2018
Delaware Science Olympiad
Wonders of Electricity Workshop
(Div B)

IEEE
DELAWARE BAY SECTION
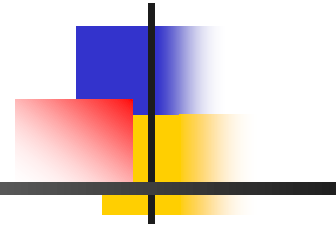
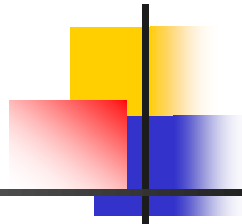**2018 Workshop Schedule at UD Evans Hall – First Floor Lab – All 9:00 AM - Noon**

Div B (Middle School) Only - Saturday January 6, 2018
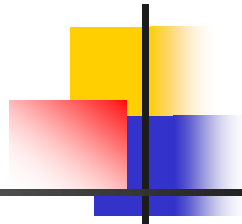Div C (High School) Only   - Saturday January 13, 2018
Div B (Middle School) Only - Saturday January 20, 2018
Div C (High School) Only   - Saturday January 27, 2018
Snow Date Div B & C **No scheduling** - Saturday February 3, 2018

Contacts

- Gordon Lipscy – acrodyn@aol.com
- Wayne Lu – wayne_l@hotmail.com
- Charlie Boncelet, PhD - boncelet@udel.edu
- Carlos Mendoza - cmendoza@udel.edu
- Aric Lu - ariclu@udel.edu

Content

- Who is IEEE
- The Brief History of Electricity
- The Nature of Electricity
    - Charge, Coulomb's Law, Electric Fields and Potential Difference
    - Electric Current and Conventional Current
    - Types of Electricity and **Safety Considerations** [Static, DC, AC]
    - Ohm's Law and Simple Circuits
    - Basic Electrical Measurements and Common Electrical Symbols
    - Capacitors and Capacitance
- Magnetism and Electromagnetism
    - Electromagnetic Force [Motors]
    - Electromagnetic Induction [Generators]
    - Direct Current
    - Alternating Current
    - Transformers
- Semiconductor PN Junctions
    - Silicon Crystalline Structure and P & N Doping
    - Electrical Characteristics of the PN Junction
    - Light Emitting Diodes
    - Silicon Solar Cells
- Basic Digital Logic (Div C)
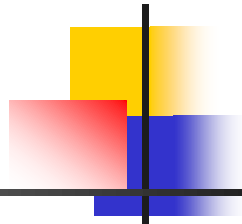
- IEEE, read I-triple-E
- The largest professional association in the world
  - More than 425,000 members in 160 countries
- Formed in 1963 by the merger of IRE (1912) and AIEE (1884)
- Notable past presidents of IEEE and its founding organizations:
  - Elihu Thomson – co-founder of Thomson-Houston Electric Co. which eventually became General Electric Company (GE)
  - Alexander Graham Bell (AIEE) – inventor of telephone
  - William R. Hewlett (IRE) – co-founder of Hewlett-Packard Company (HP)
  - Ivan A. Getting – contributed to development of GPS
- IEEE Standards
  - IEEE standards affect a wide range of industries, including power, energy, biomedical and healthcare, information technology, telecommunications, transportation, nanotechnology and many more.
  - In 2013, IEEE has over 900 active standards and more than 500 standards under development.
  - One notable IEEE standard is IEEE802 LAN/MAN group of standards
    - IEEE 802.3 Ethernet standard – governs data communications
    - IEEE 802.11 Wireless Network standard – WiFi as commonly called.

If Volta invented battery, who invented this one?
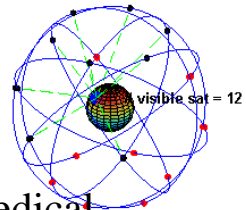
- Electricus – "like amber" in Greek
  - Refer to the amber's property of attracting small object after being rubbed
- Charles-Augustine de Coulomb (1736-1806)
  - Coulomb's Law – "like-charged objects repel and opposite-charged objects attract
  - Coulomb (C) – SI unit for electric charge
- Benjamin Franklin (1706 – 1790)
  - Discovered lightning was electrical in nature
- Alessandro Volta (1745-1827)
  - Invented battery and means to study electrical potential and charge
  - Volt (V) – SI unit for electrical potential (voltage)
- Andre-Marie Ampere (1775 – 1836)
  - Ampere's circuital law determines the relationship between electrical current and magnetic field
  - Ampere (A) – SI unit for electrical current
- Michael Faraday (1791-1867)
  - Discovered electromagnetic induction, diamagnetism (superconductor) and electrolysis
  - Farad (F) – SI unit for capacitor
- Joseph Henry (1797-1878)
  - Discovered electromagnetic induction independently of Michael Faraday
  - Invented the electric door bell.
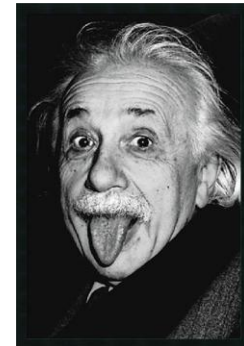 - Henry (H) – SI unit of inductance

SI - International System of Units
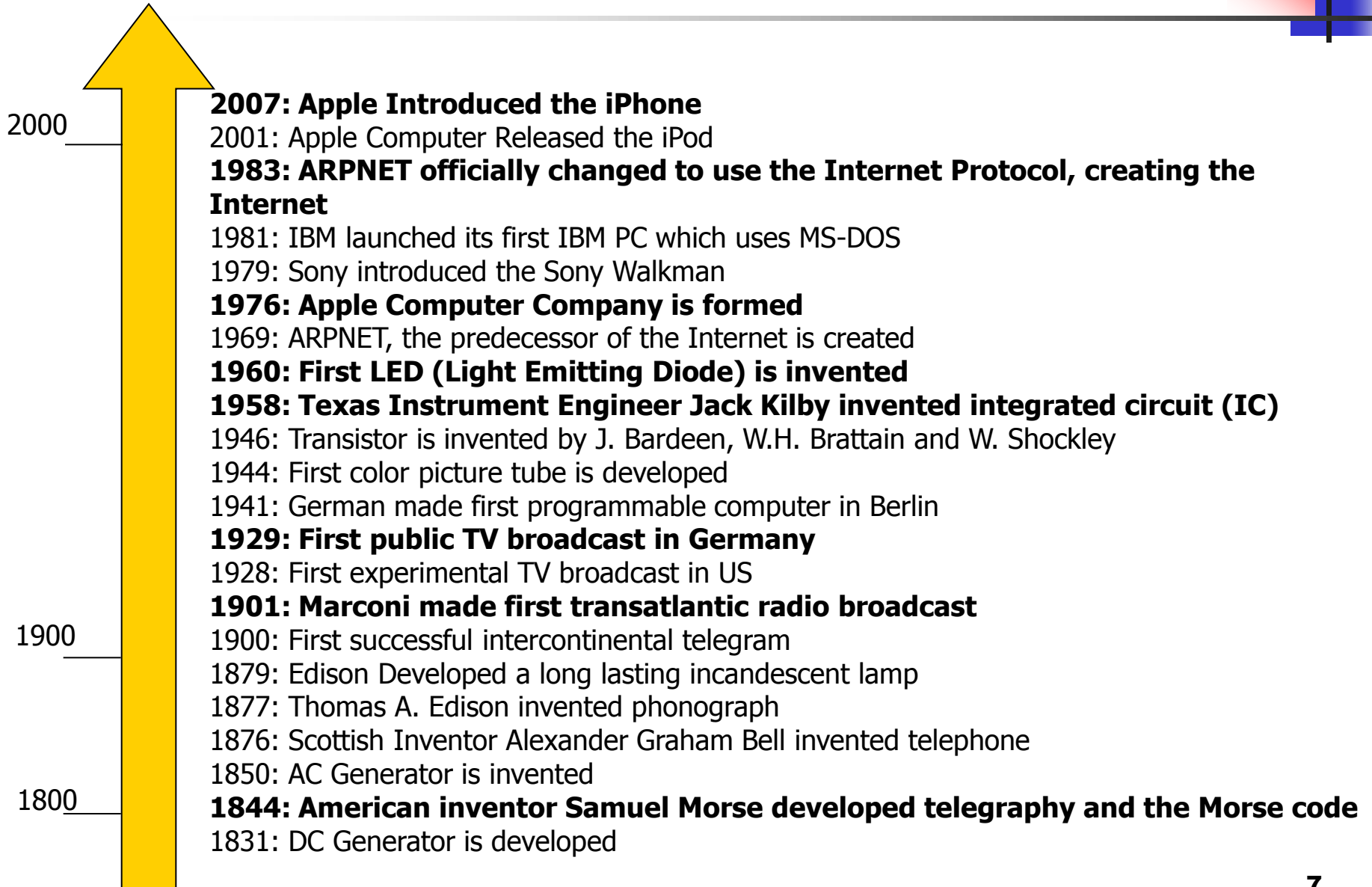
cgs – centimeter, gram and second

Brief History of Electricity (2)

- **Georg Ohm (1789-1854)**
    - Ohm's law – direct proportionality between the potential difference (voltage) applied to a conductor and the resultant electric current
    - Ohm (Ω) – SI unit for electrical resistance
- **James Clerk Maxwell (1831 – 1879)**
    - Unified Electricity, Magnetism and Light (Electromagnetic Theory of Light)
- **Johann Carl Friedrich Gauss (1777-1855)**
    - German mathematician and physical scientist contributed significantly to many fields including number theory, algebra, statistics, analysis, differential geometry, geodesy, geophysics, electrostatics, astronomy and optics
    - Gauss Law of Magnetism
    - His student, Gustav Kirchhoff, discovered Kirchhoff's circuit laws
    - Gauss (G) – cgs unit for a magnetic field, magnetic flux density
        - SI unit for magnetic field is Tesla, named after Nikola Tesla
- **Heinrich Rudolf Hertz (1857-1894)**
    - Proved existence of electromagnetic waves and the electromagnetic waves can travel over distance in space
    - Hertz (Hz) – SI unit for frequency, or cycles per second
- **Albert Einstein (1879- 1955)**
    - Won Nobel Prize for his work on photoelectric effect
        - not for Theory of Relativity
   - Photoelectric effect is used in photocell, solar panels

SI - International System of Units

cgs – centimeter, gram and second

Some Important Electrical Inventions

2007: Apple Introduced the iPhone
2001: Apple Computer Released the iPod
1983: ARPNET officially changed to use the Internet Protocol, creating the Internet
1981: IBM launched its first IBM PC which uses MS-DOS
1979: Sony introduced the Sony Walkman
1976: Apple Computer Company is formed
1969: ARPNET, the predecessor of the Internet is created
1960: First LED (Light Emitting Diode) is invented
1958: Texas Instrument Engineer Jack Kilby invented integrated circuit (IC)
1946: Transistor is invented by J. Bardeen, W.H. Brattain and W. Shockley
1944: First color picture tube is developed
1941: German made first programmable computer in Berlin
1929: First public TV broadcast in Germany
1928: First experimental TV broadcast in US
1901: Marconi made first transatlantic radio broadcast
1900: First successful intercontinental telegram
1879: Edison Developed a long lasting incandescent lamp
1877: Thomas A. Edison invented phonograph
1876: Scottish Inventor Alexander Graham Bell invented telephone
1850: AC Generator is invented
1844: American inventor Samuel Morse developed telegraphy and the Morse code
1831: DC Generator is developed

2000

1900

1800

The Nature of Electricity

- Atoms are composed of electrons, protons and neutrons
  - In its natural state, an atom of any element contains an equal number of electrons and protons
    - The negative (-) charge of each electron is equal in magnitude to the positive (+) charge of each proton, the opposite charges cancel. An atom in this condition is electrically neutral or in balance.
- The outer or valence electrons of an atom, which greatly influence its chemical properties, can be shared or exchanged with other atoms to create electrical charges and electrical currents.
- An object with an excess number of electrons will have a negative static charge or (-) electric polarity.
- Conversely, an object with missing electrons (called holes) will have a positive static charge or (+) electric polarity.
- Some elements and chemical compounds have tightly held valence electrons which resist sharing. Such substances have a high resistance to the flow of electricity and are good electrical insulators.
- Metals and other substances with loosely held valence electrons have low resistance to the flow of electricity and are good electrical conductors.
- The basic SI unit of electrical resistance is the Ohms which uses the omega symbol (Ω).

6 protons
+ 6 neutrons

⊖ electron
⊕ proton
⬤ neutron

Carbon atom
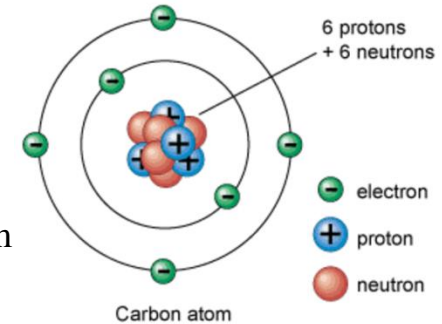
Electrostatic Charge
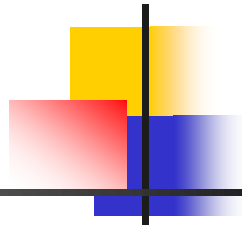
- Like charges repel each other;
- Unlike charges attract each other.
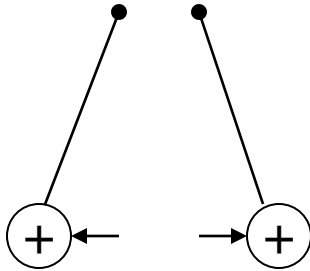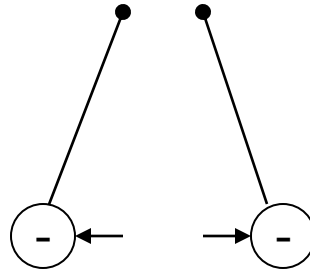
| Like − charges repel | Like + charges repel | Unlike charges attract |
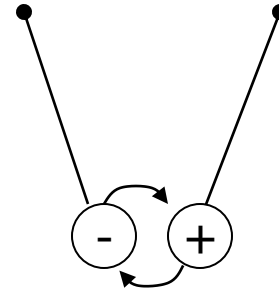
- The magnitude of electric charge a body possesses is determined by the difference in the number of electrons compared with the number of protons within the body.
- The symbol for the magnitude of the electric charge is Q, expressed in units of Coulomb (C).
- A charge of one negative Coulomb,
  - 1 unit of -Q means a body contains a charge of 6.25×10^{18} more electrons than protons
  - **One electron contains a charge of 1.6×10^{-19} Coulomb**
  - Electrons are elementary particles, indivisible and unbreakable (at least not yet)

Coulomb's Law

- Coulomb's inverse-square law, is a law of physics describing the electrostatic interaction between electrically charged particles.

- The law was first published in 1785 by French physicist Charles Augustin de Coulomb and was essential to the development of the theory of electromagnetism. It is analogous to Isaac Newton's inverse-square law of universal gravitation.

- The law has been tested heavily, and all observations have upheld the law's principle

$$F = k \frac{q_1 q_2}{r^2}$$

F = electrostatic force
q = electric charge
r = distance between charge centers
k = Coulomb constant
9.0×10^9 N · m²/C²
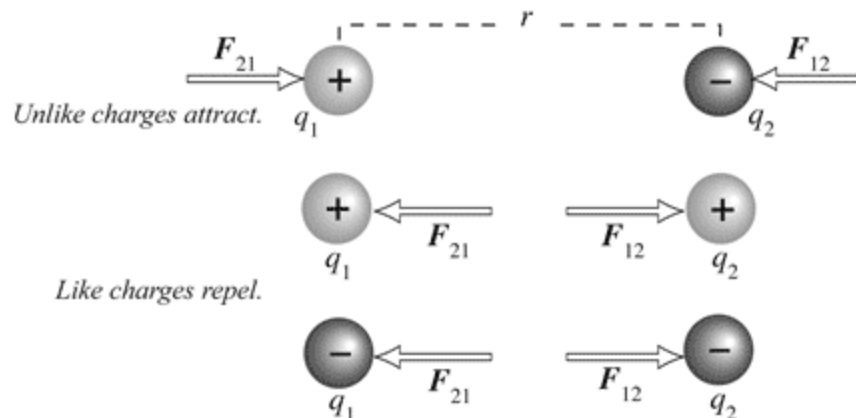
Electric Fields

- An **electric field** is generated by electric charge and time-varying magnetic fields. At each point in space, the electric field describes the electric force that would be experienced by a motionless test particle of unit positive charge.
  - The concept of an electric field was introduced by Michael Faraday.
- One charge is considered the source of an electric field that extends outward into the surrounding space.
- The direction of the force on a positive charge is chosen arbitrarily as the direction of the electric field.
- When they are represented by lines of force, or field lines, electric fields are depicted as starting on positive charges and terminating on negative charges
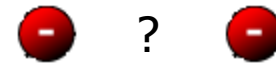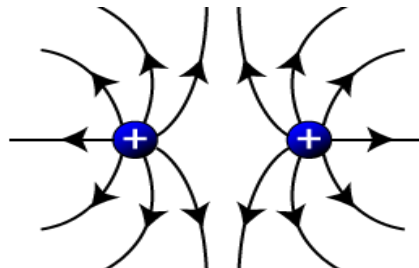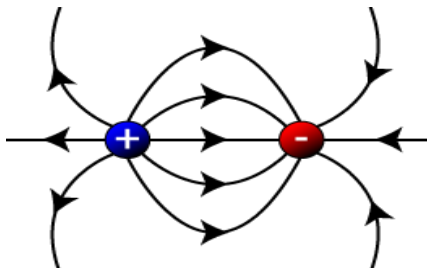
Potential Difference
Electromotive Force (EMF) or Voltage
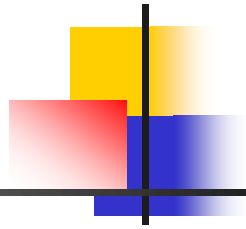
- Because of the force of its electrostatic field, an electric charge has the ability to do the work of moving another charge by attraction or repulsion.
- The ability to do such work is called its potential.
  - When one charge is different from other, there must be a difference in potential between them.
  - The sum of the difference of potential of all the charges in the electrostatic field is referred to as electromotive force (EMF)
- The basic SI unit of the potential difference is the volt (V).
  - So is it called Voltage.
- The symbol for the potential difference is V

Electric Current

- The movement or the flow of electrical charge is called current
  - To produce a current, the charge must be moved by a potential difference.
- Current is represented by the letter symbol I
- The basic SI unit for measuring current is the Ampere (A) [Often abbreviated as Amp].
  - One Ampere (1A) of current is defined as the movement of one coulomb past any point of a conductor during one second of time

$$I = \frac{Q}{T}$$

- In a conductor, the free electrons are charges that can be forced to move with relative ease by a potential difference.

Current flows in the same direction as positive ions but the opposite direction as free electrons.

Positive Ions   Negative Ions

13

Conventional Electric Current
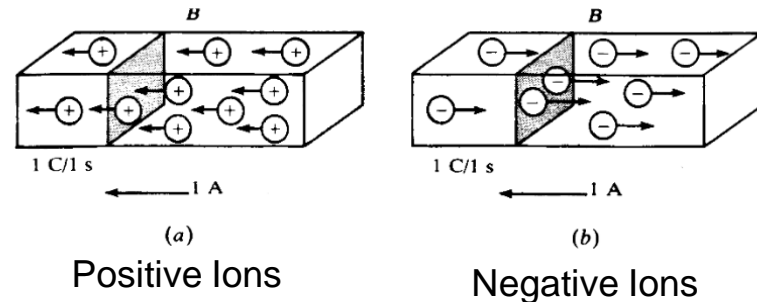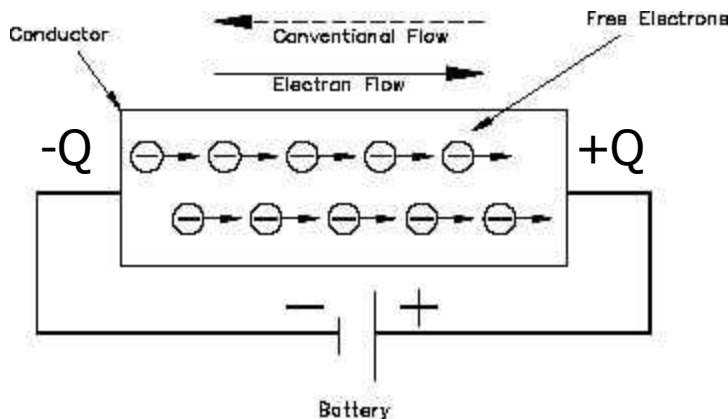
- Before electrons were discovered, experiments in electrolysis suggested a current that moved bits of metal from one electrode to another. That current, which is basically the movement of positive ions, led to the electrical convention of **current being the flow of positive charge** out of the positive terminal of a source.

- This convention has continued within all the circuitry symbols , analysis techniques and literature used by the electrical professions. However, many physics texts and their supporting diagrams may show current as the flow of electrons in the opposite direction from conventional current. **All discussions in this presentation use conventional current** – the flow of positive charges or electron holes. (When an electron moves east to fill a hole left by another electron that moved east, the hole effectively moved to the west. Thus, conventional current is in the direction of the movement of the holes which is opposite the direction of electron flow.
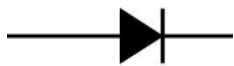
The symbol for a diode has an arrow head pointed in the direction of conventional current. Electron current flows in the opposite direction.

- Step 1: Complete the circuit as show
- Step 2: Write down the combination of the switch 1 and switch 2 in relation to the lamp on and off

K1 (L or R)	K2 (L or R)	Lamp (On or Off)
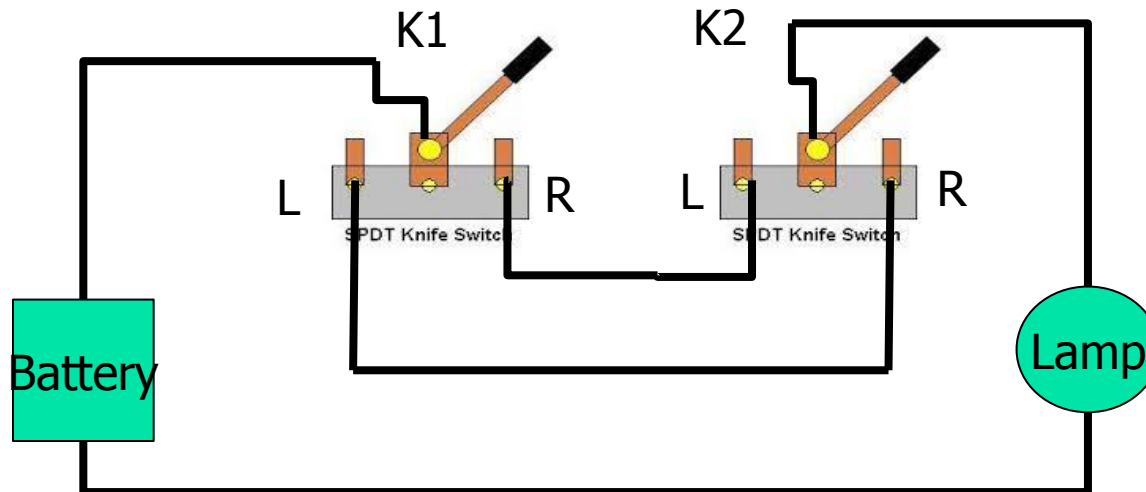
Types of Electricity
STATIC
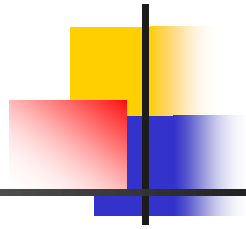
- Sources - friction between materials including clouds

- Characteristics - 30,000 volts per centimeter of air gap, ionization of air = spark, lightning current levels can be huge

- Safety Hazards - Shock/burns, power line surges harm motors, destruction of microelectronics can occur from clothes or carpet static

DIRECT CURRENT (DC)
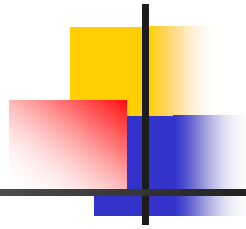
- Sources - batteries (chemical to electrical), rotating alternators and generators (mechanical to electrical), solar panels (light to electrical), fuel cells (chemical to electrical), piezoelectric (stress to electrical), thermionic (heat to electrical), power supplies (AC to DC), solar wind (ions moving through space -northern lights)

- Characteristics – **By convention, current flows from (+) to (-) [flow of holes],** no easy voltage transformation, arcs difficult to suppress.

- Safety Hazards - high voltage shock/burns, low voltage/high current burns/welding [car batteries] , no switch at some sources [solar panels], fires and burns from rapid battery discharge, internal burns from infants swallowing coin batteries.

Types of Electricity
ALTERNATING CURRENT (AC)

- Sources - rotating generators in power plants (mechanical to electrical) & inverters (DC to AC).
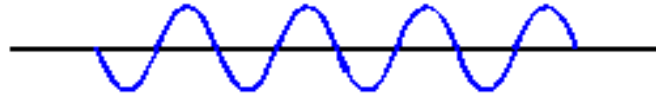
- Characteristics - sine wave with frequency and amplitude, ease of generation, ease of voltage transformation, easy arc suppression. Generally distributed from power plants to users with return path grounded. Household 60 hertz, voltages = +120 v, -120 v and grounded neutral. Large loads use 240 v by connecting from +120 v to -120 v. Root mean squared (RMS) voltage, current & power measured to derive true consumption of the sine wave supply.

- Safety Hazards - heart fibrillation from milliamp currents (120 volt household power can be deadly if passed through the heart), shock/burns, downed wires, insulation breakdown from moisture, contamination or abrasion (frayed cords), outlets, portable appliances, contact resistance (burns/fires in the wall).

Household AC
SAFETY FEATURES

- **National Electrical Code is the Law**.

- Breakers/Fuses

- Polarized Plugs & Outlets
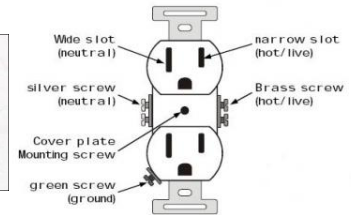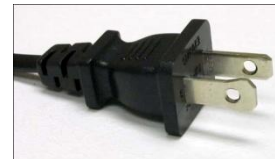
- Switching the Power, Not the Return
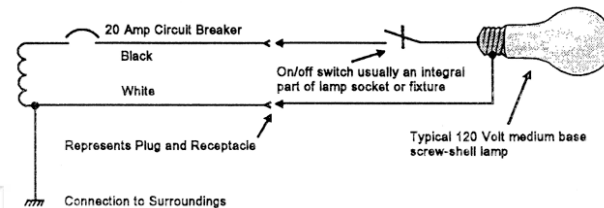
- GFI (Ground Fault Interrupter)
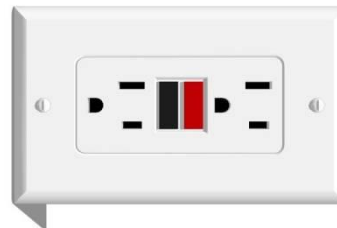
Ohm's Law

- A practical electric circuit has at least four parts:
  - A source (the battery)
  - Conductors (wires)
  - A load (light bulb)
  - A means of control (switch)
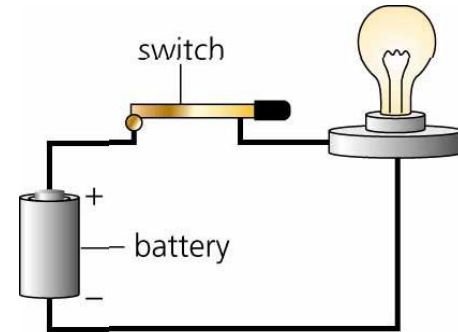
- A complete or closed circuit is an unbroken path for the current from the source through a load and back to the source.

- A circuit is called incomplete or open if a break in the circuit doesn't provide a complete path for current

- Ohm's Law defines the relationship between current, voltage and resistance.
  - The current in a circuit is equal to the voltage applied to the circuit divided by the resistance of the circuit: $I = \dfrac{V}{R}$
  - The resistance of a circuit is equal to the voltage applied to the circuit divided by the current in the circuit: $R = \dfrac{V}{I}$
  - The applied voltage to a circuit is equal to the product of the current and resistance of the circuit: $V = I * R$

20

Simple Circuits

- Components of an electrical circuit or electronic circuit can be connected in many different ways. The two simplest of these are called **series** and **parallel** and occur very frequently.

- Components connected in series are connected along a single path, <u>so the same current flows through all of the components</u>.

- Components connected in parallel are connected <u>so the same voltage is applied to each component.</u>
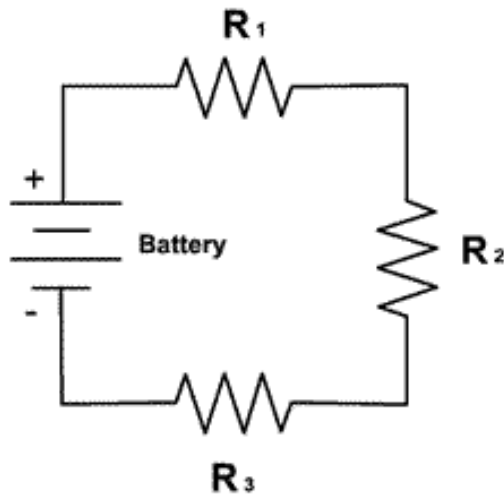
Serial Circuit
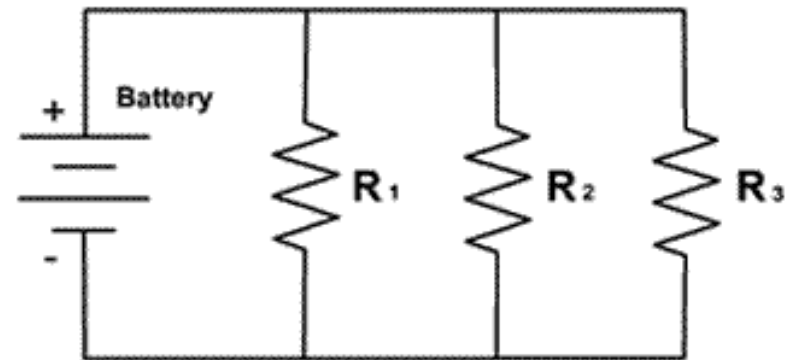
Parallel Circuit

- 3 Resistors (R1,R2 and R3) are connected in serial along with the Battery. So, this circuit is a serial circuit
- Serial circuit has only one path for the electric current to flow. So, the same amount of current flows through R1, R2 and R3
- Using Ohm's Law,
  - $V1 = R1 * I$
  - $V2 = R2 * I$
  - $V3 = R3 * I$
- The direction of the voltages of each resistors follows the current flowing through the resistors
- The battery voltage is
  - $Vb = V1 + V2 + V3$
    $= R1 * I + R2 * I + R3 * I$
    $= (R1 + R2 + R3) * I$
- The equivalent circuit at the right:
  $R = Vb/I$
  $= (R1+R2+R3)$

- 3 Resistors (R1,R2 and R3) are connected in parallel. So this circuit is a parallel circuit

- A parallel circuit has multiple path for electrical current to flow. However, all resistors are connected to the same battery. So, the voltages across each resistors are the same

- Using Ohm's Law,
  - $I1 = Vb/R1$
  - $I2 = Vb/R2$
  - $I3 = Vb/R3$

- The direction of the current of each resistors follows the voltage across the resistors

- Since the battery supplies all currents for each resistor. The total current out of the battery I is
  - $I = I1 + I2 + I3$
    $= Vb/R1 + Vb/R2 + Vb/R3$

- The equivalent circuit at the right:
  $R = Vb/I$
  $= 1/ (1/R1 + 1/R2 + 1/R3)$

Power & Energy
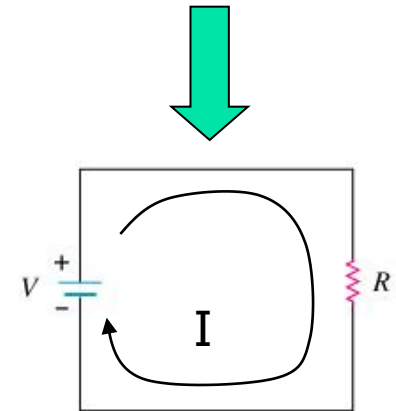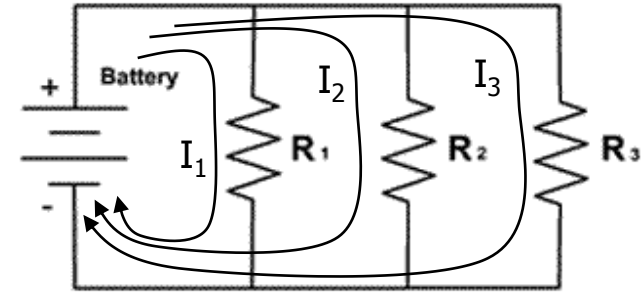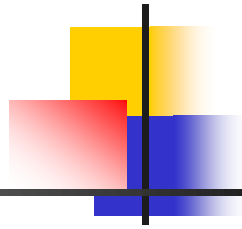
- The **power** consumed by an electrical component is equal to the product of the voltage drop across the component and the current flowing through the component. The unit of power is the watt (w).

    Power(w) = Voltage(v) x Current(amps)

- Using Ohm's Law, power can be computed as $P = I^2 \ x \ R$ or V^2 / R

- The **energy** consumed by an electrical component is equal to the product of the power and the amount of time that the component is energized. The units of power are watt seconds, watt hours, kilowatt hours, etc.

- Household electrical consumption is metered by kilowatt hours (kwh) used and is billed at around 10 -20 cents per kwh.

Basic Electrical Measurements (1)

- Metric units

    Electrical potential = volts (v),

    Electrical current = amperes or amps(a)

    Electrical resistance = ohms (Ω)

    Electrical power = watts (w)

    Electrical energy = watt **hours** (wh)

- Metric prefixes:

    Mega (M)= 1,000,000 or 10^6

    kilo (k)=1,000 or 10^3

    milli (m) = 1/1,000 or 10^{-3}

    micro (μ) = 1/1,000,000 or 10^{-6}

Please show your thanks to Harbor Freight Tools in Newark for their help in supplying the multimeters for each team at these Workshops.

Basic Electrical Measurements (2)

- ## <u>Measuring resistance</u>

  - Ohmmeter measures the resistance using Ohm's Law. It has an internal voltage source and a resistor.

  - A complete circuit is formed when the test leads are connected to the component to be measured.

  - **Ensure circuit deenergized**, test leads in COM & VΩmA jacks, start at highest Ω setting on meter and reduce until most accurate reading is obtained.
    - If the component to be measured is part of a circuit and that circuit is energized, the extra current and voltage source will cause inaccurate measurement, or worse, damage to the meter

- ## <u>Measuring DC voltage</u>

  - This is the safest measurement to be made on an energized circuit since the internal resistance of the meter in any DCV setting is near infinite: however, you should always select the highest voltage setting that you might expect in the circuit and reduce the range setting to get the most accurate reading. If you always use the convention of putting the BLACK test lead in the COM jack and the RED lead in the VΩmA jack, the meter will then always show the voltage at RED minus the voltage at BLACK (the voltage difference). If the reading is negative, the voltage at BLACK is higher than at RED.
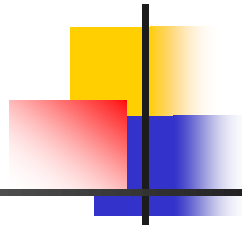
- <u>Measuring DC current</u>
  - CAUTION: internal resistance of the meter in DCA settings is close to zero and any voltage applied directly to the meter will most likely damage the meter. Rather than using this capability of the multimeter, it is recommended that you measure the voltage across a resistor in the circuit and use Ohm's law to determine the current or install a low resistance into the circuit and then measure the voltage drop to calculate the current.
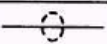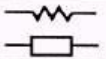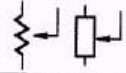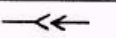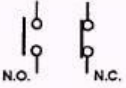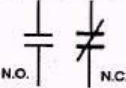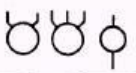
- <u>Measuring AC voltage</u>
  - Students are discouraged from using their multimeters to measure AC voltages around home or at school due to the lethal shock hazards and the potential for severe burns from high currents.

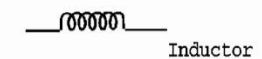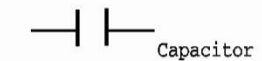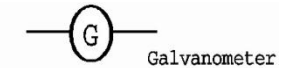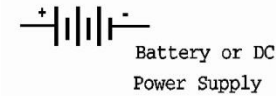|	
COAXIAL CABLE	CAPACITOR
SHIELDED WIRE	RESISTOR
TIEPOINT	POTENTIOMETER
GROUND CONNECTION	NPN TRANSISTOR
CHASSIS GROUND	PNP TRANSISTOR
CONNECTOR	DIODE
ILLUMINATING OR INDICATING LAMP, LETTERS ADDED WITHIN SYMBOL DENOTE LAMP COLOR	ZENER DIODE
PUSHBUTTON INDICATING LAMP, LETTERS ADDED WITHIN HALF CIRCLE DENOTES SIDE OF SYSTEM IN OPERATION	KLIP-SEL TRANSIENT SUPPRESSOR
ELEMENT OF ANY MANUALLY/MECHANICALLY OPERATED SWITCH. NORMALLY OPEN OR CLOSED AS INDICATED N.O. N.C.	TRIAC
CONTACTS OR ANY MICROSWITCH OR RELAY, NORMALLY OPEN OR CLOSED AS INDICATED N.O. N.C.	SYNCHRO
	TACHOMETER
CIRCUIT BREAKER	ELECTRIC MOTOR
COIL OF A SOLENOID OR RELAY	LOUDSPEAKER
TRANSFORMER	TELEPHONE JACK
FUSE	BATTERY

GMNP0277

Battery or DC Power Supply

Galvanometer

Variable DC Supply

Ampermeter

AC Voltage Supply

Voltmeter

Wire

Resistor

Wire Connection

Capacitor

Switch

Inductor

Diode

28

- Material: Battery, 3 resistors with different values, a knife switch, Some wires and a digital multimeter.

- Step 1: Use Digital Multimeter to measure the resistance of all 3 resistors

	R1	R2	R3
Resistance (ohm)			

- Step 2: Connect all 3 resistors in serial
- Step 3: Connect those parts according to the drawing

Note	Red Probe	Black Probe	DC Voltage
Vb	1	2	
VR1	5	6	
VR2	7	8	
VR3	9	10	

- Step 4: With Switch "Closed" measure voltage between those points in the table
  - Verify if Vb = VR1 + VR2 + VR3
- Step 5: Open the Switch
- Step 6: Set the Digital Multimeter to measure current
- Step 7: Insert Red Probe to point 3 and Black Probe to point 4.
  - Read Current: I = _____
- Step 8: Verify if
  - $Vb = I * (R1 + R2 + R3)$

29
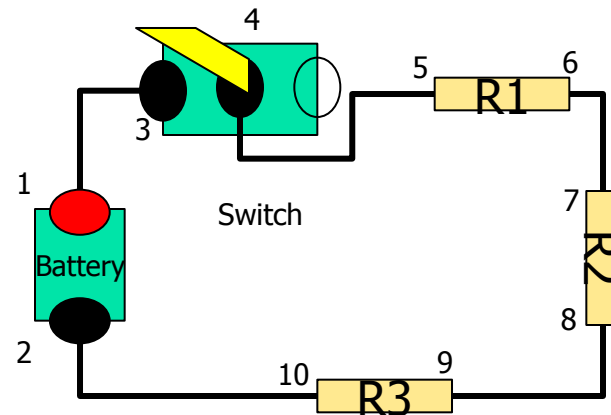
Capacitors

- A capacitor is a passive two-terminal electrical device used to store energy electrostatically in an electric field. It contains:
  - Two electrical conductors and
  - An insulator called dielectric separates the two conductors
- When there is a potential (voltage) difference across the two conductors, an electrical field develops across the dielectric, causing positive charge to collect on one plate and negative charge on the other plate. Energy is stored in the electrostatic field.
- An ideal capacitor is characterized, or described, by a single constant value, capacitance.
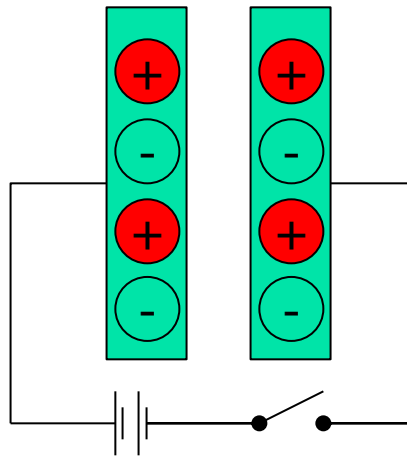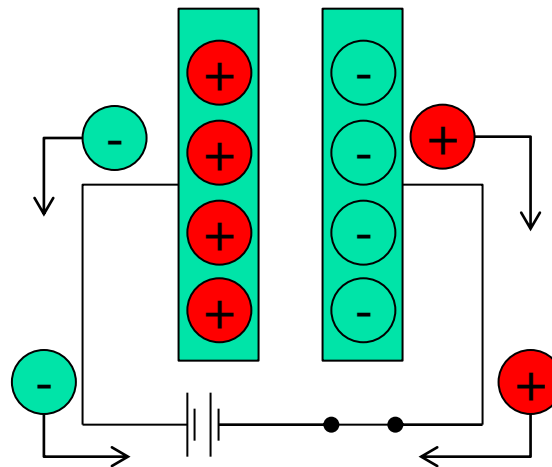
Neutral Capacitor   Charged Capacitor   Discharging Capacitor
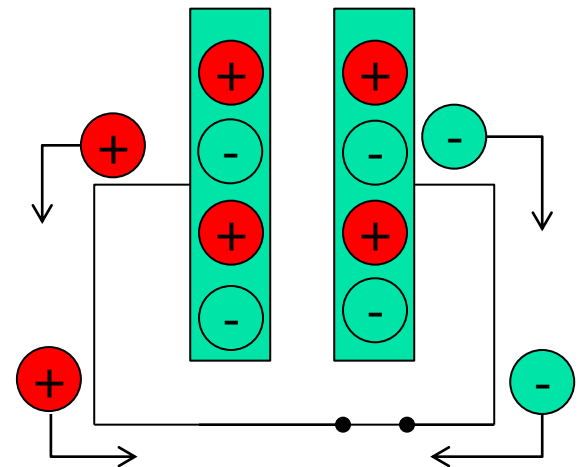
Capacitance

- Capacitance is the ability of a capacitor to store an electric charge
- Capacitance is the ratio of the electric charge on each conductor to the voltage potential between them
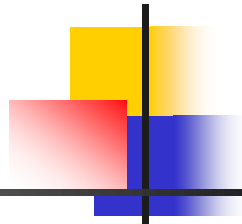
$$C = \frac{Q}{V}$$

- The SI unit of capacitance is the Farad (F) – Named after Michael Faraday
- The farad is usually too high a unit for most capacitor. Therefore, we conveniently use the microfarad (uF) which equals one-millionth farad.

(Div C) RC Circuits (1)

- RC Circuit consists of a resistor and a capacitor. It is one of the simplest forms of analog circuit.
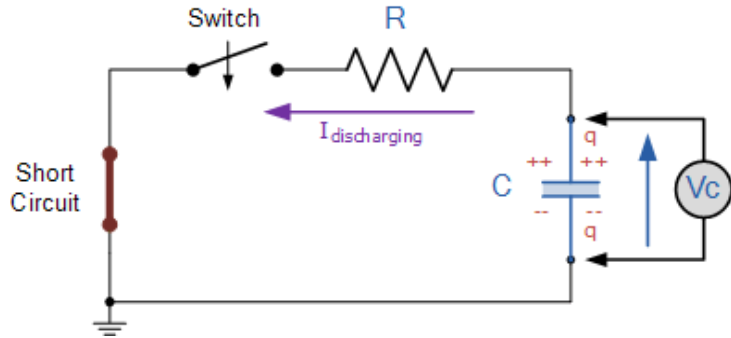
$$V_c = V_{c0} \times e^{\left(-\frac{t}{RC}\right)}$$

- If the capacitor is charged up, there is a charge (q) stored in the capacitor.
- When switch is closed, the charge (q) in the capacitor start to leak out. The movement of the charge is the current ($I_{discharging}$)
- When the capacitor losses charge (or discharges), the voltage of the capacitor drops as the result.

(Div C) RC Circuits (2)
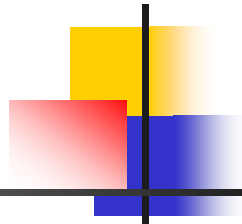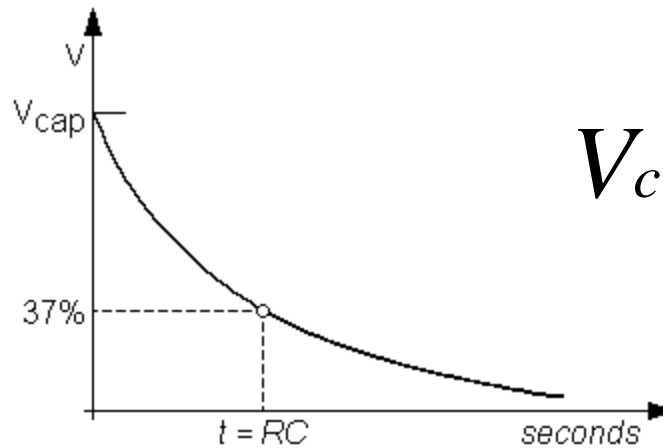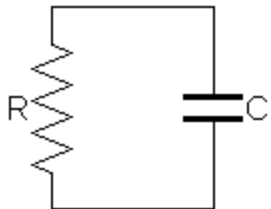
- The capacitor voltage will drop following the equation.
- The product of RC is called RC time constant.
- The RC time constant determines the rate of discharging or charging (if the capacitor is being charged)
- When the time reaches 1x of time constant, the capacitor has lost about 63% of its original charge.

RC Discharge

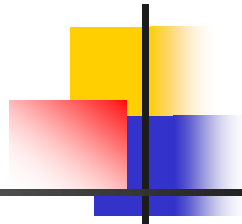$$V_c = V_{c0} \times e^{\left(-\frac{t}{RC}\right)}$$

IEEE
DELAWARE BAY SECTION

- Material: Battery, 2 resistors with different values, a knife switch, a 100 µ farad capacitor, stop watch, some wires and a digital multimeter
- Step 1: Use Digital Multimeter to measure the resistance of both resistors and the battery voltage. Calculate 37% and 63% of battery voltage.
- Step 2: Connect the circuit below (Switch open) with R10.
- Step 3: Connect multimeter to measure voltage across capacitor (1 to 2)
- Step 4: Close the switch to position B to verify no charge on capacitor. When capacitor voltage is zero and stop watch ready, close switch to position A and <u>record</u> the time required for the volt to reach the 63% value. Leave the switch in position A until the battery voltage is observed across the capacitor
- Step 5: With the stop watch ready, move the switch from position A to B and <u>record</u> the time required for the volt to reach the 37% value.
- Step 6: Change the circuit resistor to R11 and repeat Steps 4 and 5.
- Step 7: Calculate the circuit time constants using the labeled capacitance and the measured resistances. µ = 10^{-6}

	R10	R11
Resistance (ohm)		
Battery Voltage(v)	37% of BV	63% of BV

| Data	Measured Time Constant =Time (s) to reach:	Calculated Time Constant (s)= Capacitance x Resistance
Charging w/ R1	63% =	R10
Discharging w/ R1	37%=	
Charging w/ R2	63% =	R11
Discharging w/ R2	37%=	

A B

Switch

Battery

1
2
C

R
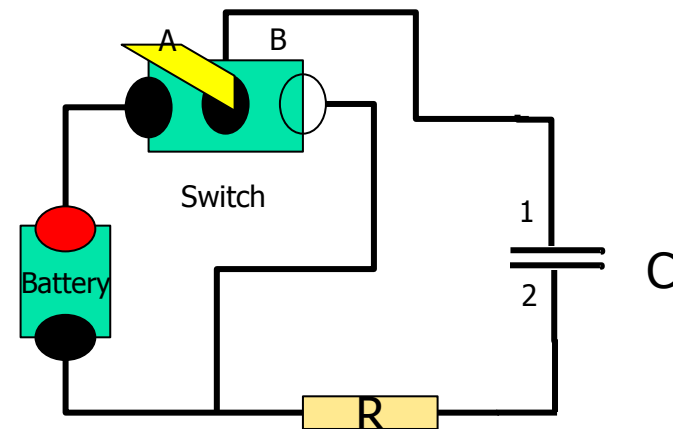
- 2 Poles – The pole of a magnet which is attracted to the earth's "northern" pole is <u>defined</u> as the North pole of that magnet, the other pole being South.

- Like poles repel each other, unlike poles attract.

  If you conclude that the earth's magnetic pole under Santa Claus's reputed home is in fact a South magnetic pole, you will be correct.

- Three types of magnets: naturally occurring, man-made & electromagnets.

- The direction of magnetic lines of force is <u>defined</u> as coming out of the North pole and going into the South pole.

- Bar magnet lines of force
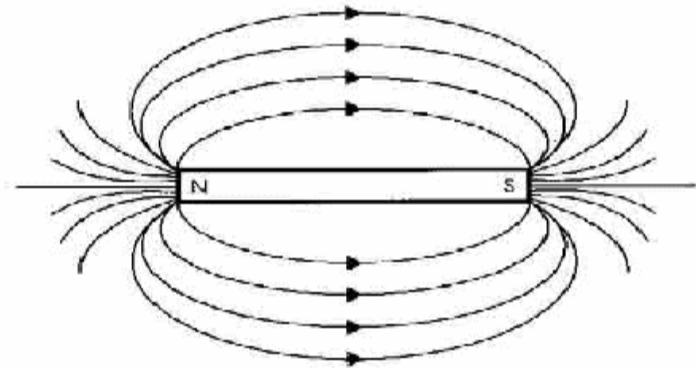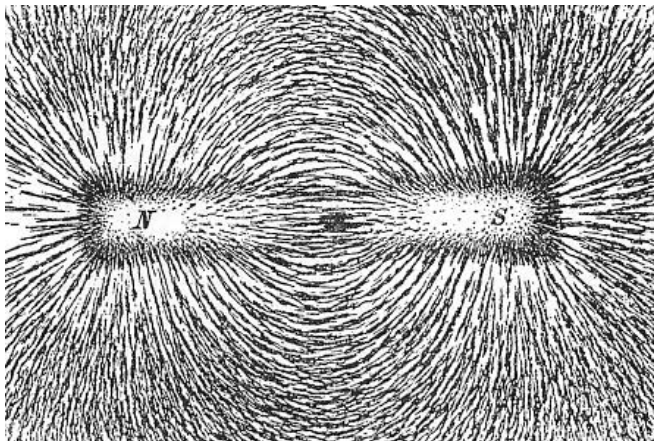
Electromagnetism

- Originally electricity and magnetism were thought of as two separate forces until their interrelationships were characterized by James Clerk Maxwell's 1873 "Treatise on Electricity and Magnetism"
  - An electric current in a wire creates a circular magnetic field around the wire, its direction (clockwise or counter-clockwise) depending on that of the current.

Electrical coil or solenoid magnetic field – Second right hand rule: With fingers wrapped around the coil in the direction of the current flow, the magnetic field is in the direction of the thumb.
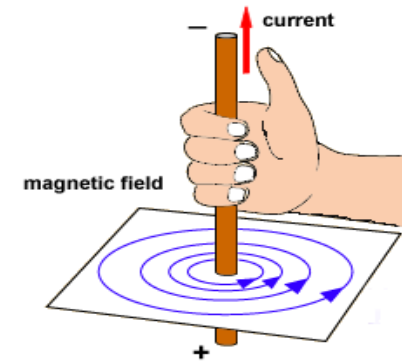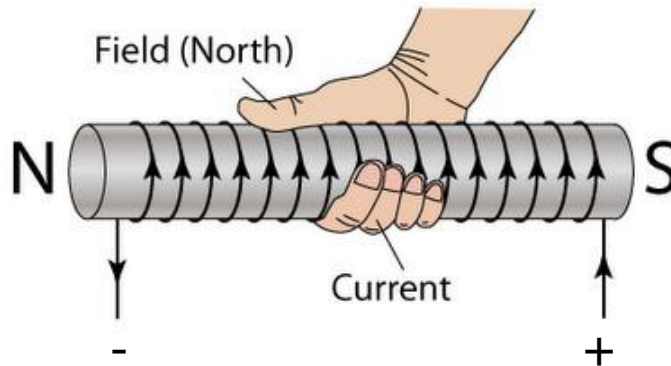
Right hand rule for determining the circular magnetic field around a current flowing through a conductor

- A current flowing perpendicular to a magnetic field will result in a force on the conductor that is **perpendicular** to both the direction of the current and the direction of the magnetic field. This so-called Lorentz Force is mathematically described as:

$$\mathbf{F}_{\text{MAGNETIC}} = \mathbf{I} \; \mathbf{X} \; \mathbf{B} \text{ where:}$$

    I is the velocity vector of the current

    X is the cross operator for vectors and

    B is the magnetic field vector

This is a third right hand rule – All fingers initially point in direction of **I** and then bend to direction of **B**. Outstretched right thumb points to direction of force, **F**.
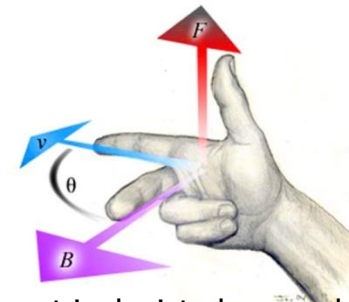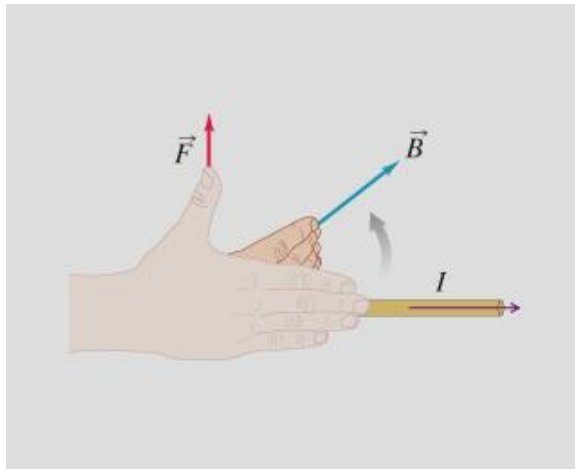
Sometimes the current is depicted as a velocity vector, V and the middle finger is used to show the direction of the magnetic field. [If V is in the direction of electron current , the force will be in the opposite direction]

Materials: Modern Faraday DC Motor Kit from IEEE Workshop

- Step 1: Remove the neodymium magnet and the wood screw from the package and observe how strongly the magnet is attracted to the iron screw. This strong magnet can damage magnetically sensitive materials such as credit cards, compasses and electronics if brought in close proximity. Please follow the cautions on the kit.

- Step 2: Determine the North pole of the magnet by balancing it on its side and allowing it to rotate to align with the earth's magnetic field and mark the north seeking side. If the magnet is allowed to drop on the floor, it may fracture.

- Step 3: Center the north pole of the magnet on the head of the screw as shown.

- Step 4: Hang the point of the screw from the + terminal of the battery as shown.

- Step 5: Hold one end of the hookup wire to the – battery terminal and gently touch the other end to the side of the magnet. Observe that the magnet and screw are caused to spin and record the direction of rotation.

- Step 6: Use the Lorentz Force equation F = I cross B to verify the direction of rotation.

- Step 7. Turn the magnet over so the south pole is on the screw head and record the direction of rotation.

- Step 8: Turn the battery upside down and observe what happens to direction of rotation.
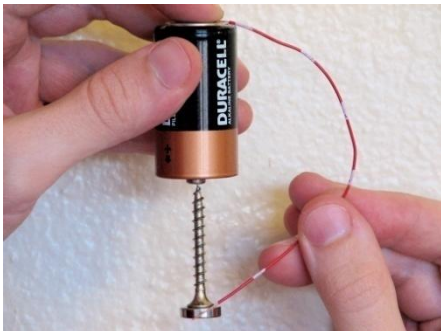
Direction of rotation looking down during Step 5 [clockwise] or [counterclockwise] (circle).

Direction of rotation looking down during Step 7 [clockwise] or [counterclockwise] (circle)

What happened when the battery was turned over?

- Moving a conductor in a magnetic field creates an induced voltage. If the conductor is part of an electrical circuit a current is induced. The induced current/voltage is greatest when the conductor, the magnetic field and the direction of motion are all perpendicular to one another. The induced current is mathematically described as:

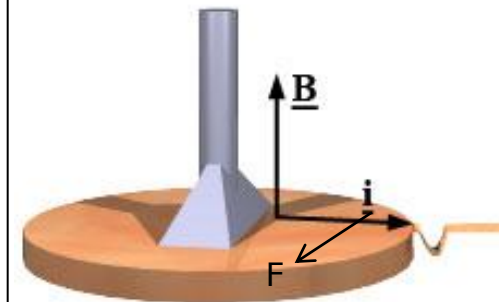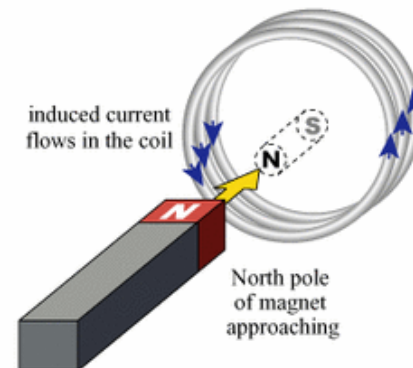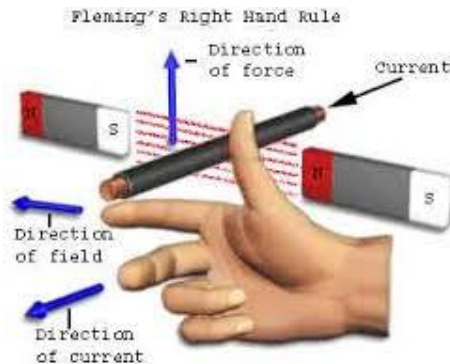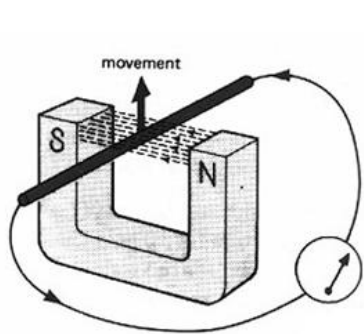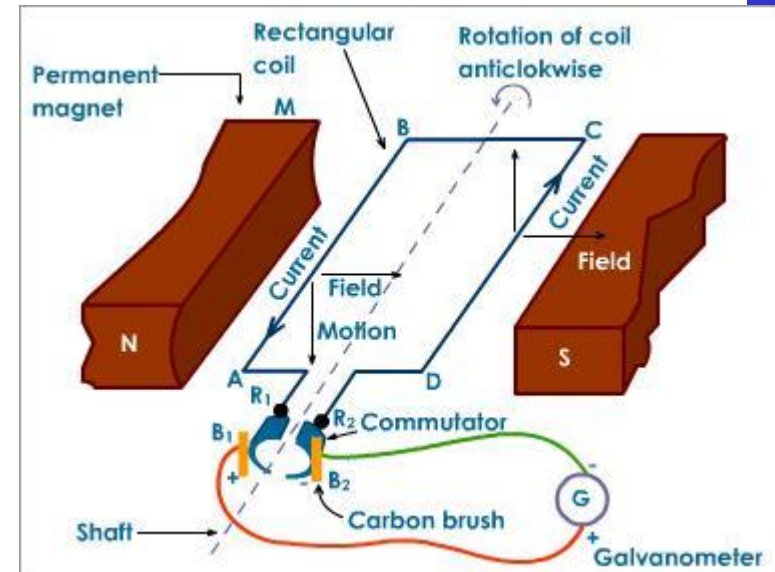- $\mathbf{I}_{INDUCED} = \mathbf{V} \ \mathbf{X} \ \mathbf{B}$ where: $\mathbf{V}$ is the velocity vector of the conductor

  $\mathbf{X}$ is the cross operator for vectors and

  $\mathbf{B}$ is the magnetic field vector

- Current can also be induced by moving or varying a magnet field near a stationary conductor. The math gets more complicated. Induced currents tend to oppose the change that causes them.

movement

Fleming's Right Hand Rule

Direction of force

Current

Direction of field

Direction of current

induced current flows in the coil

North pole of magnet approaching

DC Generator

- A simple DC generator consists of an armature coil with a single turn of wires

- The armature coil cuts across the magnetic field lines to produce voltage.

- If a complete path is present (the circuit is complete), current will move through the circuit.

- The Current in the coil follows the right hand rule.

Direction of
Magnetic Field

Fleming's Right Hand Rule

Direction of force
Current
Direction of field
Direction of current
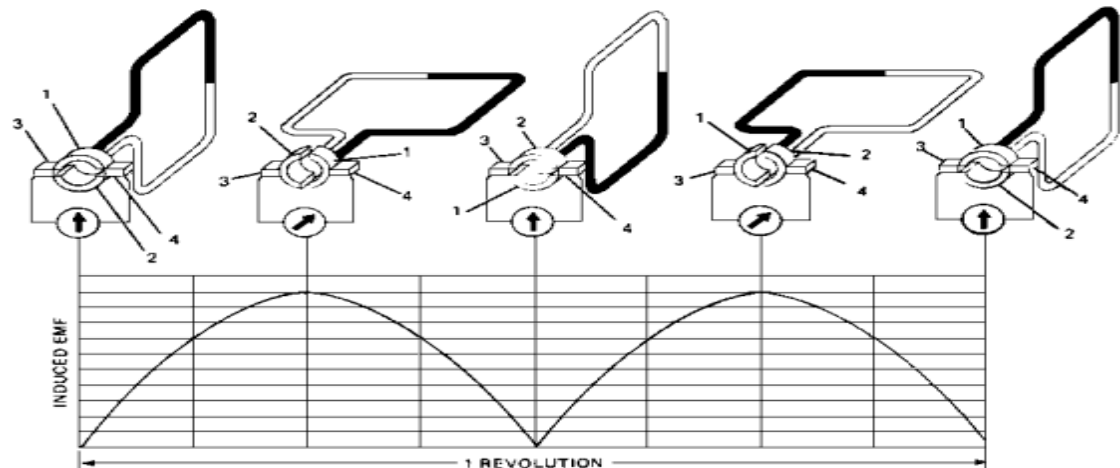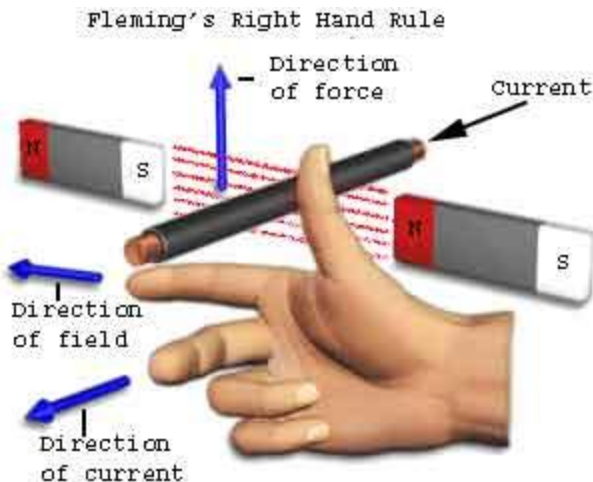
DC Motors

- Construction of a DC motor is very similar to a DC generator.
  - A DC generator is to generate a voltage when conductors are moved thru a magnetic field
  - A DC motor is to develop a turning effort (torque) to produce mechanical rotation by sending a current through a conductor that is placed in a magnetic field.
- Characteristics of a DC motor:
  - Force Vector = I cross B
  - Changing + to – reverses the rotation
  - More voltage increases the speed
  - Commutator reverses current direction each half rotation
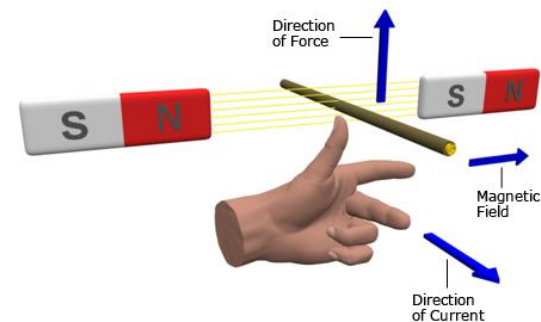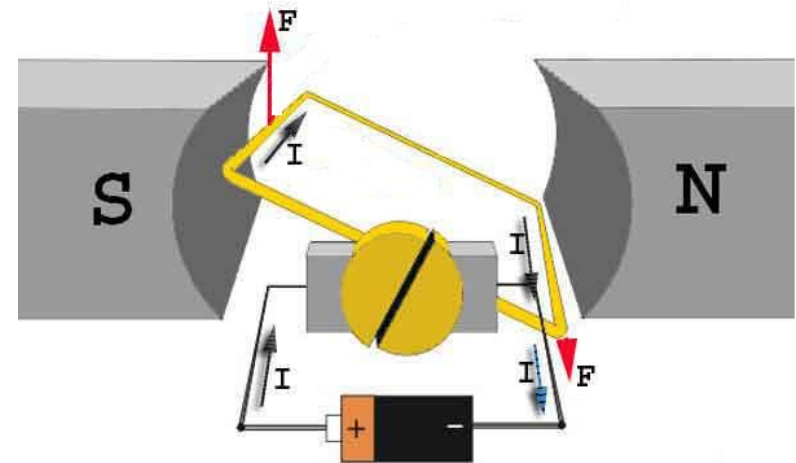
Fleming' Left Hand Rule

AC Generator

- Alternating-Current generators are also called Alternators.
- Almost all electrical power for homes and industry is supplied by alternators in power plants
- A simple alternator consists of
  - A strong constant magnetic field
  - Conductors that rotates across the magnetic field (rotating armature)
  - Some means of making a continuous connections to conductors as they are rotating
- Each time the rotor turn makes one complete revolution, one complete cycle of alternating current is developed.
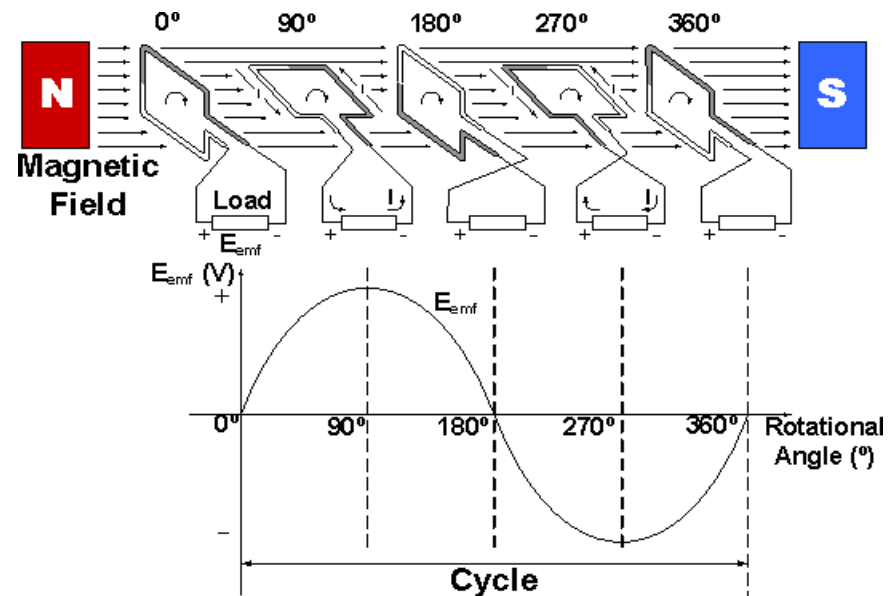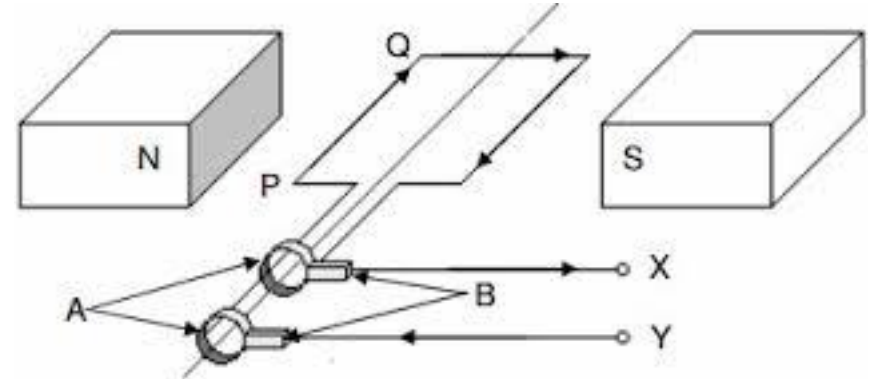
- AC motor construction is also nearly the same as AC Generator,
  - Just like in the DC motor case, a current is passed through the coil, generating a torque on the coil.
  - Since the current is alternating, the motor will run smoothly only at the frequency of the sine wave.
   - It is called a synchronous motor.
- One of the drawbacks of this kind of AC motor is the high current which must flow through the rotating contacts. Sparking and heating at those contacts can waste energy and shorten the lifetime of the motor.
- In common AC motors the magnetic field is produced by an electromagnet powered by the same AC voltage as the motor coil. The coils which produce the magnetic field are sometimes referred to as the "stator", while the coils and the solid core which rotates is called the "armature".
- In an AC motor the magnetic field is sinusoidally varying, just as the current in the coil varies.
- Characteristics of an AC motor:
  - Force Vector = I cross B
  - Speed is controlled by the frequency of the supply voltage and the number of magnetic poles (2 shown)
  - Direction of rotation is controlled by the starting technique built into the motor design to initially push it in the desired direction

Magnetic field from "field coils" which also have AC current

Slipping contacts called "brushes"

AC current in coil
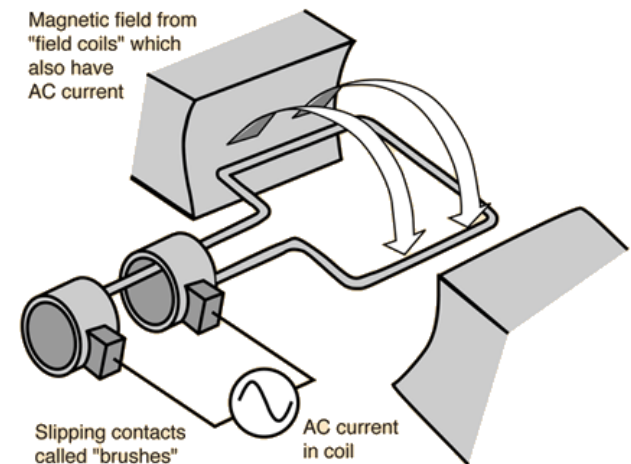
Transformers

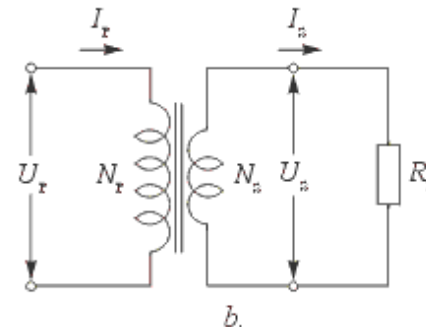- A **transformer** is an electrical device that transfers energy between two or more circuits through electromagnetic induction. .

- A varying current in the transformer's primary winding creates a varying magnetic flux in the core and a varying magnetic field impinging on the secondary winding.
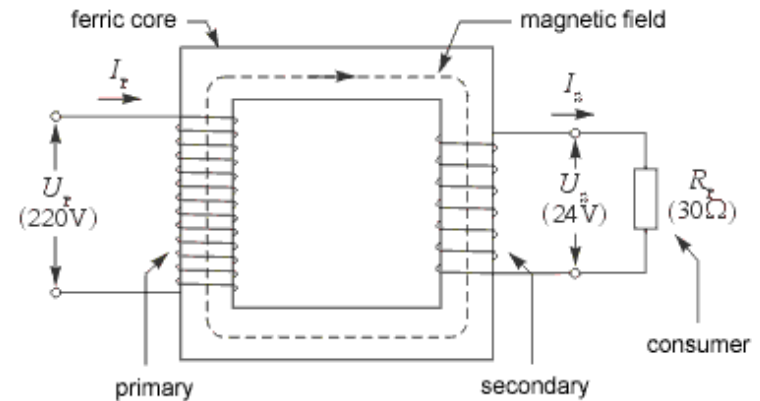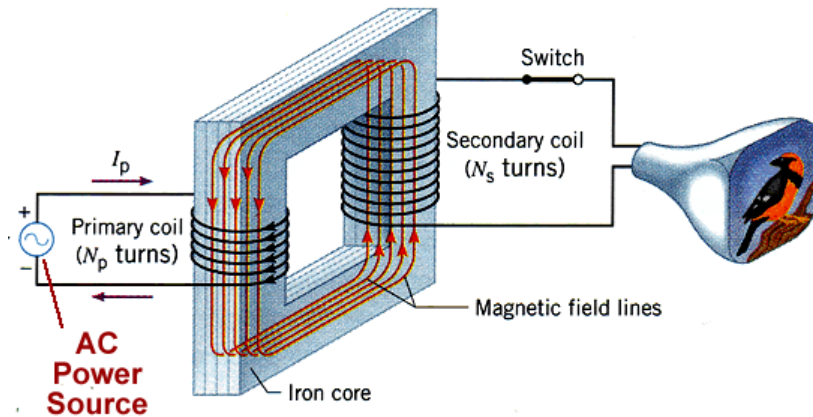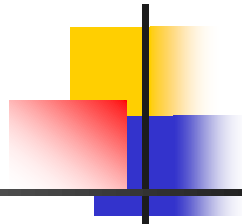
$$\frac{Vp}{Vs} = \frac{Np}{Ns} \qquad \frac{Ip}{Is} = \frac{Ns}{Np}$$

$$P = Vp * Ip = Vs * Is$$

- Step 1: Set the Digital Multimeter to measure current
- Step 2: Set the knife switch to Open
- Step 3: Connect components according to the drawing
- Step 4: Close the knife and obverse the speed of the motor and reading on the multimeter.
- Step 5: Rotate the potentiometer wiper and record below:
- Step 6: Reverse the battery leads and observe _____

Potentiometer Wiper Position	Current Reading	Motor Speed
Left		Fastest Middle Slowest
Middle		Fastest Middle Slowest
Right		Fastest Middle Slowest

Potentiometer

Battery

Motor

Switch

45
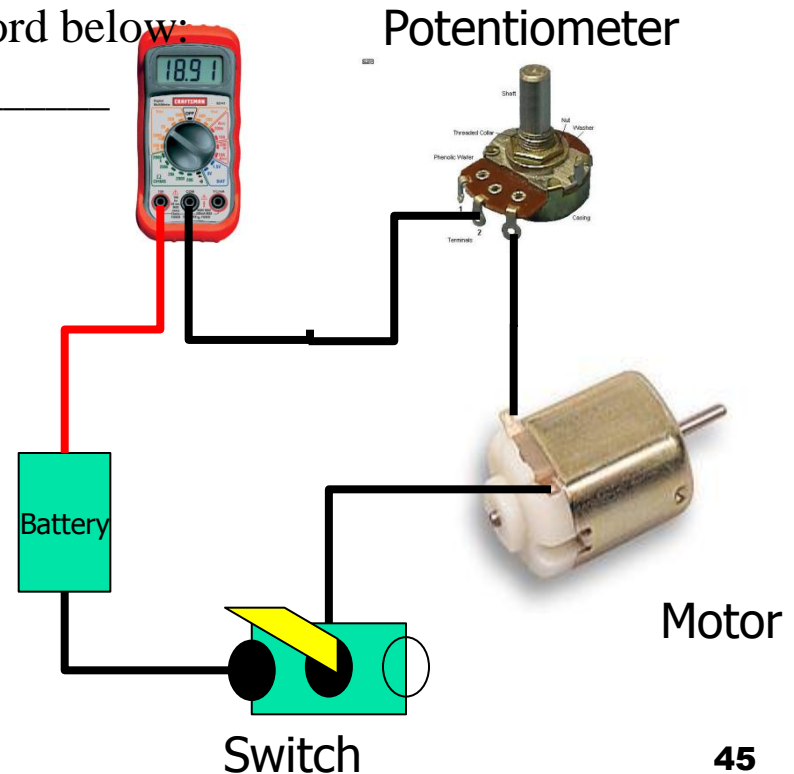
Lab 6 – Electromagnet

Materials Required: Magnet wire, iron nail, AA battery, compass, paper clips, multimeter.

- Step 1: Cut a three meter length of magnet wire.
- Step 2: Sand a couple inches of insulation off each end of the wire and verify good contact with the multimeter.
- Step 3: Mark the midpoint of the wire, select a nail and wind half the wire tightly around it while counting the number of turns and leaving sufficient length at both ends to hold the bare ends to a Double A battery.
- Step 4: Using the right hand rule, determine which battery terminal needs to be connected to the Nail Head end of the wire to make the Head a North Pole.
- Step 5: Connect the battery to the electromagnet as determined in Step 4 and check that the **SOUTH** seeking end of the compass needle is attracted to the Nail Head. Resolve any differences.

Caution: When your fingers get hot holding the wire ends to the battery, stop and let things cool.
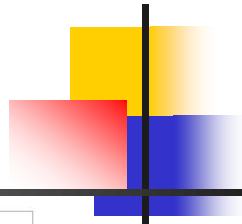
- Step 6: Determine how many paper clips can be pulled from a box by the magnetized nail head.
- Step 7: Wind the remaining length of wire while counting the turns and repeat step 6.
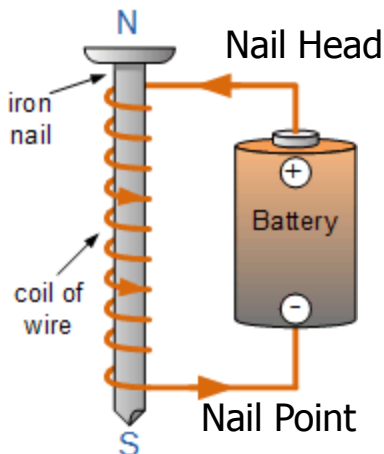
	Half of wire	All of Wire
Number of turns		
Number of paper clips		

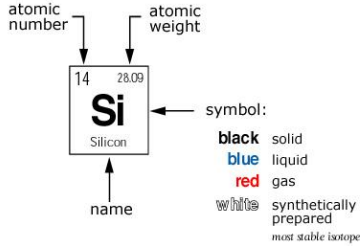Battery terminal connection required at Nail Head to make the Head a North pole: [+] or [-] (circle correct terminal)

Periodic Table of the Elements

Copyright © 2009 Oxford Labs

Diamond Crystalline Structure

- The Periodic Table is organized to have elements with similar chemical properties aligned in the same columns. For example, the noble gasses in the far right column do not chemically combine with any other elements or with themselves.

- The outer shell electrons of atoms control their chemical properties.

- Carbon atoms have 4 electrons in their outer shell and need to bond with 4 more electrons to achieve chemical stability.

- Within a diamond crystal, each carbon atom is covalently bonded to 4 adjoining carbon atoms in a tetrahedral configuration.

- With all of the electrons tightly bonded within the structure, diamonds are an electrical insulator.

- Silicon is directly below carbon on the periodic table and shares the same diamond crystalline structure.
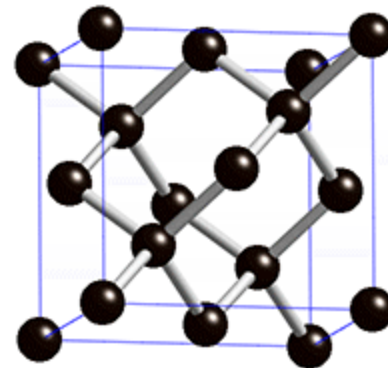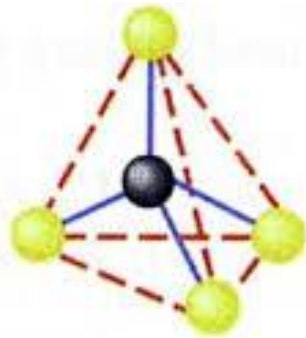
A Silicon P-N Junction

- Similar to diamond crystals, pure silicone crystals do not conduct electricity very well unless impurities are introduced into the crystalline structure.

- If a small amount of boron with 3 valence electrons is mixed into the batch, those boron atoms will bond with the silicon but be one electron short of the 8 requires for stable bonding. Such crystals with electron holes are called p-type and the boron is the doping agent. P-type crystals will conduct electricity. Other elements beside boron can be used for p-type doping – What are they?

- Similarly, if a small amount of phosphorus with 5 valence electrons is mixed into the batch, those phosphorus atoms will bond with the silicon but have one excess electron over the 8 requires for stable bonding. Such crystals with excess electrons are called n-type and the phosphorus is the doping agent. N-type crystals will also conduct electricity. Other elements beside phosphorus can be used for n-type doping – What are they?

- When p-type and n-type silicon are joined together, a diode is created that will only allow current to flow in one direction – from the p-type to the n-type or in the direction of the symbol arrowhead.
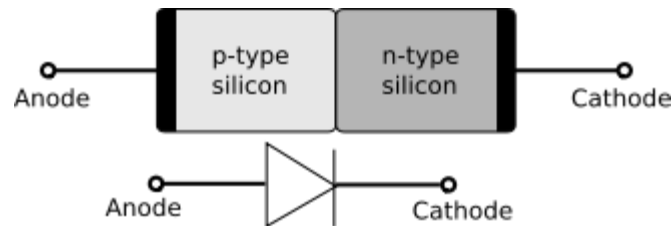
P-N Junction in Equilibrium
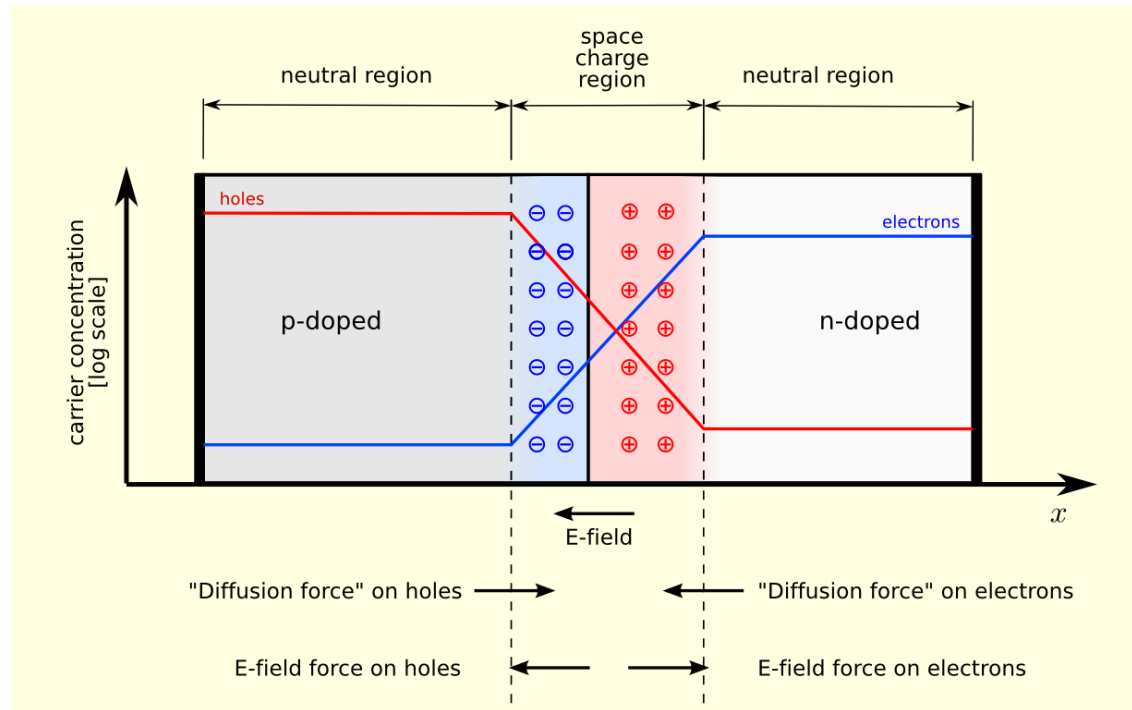
A p–n junction in thermal equilibrium with zero-bias voltage applied. Electron and hole concentration are reported with blue and red lines, respectively. Gray regions are charge-neutral. Light-red zone is positively charged. Light-blue zone is negatively charged. The electric field is shown on the bottom, the electrostatic force on electrons and holes and the direction in which the diffusion tends to move electrons and holes.

- The E-field for a typical p-n junction is 0.6 volts
- When a voltage in excess of 0.6 volts is applied to the p-doped side(called forward bias), current flows with little resistance.
- When a voltage is applied to the n-doped side, it adds to the E-field and simply widens the space charge region (also called the depletion zone) and no current flows. This is called the reverse bias condition.
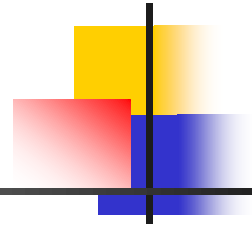
- The holes in the p-type are located in the valence band while the free electrons in the n-type are in the higher energy conduction band as shown in Figure 1.

- When positive voltage is applied to the p-type, the depletion zone narrows and free electrons travel across the depletion zone and combine with holes on the p-side. This creates a current with low resistance from p to n.

- When the free electrons move from the conduction band in the n-type to valence holes in the p-type as shown in Figure 2, they give up energy by emitting a photon. For most diodes, the photons emitted are in the infrared spectrum and not visible.
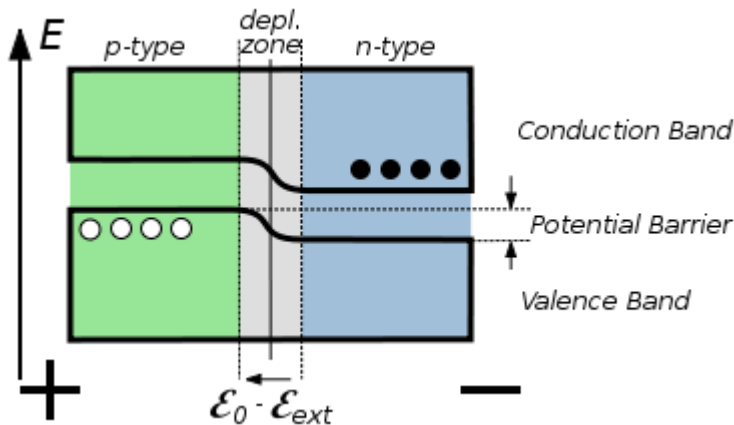
Figure 1
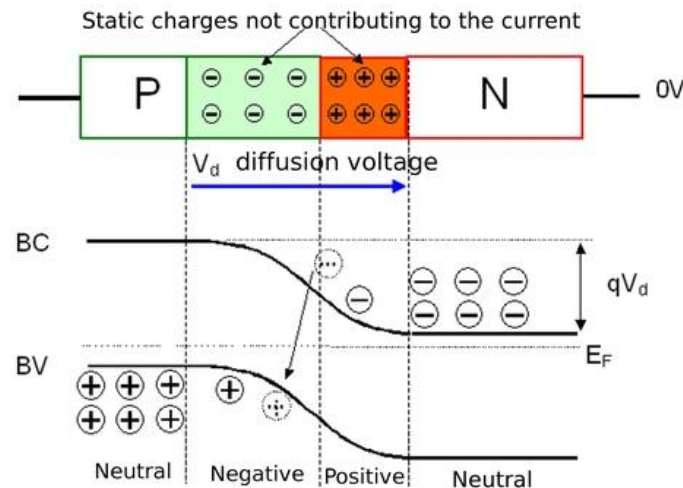
Figure 2

Light Emitting Diode (LED)

- To get p-n junctions to emit photons in the visible light spectrum, scientists had to find materials with a higher energy difference between the n-type conduction band electrons and the p-type holes. Various gallium compounds have been found to meet these needs, including gallium nitride which is used for blue LEDs. The Japanese inventors who developed the blue LED less than 20 years ago received the 2014 Nobel prize in physics. Although the red and green LEDs were discovered in the middle of the 20th Century, white light from LEDs requires the combination of red, green and blue LEDs which are now being produced.
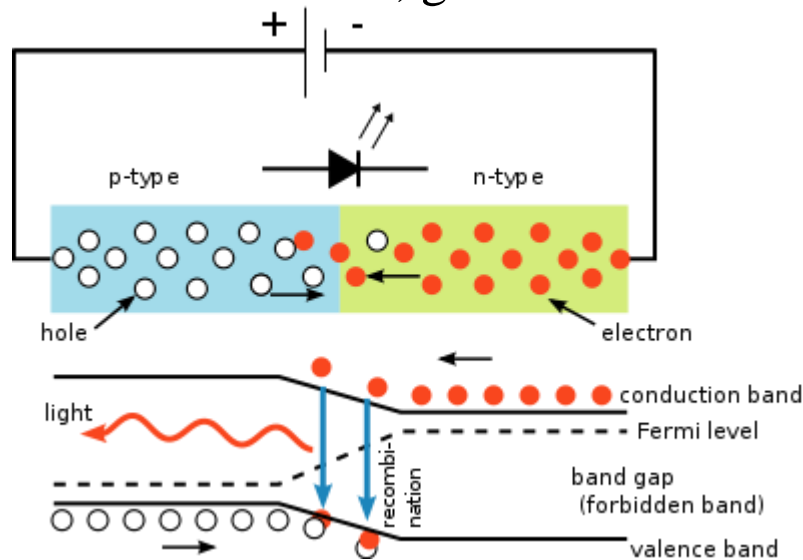
- A specially configured p-n junction in which photons bang into the junction and separate electrons from atoms – creating free electrons and holes.

- The electric field in the depletion zone pushes the free electrons to the n-layer and the holes to the p-layer. Thus creating a potential difference of approximately 0.6 volts .

- A current will result by connecting a load.
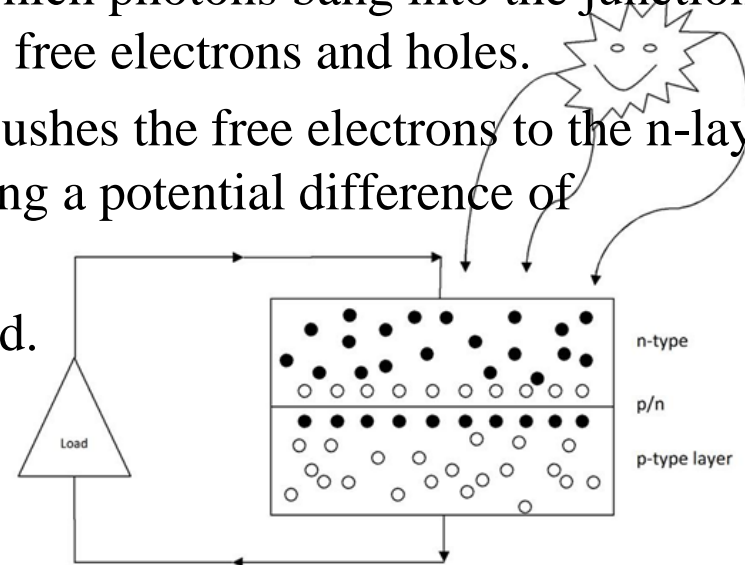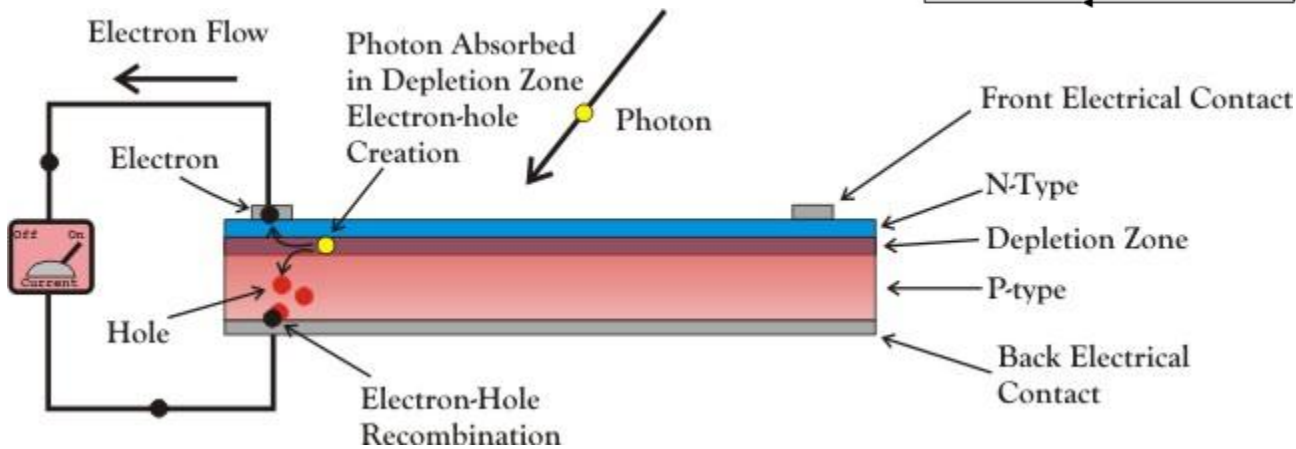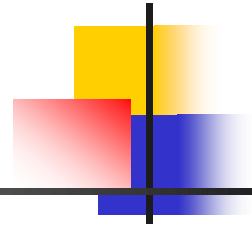
- Material: Hand crank DC generator, light bulb & socket, LED and TWO digital multimeters **Caution: The generator has plastic gears that will not take a lot of force. Please be gentle this these machines so that you do not strip the gears or damage the bearings.**

- Step 1: Unscrew the light bulb from the front of the generator and put it aside.

- Step 2: Connect the generator output alligator clips to the freestanding lamp socket and connect the multimeter to measure voltage. Turn the generator handle at a moderate speed . Record the DC voltage and polarity, observe the bulb brightness and feel the amount of force required on the handle.

- Step 3: Stop, unscrew the bulb and repeat operation at the same crank speed and no-load. Record the DC voltage and polarity and feel the amount of force required on the handle.

- Step 4: Repeat Step 3 but crank the generator in the opposite direction.

- Step 5: Reinstall the socket bulb and attach the second multimeter to measure both the generator output voltage and the current going to the light. Spin the generator at a moderate speed and record the voltage and current. Compute the power being consumed by the light using P = V time I.

- Step 6: Replace the lamp socket in Step 5 with an LED and compute the power consumed by the LED. What happens when you change the direction of handle rotation? _____ Why?_____

	Step 2	Step 3	Step 4	Step 5	Step 6
LOAD	light bulb	no load	no load	light bulb	LED
DC Volts (v)					
POLARITY + or -					
DC CURRENT (a)	n/a	n/a	n/a		
POWER (w)	n/a	n/a	n/a		
Change in force to turn handle	n/a				

Material: 120 VAC to 8 VAC plug-in transformer, mystery transformer of unknown turns ratio, diode, multimeter and oscilloscope

- Step 1: Attach the multimeter and the oscilloscope to the output (8 VAC) side of the plug-in transformer.

- Step 2: Energize the plug-in transformer and record: _____

  AC voltage:_____Peak-to-peak Voltage of waveform _____ Sketch waveform

- Step 3: Attach a diode to the output of the plug-in transformer and attach the multimeter and oscilloscope downstream of the diode. Record the AC voltage _____ and sketch the waveform.

- Step 4: Connect primary side of the mystery transformer to the 8 VAC output of the plug-in transformer Record the input voltage: _____ and output voltage: _____ of the mystery transformer.

- Step 5: Compute the turns ratio of the mystery transformer by dividing the two voltages: _____ [larger voltage/ smaller voltage]

- Step 6: Connect secondary side of the mystery transformer to the 8 VAC output and
  Record the input voltage: _____ and output voltage: _____ of the mystery transformer.

- Step 7: Re-compute the turns ratio of the mystery transformer by dividing the two voltages: _____ [larger voltage/ smaller voltage]

110V AC Input   8V AC Output

$n_1 : n_2$

Primary Side   Secondary Side
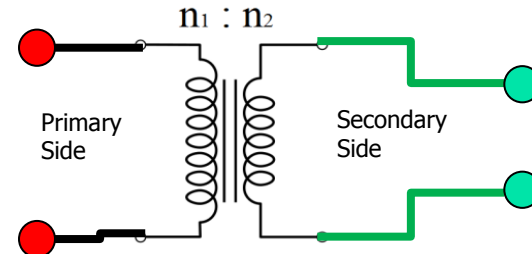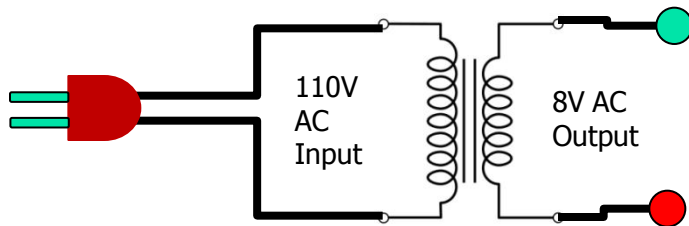
- Digital logic is the representation of signals and sequences of a digital circuit through numbers.

- It is the basis for digital computing and provides a fundamental understanding on how circuits and hardware communicate within a computer.

- Digital logic is typically embedded into most electronic devices including calculators, computers, video games and watches.

- Electronic signals can be divided into two categories: <u>analog and digital</u>.

- <u>Analog signals</u> can take any shape and represent an infinite number of possible values.

- <u>Digital signals</u> have a very defined, discrete set of possible values
  - usually only *two, 0 or 1*.
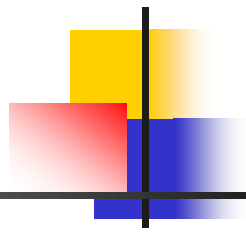
- There is logic in <u>all</u> circuits.
    - A connection to a power source is an example of an AND. Only if both power AND ground are connected will the circuit allow electricity to run through it.
- The traffic light in a city uses logic when pedestrians push the walk button.
    - The button starts a process that uses an AND logic gate.
    - If someone pressed the walk button AND there is a red light for traffic where the pedestrian will be walking, the walk signal will activate.
    - If both conditions of this AND statement are not true, the walk signal will never be illuminated.

- Rather than referring to voltage levels of signals, we should consider signals that are logically 1 or 0 (or asserted or de-asserted)

Logic operation

NOT

A	$\overline{A}$
0	1
1	0

AND

A	B	A and B
0	0	0
0	1	0
1	0	0
1	1	1

OR

A	B	A or B
0	0	0
0	1	1
1	0	1
1	1	1

XOR

A	B	A xor B
0	0	0
0	1	1
1	0	1
1	1	0

Truth tables
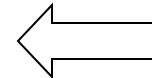
Gates

Output is 1 iff:

| Input is 0 | Both inputs are 1s | At least one input is 1 | Inputs are not equal |

- Gates are simplest digital logic circuits, and they implement basic logic operations (functions)
- Gates are designed using transistors
- Gates are used to build more complex circuits that implement more complex logic functions.

- Operation AND: *
- Operation OR: +
- Inverse of A: $\overline{A}$
- Identity Laws: A + 0 = A,   A * 1 = A
- Inverse laws: A+$\overline{A}$ = 1, A *$\overline{A}$ = 0
- Zero and one laws A + 1 = 1, A * 0 = 0
- Commutative laws: A+B = B + A, A * B = B * A
- Associative laws:
  - A+(B+C) = (A+B) + C;   A*(B*C) = (A*B)*C
- Distributive laws:
  - A * (B+C) = (A*B) + (A *C);   A + (B * C) = (A+B) * (A +C)
- DeMorgan's laws:

$$\overline{(A+B)} = \overline{A} * \overline{B}$$

$$\overline{(A*B)} = \overline{A} + \overline{B}$$

■ Consider one of logic equations:

$$y1 = \overline{x_1} * \overline{x_2} * \overline{x_3} + \overline{x_1} * \overline{x_2} * x_3 + \overline{x_1} * x_2 * x_3 + x_1 * x_2 * x_3$$

$$= \overline{x_1} * \overline{x2} * (\overline{x_3} + x_3) + x_2 * x_3 * (\overline{x_1} + x_1)$$

$$= \overline{x_1} * \overline{x_2} + x_2 * x_3$$

■ But if we start grouping in some other way, we may not end up with the minimal equation.

Digital Logic Integrated Circuit

- BCD – Binary Coded Decimal. Decimal numbers are represented by a fixed number of bits, usually 4 or 8.

- 74LS42 – A BCD decoder
  - The LS42 decoder accepts four active HIGH BCD inputs and
  - provides ten mutually exclusive active LOW outputs, as shown by logic symbol or diagram.
  - The active LOW outputs facilitate addressing other ciruit units with LOW input enables

LOGIC DIAGRAM

Vcc = PIN 16
GND = PIN 8
○ = PIN NUMBERS
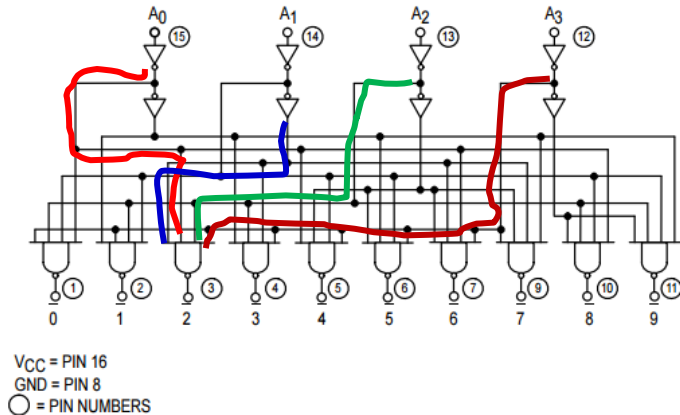
Decimal digit	BCD			
	8	4	2	1
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1

TRUTH TABLE

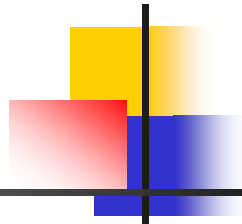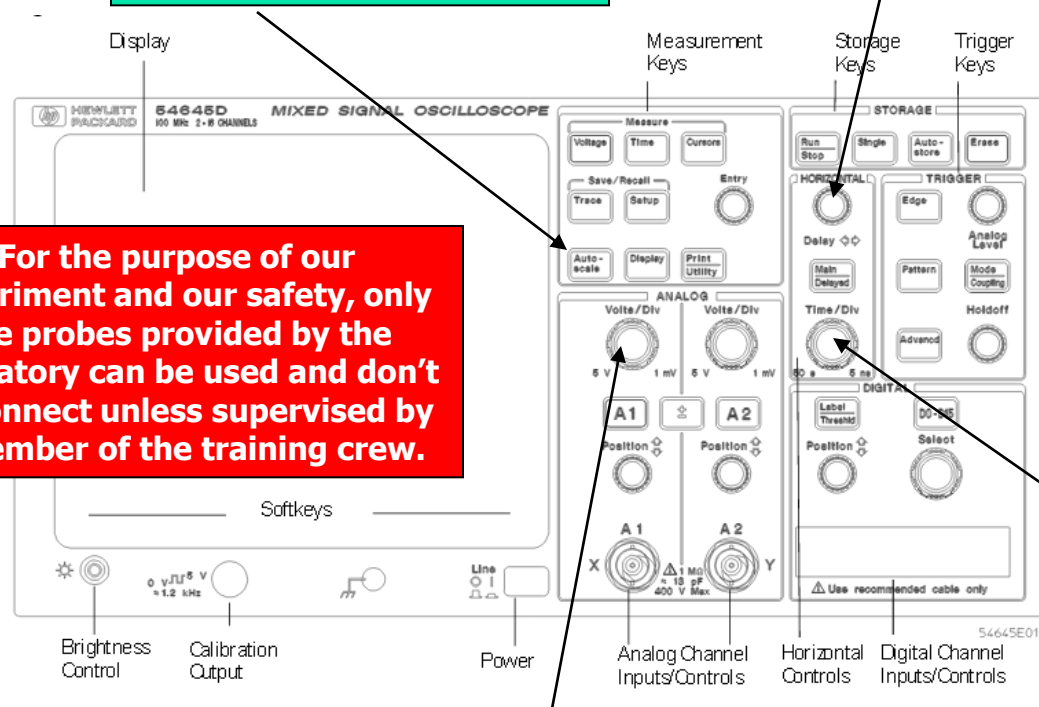| A0	A1	A2	A3	0	1	2	3	4	5	6	7	8	9
L	L	L	L	L	H	H	H	H	H	H	H	H	H
H	L	L	L	H	L	H	H	H	H	H	H	H	H
L	H	L	L	H	H	L	H	H	H	H	H	H	H
H	H	L	L	H	H	H	L	H	H	H	H	H	H
L	L	H	L	H	H	H	H	L	H	H	H	H	H
H	L	H	L	H	H	H	H	H	L	H	H	H	H
L	H	H	L	H	H	H	H	H	H	L	H	H	H
H	H	H	L	H	H	H	H	H	H	H	L	H	H
L	L	L	H	H	H	H	H	H	H	H	H	L	H
H	L	L	H	H	H	H	H	H	H	H	H	H	L
L	H	L	H	H	H	H	H	H	H	H	H	H	H
H	H	L	H	H	H	H	H	H	H	H	H	H	H
L	L	H	H	H	H	H	H	H	H	H	H	H	H
H	L	H	H	H	H	H	H	H	H	H	H	H	H
L	H	H	H	H	H	H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H	H	H	H	H	H	H

H = HIGH Voltage Level
L = LOW Voltage Level

$$Output\ 2 = \overline{\overline{A3} * \overline{A2} * A1 * \overline{A0}}$$

An oscilloscope is a laboratory instrument commonly used to display and analyze the waveform of electronic signals. In effect, the device draws a graph of the instantaneous signal voltage as a function of time

Autoscale (a.k.a. The Idiot Button)
Use this button to let the oscilloscope to find the signal and setup the oscilloscope for your viewing

Horizontal Delay
Turn this knob to change the location in time of the signal you want to see

For the purpose of our experiment and our safety, only the probes provided by the laboratory can be used and don't disconnect unless supervised by a member of the training crew.

HP 54645D Mixed-Signal Oscilloscope Front Panel

Time/Div (Horizontal or Time Scale)
Turn this knob to change how small in time the signal appears on the screen

Volts/Div (Vertical or Voltage Scale)
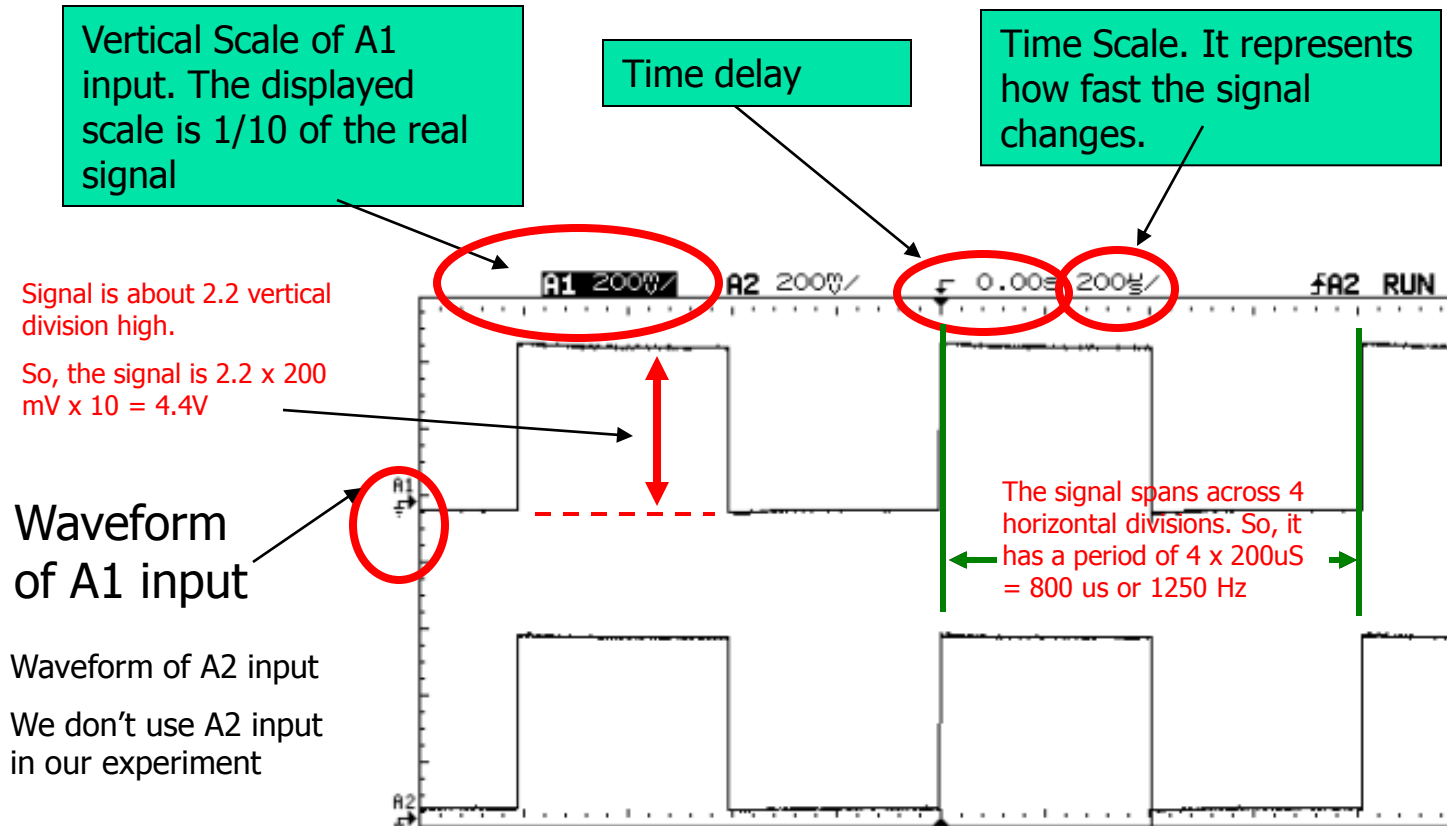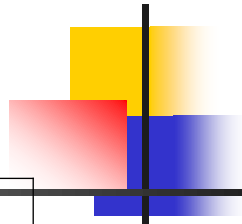Turn this knob to change how high the signal appears on the screen
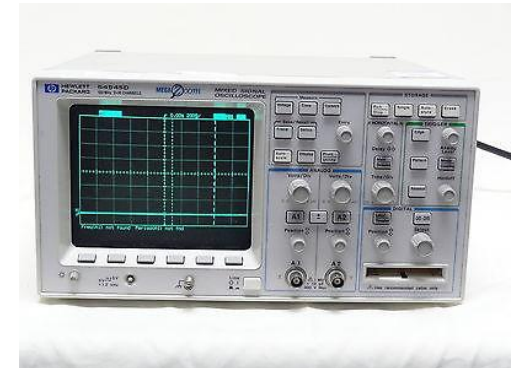
Sample display of an oscilloscope

The oscilloscope display is divided into 8 vertical and 10 horizontal divisions.

Equipment for One Station

LAB	Special Equipment	AA battery	switch	resistor	B-B wires	motor	6 v lamp	LED	diode
1 3 Way Switch		power pack of 2	2		5		1		
2 Multimeter		power pack of 2	1	Ri, R2 & R3	5				
3 R/C Time Constant	Stop watch Calculator 100 Microfarad capacitor	power pack of 2	1	R10 & R11	4				
4 Faraday Motor	motor kit w/ battery								
5 DC Motor	100 ohm potentiometer	power pack of 2	1		4	1			
6 Electromagnet	1 nail & three meters of magnet wire paper clips to lift	1							
7 Generator	DC hand crank generator two multimeters				alligator		1	1	
8 Transformer	120 to 8 VAC plug in transformer mystery transformer oscilloscope				2				1