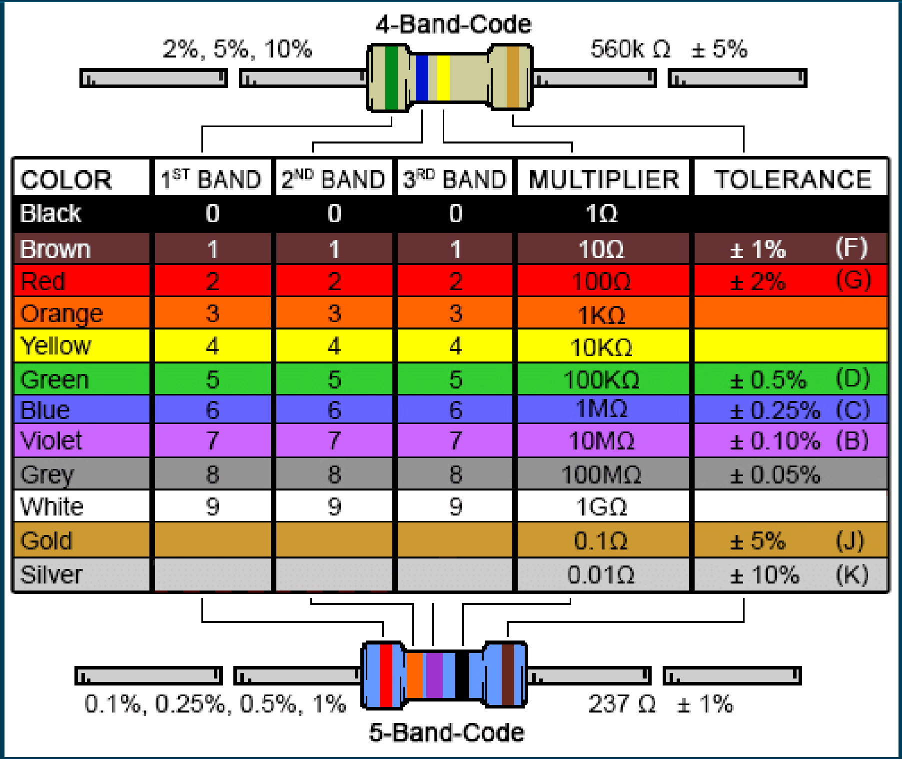
- Resistance is a measure of an object’s opposition to the flow of electric current.
- It is the inverse of conductivity.
- $Resistance = \frac{1}{Conductivity}$
- Insulators have a very high resistance.
- Conductors have a very low resistance.
- Units are Ohms (Ω). Abbreviation is uppercase “R”.

Resistors

- A passive circuit component that provides a constant resistance.
- Can be lab power supply, batteries, generator, etc.



Resistor Color Guide



COLOR	1^{ST} BAND	2^{ND} BAND	3^{RD} BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8	100MΩ	± 0.05%
White	9	9	9	1GΩ	
Gold				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)

- https://www.digikey.com/en/resources/conversion-calculators/conversion-calculator-resistor-color-code-4-band

Resistors in Your Kit

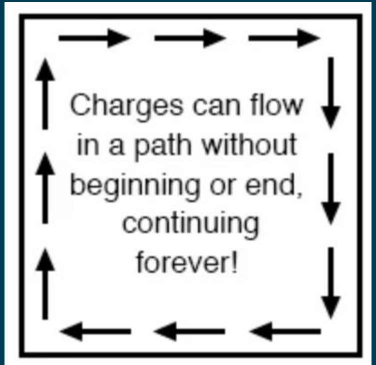
- You should have the following resistors in your kit
  - 10x 10 Ω Resistors
  - 10x100 Ω Resistors
  - 10x 220 Ω Resistors
  - 10x 330 Ω Resistors
  - 10x 1 kΩ Resistors
  - 10x 2 kΩ Resistors
  - 10x 5.1 kΩ Resistors
  - 10x 10 kΩ Resistors
  - 10x 100 kΩ Resistors
  - 10x 1 MΩ Resistors
- See if you can identify them by their color bands.

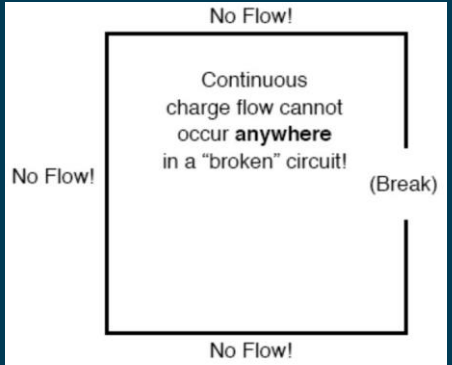
CIRCUITS

Circuit

- Circuit - a circular journey or one beginning and ending at the same place; a round. (Dictionary definition)
- In terms of an electricity, a circuit is a never-ending path for electrical charge to be carried.
- If a circuit is broken, it ceases to be a circuit.
  - The charge cannot continue to flow.
  - There is no more current. I = 0 A

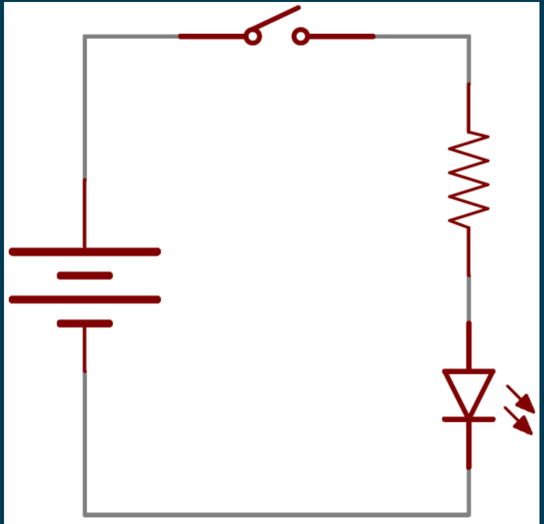
*Known as an open circuit





Circuits and Switches

- Switches – turn circuits on or off by allowing current to either flow or not.
- Switches are either in the open state (off, no current flow) or closed state (on, current flow)
- Switch closed = on or short
- Switch open = off or open



OHM’S LAW

Ohm's Law

- Developed by Georg Ohm developed a relationship between voltage, current, and resistance in 1827.
- Ohm's law states that the current through a conductor between two points is directly proportional to the voltage across the two points.
- $I = \frac{V}{R}; \quad V = IR; \quad R = \frac{V}{I}$

Ohm's Law Animation

- https://phet.colorado.edu/sims/html/ohms-law/latest/ohms-law_en.html
- https://www.falstad.com/circuit/circuitjs.html
  - Basics – Ohm's Law
  - Basics – Resistors

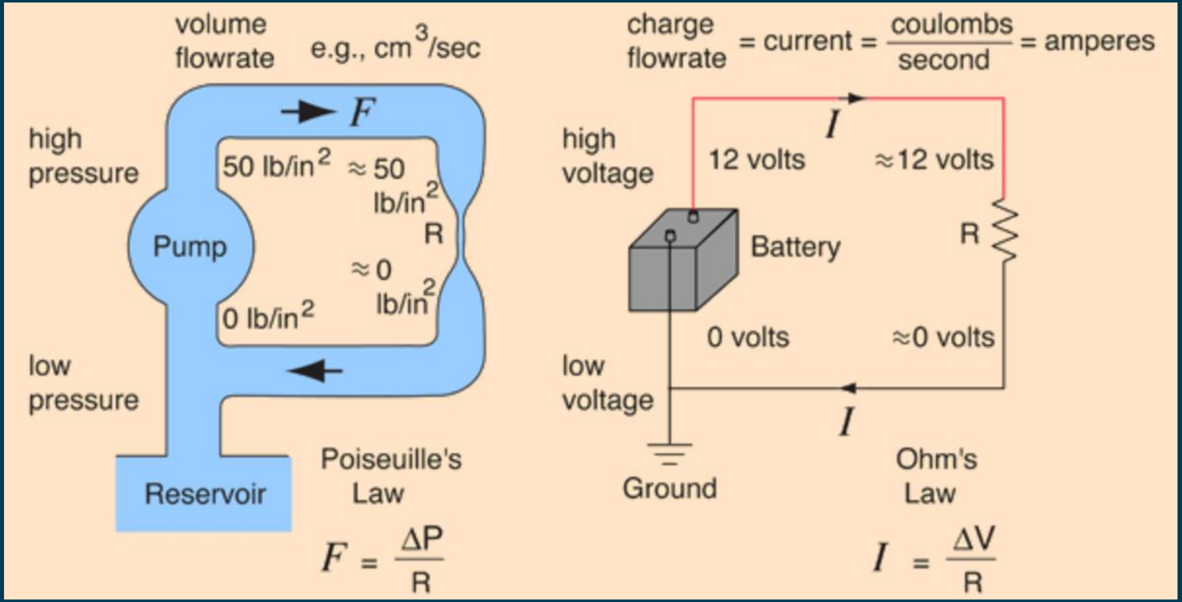
WATER FLOW ANALOGY

Water Flow Analogy

- Voltage – water pressure
- Current – water flow rate. Water flows from high pressure to low pressure
- Charge – quantity of water
- Conductor – a simple pipe
- Resistor – a constricted pipe (smaller diameter, harder to flow through).

Water Flow Analogy

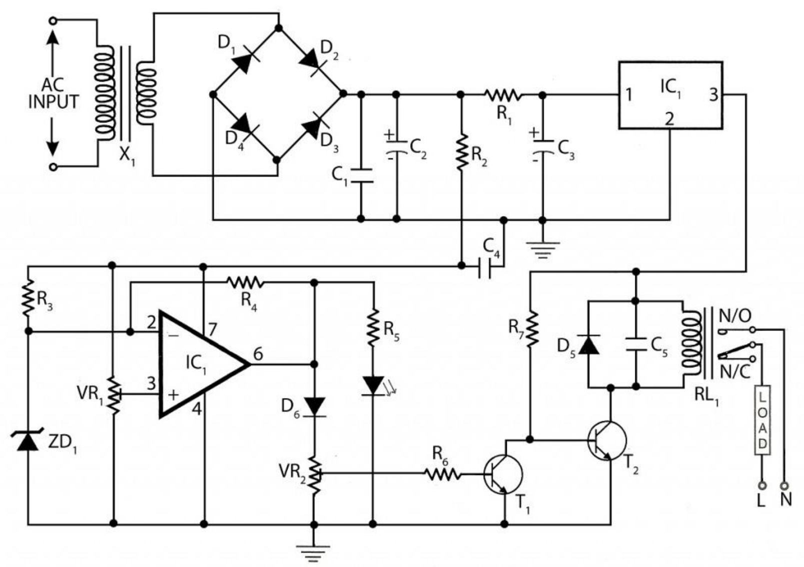
- http://hyperphysics.phy-astr.gsu.edu/hbase/electric/watcir.html



VOLTAGE REFERENCES

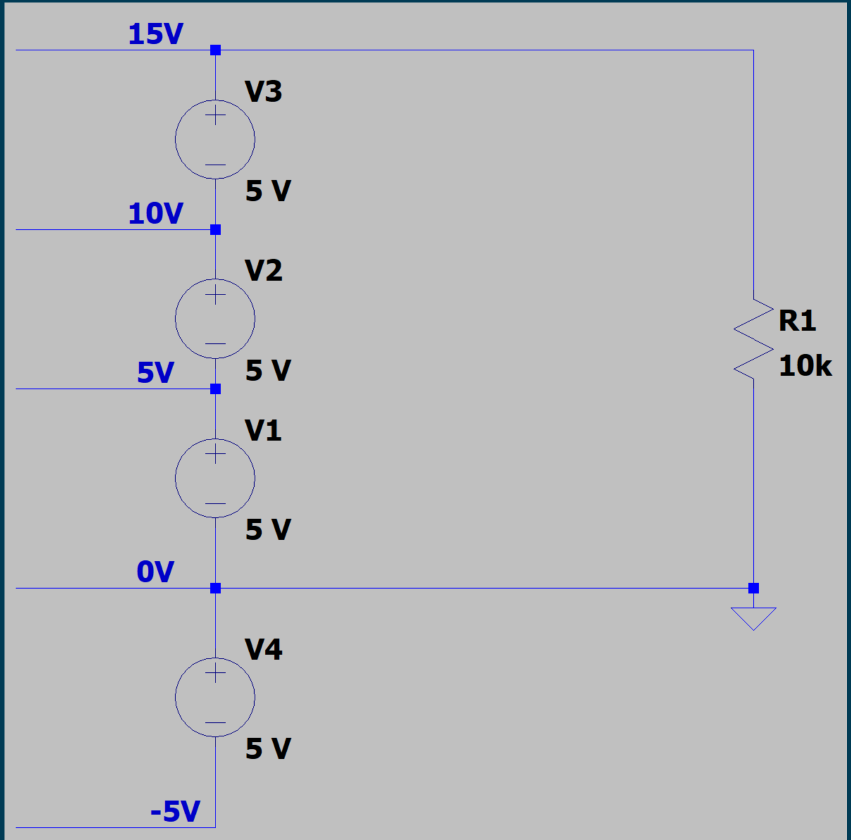
Common or Ground Reference

- The ground signal in our circuit is used to show a common reference.
- Anything connected to Ground is 0V.
- In electronics, it is used as a common reference to 0 V. It does not necessarily mean that it is earth grounded. More on this later.



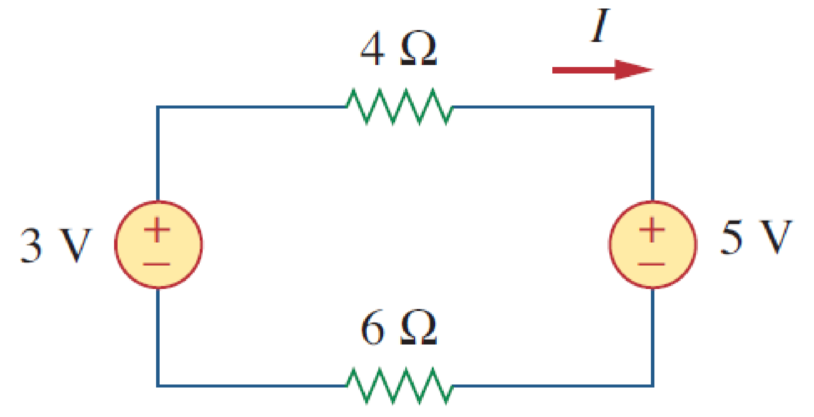
Voltage References

- Start from ground reference and go from there.

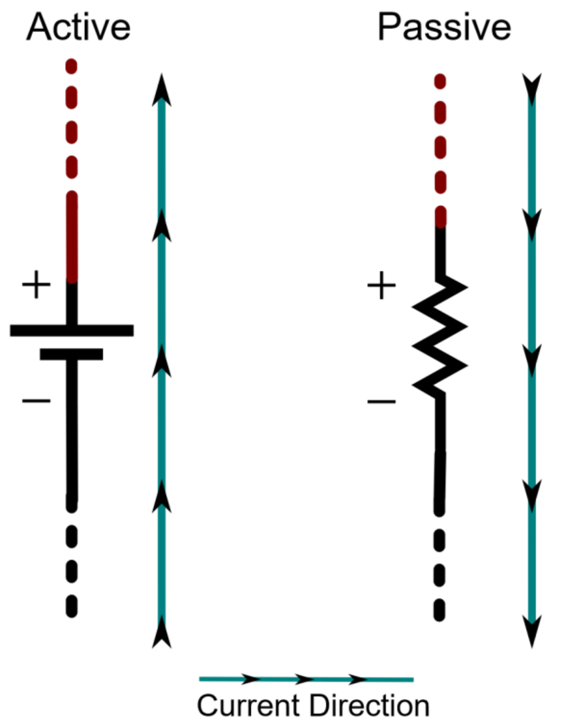


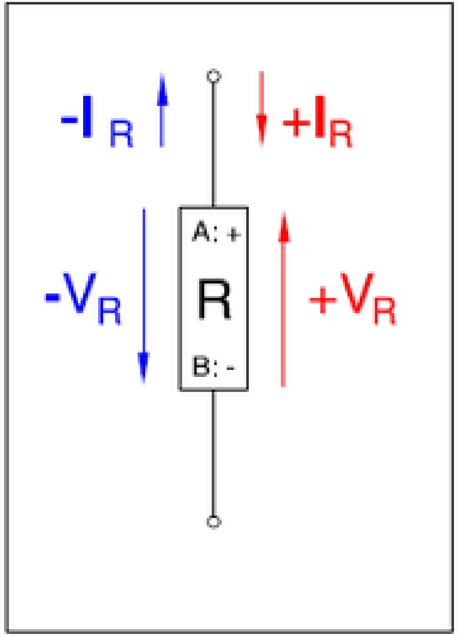
Voltage References Continued

- If current flows into the positive side of a component in a circuit, voltage is dropped.
- If current flows into the negative side of a component in a circuit, the voltage is gained.
- Called the Passive Sign Convention.



Sign Convention



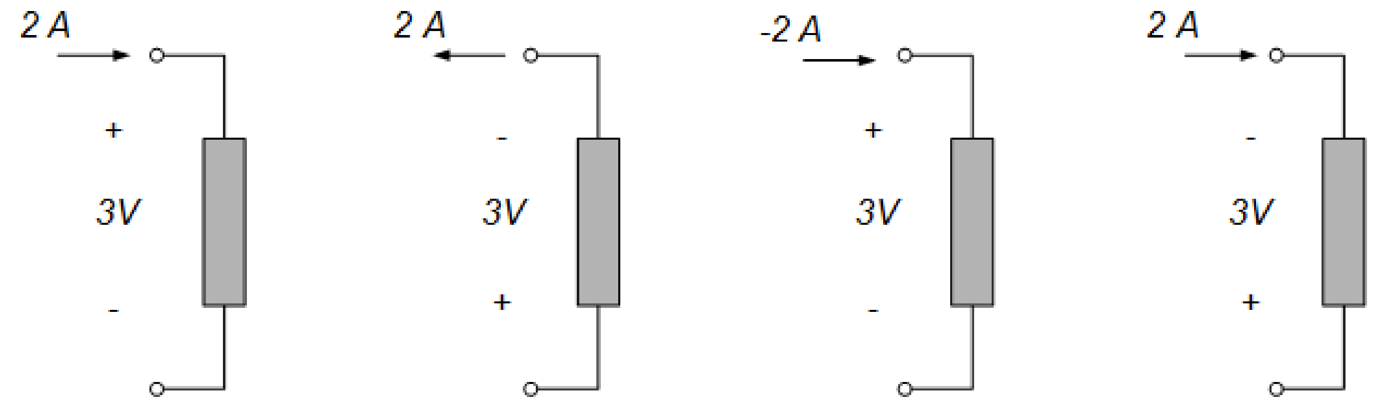


+V & +I :
-V & -I :
Power Absorbed

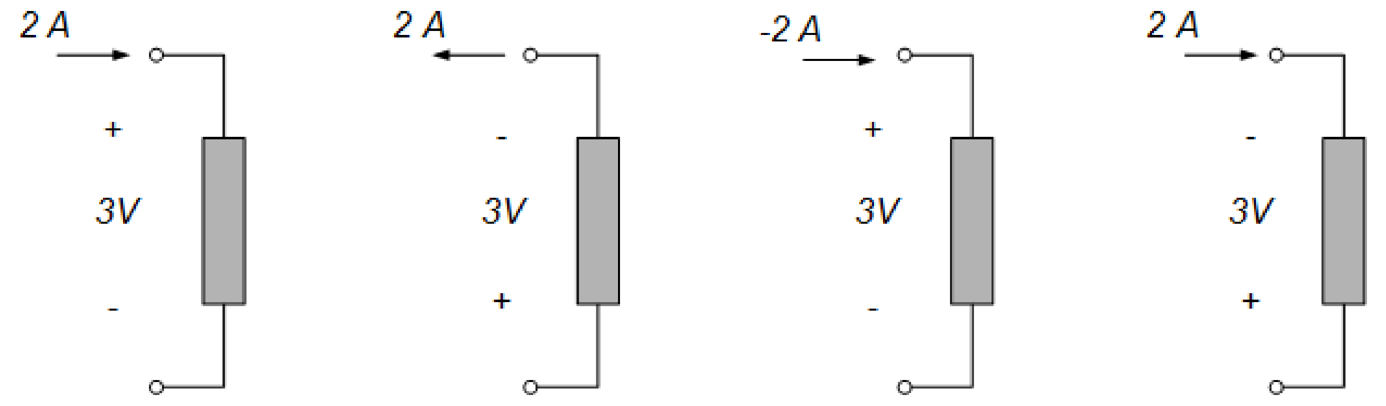
+V & -I :
-V & +I :
Power Supplied

P = V x I
+P = Power Absorbed
-P = Power Supplied

Is power absorbed or generated?



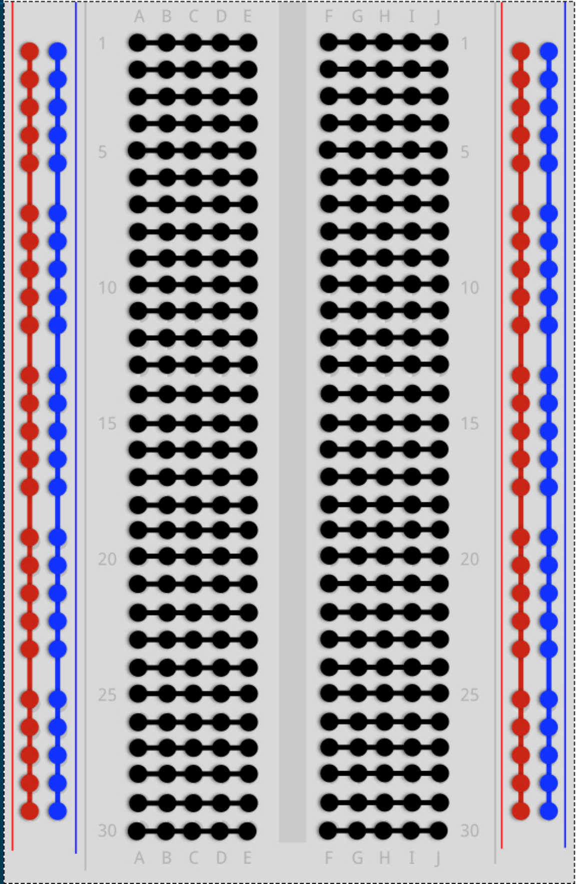
Is power absorbed or generated?



(a) 6W absorbed (b) 6W absorbed (c) 6W generated (d) 6W generated

OHM'S LAB

Solderless Breadboard Connections



Breadboards

- Why is it called a breadboard?

- Collin’s Lab Breadboard:

https://www.youtube.com/watch?v=HrG98HJ3Z6w

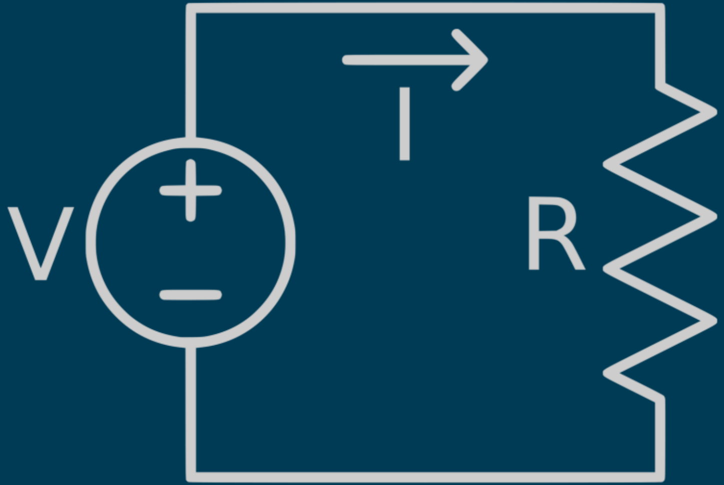
Activity: Measuring V, I, R

- Voltmeter – measures voltage
  - Must be put in parallel with the component you would like to measure the voltage across.
- Ammeter – measures current
  - Must be put in series with the circuit so the current flows through it. (circuit must be broken)
- Ohmmeter – measures resistance
  - Must be put in parallel with the component you would like to measure the resistance of.
- Multimeter – measures V, I, & R. Must move probes to measure I, then back again to measure V or R.

Activity: Ohm’s Law

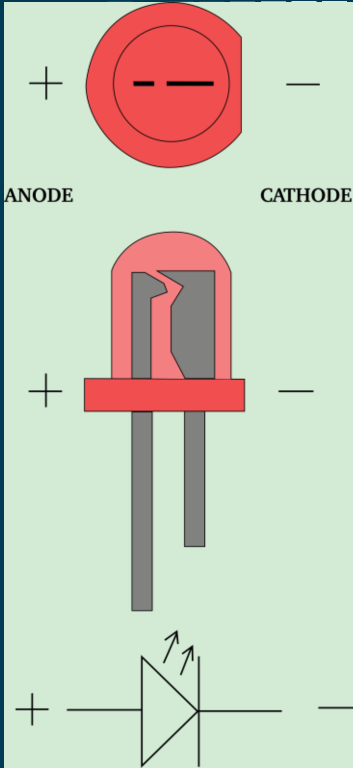
- Set up circuit as shown below using 5V supply.
- What happens to the current as you increase resistance?
  - Use at least 3 different resistors.
  - Measure V, I, & R.
  - Do your measurements agree with Ohm’s law?

*Make sure probes are properly connected to multimeter.



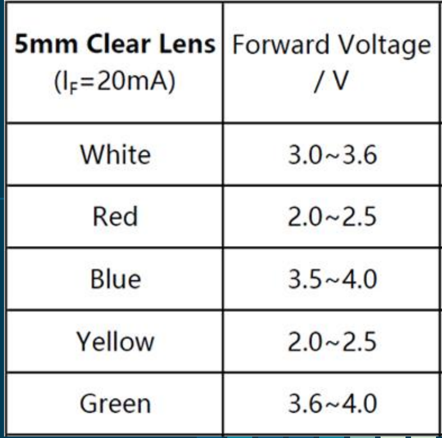
Quick Note about LEDs

- LED or light emitting diode is a type of semiconductor that we will discuss in more detail later.
- LEDs have polarity and only allow current flow in one direction from the anode to cathode.
- LEDs have a specific turn-on or forward voltage.
  - Typically between 1.8 and 3.3V, depends on color.
- LEDs want to maintain that forward voltage.
  - If there is too much voltage across them or too much current flowing through them, they will blow.
  - Typically only want 10-20 mA of current.

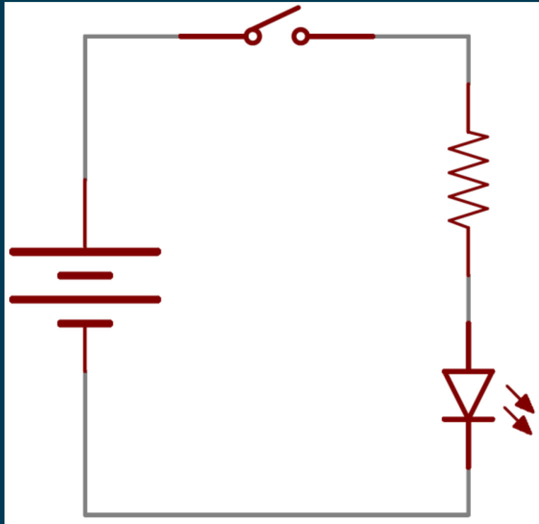


LEDs – Series Resistor

- In order to protect LEDs, we add a series resistor.
- Series resistors limit current by helping the LED maintain the forward voltage.
- $V_s = V_R + V_F$
  - V_s - supply voltage
  - V_R - voltage across resistor
  - V_F - forward voltage (V across LED)
- How do we calculate series resistor value?
  - Hint: Use Ohm's Law

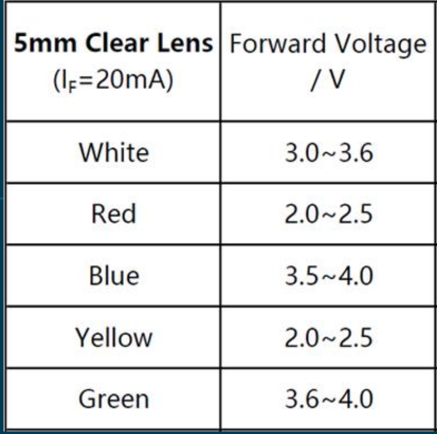


5mm Clear Lens (I_F=20mA)	Forward Voltage / V
White	3.0~3.6
Red	2.0~2.5
Blue	3.5~4.0
Yellow	2.0~2.5
Green	3.6~4.0



LEDs – Series Resistor

- $V_s = V_R + V_F$
- $V_R = I \times R; \quad R = \frac{V_R}{I}; \quad V_R = V_s - V_F$
- $R = \frac{V_S - V_F}{I}$
    - V_s - supply voltage
    - V_R - voltage across resistor
    - I – target current (typically 10-20mA)



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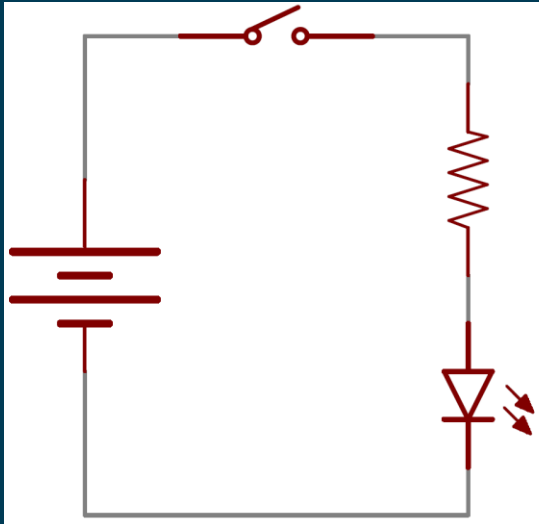
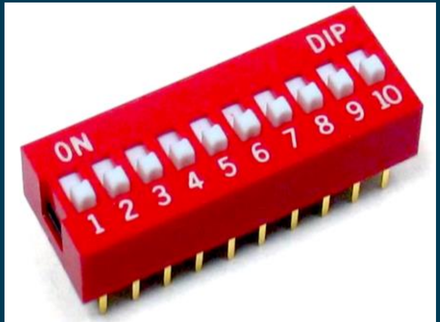


Types of Switches

- Types of switches: pushbutton, rocker switch, DIP switch, knife switch, toggle switch, rotary switch, and many, many more.
- We will mostly use these three:

DIP Switch

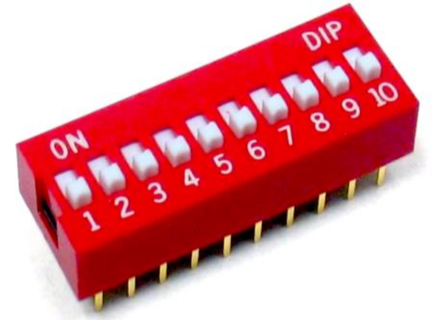


Pushbutton

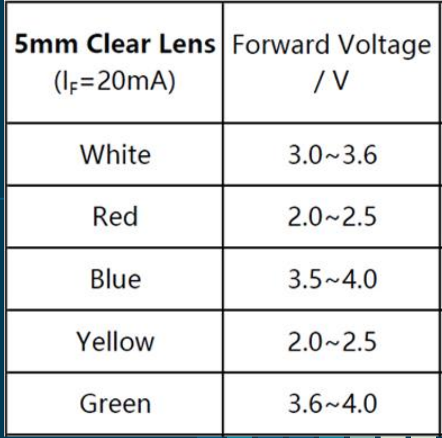
Tilt Ball Switch

Activity: Switches?

- Figure out how these switches work using a multimeter to test conductivity or measure resistance.
- When is it opened?
- When is it closed?



Lab Activity: Switch on/off LED



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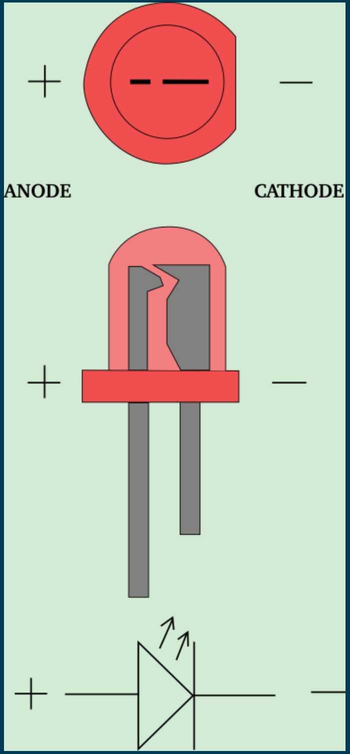
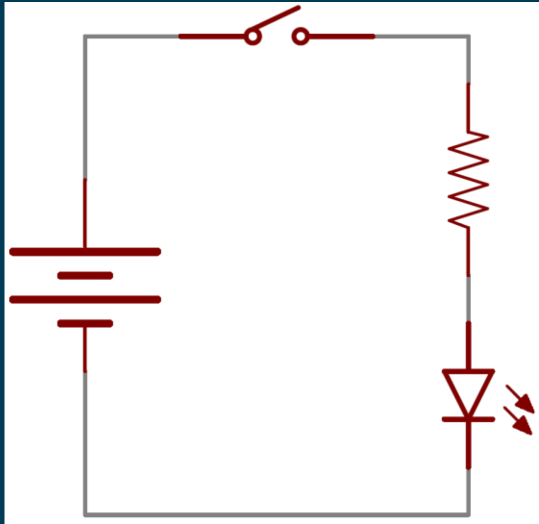
- Use 5V supply voltage.
- Use LED of your choice.
- Use switch of your choice.
- Calculate appropriate series resistor value.
- $R = \frac{V_S - V_F}{I}$
- Try other LEDs, switches, & resistors.
- Measure/record I, V_R, V_F for each iteration of your circuit.





OHM’S LAW
PRACTICE PROBLEMS