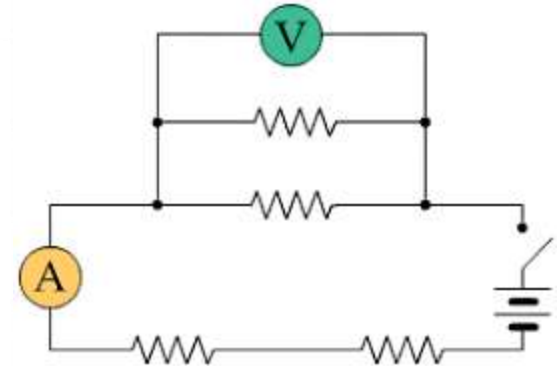
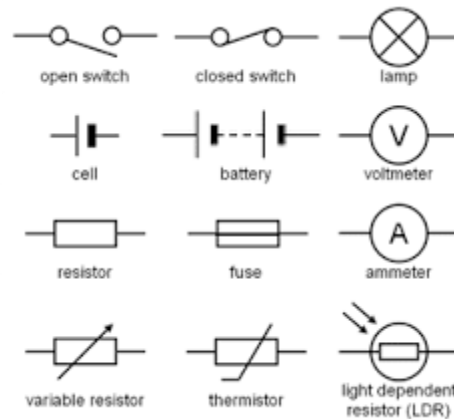
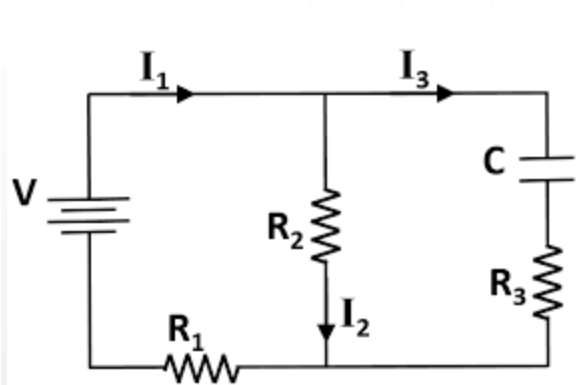




Circuit Lab

Adapted from - Russ Burleson
David Hein

Event Description



Exploring the World of Science

Tests knowledge of:

History, electricity, magnetism, electrical devices, electrical circuits

20-50% of score from practical portion (hands-on tasks)

50% to 75% of score from theoretical portion (written questions)

Students bring:

Any calculators – up to 2

Reference material in 3-ring binder any size

Basic multimeters (optional- but recommended)

2 students per team allowed

Points awarded for correct answers or techniques

Written Test Topics



Exploring the World of Science

Must have at least 1 task / question from each of these areas:

Historical perspective of the electricity discoveries made by Volta, Ohm, Tesla, Hertz, & Faraday, **Ampere, Coulomb, Kirchhoff**

Properties of electric charge/fields, sources/hazards of static electricity, Coulomb's Law, capacitance

Direct current (DC) characteristics, sources, uses, simple circuit diagrams, DC hazards

Alternating current (AC) characteristics, sources, uses, AC hazards

Concepts and units of current, voltage, resistance, power, energy, and using Ohm's law

Magnetic poles/fields, electromagnets, transformers, motors/generators, right-hand rule

Electrical control devices including 3-way light switch circuits

Simple ~~measurements~~ **calculations**, constructions, and configurations of a circuit and individual components

Fundamental characteristics and operation of a light emitting diode (LEDB)

Simple circuit analysis using Kirchhoff's Voltage & Current Laws

Written Test Topics



Exploring the World of Science

Division C only

Basic digital logic and digital logic operations

~~Time constant of a RC circuits~~

Electrical characteristics of silicon PN junctions **(eg, diodes, PNP, NPN)**

Basics and application of Operational Amplifiers (OpAmps)

Excluded topics:

Semiconductors

AC circuit theory ~~/ devices~~

Inductance

Calculations using calculus or Dif Eq

Non Linear Devices

~~Advanced digital~~ Three State Logic Devices, Sequential Logic

3 Phase Power

Oscilloscopes

Hands On Tasks



Examples include:

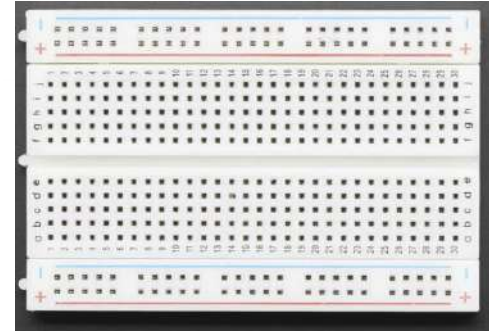
Figure out the value of a mystery resistor

Calculate the power supplied to a circuit

Hooks up 2 LEDs to be equally bright

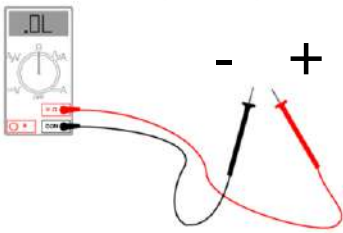
Construct an electromagnet

Where are the poles on a refrigerator magnet



Must be familiar with breadboards

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

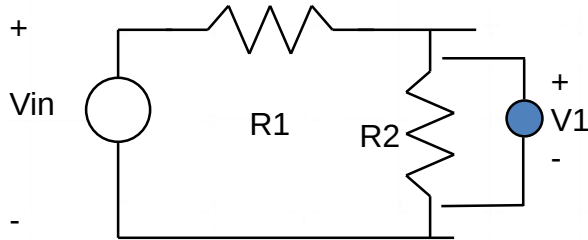


Using Meters



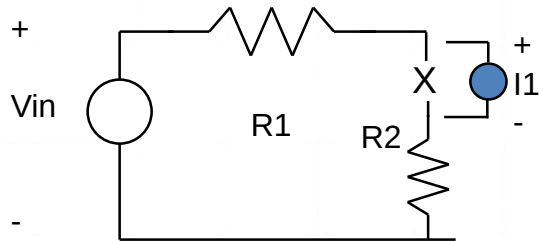
Measure Voltage

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



Measure Current

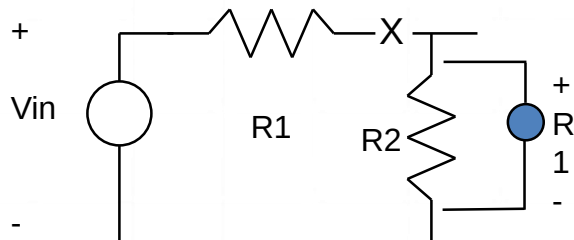
Current is measured as a flow through a component. In order to measure current through a component, you will have to disconnect the circuit and hook the meter in series with the component to measure the current through.



Watch for Short Circuit

Measure Resistance

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



When measuring small values of resistance, you will need to subtract the resistance of the meter leads to get an accurate measurement.

Binder

3 Ring Binder (nothing can fall out)

Must be attached in the rings of the binder

“Cheat Sheet”

Constants

Equations

Detailed sections

History

Definitions and terminology

Graphs / tables / diagrams



Metric Prefix Scale

Resistance is normally in $k\Omega$ —kilohms (thousands of Ohms) or $M\Omega$ --Megaohms (millions of Ohms)

Voltage can be in the Volts range, but often is in mV--millivolts (thousandths of Volts) up to MV--Megavolts (millions of Volts)

Current is normally in mA—milliamps (thousandths of Amps), but can sometimes be in Amps

12 V on a $3 k\Omega$ resistor would produce 4 mA.

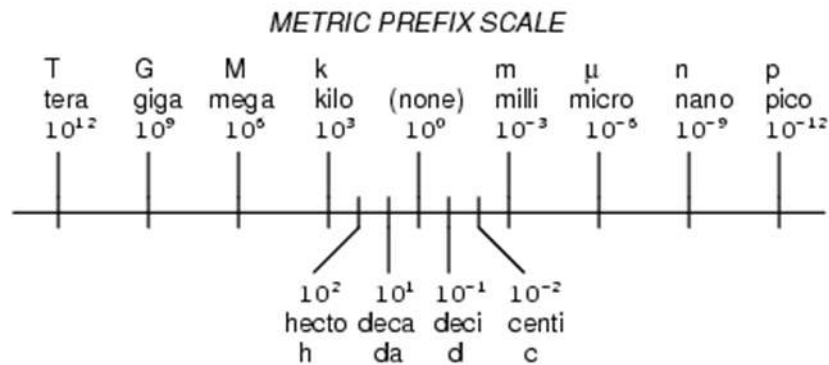
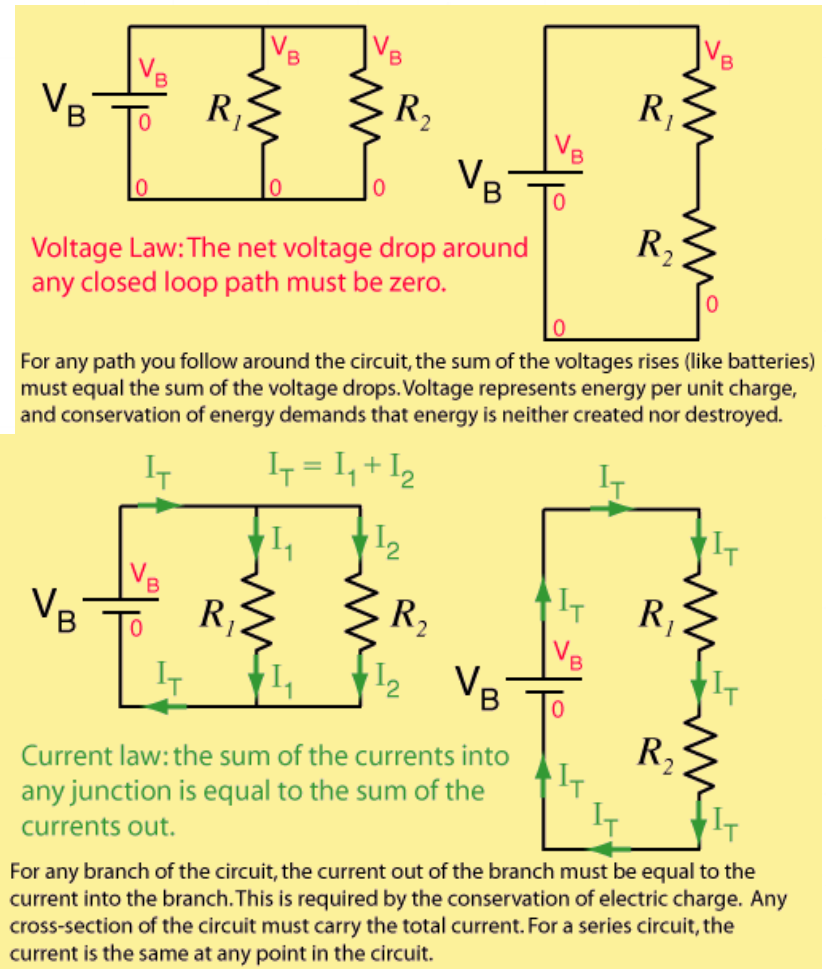


Table 12.1. Units for magnetic quantities

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

or: All current into a node equals all current out!

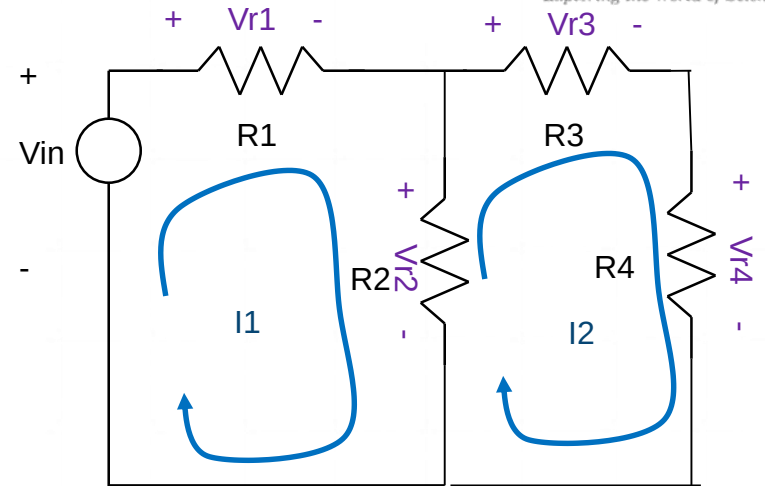


Kirchhoff's Voltage & Current Law (KCL&KVL)



KVL

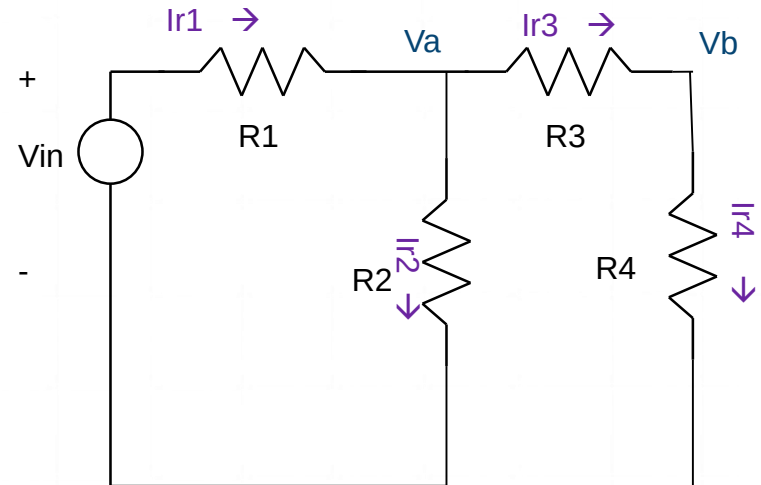
- Step 1 -> Draw the current Loops
- Step 2 -> Label voltages, + and -
- Step 3 -> Write KVL Equations
- Step 4 -> Replace voltages by using Ohms Law
- Step 4 -> Solve KVL Equations for unknowns



$$\begin{aligned}
 -V_{in} + V_{r1} + V_{r2} &= 0 & -V_{in} + I_1 * R_1 + R_2 * (I_1 - I_2) &= 0 \\
 -V_{r2} + V_{r3} + V_{r4} &= 0 & -R_2 * (I_1 - I_2) + I_2 * R_3 + I_2 * R_4 &= 0
 \end{aligned}$$

KCL

- Step 1 -> Place the Node Voltages
- Step 2 -> Label the currents and direction
- Step 3 -> Write KCL Equations
- Step 4 -> Solve KCL Equations for unknowns



$$\begin{aligned}
 I_{r1} - I_{r2} - I_{r3} &= 0 & (V_{in} - V_a)/R_1 - V_a/R_2 - (V_a - V_b)/R_3 &= 0 \\
 I_{r3} - I_{r4} &= 0 & (V_a - V_b)/R_3 - V_b/R_4 &= 0
 \end{aligned}$$

NPN and PNP Transistors (Division C Only)



An NPN or PNP transistor is a three terminal electronic component that can act as a switch or amplifier when connected correctly in a circuit.

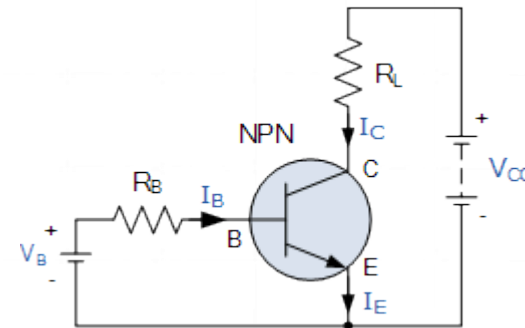
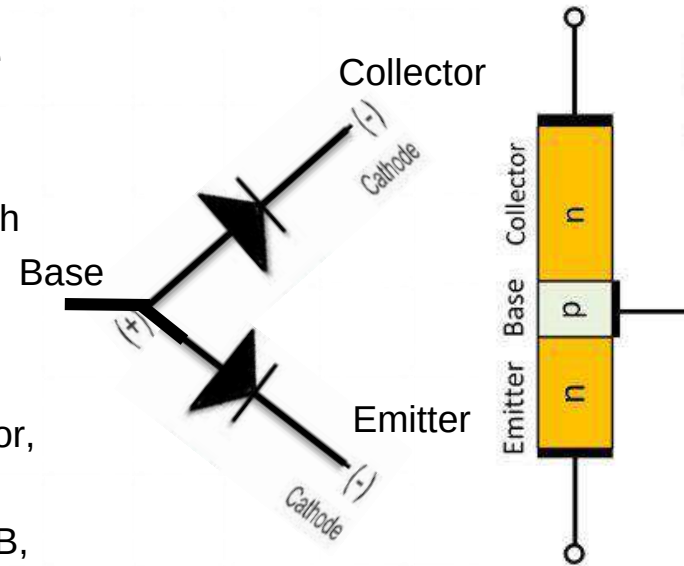
The transistor in which one p-type material is placed between two n-type materials is known as NPN transistor.

For a NPN transistor to conduct the Collector is always more positive with respect to both the Base and the Emitter.

Then the voltage sources are connected to an NPN transistor as shown. The Collector is connected to the supply voltage V_{CC} via the load resistor, R_L which also acts to limit the maximum current flowing through the device. The Base supply voltage V_B is connected to the Base resistor R_B , which again is used to limit the maximum Base current.

Used as a switch, a positive voltage applied to the base (V_b) causes current to flow from the collector to the emitter this causes the voltage of the collector to drop near the voltage of the emitter (0.1 V).

When Voltage is removed from the base, the current stops flowing from the collector to the emitter and the voltage at the collector goes back to about V_{cc} .



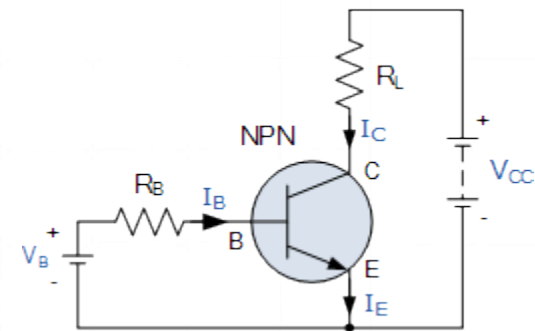
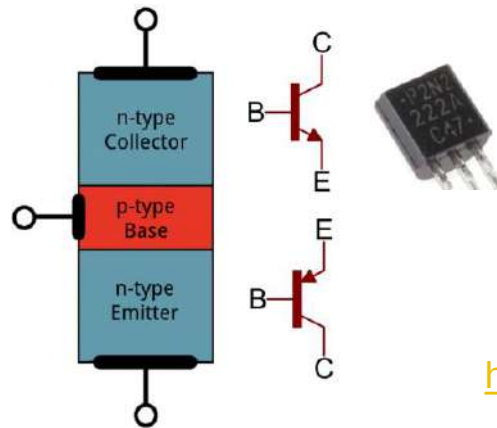
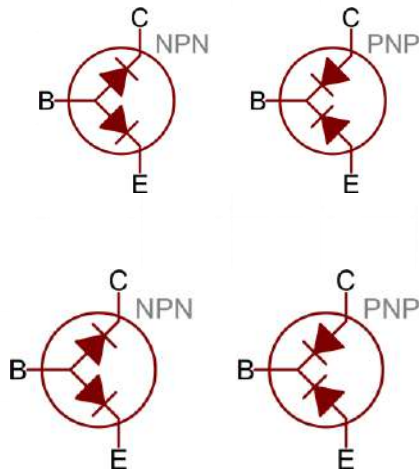
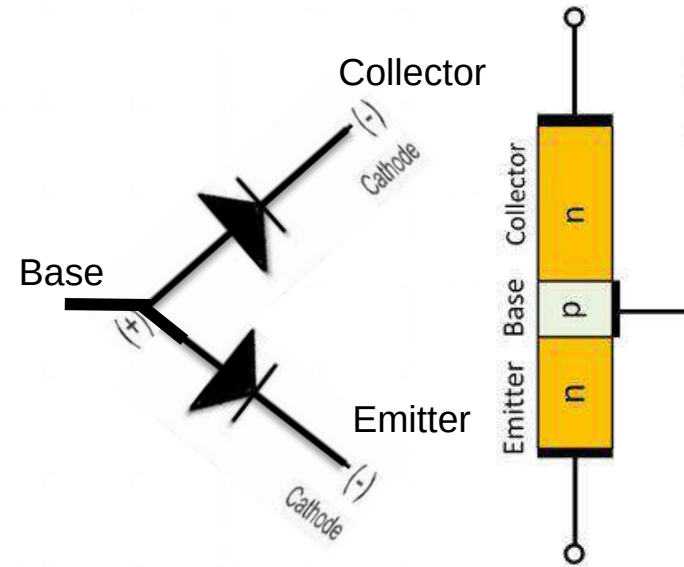
NPN and PNP Transistors (Division C Only)



Used as an amplifier, a positive voltage applied to the base (V_b) causes current to flow from the collector to the emitter. The current that flows is a multiple of the current in the base.

The current in a NPN transistor is the ratio of these two currents (I_c/I_b), called the DC Current Gain of the device and is given the symbol of h_{fe} or nowadays Beta, (β).

The value of β can be large up to 200 for standard transistors, and it is this large ratio between I_c and I_b that makes the bipolar NPN transistor a useful amplifying device when used in its active region as I_b provides the input and I_c provides the output. Note that Beta has no units as it is a ratio.



<https://learn.sparkfun.com/tutorials/transistors/all>

https://en.wikipedia.org/wiki/Bipolar_junction_transistor

Resources

Wikipedia pages are great places to start your investigation, but you will need more Khan academy, Hyper Science, Bozeman Science, and electronics tutorials have some great resources and videos

Remember that SOINC.Org is the official website and the rules/clarifications there are the official rules

Many good resources and links

SCIOLY.org is an alumni run website that has lots of great resources and old tests, but it is NOT official. Everything there is just opinion.

Basics of Electricity

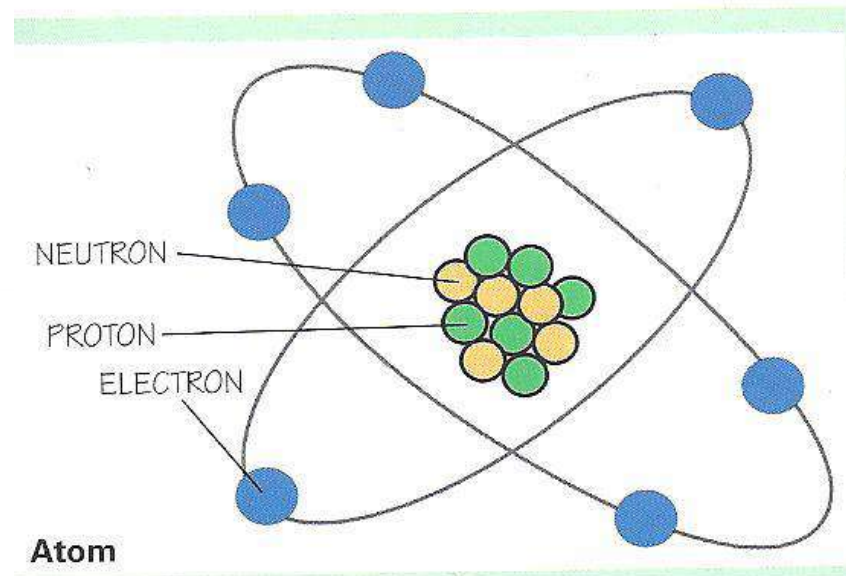
Atoms

Protons

Neutrons

Electrons

Electrical current



Famous Electric Scientist



Exploring the World of Science

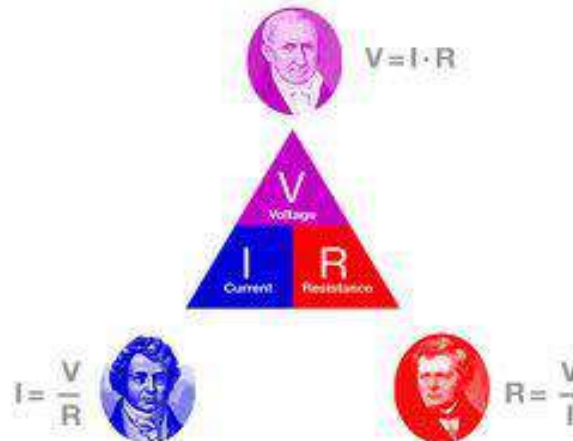
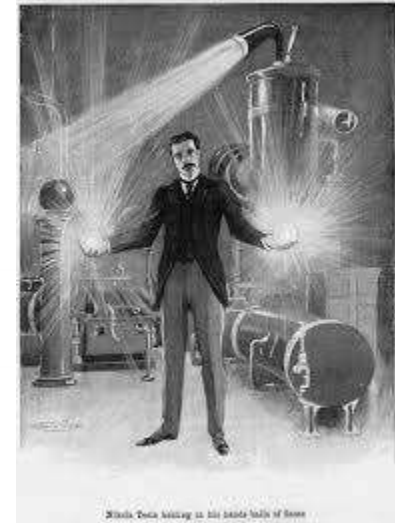
Thales of Miletus



Benjamin Franklin



Nikola Tesla



Important Terms



Ampere (A)—unit of electric current or how many electrons go past a given point in a second.

Also called an “Amp”

Amperage can heat up a wire and too much can melt a wire or start a fire. That is why we have breakers and fuses.

Volt (V)—unit of electric potential or how much strength the charge is “pushed”

Batteries are 1.5-24 V

Home electricity 110-220 V

Lightning can be millions of volts

Also called Potential Difference

Is the force behind the electrons

Direct Current (DC) is an electric current of constant direction.

All batteries are DC

Most electronics need DC, so you have special transformers and rectifiers to convert house AC voltage to DC.

Most of the problems in Circuit Lab are DC.

Alternating Current (AC) is electric current that regularly reverses direction.

House electricity and power lines are AC

AC is even more dangerous than DC

AC has less power loss to heat during transmission so it is used for generation and transmission

AC is transmitted at very high voltages and stepped down using a transformer for home usage (normally around 220V AC in the US)

Important Terms



Resistance is the opposition against the free transfer of electrons in a conductor.

Copper, Silver, and other conductors have low resistance

Glass, wood, rubber, plastic, and other insulators have high resistance.

Transfer (or current) is usually due to some force like the EMF from the Voltage of a battery

Ohms (Ω)—unit of electric resistance which is equal to the ratio of voltage to amperage.

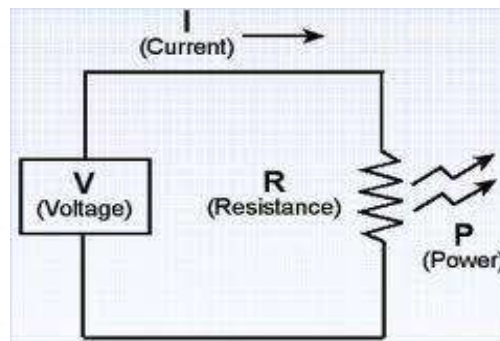
Superconductors = $0 \Omega \cdot m$

Metals/Conductors $\sim 10^{-8} \Omega \cdot m$

Semiconductors (variable upon doping)

Insulators $\sim 10^{16} \Omega \cdot m$

Superinsulators $\sim \infty \Omega \cdot m$



Many resistors and conductors have a uniform cross section with a uniform flow of electric current, and are made of one material. In this case, the electrical resistivity ρ (Greek: rho) is defined as:

$$\rho = R \frac{A}{\ell}$$

$$R = \rho \frac{\ell}{A}$$

Resistance increases

Longer lengths

Less area/smaller cross section

Higher temperature

Less conductive material

Resistance decreases

Shorter lengths

Larger area/cross section

Lower temperature

More conductive material

Top Common Conductors

Silver $\rho = 1.59 \times 10^{-8} \Omega \cdot m$

Copper $\rho = 1.68 \times 10^{-8} \Omega \cdot m$

Gold $\rho = 2.44 \times 10^{-8} \Omega \cdot m$

Aluminum $\rho = 2.65 \times 10^{-8} \Omega \cdot m$

Top Common Semiconductors

GaAs $\rho = 1 \times 10^{-3}$ to $1 \times 10^8 \Omega \cdot m$

Germanium $\rho = 4.6 \times 10^{-1} \Omega \cdot m$

Silicon $\rho = 6.4 \times 10^2 \Omega \cdot m$

Top Common Insulators

Deionized water, Glass, Diamond, Hard Rubber, Air, and Dry Wood

Fused Quartz $\rho = 7.5 \times 10^{17} \Omega \cdot m$

PET $\rho = 1 \times 10^{21} \Omega \cdot m$

Teflon $\rho = 1 \times 10^{23}$ to $1 \times 10^{25} \Omega \cdot m$

Physics Teachers versus Engineers

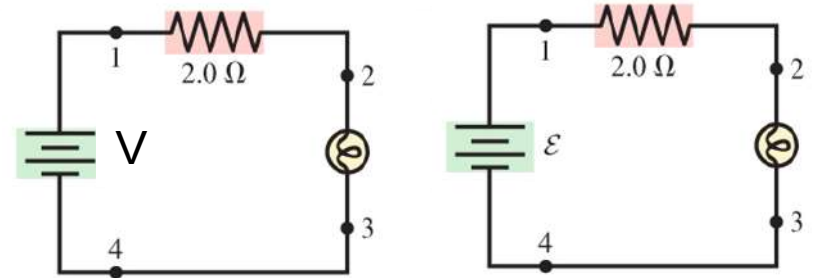


Physicists and Engineers look at circuit problems differently and sometimes put focus on different areas

Both are right, but you should be prepared because you don't know who writes your test

Always look at lots of different sample tests to get a flavor for all the ways a question may be asked

The diagrams to the right are equivalent, one uses a Voltage Source and one an Electromotor Force source (EMF)—same thing

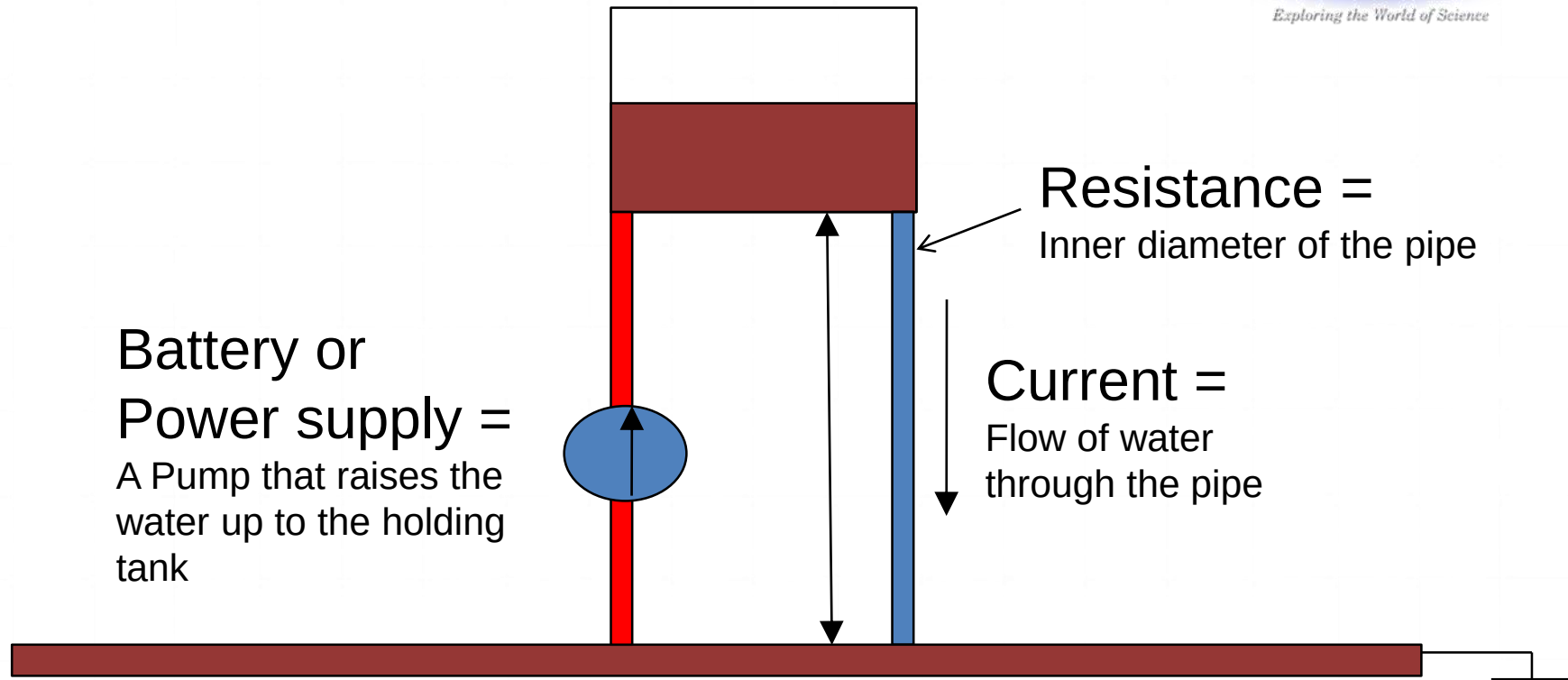


Conventional current (which is what is mainly used) flows from the positive terminal of a battery or EMF source and would be clockwise in the diagrams above

This is the direction of positive charges, but not electrons which flow the opposite way

Physicists often prefer to use “Real Current” which flows the opposite direction to match electron flow (counter clockwise or out of negative to positive)

Basic Electrical Concepts – Water Analogy



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

Static Electricity



Exploring the World of Science

Electricity that doesn't flow

It has a Voltage

It has zero Current

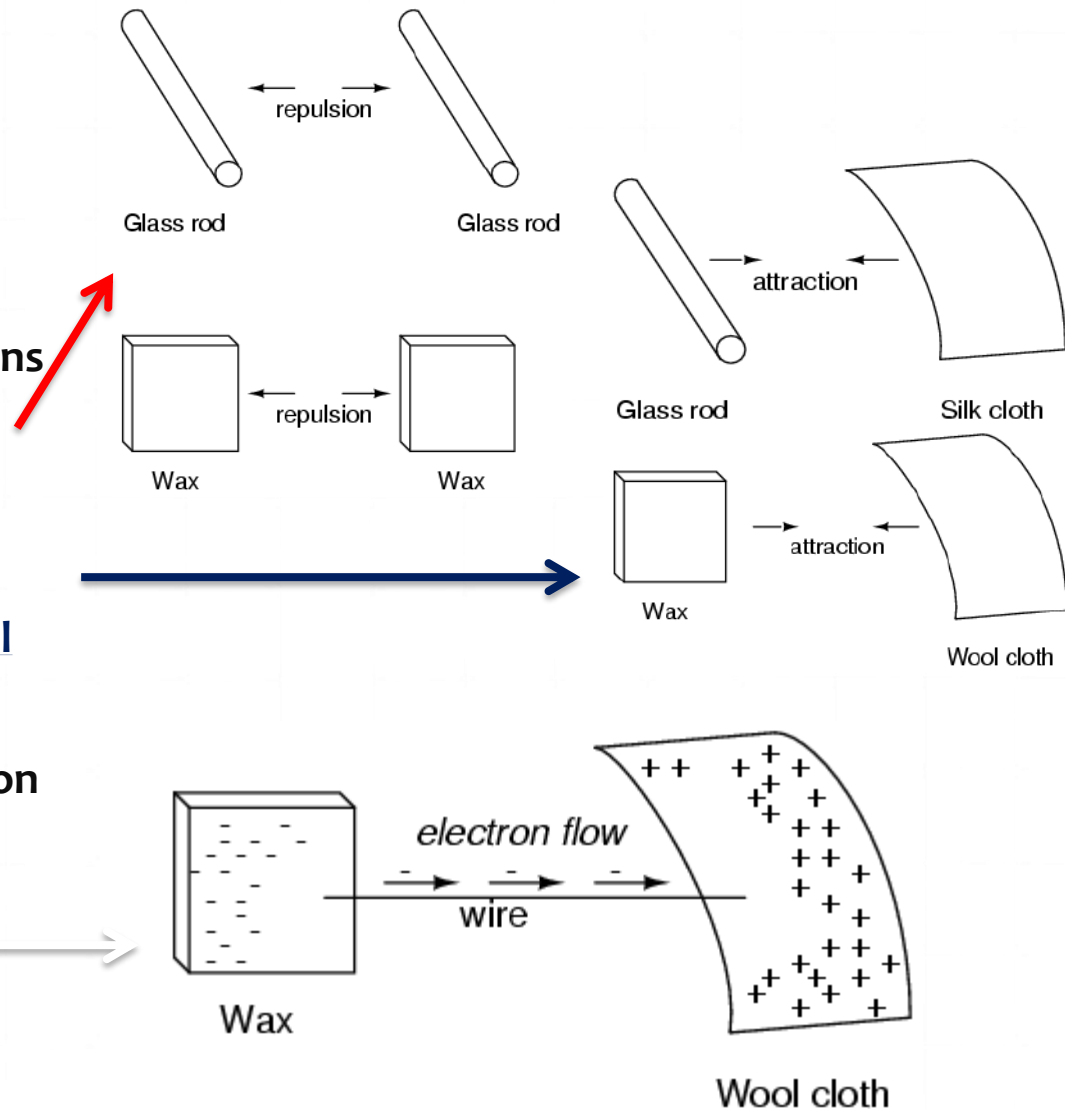
Caused by imbalance of electrons
in two materials

**Alike charges repulse or push
away from each other**

**Opposite charges attract or pull
towards each other**

Clingy socks and hair standing on
end

Can be changed by electrons
moving from one material to
another



What is an electric charge?



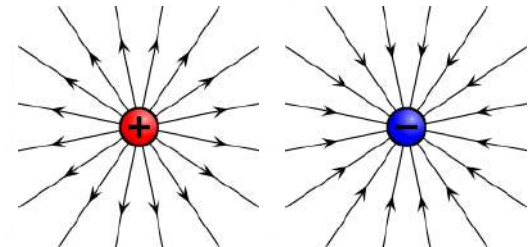
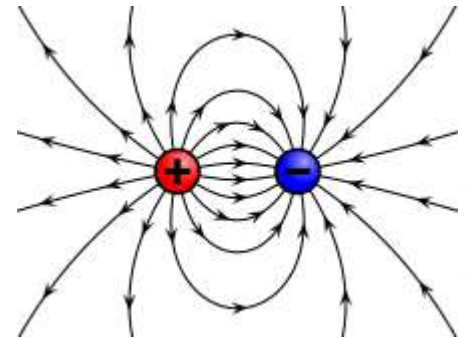
Electric charge is the physical property of matter that causes it to experience a force when placed in an electromagnetic field.

There are two types of electric charges; positive and negative (commonly carried by protons and electrons respectively). Like charges repel and unlike attract. An object with an absence of net charge is referred to as neutral

Charge is in unit Columbs (C) , it is always conserved

An electron has a charge of $1.602 \times 10^{-19} \text{ C}$

Electric field lines are drawn as radiating from a positive (+) charge and towards a negative (-) charge. Electric fields can be drawn as below.



Coulomb's Law

Coulomb's Law determines the force of attraction or repulsion between two charges.

F is the force in Newtons

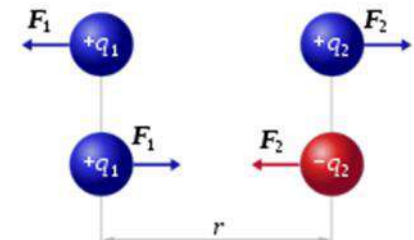
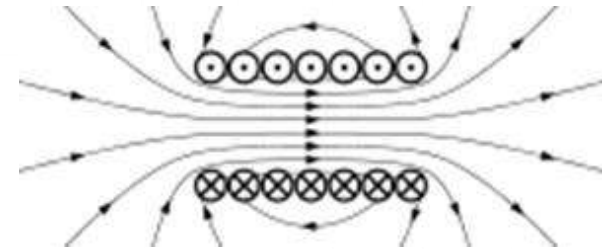
k_e is Coulomb's constant $8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$

q_1 and q_2 are the charges in Coulombs

r is the distance in Meters between the centers of charges

Groups of charges can be combined into an equivalent charge (i.e. like for an ion)

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



$$|F_1| = |F_2| = k_e \frac{|q_1 \times q_2|}{r^2}$$

Electron Info



- Electron Charge is -1.602×10^{-19} coulomb
- The force between two charged locations is
 - $F = 1/(4 * \pi * \epsilon_0 * \epsilon_r) * q_1 * q_2 / r^2$
 - Where ϵ_0 is the permittivity of free space $= 8.854 * 10^{-12} \text{ C}^2 / (\text{N} * \text{m}^2)$
 - Where ϵ_r is the relative permittivity of the material
 - And r is the distance between the two charged bodies
 - The direction of the force is based on if they are like or opposite charges
- Power is the rate of change of the work
- Energy is the capacity to do work or amount of work done
- Work is force acting through a distance $= F * d$
- Electromotive force or voltage is the electron pressure to move back to a neutral / non charged state.
- $V = W/Q = \text{Work} / \text{Charge} = \text{J} / \text{coulombs}$
- $\text{Current} = Q / t = \text{Charge} / \text{time} = \text{coulombs} / \text{second}$
- $P = V * I = W/Q * Q/t = W/t$
- 1,000,000 electrons are pumped from one side to the other side of a 1mm thin insulator wall. The relative permittivity of the wall is 3000.
 - What is the force that is exerted by the electrons to the conductors on either side of the insulator
 - How much power was required to move the electrons
 - What is the voltage
 - If it took 0.5 seconds to move the electrons, what was the current
 - What would the voltage be if the insulator wall was thinned to 0.01mm with the same permittivity?

Capacitors



Exploring the World of Science

A capacitor is a passive two-terminal electrical component that stores potential energy in an electric field

Most capacitors contain at least two electrical conductors often in the form of metallic plates or surfaces separated by a dielectric medium (glass, ceramic, plastic, paper, mica, etc.). A conductor may be a foil, thin film, sintered bead of metal, or an electrolyte.

Unit of capacitance is a Farad (F). Most capacitors have small values like μF , pF, etc.

Charge equals Capacitance times Potential

$$Q = C V$$

The simplest model of a capacitor consists of two parallel plates with a thin dielectric in between.

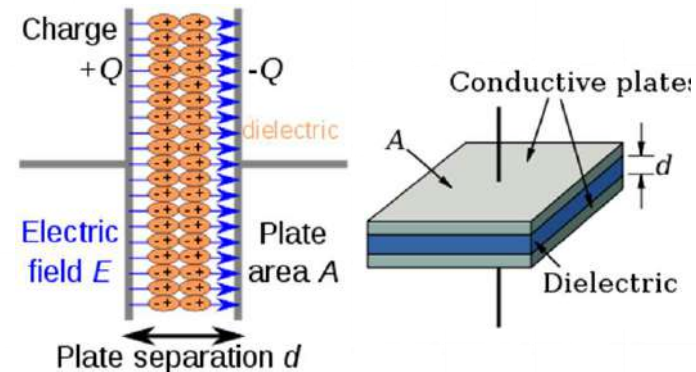
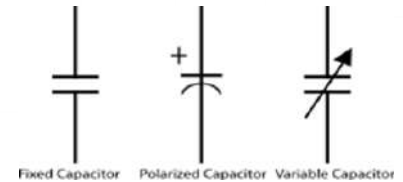
The dielectric is much thinner than the dimensions of the plates

The dielectric permittivity (ϵ) of the material determines how much capacitance can be held

$$C = \epsilon A / d$$

Energy stored in a capacitor is $E = \frac{1}{2} CV^2$

Free space/vacuum has a permittivity of $\epsilon_0 = 8.854 \times 10^{-12}$ F/m, all other materials are higher



Capacitor



- A capacitor is made from two conductors separated by an insulator
- Capacitance = $\text{Area} * e_0 * e_r / \text{distance}$
 - Where area is the area of the each of the conductors (the smallest one)
 - Distance is the distance between the conductors or thickness of the insulator barrier
 - Where e_0 is the permittivity of free space= $8.854 * 10^{-12} \text{ C}^2 / (\text{N} * \text{m}^2)$
 - Where e_r is the relative permittivity of the material
 - Area is measured in square meters
- Capacitance is measured in Farads or F
- Capacitance can also be calculated by $C = Q / V$; $Q = C * V$
- When discharging a capacitor the current $I = \text{change in } Q / \text{change in } t$
- $I = dQ / dt = C * dV / dt$
- For a capacitor that has plates that are 2 meters long, and 1cm wide with an insulator thickness of 1mm and a permittivity of 50,
 - What is the capacitance
 - If you charge it up to 10 volts, how much charge is stored in the capacitor?
 - If it took you 1 second to charge the capacitor, what was the current
 - Repeat the calculations if the insulator thickness was 0.1mm

Important Terms



Circuit is a loop-shaped path through which electric current travels from a source around and back (or to ground)

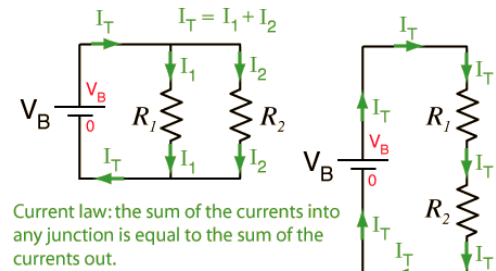
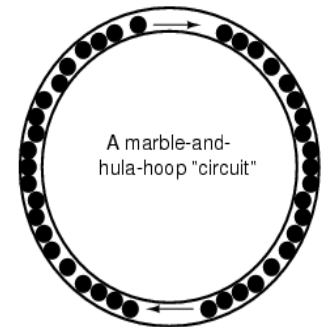
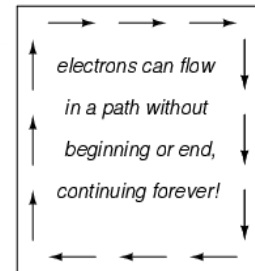
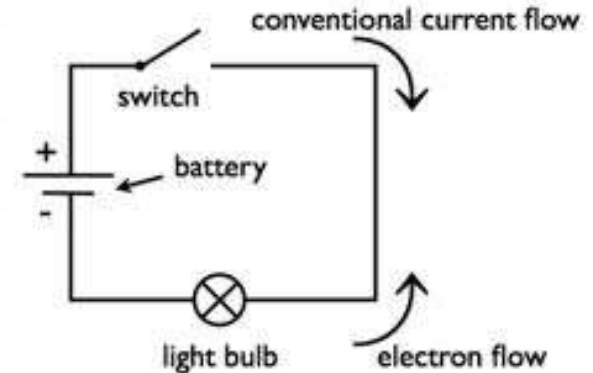
Short circuit is a circuit with a zero or low resistance path. Can be very dangerous as it may lead to fire, or other damage to the system.

Open circuit is a circuit that is broken and therefore nothing can flow.

Current flows from the POSITIVE (+) terminal of the source/battery to the NEGATIVE (-) or GROUND.

Electrons flow in the opposite way to current because of the way Ben Franklin thought they flowed.

If the circuit is OPEN, no current flows.



For any branch of the circuit, the current out of the branch must be equal to the current into the branch. This is required by the conservation of electric charge. Any cross-section of the circuit must carry the total current. For a series circuit, the current is the same at any point in the circuit.

How do the electrons move or conduct?



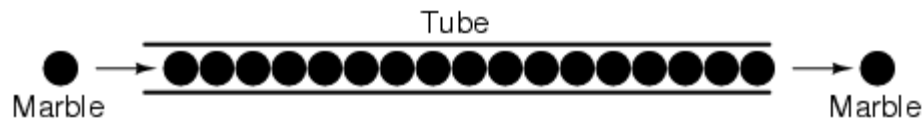
Electrons need to conduct/move through a material that allows electrons to easily pass.

The materials that electrons most easily pass through are called **CONDUCTORS**

The materials that electrons have the most difficulty passing through are called **INSULATORS**

See notes for examples

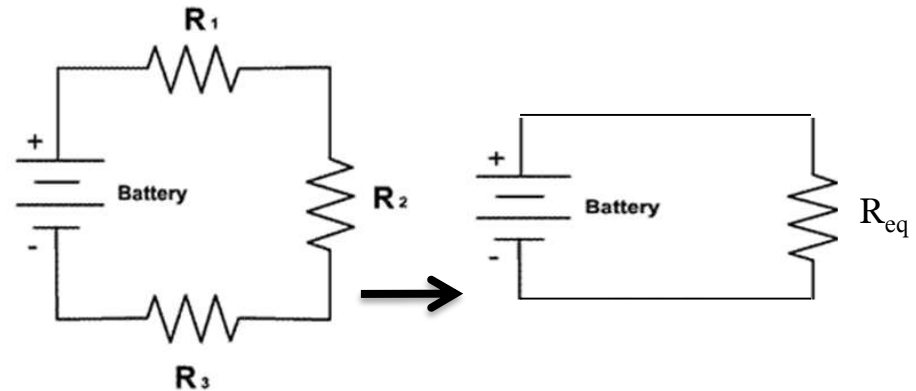
The electrons flow through the materials like marbles in a tube.



Equivalent Resistance or Load

Multiple resistors can be combined into a single resistance to represent all of them called an Equivalent Resistance or R_{eq}

The current flowing through both of the circuits on the right is exactly the same



Series Circuit



Two or more resistors in series

Current is the same through all resistors
(electrons have no other path)

Voltage is split between resistors

$$R_{eq} = R_1 + R_2 + R_3$$

R_{eq} is always greater than the largest single resistance

$$\text{Current} = \text{Voltage} / R_{eq}$$

$$R_{eq} = R_1 + R_2 + R_3$$

$$R_1 = 300 \, \Omega$$

$$R_2 = 300 \, \Omega$$

$$R_3 = 400 \, \Omega$$

$$R_{eq} = 300 \, \Omega + 300 \, \Omega + 400 \, \Omega$$

$$R_{eq} = 1,000 \, \Omega \text{ or } 1 \, \text{k}\Omega$$

$$\text{If } V = 1,000 \, \text{V or } 1 \, \text{kV}$$

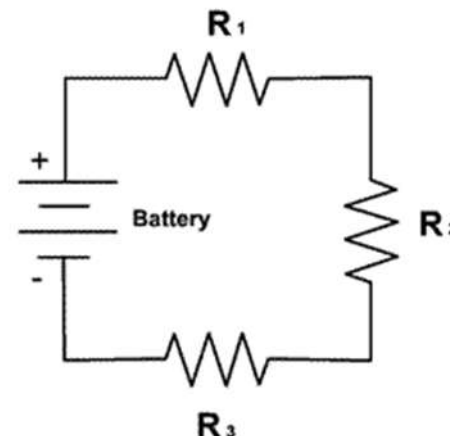
$$I = V/R = 1\text{kV} / 1 \, \text{k}\Omega = 1 \, \text{A}$$

**** R_{eq}** = the sum of the resistors or if they are all the same value then multiply them by that number

Two 300Ω resistors in series = $2 \times 300\Omega = 600\Omega$

Three 300Ω resistors in series = $3 \times 300\Omega = 900\Omega$

Two 200Ω resistors in series = $2 \times 200\Omega = 400\Omega$



Series connection



only one path for electrons to flow!

Parallel Circuit



Two or more resistors in parallel

Voltage is the same through all resistors

R_{eq} is always less than the smallest single resistance

Current is split between resistors (electrons are split between all branches)

$$1/R_{eq} = 1/R_1 + 1/R_2 + 1/R_3$$

Current (from battery) = Voltage / R_{eq} , which is then split among the three branches

$$1/R_{eq} = 1/R_1 + 1/R_2$$

$$R_1 = 2 \Omega$$

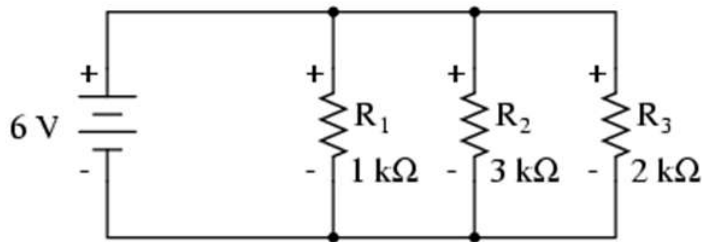
$$R_2 = 2 \Omega$$

$$1/R_{eq} = \frac{1}{2}\Omega + \frac{1}{2}\Omega = 1/\Omega$$

$$R_{eq} = 1 \Omega$$

$$\text{If } V = 6 \text{ V}$$

$I = V/R = 6 \text{ V} / 1 \Omega = 6 \text{ A}$, which is split among the two resistors



Short Cut

If Parallel Circuits have the same value you can easily calculate the Equivalent

If the resistors have the same value, R_{eq} = the resistance is divided by the number in parallel

For three resistors of the same value,
Equivalent = $R/3$

For four resistors of the same value,
Equivalent = $R/4$

If Parallel Circuits have a short, Equivalent = 0

Doesn't matter the number or size of other resistors. Example, $R_1 = 0$, $R_2 = R_3 = 3 \text{ k}\Omega$

Equivalent = 0, it is a short circuit and very dangerous because current is high

Combination Circuit or Series Parallel Circuit



Two or more resistors in parallel, plus series resistance
Voltage and Current are both split.
Have to solve by combining series and parallel elements

$$V = 10 \text{ V}, R_1=R_2=R_3=R_4=100 \Omega$$

Combine Series Resistors where possible

None at start

Combine Parallel Resistance where possible

$$1/\text{Req1} = 1/100\Omega + 1/100\Omega = 0.02 \text{ S}$$

$$\text{Req1} = 1/0.02 \text{ S} = 50\Omega$$

$$1/\text{Req2} = 1/100\Omega + 1/100\Omega = 0.02 \text{ S}$$

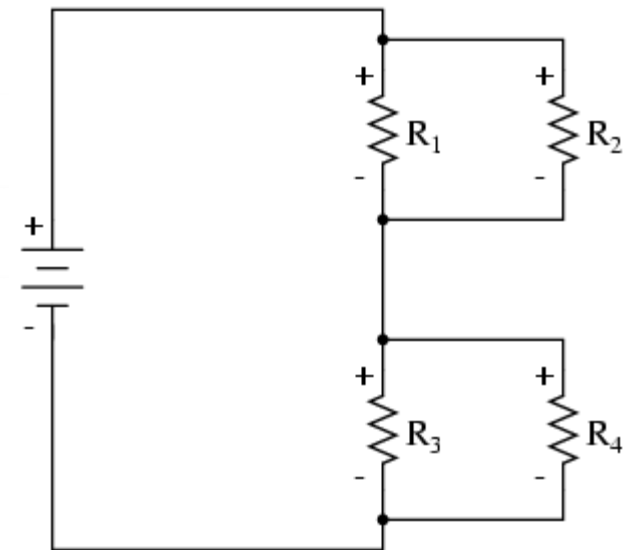
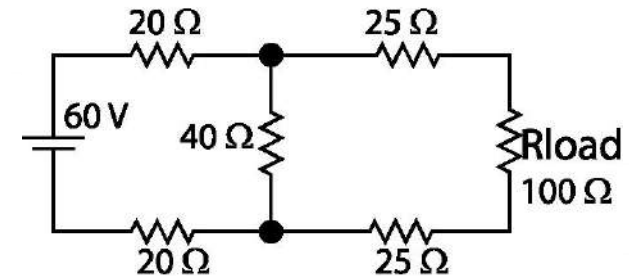
$$\text{Req2} = 1/0.02 \text{ S} = 50\Omega$$

Repeat until you get a single Requivallent

$$\text{Requivallent} = 50\Omega + 50\Omega = 100\Omega$$

Use final Requivallent to calculate total I out of battery

$$I_{\text{total}} = V / \text{Reqtotal} = 10\text{V}/100\Omega = 0.1\text{A}$$



Short Cuts for Some Parallel Circuits (Short Circuit)



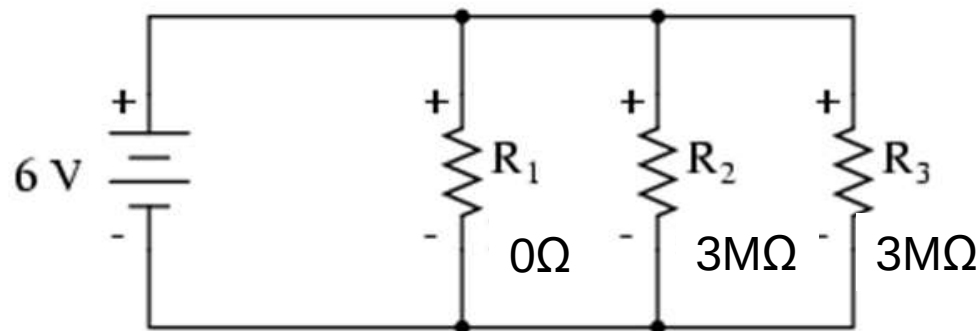
If Parallel Circuits have a short, $R_{\text{equivalent}} = 0$

Doesn't matter the number or size of other resistors.

In example below, $R_1 = 0$, $R_2 = R_3 = 3\text{k}\Omega$

$R_{\text{equivalent}} = 0$, it is a short circuit and very dangerous because current is high (theoretically infinity)

All the current will flow through the Short



What is a Load



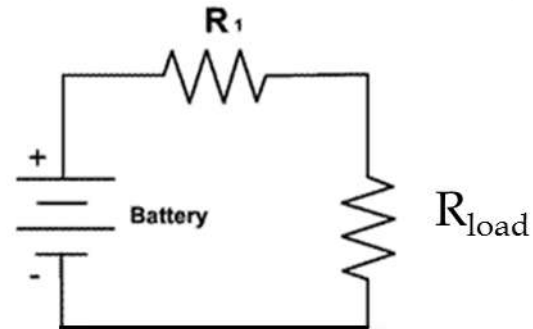
An element (resistor, light, speaker, motor, etc.) connected across the output terminals of a circuit that draws current from the circuit

Normally the element in a circuit upon which work is done.

Impedance Matching is a technique used to match a load resistance to a source resistance in order to achieve maximum transfer of power.

For instance most speakers are 8 ohm speakers (Load) and the source resistance is then usually set to 8 ohms to get maximum power.

In this example, the Impedance/Resistance is matched when $R_1 = R_{\text{load}}$



Voltage + Current Divider



A Series Circuit acts as a voltage divider

Voltage is split between resistors

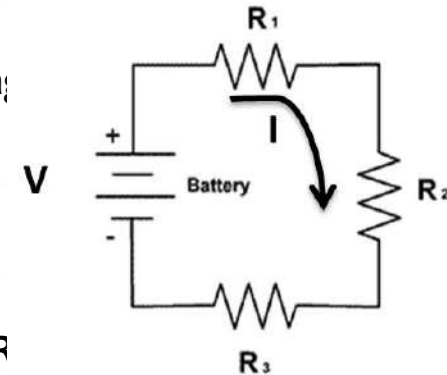
The Voltage summed across all resistors equals the Source Voltage

V_{source} = the source voltage

$$R_{\text{total}} = R_1 + R_2 + R_3 \quad I = V_{\text{source}}/R_{\text{total}}; \quad V_{R1} = I R_1, \quad V_{R2} = I R_2, \quad V_{R3} = I R_3$$

Combining the two equations

$$V_{R1} = V_{\text{source}} R_1/R_{\text{total}} \quad V_{R2} = V_{\text{source}} R_2/R_{\text{total}} \quad V_{R3} = V_{\text{source}} R_3/R_{\text{total}}$$



Current is split between resistors (electrons are split between all branches)

$$1/R_{\text{total}} = 1/R_1 + 1/R_2 + 1/R_3$$

R_{total} is always less than the smallest single resistance

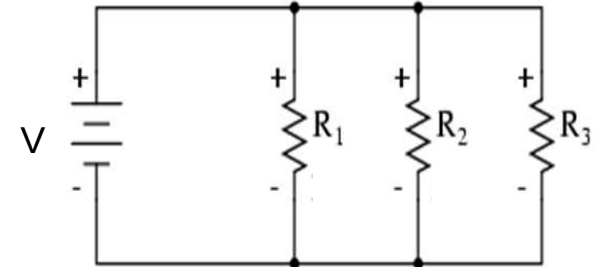
$$I_{\text{total}} = V_{\text{source}}/R_{\text{total}}$$

$$I_{R1} = V/R_1, \quad I_{R2} = V/R_2, \quad I_{R3} = V/R_3$$

Combining the two equations

$$I_{R1} = I_{\text{total}} R_{\text{total}}/R_1 \quad I_{R2} = I_{\text{total}} R_{\text{total}}/R_2$$

$$V_{R1}=V_{R2}=V_{R3}=V$$



Power



Power –The rate of energy usage equal to the voltage times the current.

$$P = VI = V^2/R = I^2R$$

The unit are Watts (W)

Maximum Power Transfer—A transfer of maximum power from a source to a load when the load resistance equals the internal source resistance.

For resistors, the Power is normally dissipated through heat. If you exceed the Power Rating, the resistor can be damaged, get hot, smoke, catch on fire, or explode.

Multiple Sources



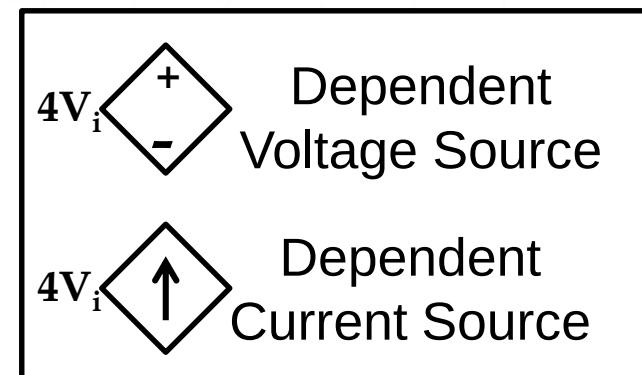
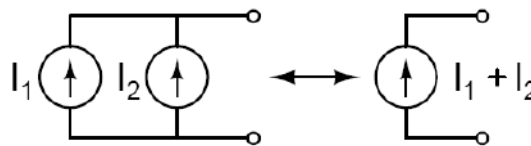
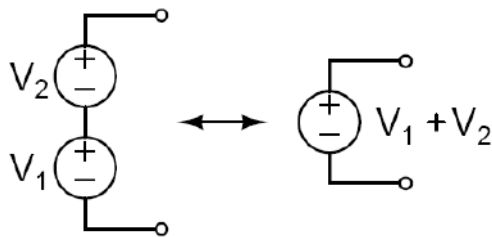
Sometimes a circuit has more than one source

Voltage Sources should be added in series

Current Sources should be added in parallel

You SHOULD **NOT** put voltage sources in parallel or current sources in series, as it can create a situation that violates circuit rules.

A dependent source creates a voltage or current based on a voltage or current somewhere in the circuit



Circuit Symbols



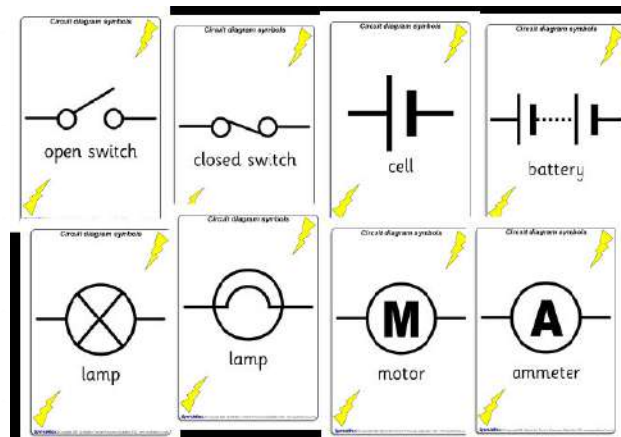
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Sometimes they also use just a picture of a light bulb or other object,

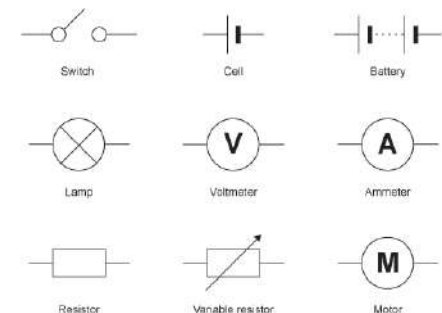
especially for a load.

Please note the different ways to see resistors and batteries

Not a full list



WIRE	LAMP INCANDESCENT
CONDUCTORS	FUSE
CONNECTED	RESISTORS
CONNECTED	
NOT CONNECTED	
GROUND	FIXED
	VARIABLE (POTENTIOMETER)
	RHEOSTAT
CELL	SWITCH
BATTERY	VOLTMETER
OR	AMMETER



Resistor Marking

Electronic Color Code Developed in early 1920's.

Sometimes the resistance is printed directly on the resistor to avoid confusion, esp. for colorblind people.

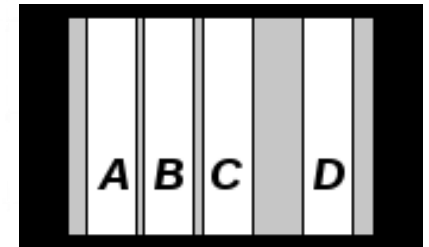
If you are colorblind, let your event supervisor know at start of test.

A is the first significant digit of the component

B is the second significant digit

C is the decimal multiplier

D (if present) indicates the tolerance—no D means 20%



This example is the following:

A=Red=2; B=Violet=7; C=Green= 10^5 ; D=Gold=5%

Or $2.7\text{M}\Omega \pm 5\%$



<http://www.okaphone.nl/calc/resistor.shtml>

Standard Color Code



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1st Digit 2nd Digit 3rd Digit Multiplier tol

B
B
R
O
Y
G
B

0	black
1	brown
2	red
3	orange
4	yellow
5	green
6	blue
7	purple
8	silver
9	white

0	
1	
2	
3	
4	
5	
6	
7	
8	
9	

0	
1	
2	
3	
4	
5	
6	
7	
8	
9	

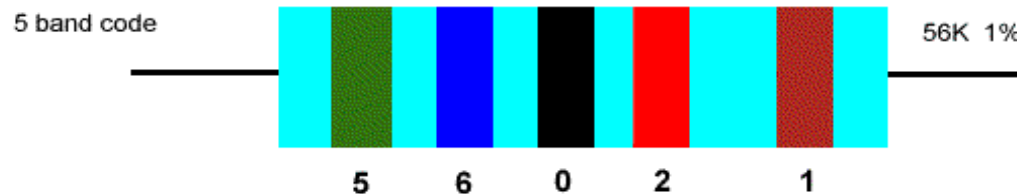
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	

1%
2%

5% Gold
10% Silver

No tolerance
stripe means
20%

P or V violet
S or G gray
W



Big Boys Race Our Young Girls But Violet Generally Wins.

Standard Resistor Types

They usually only pick a few resistor sizes and repeat them for every decade of magnitude (i.e. 6.8Ω , 68Ω , 680Ω , $6.8k\Omega$, etc.)

They are picked based upon the tolerance and geometric progression.

The 12 most common are in the table below with markings (for 10% resistors).

 10	 12	 15	 18
 22	 27	 33	 39
 47	 56	 68	 82

Superposition



The superposition theorem for electrical circuits states that for a linear system the response (Voltage or Current) in any branch of a circuit having more than one independent source equals the algebraic sum of the responses caused by each independent source acting alone, while all other independent sources are replaced by their internal impedances.

To ascertain the contribution of each individual source, all of the other sources first must be "turned off" (set to zero) by:

Replacing all other independent voltage sources with a short circuit (thereby eliminating difference of potential. i.e. $V=0$, internal impedance of ideal voltage source is ZERO (short circuit)).

Replacing all other independent current sources with an open circuit (thereby eliminating current. i.e. $I=0$, internal impedance of ideal current source is infinite (open circuit)).

Does NOT work with DEPENDENT SOURCES or POWER

Kirchhoff's Voltage & Current Law (KCL&KVL)



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The directed sum of the electrical potential differences (voltage) around any closed network is zero

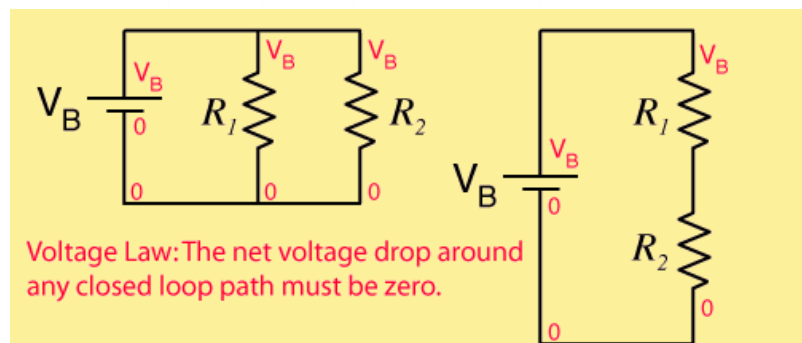
or: the sum of the voltage in any closed loop is equivalent to the sum of the potential drops in that loop

Kirchhoff's Current Law (KCL)

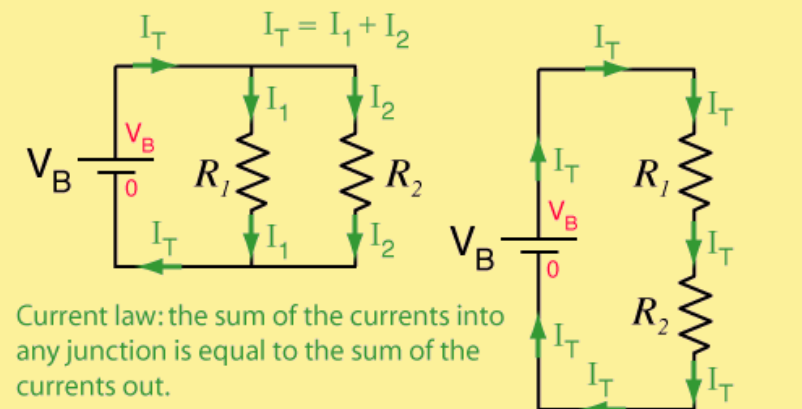
At any node (junction) in an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node

or: The algebraic sum of currents in a network of conductors meeting at a point is zero.

or: All current into a node equals all current out!



For any path you follow around the circuit, the sum of the voltages rises (like batteries) must equal the sum of the voltage drops. Voltage represents energy per unit charge, and conservation of energy demands that energy is neither created nor destroyed.



For any branch of the circuit, the current out of the branch must be equal to the current into the branch. This is required by the conservation of electric charge. Any cross-section of the circuit must carry the total current. For a series circuit, the current is the same at any point in the circuit.

Wheatstone Bridge



A Wheatstone bridge is an electrical circuit used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component.

It was invented by Samuel Hunter Christie in 1833 and improved and popularized by Sir Charles Wheatstone in 1843.

One of the Wheatstone bridge's initial uses was for the purpose of soils analysis and comparison

R_x is the unknown resistance

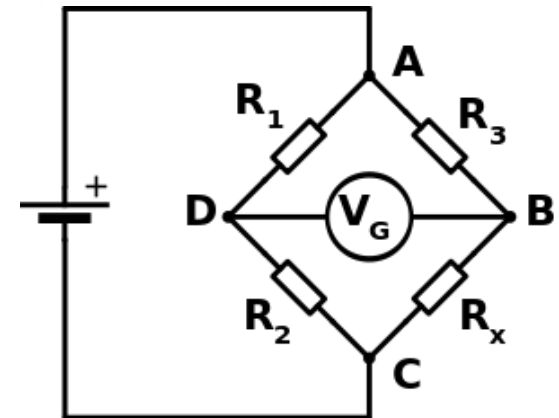
R_1 , R_2 , and R_3 are the known resistance

If the bridge is balanced then the ratio of $R_2/R_1 = R_x/R_3$, and the voltage and current between Node D and Node B equals zero.

Or $R_x = R_2/R_1 * R_3$

Normally R_2 is a variable resistor

If the bridge is unbalanced, the direction of the current indicates whether R_2 is too big or too small.



Thévenin's + Norton's Theorem/Equivalent

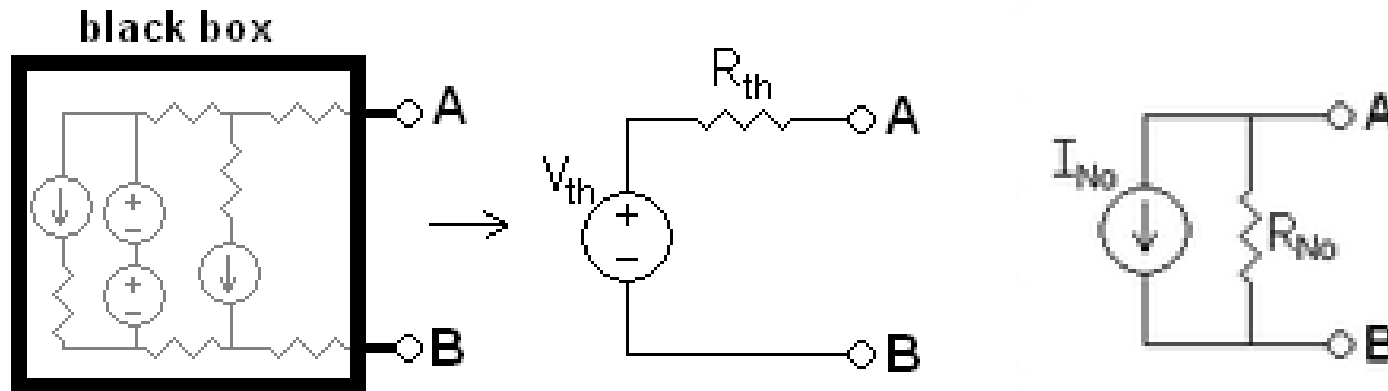


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Thévenin's theorem states that any combination of voltage sources, current sources, and resistors with two terminals is electrically equivalent to a single voltage source V and a single series resistor R .

Norton's theorem states that any collection of voltage sources, current sources, and resistors with two terminals is electrically equivalent to an ideal current source, I , in parallel with a single resistor, R .

$$\begin{aligned}R_{no} &= R_{th} \\ V_{th} &= I_{no} * R_{no} \\ I_{no} &= V_{th} / R_{th}\end{aligned}$$



How to find Thévenin + Norton Equivalent Values



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Calculate the output voltage, V_{AB} , when in open circuit condition (no load resistor—meaning infinite resistance). This is V_{Th} .

Calculate the output current, I_{AB} , when the output terminals are short circuited (load resistance is 0). R_{Th} equals V_{Th} divided by this I_{AB} .

or Replace independent voltage sources with short circuits and independent current sources with open circuits. The total resistance across the output port is the Thévenin impedance R_{Th} .

Find the Norton current I_{No} . Calculate the output current, I_{AB} , with a short circuit as the load (meaning 0 resistance between A and B). This is I_{No} .

Find the Norton resistance R_{No} . When there are no dependent sources (all current and voltage sources are independent), there are two methods of determining the Norton impedance R_{No} .

Calculate the output voltage, V_{AB} , when in open circuit condition (i.e., no load resistor — meaning infinite load resistance). R_{No} equals this V_{AB} divided by I_{No} .

or Replace independent voltage sources with short circuits and independent current sources with open circuits. The total resistance across the output port is the Norton impedance R_{No} .

Switches



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A switch is an electrical component that can break an electrical circuit or divert it from one conductor to another.

Usually has two states “Open” or “Closed”

Open is the circuit is Open or OFF

Closed is the circuit is connected/short or ON

Can be a Toggle or Momentary

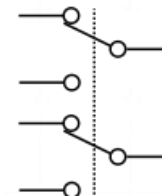
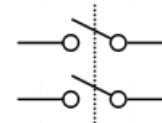
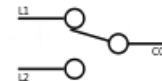
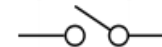
When doing switch problems, redraw the circuit for every configuration you want to test.

Single Pole Single Throw (SPST)—a simple on/off switch. Light switch.

Single Pole, Double Throw (SPDT)—a simple change over switch. Turns on one thing or another, not both.

Double pole, Single Throw (DPST)—equal to two SPST switches controlled by a single mechanism. Like flipping two light switches at once.

Double Pole, Double Throw (DPDT)—equivalent to two SPDT switches controlled by a single mechanism.



Fuses + Circuit Breakers



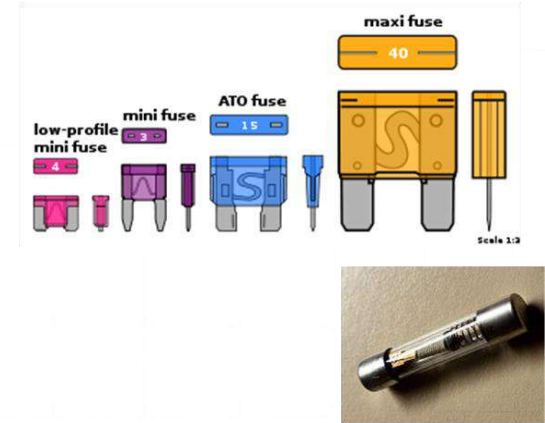
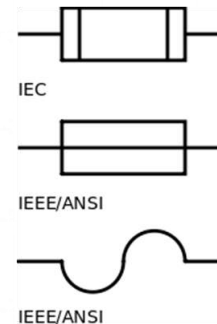
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Fuse: A safety device which “burns out” at a given current

Prevents a short or high current from damaging other systems, melting wires, etc. from a short or other problem

Fuses must be replaced after burn out, but not before the problem is resolved.

Usually faster than circuit breakers.



Circuit Breaker A safety device which “trips” at a given current

Prevents a short or high current from damaging other systems, melting wires, etc. from a short or other problem

Circuit Breakers may be reset after tripping, but should not be reset unless the problem has been resolved.

Usually a little slower than fuses.



How to identify batteries?

All batteries are Direct Current (DC)

They are usually denoted by their Voltage

POSITIVE (+) terminals are either marked or painted RED, sometimes with a cover to reduce chance of a SHORT CIRCUIT

NEGATIVE (-) terminals are normally marked or painted BLACK or BLUE.

A popular hands on activity is to identify voltages and polarities of batteries by inspection only.



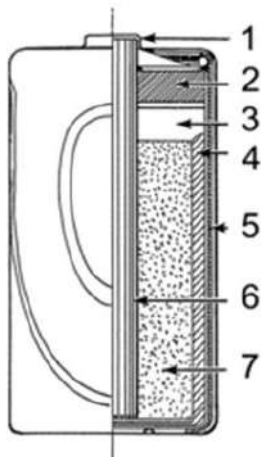
Batteries

Dry CELL

Electrolyte is immobilized as a paste

Zinc-carbon

Alkaline batteries



I batteries

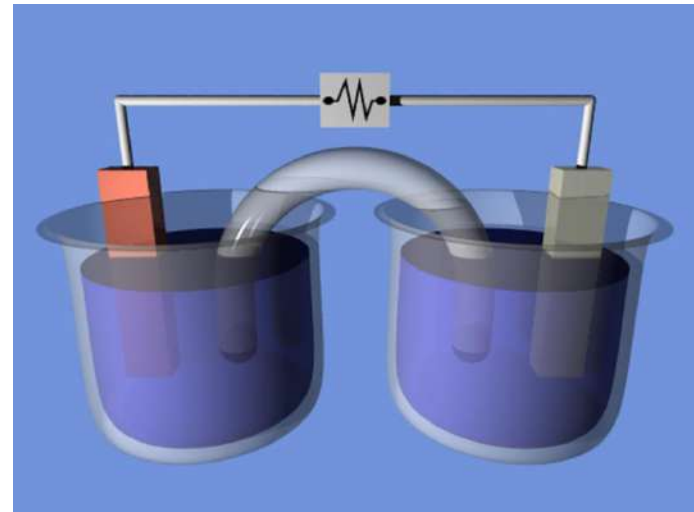
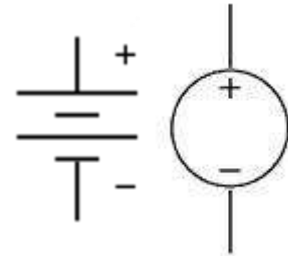
Line art drawing of a dry cell:
 1. brass cap,
 2. plastic seal,
 3. expansion space,
 4. porous cardboard,
 5. zinc can,
 6. carbon rod,
 7. chemical mixture
 (wikipedia.org)

WET CELL

Has a liquid electrolyte

Lead-acid (car batteries)

Nickel-Cadmium



Diode (Division C Only)



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A diode is a two-terminal electronic component that conducts current primarily in one direction (asymmetric conductance); it has low (ideally zero) resistance in one direction, and high (ideally infinite) resistance in the other

Ideally can be replaced with

A short (0Ω) when forward biased or closed switch

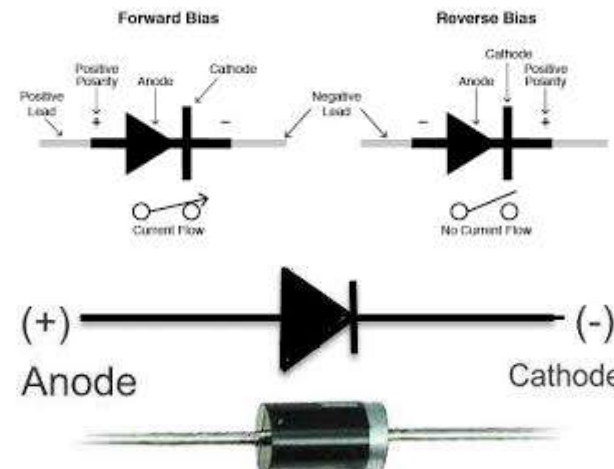
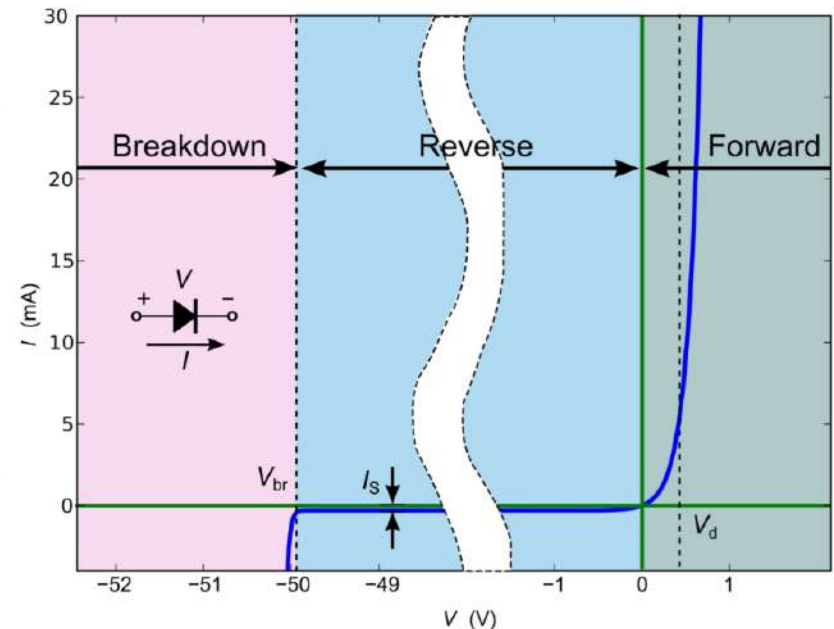
An open ($\infty\Omega$) when reverse biased or open switch

When forward biased has a small resistance and a bias depending upon semiconductor material

0.6-0.7V for Si Diodes

0.25 to 0.3V for Ge Diodes

LEDs can be as high as 4.0V



Ideal Diode

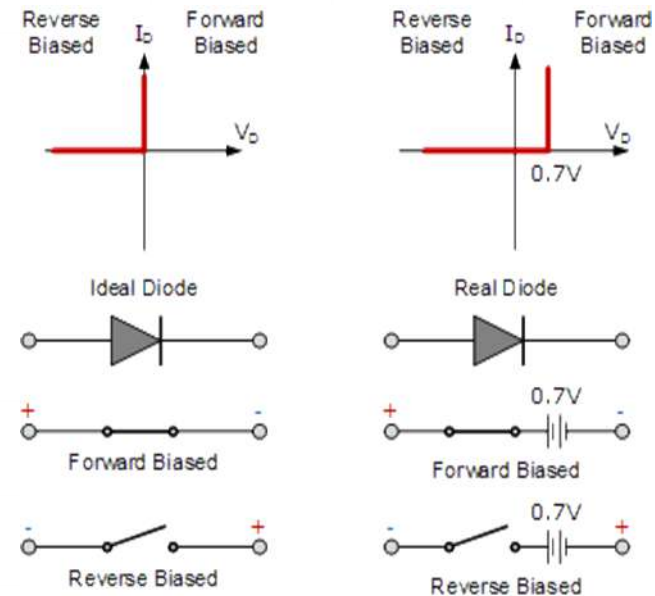
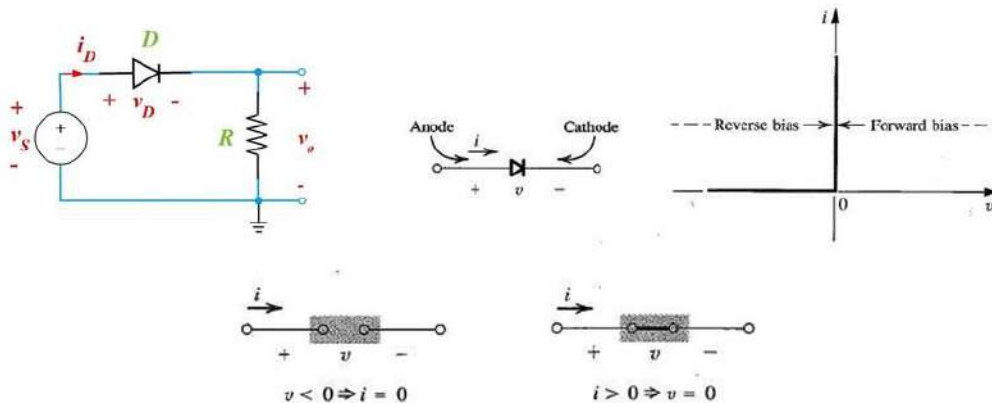
Ideal diode has zero resistance in Forward Bias with the forward bias voltage and infinite resistance in Reverse Bias.

Note that normally they assume the bias voltage is for Si $\sim 0.7V$

In Examples below:

If $v_S \geq 0.7V$, then the diode is in forward bias, no resistance by still account for $v_D = 0.7V$, therefore $v_O = v_S - 0.7V$

If $v_S < 0.7V$, the diode is in reverse bias and can be treated as open



Light Emitting Diodes (LEDs)

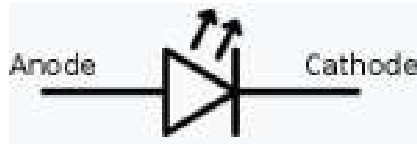


A light-emitting diode (LED) is a two-lead semiconductor light source. It is a p-n junction diode that emits light when activated

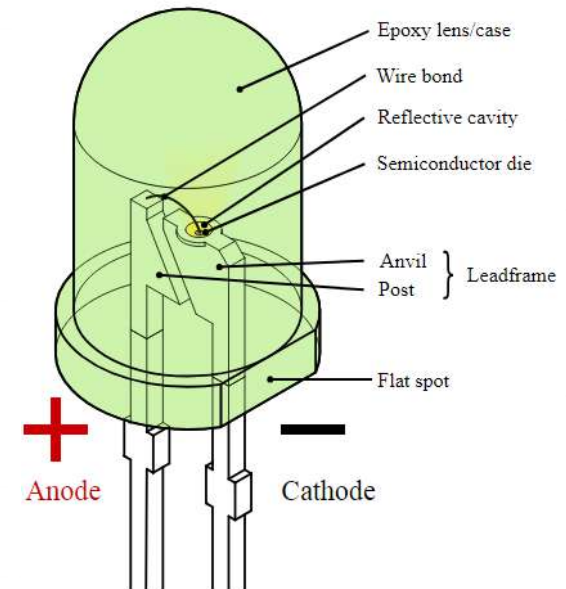
Color is determined by the energy band gap of the semiconductor, which also affects the voltage drop

Full table has been put in the Homework Generator, LED Datasheet tab

https://en.wikipedia.org/wiki/Light-emitting_diode#cite_note-79



https://en.wikipedia.org/wiki/Light-emitting_diode



Linear Approximation to Non-Ideal Diode

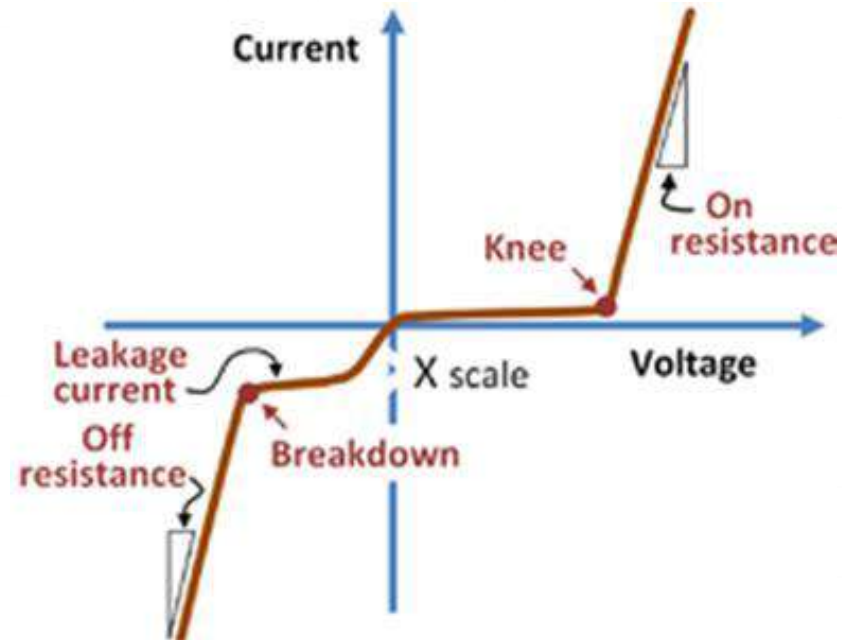


$V_D < V$ is Forward Biased and has a small “On” Resistance

$0 < V < V_D$ is off with very little current

$-V_Z < V < 0$ is off with very little Leakage current

$V < -V_Z$ is in Zener or Avalanche Reverse Bias mode and has a very small “Off” Resistance



PN Junctions



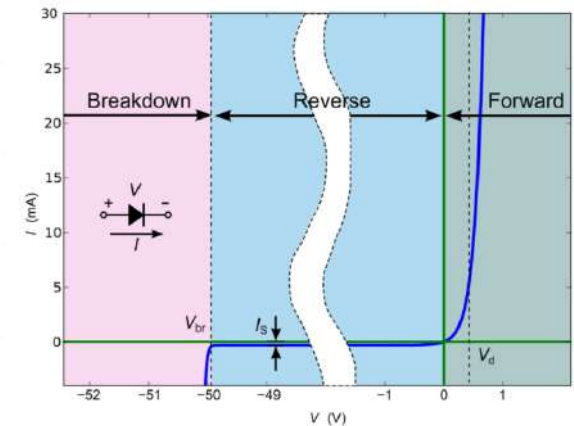
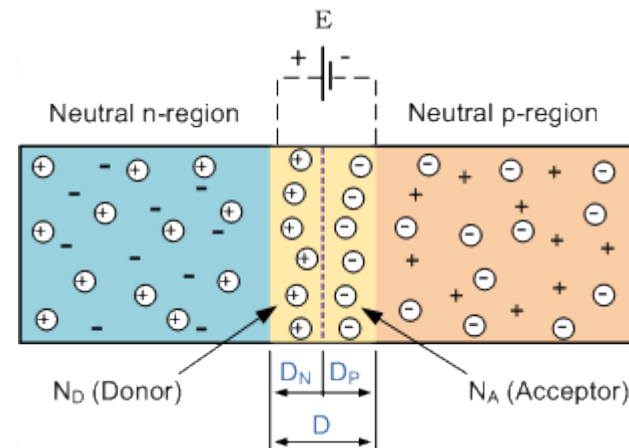
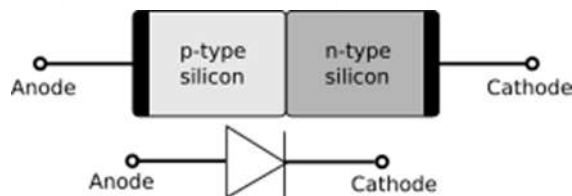
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A p-n junction is a boundary or interface between two types of semiconductor materials, p-type and n-type, inside a single crystal of semiconductor

P (positive) side contains an excess of holes, free positive charges in the outer shells of the doped atoms

N (negative) side contains an excess of electrons, free negative charges in the outer shells of the doped atoms

This allows electrical current to pass through the junction only in one direction—a diode



<http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/pnjun.html>

https://www.electronics-tutorials.ws/diode/diode_1.html

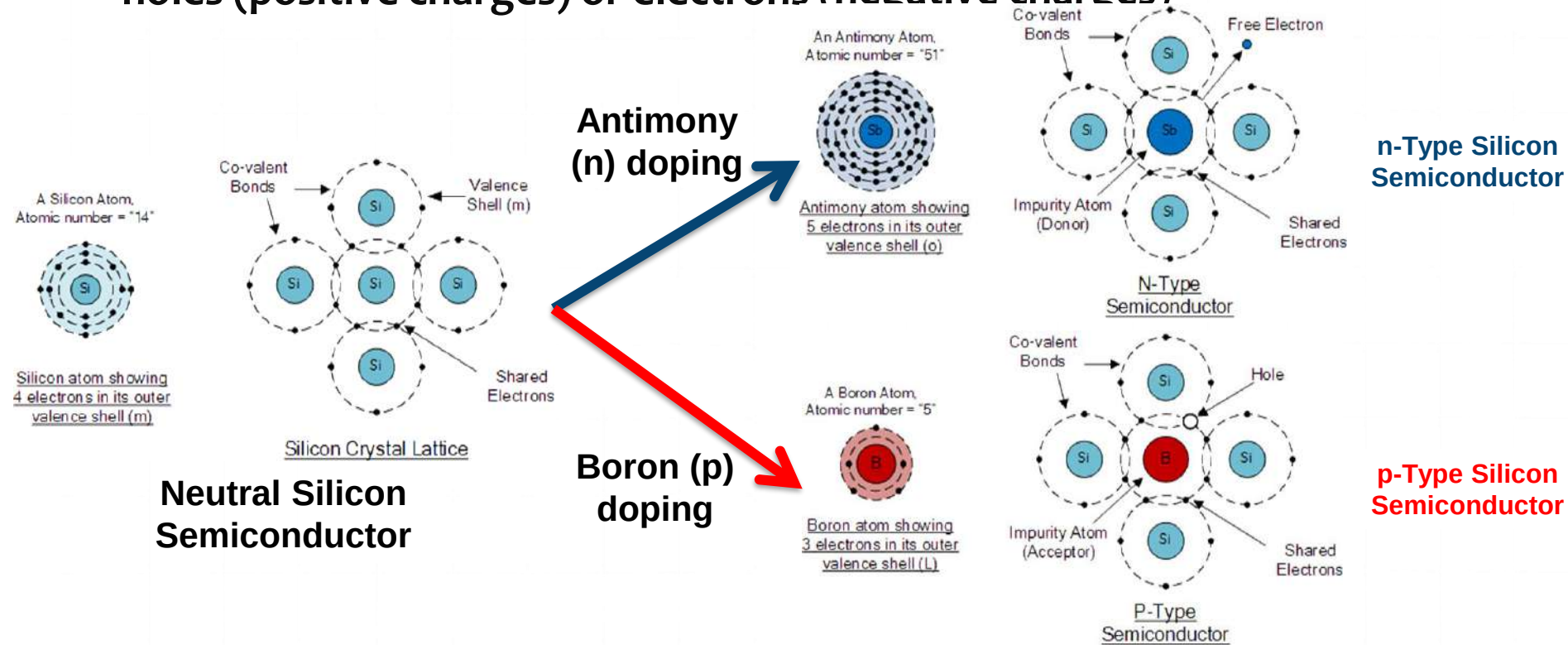
https://en.wikipedia.org/wiki/P%E2%80%93n_junction

Semiconductor Doping



Exploring the World of Science

Semiconductors can be doped with different materials to provide excess holes (positive charges) or electrons (negative charges)



n-Type Silicon Semiconductor

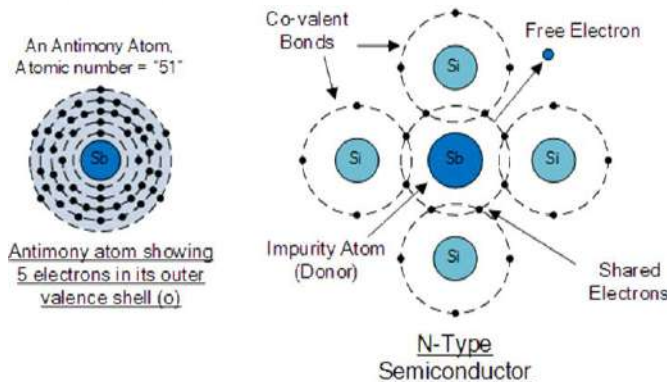
p-Type Silicon Semiconductor

<http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/pnjun.html>

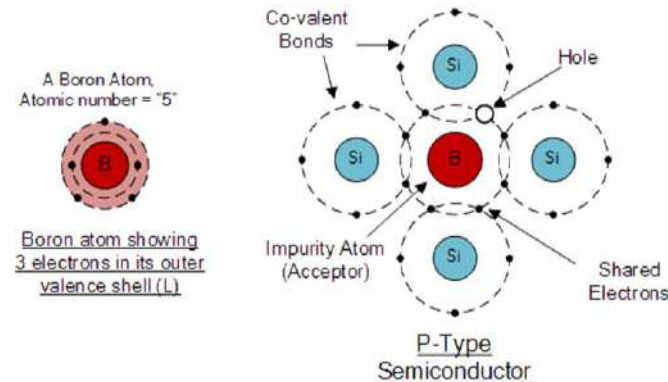
https://www.electronics-tutorials.ws/diode/diode_1.html

https://en.wikipedia.org/wiki/P%E2%80%93n_junction

N-Type and P-Type



n-Type Silicon Semiconductor



p-Type Silicon Semiconductor

The Donors are positively charged.
There are a large number of free electrons.

A small number of holes in relation to the number of free electrons.
Positively charged donors.

Negatively charged free electrons.
Supply of energy gives:

The Acceptors are negatively charged.

There are a large number of holes
A small number of free electrons in relation to the number of free electrons.

Negatively charged acceptors.
Positively charged holes
Supply of energy gives:

<http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/pnjon.html>

https://www.electronics-tutorials.ws/diode/diode_1.html

https://en.wikipedia.org/wiki/P%E2%80%93n_junction

What to use for doping?



Single semiconductors come from Group 14 of the Periodic Table (Si, Ge, C)

P-Type doping usually comes from Group 13—one less electron

N-Type doping usually comes from Group 15—one extra electron

GaAs is a semiconductor as well (notice how they cancel out)

p-Type doping **Neutral Semiconductor** **n-Type doping**
Periodic Table of Semiconductors

Elements Group 13	Elements Group 14	Elements Group 15
3-Electrons in Outer Shell (Positively Charged)	4-Electrons in Outer Shell (Neutrally Charged)	5-Electrons in Outer Shell (Negatively Charged)
(5) Boron (B)	(6) Carbon (C)	
(13) Aluminium (Al)	(14) Silicon (Si)	(15) Phosphorus (P)
(31) Gallium (Ga)	(32) Germanium (Ge)	(33) Arsenic (As)
		(51) Antimony (Sb)

PN Junctions I-V Characteristics



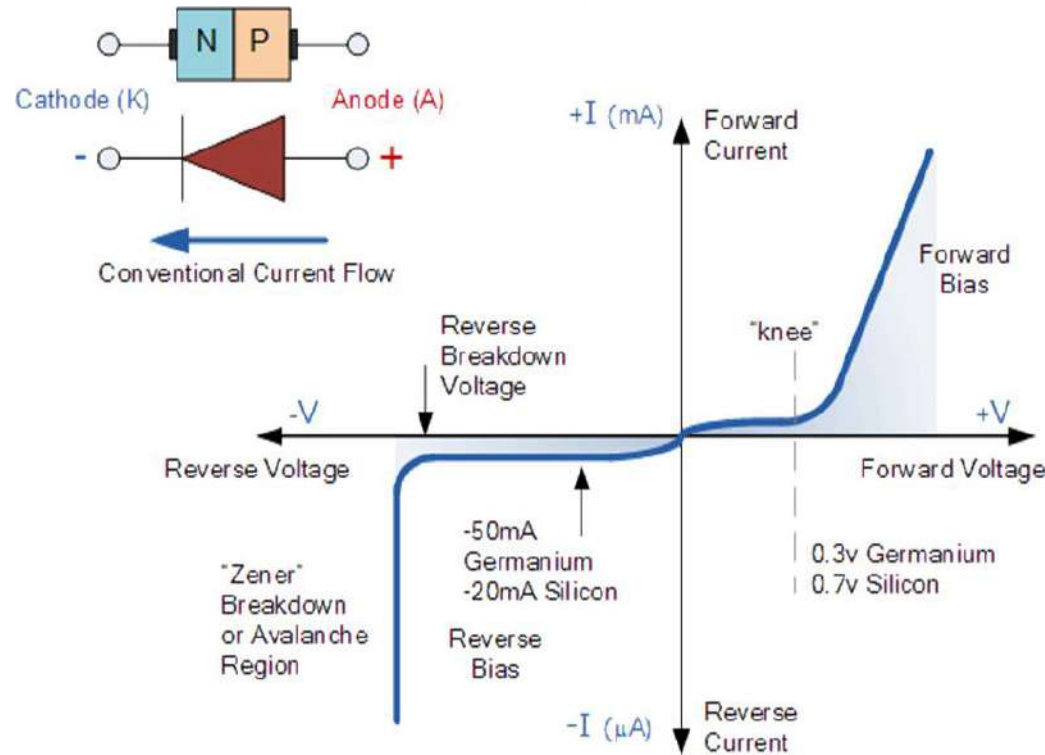
A p-n junction or junction diode usually allows current through in two main modes

Forward Bias (or on) with relatively low resistance, but a forward bias voltage occurs above the Forward Bias voltage (0.3V for Ge and 0.7V for Si)

Reverse Bias (or off) with very little current/high impedance below the Forward bias voltage up to the Reverse Breakdown Voltage

Below the Reverse Breakdown Voltage the current avalanches through the PN junction and we have a Zener Breakdown or Avalanche current with very high reverse current

Some diodes are specifically designed to operate in this region, others will be damaged



<http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/pnjon.html>

https://www.electronics-tutorials.ws/diode/diode_1.html

https://en.wikipedia.org/wiki/P%E2%80%93n_junction

Reverse Biased PN Junction



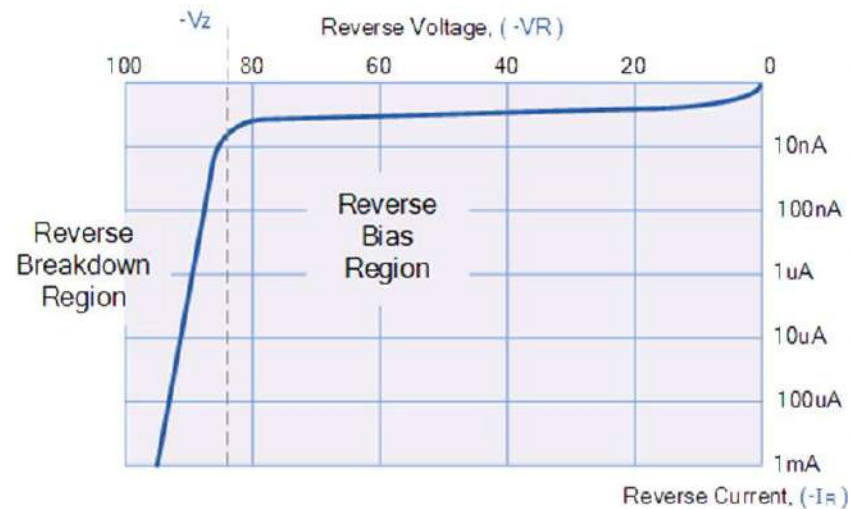
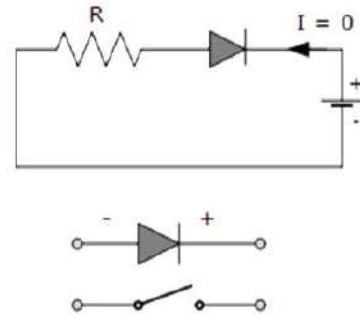
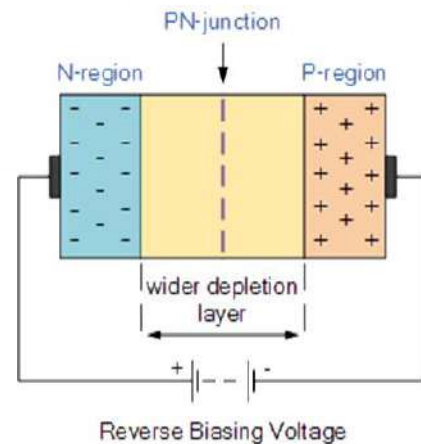
A p-n junction with a voltage below the Forward Bias voltage is called Reverse Biased.

At this point the diode is considered off
The area in between the n and p regions is called the depletion area

In reverse bias, the depletion area is becomes larger and virtually no current can flow

Zener Diode or “Breakdown Diode” are basically the same as the standard PN junction diode but are designed to have a low and specified Reverse Breakdown Voltage which takes advantage of any reverse voltage applied to it.

You use these to enter the Breakdown or Zener region to get very low impedance (all voltages below $-V_z$ or Zener Breakdown Voltage)



Note the current is a log scale and very low

<http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/pnjon.html>

https://www.electronics-tutorials.ws/diode/diode_1.html

https://en.wikipedia.org/wiki/P%E2%80%93n_junction

Forward Biased PN Junction

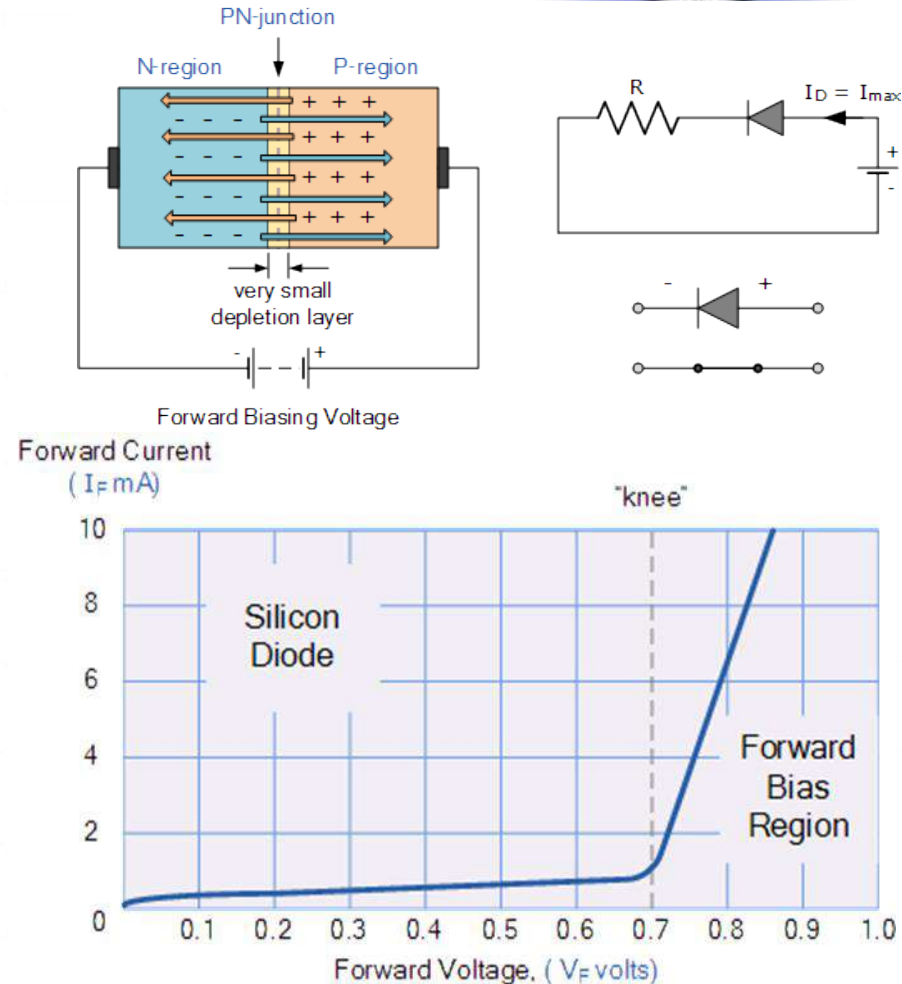


A p-n junction with a voltage at or above the Forward Bias voltage is called Forward Biased.

At this point the diode is considered on

The area in between the n and p regions is called the depletion area

In forward bias, the depletion area is very small and current can flow with very little impedance



Note the current is linear scale and much higher

<http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/pnjon.html>

https://www.electronics-tutorials.ws/diode/diode_1.html

https://en.wikipedia.org/wiki/P%E2%80%93n_junction

Operational Amplifiers (Division C Only)



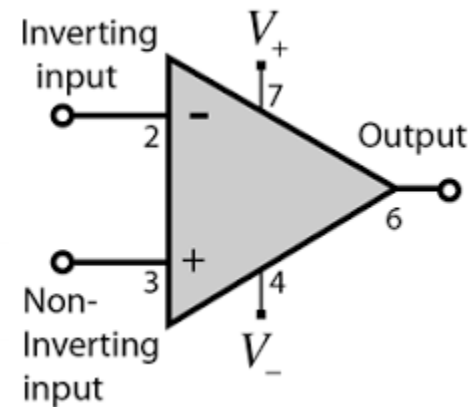
Exploring the World of Science

An operational amplifier (often op-amp or opamp) is a DC-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output

Very popular due to its versatility as a differential amplifier.

Can be set up easily as a comparator, inverting amplifier, or non-inverting amplifier

NEVER, EVER use a KCL at the output of an **Op-Amp**



https://en.wikipedia.org/wiki/Operational_amplifier

Ideal Op-Amps



Exploring the World of Science

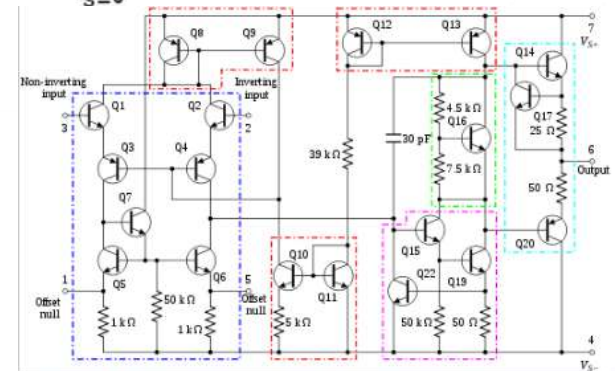
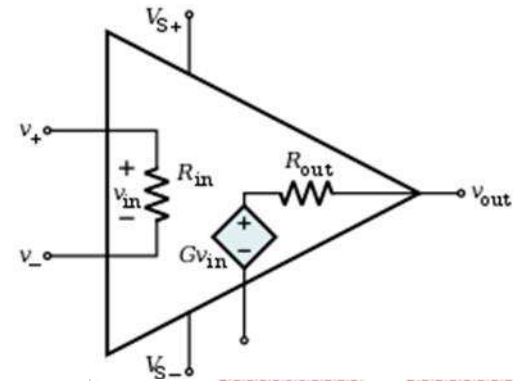
Full List for Ideal Op-Amps

- Infinite Open-Loop Gain (G)
- Infinite Input Impedance (R_{in})
- Infinite Out Voltage Range ($v_{out \text{ max}}$)
- Infinite Common-Mode Rejection Ratio
- Infinite Power Supply Reject Ratio
- Zero Input Offset Voltage
- Zero Output Impedance (R_{out})
- Zero Noise
- Zero Input Current (v_{in}/R_{in})
- None of these are actual

Two Golden Rules

$$V_+ = V_-$$

Current is zero at V_+ and V_-



A component-level diagram of the common 741 op-amp. Dotted lines outline:
■ current mirrors; ■ differential amplifier; ■ class A gain stage; ■ voltage level shifter;
■ output stage.

Op-Amp Uses



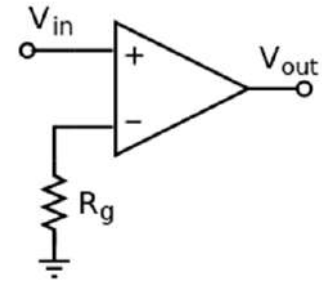
Comparator

Since the Gain is normally 100,000 or more for Op-Amps, a small difference between V_+ and V_- will cause the Output (V_{out}) to go to very near the supply voltage (called Saturation)

If $V_+ > V_-$, then maximum output voltage

If $V_- > V_+$, the maximum negative output voltage

Also called a Comparator

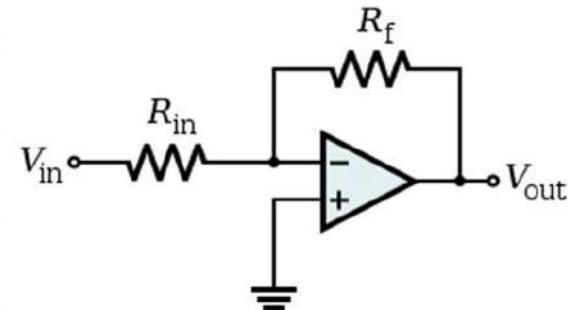


Inverting Amplifiers

Inverting Amplifiers can give a large amplification (up to near the Source voltages) and can be easily adjusted—but the polarity is swapped (the inversion)

If V_{in} is negative, V_{out} will be positive or vice versa

Gain is equal to $-R_f/R_{in}$



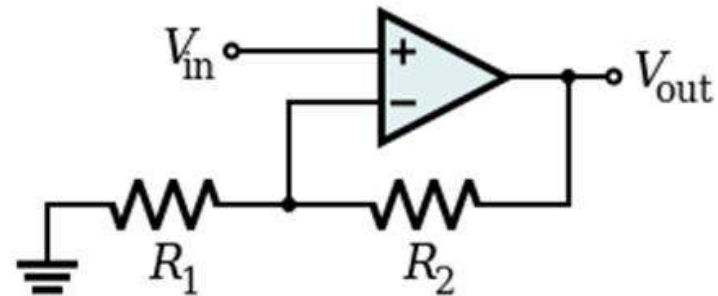
Op-Amp Uses Non-Inverting Amplifier



Non-Inverting Amplifiers can give a large amplification (up to near the Source voltages) and can be easily adjusted—the polarity is remains the same (no inversion)

If V_{in} is negative, V_{out} will be negative or the same for positive

Gain is equal to $(1 + R_2/R_1)$



What causes magnetism?



Magnetism, at its root, arises from two sources:

Electric current (moving charges) including electron magnetic moments

Electron magnetic dipole moment is the magnetic moment of an electron caused by its intrinsic property of spin. This normally cancels out, but sometimes— either spontaneously, or owing to an applied external magnetic field — each of the electron magnetic moments will be, on average, lined up. Then the material can produce a net total magnetic field, which can potentially be quite strong.

Nuclear magnetic moments of atomic nuclei. These moments are typically thousands of times smaller than the electrons' magnetic moments, so they are negligible in the context of the magnetization of materials.

Permanent Magnets



Over 2500 years ago it was discovered that lodestone or magnetite was attracted to iron

It would also orient itself to North-South, creating the first compasses

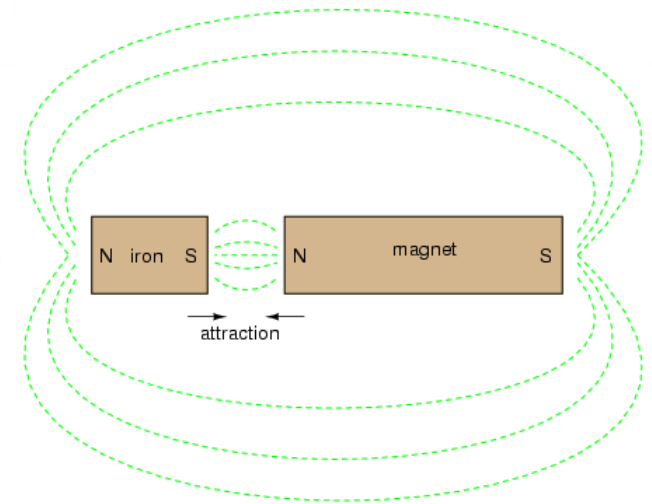
Peter Pergrinus discovered in 1269 that one could make steel “magnetic” by rubbing it against a pole of the lodestone

These magnetic materials possess two poles of opposite effect (North and South)

Like electrical charges Alike Poles Push against each other and Different Poles Pull towards each other.

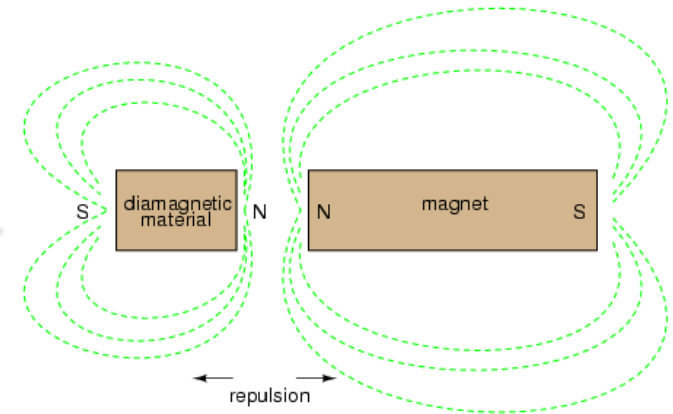
Magnetic Materials

Magnetic or Ferromagnetic Materials are readily magnetized (its constitute atoms easily orient their electron spins to conform to the external magnetic force)



Paramagnetic Materials are slightly magnetic,.

Diamagnetic Materials are materials which tend to exclude magnetic fields and actually slightly repulse a magnet.



Ferromagnetic materials



Exploring the World of Science

Curie temperatures for
some crystalline
ferromagnetic
(* = ferrimagnetic)
materials^[4]

Material	Curie temp. (K)
Co	1388
Fe	1043
Fe ₂ O ₃ *	948
FeOFe ₂ O ₃ *	858
NiOFe ₂ O ₃ *	858
CuOFe ₂ O ₃ *	728
MgOFe ₂ O ₃ *	713
MnBi	630
Ni	627
MnSb	587
MnOFe ₂ O ₃ *	573
Y ₃ Fe ₅ O ₁₂ *	560
CrO ₂	386
MnAs	318
Gd	292
Dy	88
EuO	69

Cobalt

Iron

Iron Oxide (iron oxide)

Ferrite (ceramic materials with Iron Oxide)—includes hematite and magnetite

Nickel

Chromium (IV) oxide

Paramagnetic materials



Exploring the World of Science

Tungsten

Cesium

Aluminum

Lithium

Magnesium

Sodium

Material ♦	Magnetic susceptibility ($\times 10^{-5}$) ♦
Tungsten	6.8
Cesium	5.1
Aluminium	2.2
Lithium	1.4
Magnesium	1.2
Sodium	0.72

Diamagnetic materials



Exploring the World of Science

Superconductor

Pyrolytic carbon

Bismuth

Mercury

Silver

Carbon (diamond)

Lead

Carbon (graphite)

Copper

Water

Notable diamagnetic materials^[2]

Material	$\chi_v (10^{-5})$
Superconductor	-10^5
Pyrolytic carbon	-40.0
Bismuth	-16.6
Mercury	-2.9
Silver	-2.6
Carbon (diamond)	-2.1
Lead	-1.8
Carbon (graphite)	-1.6
Copper	-1.0
Water	-0.91

North and South Poles

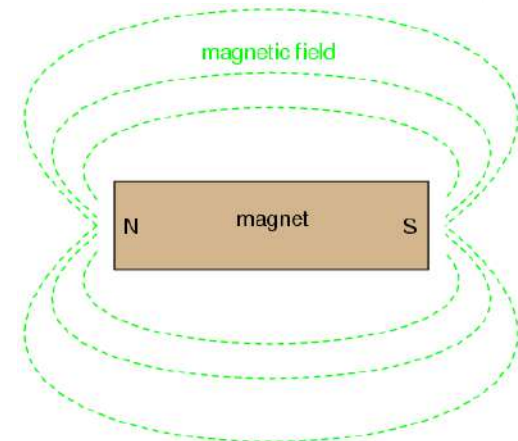
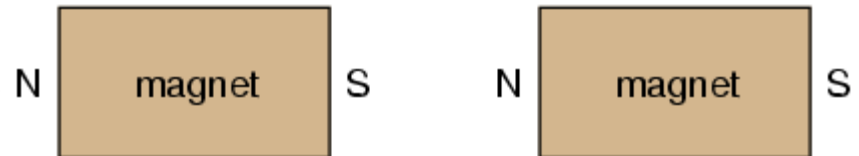


If you break a magnet in half, it forms two magnets—each with a **North** and **South** Pole

The magnetic field can be displayed by lines drawn from the **North Pole** to the **South Pole**



... after breaking in half ...

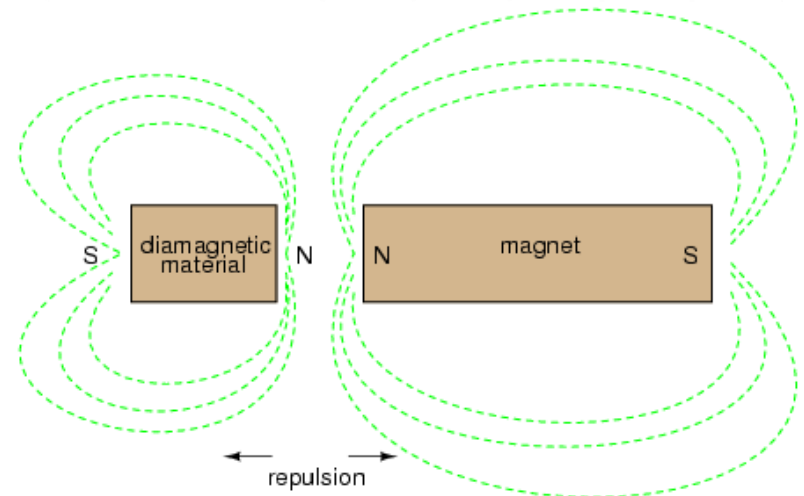
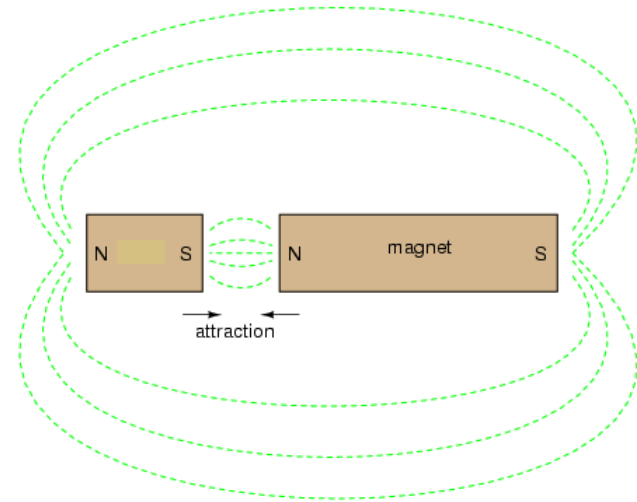


Magnetic Attraction and Repulsion

When magnets are near, the lines of force go from North to South Pole from the two magnets.

North Pole would be attracted to the South Pole

North Pole would be repulsed from the North Pole



Magnetic Compass



Exploring the World of Science

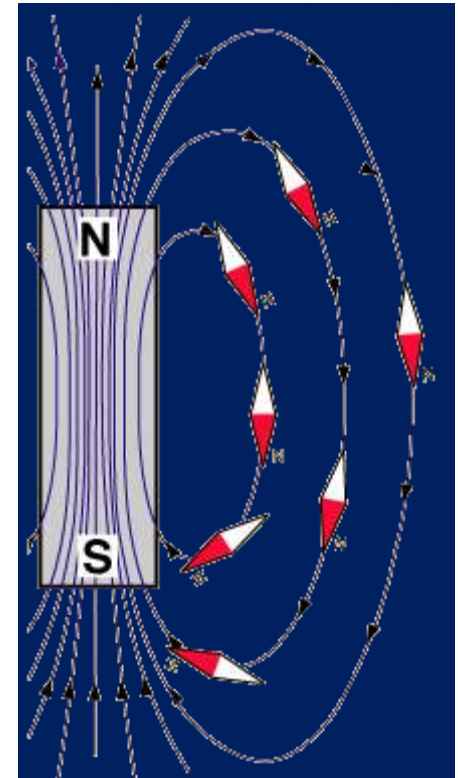
A compass is a navigational instrument that measures directions using a free floating magnetic and the Earth's magnetic field to point towards the Magnetic North Pole.

Magnetic North Pole is not quite at the geographical North Pole and it moves

Magnetic North Pole is actually a South Pole of Earth's magnetic field—allowing the North Pole of the compass to be attracted.

Compasses become useless near the Poles

Invented first by the Chinese during the Han Dynasty. Europe invented the dry compass around 1300.



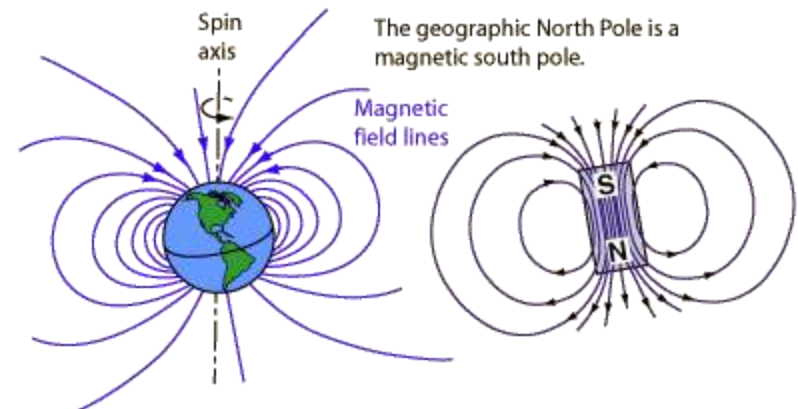
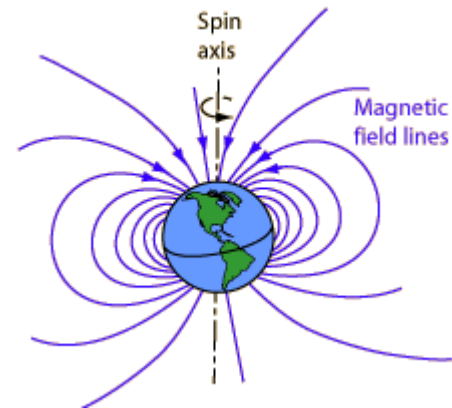
Earth's Magnetic Field

The Earth's magnetic field is similar to that of a bar magnet tilted 11 degrees from the spin axis of the Earth.

Magnetic fields surround electric currents, so we surmise that circulating electric currents in the Earth's molten metallic core are the origin of the magnetic field.

Rock specimens of different age in similar locations have different directions of permanent magnetization. Evidence for 171 magnetic field reversals during the past 71 million years has been reported.

Interaction of the terrestrial magnetic field with particles from the solar wind sets up the conditions for the aurora phenomena near the poles.



Magnet Shapes



Exploring the World of Science

All have a **North Pole** and a **South Pole**

Different shapes for different purposes



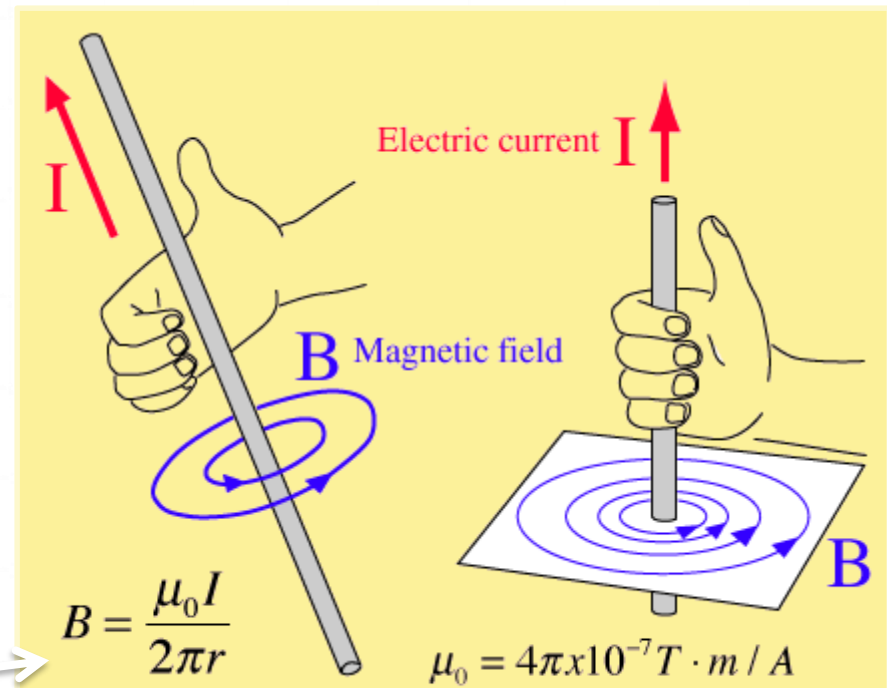
Magnetic Field of Current

Current going through a wire causes a magnetic field going around it in a “right hand rule”

Point your right thumb in the direction of the current.

The magnetic field (B) goes around the wire like your right hand fingers

See the formula for B



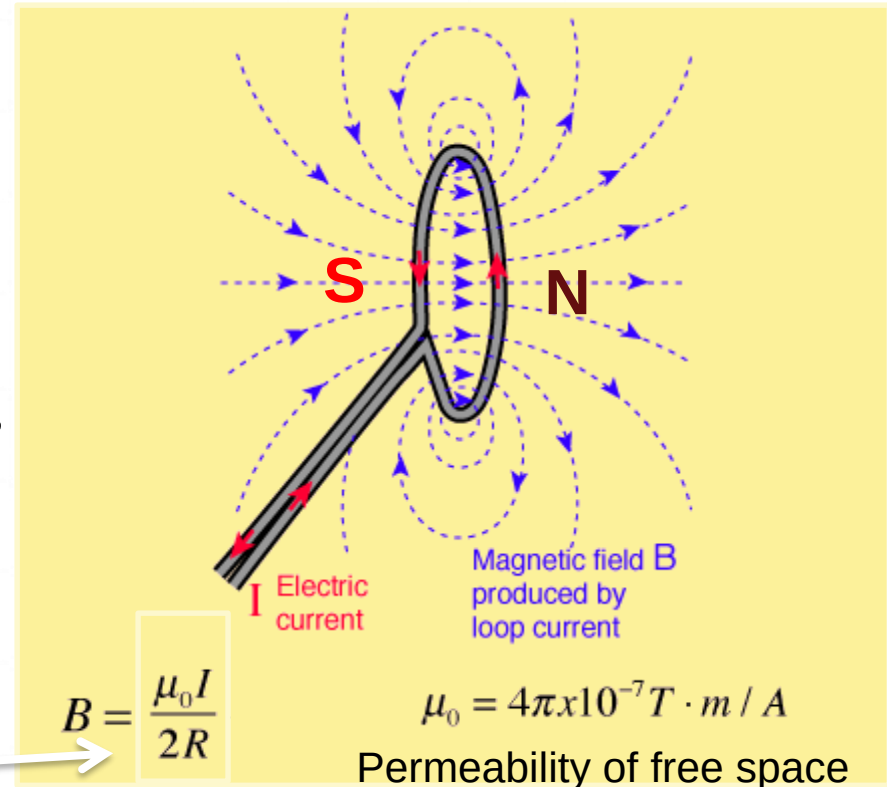
Magnetic Field of Current Loop

Current going through a wire loop causes a magnetic field that is concentrated in the inside of the loop

Have your right hand fingers follow the current

The magnetic flux (B) goes through the loop with your right thumb

See the formula for B for center of the loop



Magnetic Field of Solenoid

Current going through a multiple wire loops causes a magnetic field similar to a bar magnet.

The magnetic field is concentrated inside the loops.

Have your right hand fingers follow the current

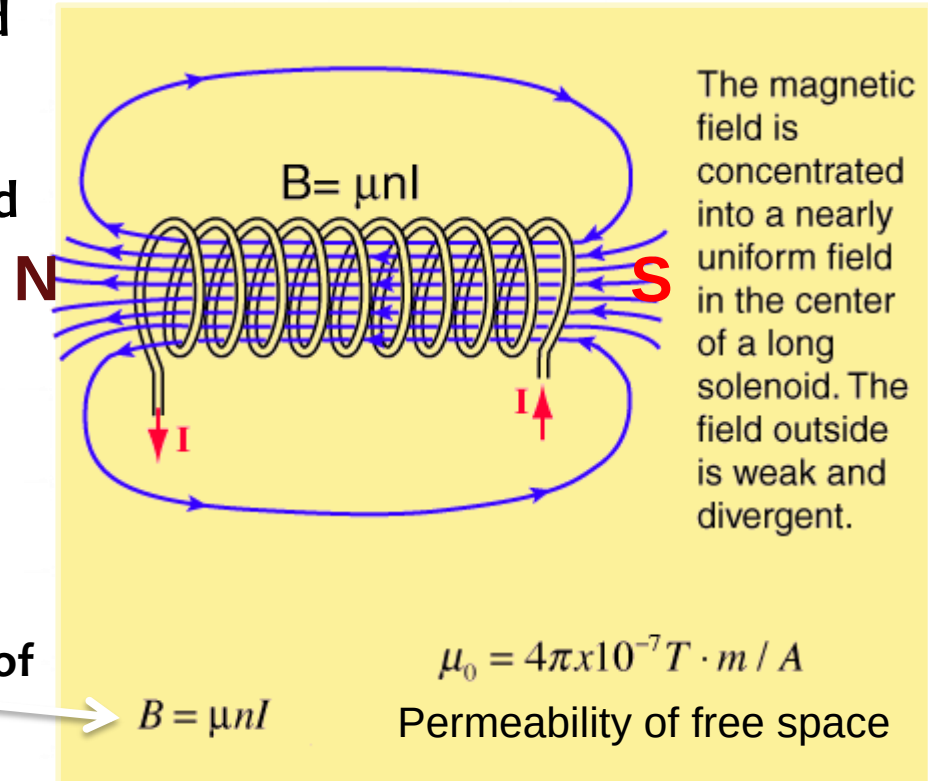
The magnetic flux (B) goes through the loop with your right thumb

See the formula for B for center of the solenoid

μ is the permeability

n is the turn density (turns/M)

I is the current



Magnetic Field of Electromagnet

An electromagnet is just a solenoid

The core material's permeability can dramatically increase the strength of the electromagnet or solenoid.

The number of turns over the length or turn density can dramatically affect the strength of the electromagnet or solenoid.

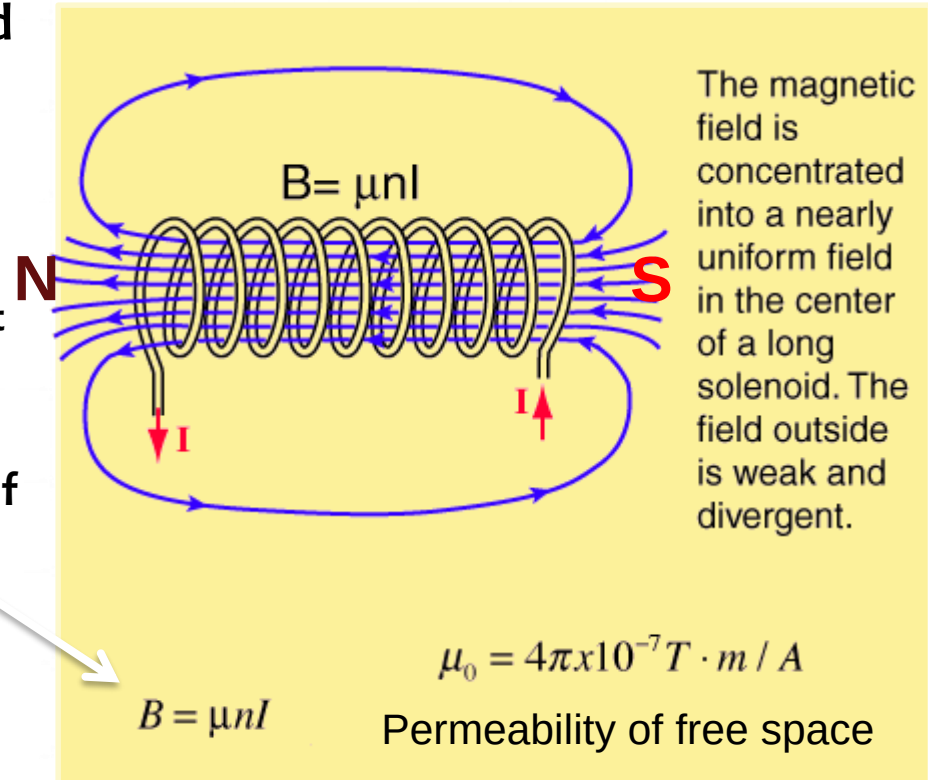
See the formula for B for center of the electromagnet

μ is the permeability

n is the turn density (turns/m)

For example if you have 100 turns per 0.01m, $n = 100/0.01 = 10,000$ turns/m

I is the current



Lorentz Force Law



Exploring the World of Science

- ▣ Force is applied on all charged particles by both magnetic and electric fields
-
- ▣ The Force of the Electric field is equal to $F_{elect} = qE$ and is in the direction of the Electric field
- ▣ The Force of the Magnetic Field is equal to $F_{mag} = q\vec{v} \times \vec{B}$ and is in the direction diagonal to the magnetic field and the moving charge
 - if the charge isn't moving there is no magnetic force
 - If the charge is moving in the line of the magnetic field there is no magnetic force

Electric field in N/C or volts/m.

$$\vec{E} = \frac{\vec{F}}{q}$$

electric force in Newtons
charge in Coulombs

Since the measured electric field can depend upon your reference frame, a more general definition of the electric field comes from the Lorentz force law. The electric field can be defined as the electromagnetic force per unit charge in the rest frame of the charge.

$$\vec{F} = \underbrace{q\vec{E}}_{\text{Electric force}} + \underbrace{q\vec{v} \times \vec{B}}_{\text{Magnetic force}}$$

Lorentz force law

A charge that is moving relative to the source will experience part of the force as a magnetic force.

What are electric motors?

Motors that turn flowing electric current into mechanical motion/work

They are the opposite of generators, which turn mechanical motion/work into flowing electrical power.

To make one you need a magnetic field and flowing current. Like with an electromagnet, the more turns the more powerful the magnetic field.

The moving part is the Rotor

The stationary part is the Stator

If you reverse the polarity (voltage/current), the motor will run in revers



How does a motor work?

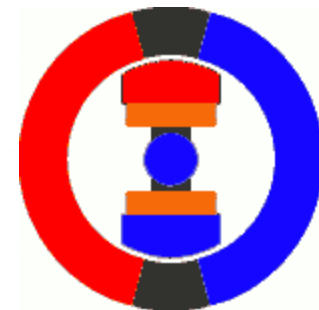
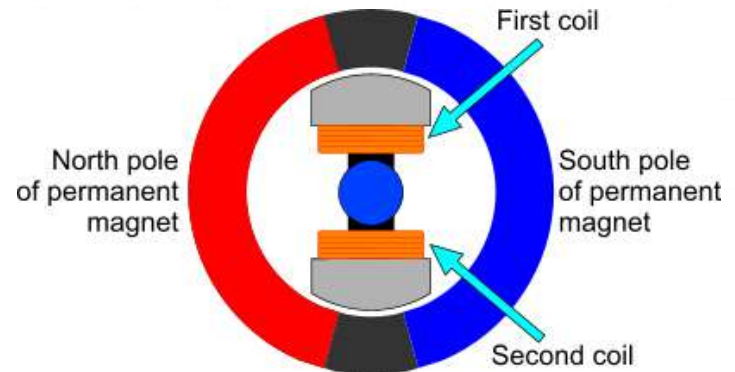


DC motor has two windings and two permanent magnets

Coils are powered from the Commutator and the Brushes

The current that runs through each windings changes direction at the halfway point (caused by the connection of the commutator)

Magnets are wound such that when one is **North**, the other is **South**



Parts of Motor



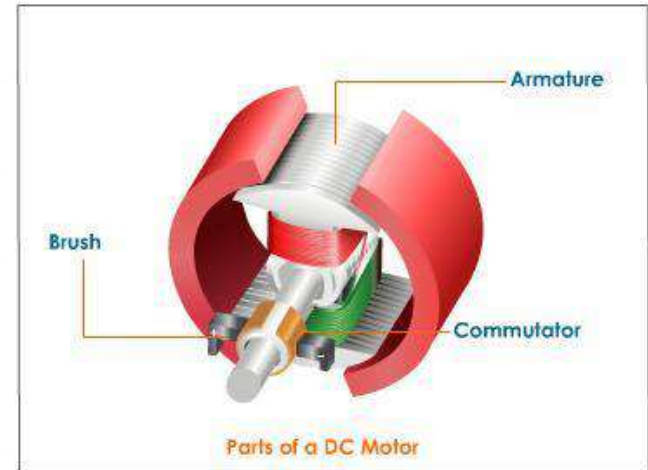
The part that rotates in the middle is called the Rotor

In a Brushed DC motor, this has the windings

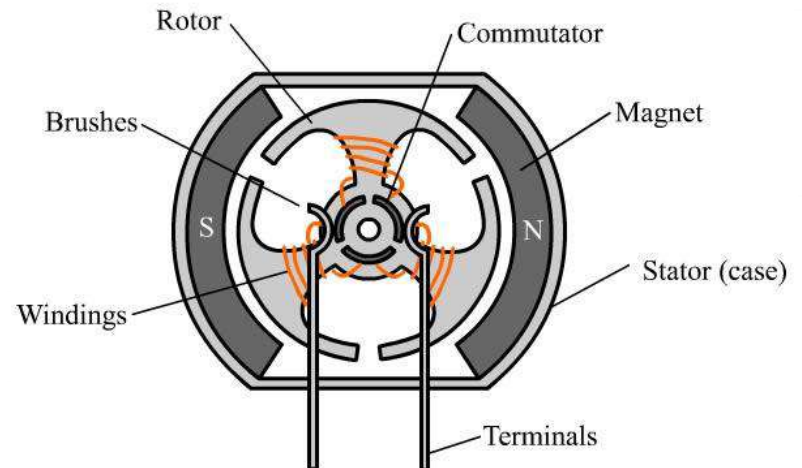
Armature is the part that contains the main current-carrying winding. The armature usually consists of a coil of copper wire wound around an iron or steel core.

The part that doesn't move on the outside is called the Stator

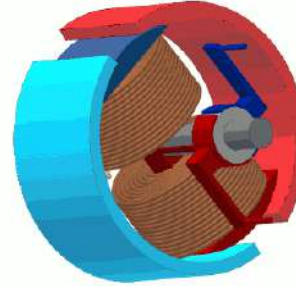
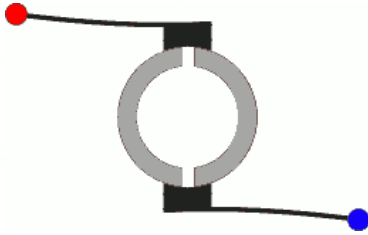
In a Brushed DC motor, this is where the permanent magnets are located



Typical Brushed Motor in Cross-section



DC Motor

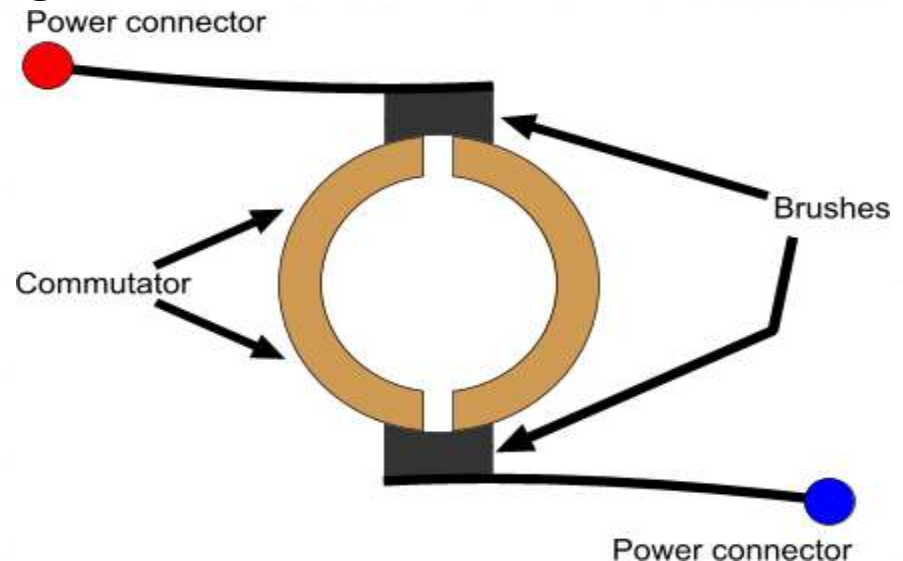


This is a “Brushed DC Motor”

Brushes (normally made out of carbon) allow the current to continue even as the Rotor rotates

There is a small gap when the brushes switch from one set of windings to the next (causing the switch of polarities) on the Commutator

Commutator is a metal ring that is fixed on the shaft of the motor, so it rotates too



Brushed versus Non-Brushed DC Motors



Brushed motors are the most common, but the brushes eventually wear out—especially if the motor was used with too much power, too fast, or is not cleaned.

Non-Brushed Motors use the magnets on the Rotor and then pulse the current on the windings on the Stator. The motor will move as fast as the pulses.

Torque Problems with a DC Motor



Brushes wear out

The angular force or Torque changes as the rotor spins around.

For a single coil system the Torque goes to zero at 180

For two coil systems you can greatly increase the average Torque and smooth out the force.

