Physics unit 2 summary

MODULE 1: Electricity and Magnetism

Electric Field

An electric field is defined as any region when an electric charge experiences an electric force.

Electric field strength, E.

Definition: The electric field strength at a point in an electric field is defined as the force exerted per unit + ve charge at that point.

E = $\frac{F}{Q}$

Notes:

- SI units of E: NC^{-1} or Vm^{-1}
- E is a vector quantity.

Electric Field Lines

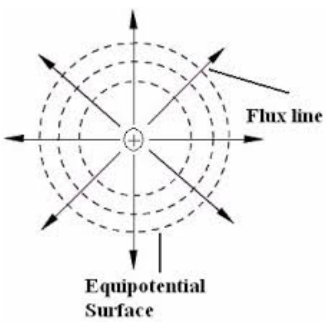
The electric field lines is rep by electric field lines. The direction of electric field at a point is taken as the direction of the force that will be exerted on a positive charge placed at that point.

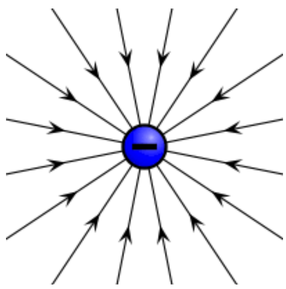
The field line direction or the tangent to it if it is curved such as the direction of the electric field strength, s.

The number of field lines per unit of cross sectional area is proportional to field strength, E.

Examples

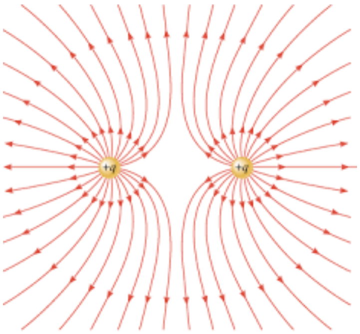
1. Positive point charge
2. Negative point charge

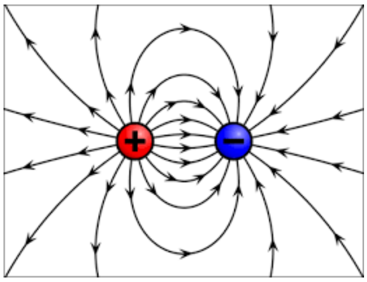




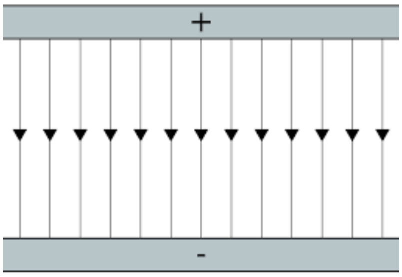
1. Like point charges
2.

3. Unlike point charges





3. Between oppositely charged parallel plates.



Near the center of the plate the field lines are parallel and equivalent indicating that the electric field is uniformed. E is constant. Near the edges of the plate the field id non-uniformed.

Near the center: E = $\frac{v}{d}$

Where V = p.d between the plates (v)

d = separation of the plates (m)

Units = Vm^{-1}

Uniform Fields

By definition: E = $\frac{F}{Q}$

➔ F = EQ

In a uniform field E is constant therefore the force exerted on a given charge, Q is also constant.

Between a pair of oppositely charged plates E = $\frac{v}{d}$

➔ F = EQ

F = $\frac{vQ}{d}$

Motion of charged particles in a uniform electric field

Consider a horizontal beam of electrons moving with a velocity, v. the beam passes between a pair of parallel plates with separation d and p.d, between the plates.

The direction of the electrons is initially perpendicular to the direction of the uniform field between the plates.

Force on an electron: F = Eq or $\frac{Vq}{d}$

a = $\frac{F}{m}$ -> a = $\frac{Eq}{Me}$ or $\frac{Vq}{Med}$ q = charge on electron

Me = mass of electron

The horizontal component of velocity is perpendicular to the electric force and therefore remains constant.

The vertical component of velocity is changed by the electric constant force which acts vertically. The acceleration is constant and therefore the equation of motion may be applied for vertical motion.

The system is analogous to the –projectile motion of a particle projected perpendicular to a uniform gravitational field.

Displacement

Horizontal displacement: s = vt…..1

Vertical displacement: s = ut + $\frac{1}{2}$at^2 → y = 0 + $\frac{1}{2}$at^2

y = $\frac{1}{2}$at^2….2

Substitute t = $\frac{x}{v}$ from 1: y = $\frac{1}{2}$a $(\frac{x}{v})^2$

Constant y = $(\frac{a}{2v^2})$ x^2

Directly proportional y ∝ x^2

Therefore the reaction takes a parabolic path.

Velocity

Horizontal velocity: horizontal velocity, v is constant

Vertical velocity: v = ut at → v = 0 + at

v = at

or

v^2 = u^2 + 2 as → v^2 = 0 + 2 ay

v = $\sqrt{2ay}$

Velocity of emerging electron: Resultant velocity, V_R = $\sqrt{v_v^2 + v^2}$

Direction θ = tan^{-1} $(\frac{v_v}{v})$

Where V_V is the vertical velocity when electron emerges from a uniform electric field.

ELECTRIC FIELD DUE TO POINT CHANGES.

Coulomb's Law

The magnitude of the force between two point charges is directly proportional to the product to the charges and inversely proportional to their square of their distance apart.

F$\propto \frac{Q_1Q_2}{r^2}$

F = $\frac{Q_1Q_2}{r^2}$

F = $\frac{Q_1Q_2}{4\pi Eor^2}$

If the medium between the charges is free space (i.e a vacuum) then the constant E is called the permittity of free space and is denoted by E = (8.85 × 10 Fm^{-1})

Electric field strength due to a point charge

The electric field strength due to a point charge, Q at a distance, r from Q is given by E = $\frac{Q_1Q_2}{4\pi Er^2}$

Electric Potential, V

Definition: The electric potential at a point in an electric field is defined as the work done per unit positive charge in moving from infinite to that point.

$$V = \frac{W}{Q}$$

Notes:

The S.I units of potential is the volt (v)

Definition: the volt is the potential at the point in an electric field if 1J of work is done per unit positive charge in moving from infinite to that point.

$$1v = 1\ J\ c^{-1}$$

The electric potential at a distance R from a point charge Q is given by:

$$V = \frac{Q}{4\pi E_0 r}$$

Recall: V = $\frac{Q}{4\pi E_0 r}$

$\frac{dv}{dr} = \frac{-Q}{4\pi E_0 r}$

The electric field strength at a point in an electric field is numerically equal to the potential gradient at that point.

The gradient of a V is r graph is numerically equal to the electric field strength.

N.B = Potential is a scalar quantity

Gravitational Field	Electric Field
Gravitational field strength, g at a point is the force per unit mass at that point. g = $\frac{F}{m}$ Unit = NKg^{-1}	Electric field strength, E at a point is the force per unit positive charge at that point. E = $\frac{F}{Q}$ Unit = Nc^{-1}
In a uniform gravitational field g is constant and therefore the force exerted on a given mass is constant.	In a uniform electric field, E is constant and therefore the force exerted on a given charge is constant
Gravitational potential $\emptyset = \frac{W}{M}$ Units: JKg^{-1}	Electric potential: V = $\frac{W}{Q}$ Units: Jc^{-1} (= v)

Point masses:	Point charges:
F = $\frac{GM_1M_2}{r^2}$ G = $\frac{GM}{r^2}$ Ø = $\frac{-GM}{r}$	F = $\frac{Q_1Q_2}{4\pi E_0 r^2}$ E = $\frac{Q}{4\pi E_0 r^2}$ V = $\frac{Q}{4\pi E_0 r}$

Capacitance, C

Definition: the capacitance of a conductor is the charge stored on the conductor per unit potential of the conductor.

$$C = \frac{Q}{V}$$

Notes: The S.I unit of the capacitance is the fared (F)

Definition: the fared is the capacitance of the conductor which carries a charge of 1 C per unit potential.

$$1F = 1CV^{-1}$$

Capacitors

A capacitor is a device used for storing electric charge.

Eventually all capacitors consists of a pair of conducting plates separated by an insulator called a dielectric (eg. Air, fuel, polystyrene)

Definition (Capacitance of a capacitor)

The capacitance of a capacitor is defined as the charge stored in either plate per unit potential difference between plates.

Capacitance, c = $\frac{Q}{V}$

One fared is a very high capacitance and is more common to find capacitances of the order mF (milli), μf (micro), pf (pico).

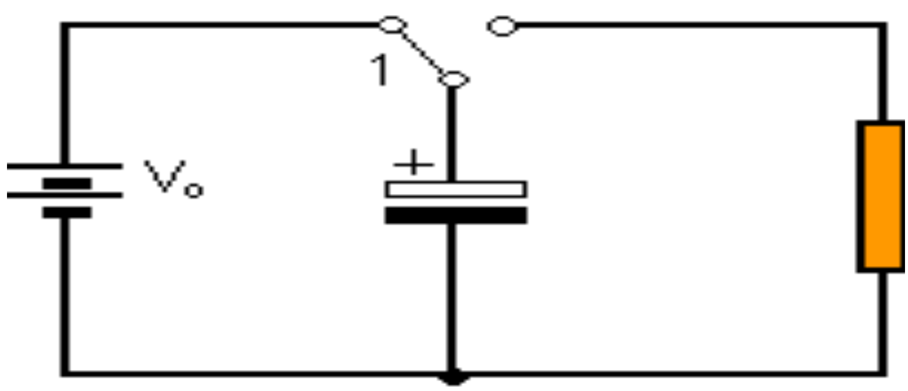
The capacitance of a parallel plate capacitor is given by c = $\frac{e\,A}{d}$ where

A = area of overlap of the plates (m^2)

d = separation of the plates (m)

E = permittivity of the free space

CHARGING AND DISCHARGING A CAPACITOR THROUGH A RESISTOR



Charging

The two – way switch is moved to position 1

Observation: Initially the current at the ammeter is at maximum I_0, it then strictly decreases to 0.

Explanation: Electrons flow from negative of a supply to the plate Y giving it a negative charge. At the same rate electrons have plate X and move towards the positive of the supply thus having a positive charge on plate X.

As charges accumulate on the plates the point across the plates increases ($v = \frac{Q}{C}$) therefore $V \propto Q$.

The increase of the point of the capacitor opposes the emf of the supply and therefore reduces the rate of flow of charge (i.e. reduces the constant).

Charges contains to accumulate on the capacitor with the point across the plates becomes equal to the emf of the supply electrons flow then stops.

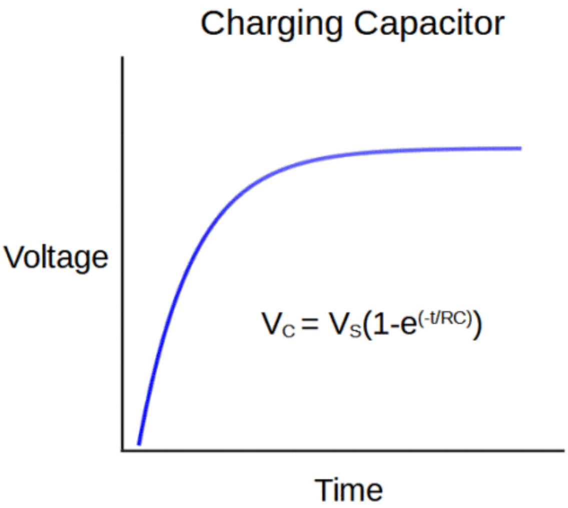
DISCHARGING

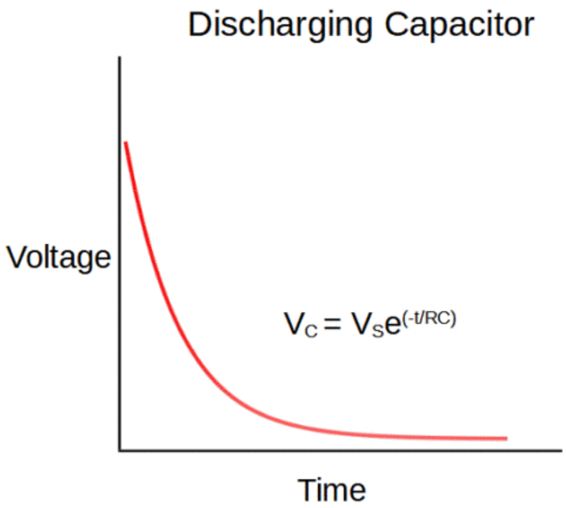
Once the capacitor is fully charged the 2 – way switch is moved to position 2.

Observations: Initially the switch is a maximum I_0 and it then slowly decreases to 0.

Explanations: Electrons flow from plate Y to plate X. this reduces the negative charges on Y and the positive charges on X.

Initially the charge on the plate is a maximum $Q_0$and the point across the plates is also a maximum X_0. As charge decreases the point decreases and hence constant decreases.





THE CONSTANT, RC.

Re for a discharging capacitor

$$Q = Q_0\, e\, \frac{t}{rc}$$

When t = RC

$$Q = Q_0\;\; c^{-\frac{RC}{RC}}$$

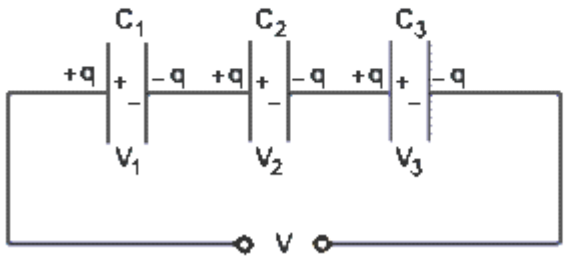
$$Q = \frac{1}{e}\, Q_0$$

The constant RC is called the time constant and is define as the time taken for the change to fall to $\frac{1}{e}$ of its maximum value.

Notes: The unit of the RC is the second (s). the value RC controls the rate of charge of the discharge of the capacitor.

CAPACITORS IN SERIES

Consider a capacitor of capacitance C_1, C_2 and C_3 respectfully connected in series with



Charge: Total charge, Q = charge stored on each capacitor

P.d = Total p.d = Sum of the p.ds

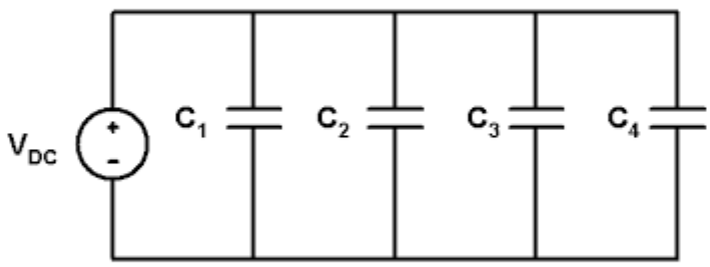
$$V = V_1 + V_2 + V_3$$

→ Total capacitance, C is given by

$$\frac{1}{c} = \frac{1}{c_1} + \frac{1}{c_2} + \frac{1}{c_3}$$

CAPACITORS IN PARALLEL

Consider a capacitors of capacitance C_1, C_2 and C_3 respectfully connected in parallel with a battery of emf v.



P.d: P.d across each parallel section is the same (in this , V)

Charge: Total charge Q = Sum of the charges

$$Q = Q_1 + Q_2 + Q_3$$

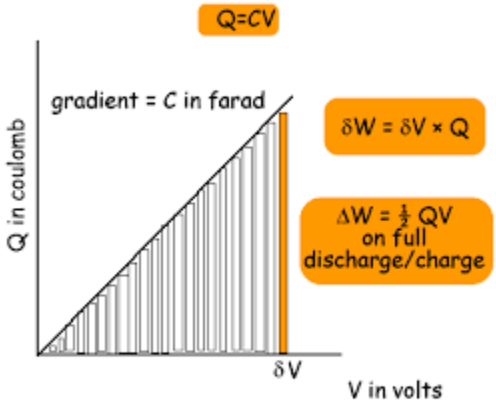
Capacitors: Re: $Q = Q_1 + Q_2 + Q_3$

But total capacitance, c = $\frac{Total\ charge, Q}{Total\ p.d\ ,v}$

$C = c_1 + c_2 + c_3$

ENERGY STORED IN A CHARGED CAPACITOR

The charge on a capacitor is directly proportional to the p.d across it (P = cv). The graph of p.d is charged and is therefore a straight line passing through the origin.



Consider a capacitance, c which stores a charge, Q where the p.d is v. if the capacitor discharges a very small charge ΔQ such that the p.d v can be considered a constant, then by definition the resulting energy lost ΔW is given by ΔW = v ΔQ

= area of the shaded strip

If the capacitor discharges completely then

Total energy loss = Area under v – Q graph

W = $\frac{1}{2}$vQ

Therefore, energy stored, W = $\frac{1}{2}$vQ

Q = cv → W = $\frac{1}{2}$cv^2

V = $\frac{Q}{c}$ → W = $\frac{1}{2}\frac{Q^2}{c}$

CURRENT ELECTRICITY, ELECTRICITY QUANTITIES

Electric Current, I

Electric current is a fundamental quantity and as such it cannot be defined in simpler terms.

A flow of charge constitutes on electric current, these charges may be positive, negative or both.

The magnitude of an electric current is numerically equal to the rate of flow of charge.

The direction of convectional current flow is taken as that in which there is a net displacement

Of positive charge over a time period (current always flow from a higher potential to a lower potential).

The S.I nit of electric current is the ampere A.

Electric current can be measured directly using an ammeter which is placed in series with the component under investigation. This means that the ammeter must have a very low resistance (ideally the resistance is zero).

ELECTRIC CHARGE, Q

Definition: The electric charge which flows past a point in a given time when a steady current flow is the product of the current and time.

$$Q = It$$

Notes: The S.I unit of electric charge is the coulomb (c).

Definition: So, the coulomb is the charge which flows past the point in 1 second when the steady current of 1 A flows.

$$1C = 1As$$

POTENTIAL DIFFERENCE (p.d) V

Definition: the p.d between two points id defined as the electrical energy converted to other forms of energy per unit charge passing from one point to the other.

$$V = \frac{W}{Q}$$

Notes: The S.I unit of p.d is the volt (V)

Definition: The volt is the p.d between two points if 1 J of electrical energy is converted to other forms of energy per unit charge passing from one point to the other.

$$1V = 1JC^{-1}$$

Resistance, R

Definition: the resistance of a conductor is defined as the ratio of the p.d across the conductor to the current flowing through it.

$$R = \frac{V}{I}$$

Notes: The S.I unit of resistance is ohm.

Definition: The ohm is the resistance if the conductor unit current flows when a p.d of 1V is applied across the conductor.

$$1 \text{ ohm} = 1VA^{-1}$$

The resistances of many conductors in particular metal depend on their physical conditions eg. temperature. The behavior was discovered by ohm and the conductors are therefore called ohmic conductors.

Ohm's Law

The current through a metallic conductor is directly proportional to the p.d across its ends and provides that temperature and other physical conditions remains unchanged.

$$I \propto V \rightarrow \frac{V}{I} = \text{constant}$$

ELECTROMOTIVE FORCE (emf)

Definition: The emf of an electrical energy source is defined as the energy converted into electrical energy from other forms of energy per unit charge through the source.

Note: Both emf and p.d are defined in terms of energy transferred per unit charge and they therefore have the same unit (i.e. volt)

DIFFERENCE
p.d.: Electrical energy → other forms per unit charge (i.e. light, heat etc)
emf: Other forms → Electrical energy per unit charge (chemical, mechanical)

RELATIONSHIP BETWEEN INTERNAL RESISTANCE, TERMAL P.D AND EMF

The chemicals within a cell causes a resistance to current flow. The resistance is called internal resistance of the source or the source resistance. The internal resistance is in series with the cell and the external circuit.
The p.d measured causes the terminal of a cell is called the terminal p.d. This p.d depends on the size of the current being drawn from the source. If zero constant is drawn (i.e. the source on open circuit, then the terminal p.d is equal to the emf of the source.
Not all of the energy supplied by the source is used in the external circuit. Some is converted to heat as charge flow through the internal resistance. The terminal p.d is therefore not equal to the emf unless it is measured when here is no flow charge.

CONSIDER CONSERVATION OF ENERGY
Energy supplied by the source per unit charge per = Energy used by the external circuit per unit charge + Energy dissipated as heat in the internal resistance per unit charge.

$V = (\frac{R}{R+r})\ E$
From 1: As R → ∞ $I = 0$
From 2: As R → ∞ V → E
As I → 0 V → E

RESISTIVITY, ρ
Definition: The electrical resistivity of a conductor at a particular temperature with a cross sectional area o 1m^2 is numerically equal to its resistance per unit length.

$$\rho = \frac{RA}{l}$$

R – resistance
A – cross sectional area (m^2)
l – length (m)
ρ – resistivity

ELECTRICAL ENERGY, W and ELECTRICAL POWER, P

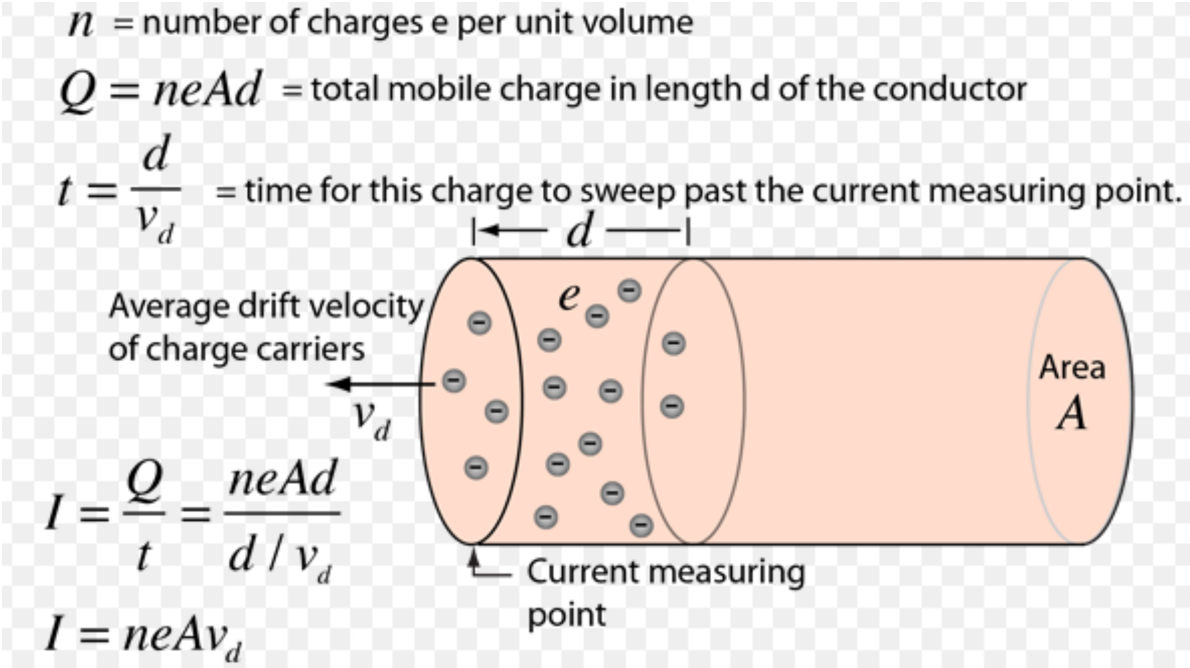
By definition: $W = VQ$ $P = \frac{W}{t}$

$Q = It \rightarrow W = VIt$ $P = \frac{VIt}{t} \rightarrow P = VI$

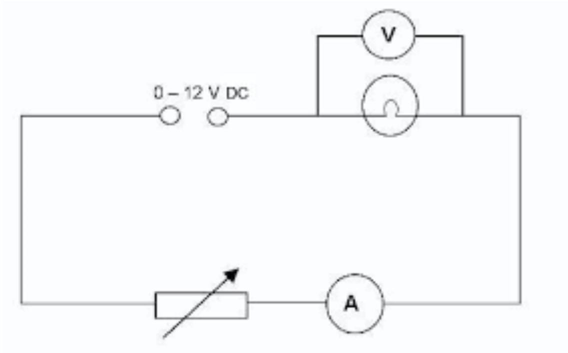
$V = IR \rightarrow W = I^2 Rt$ $P = \frac{I^2Rt}{t} \rightarrow P = I^2 R$

$I = \frac{v}{R} \rightarrow W = \frac{v^2t}{R}$ $P = \frac{v^2t}{t} \rightarrow P = \frac{v^2}{R}$

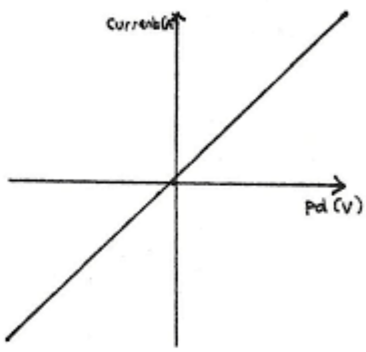
Drift velocity



ELECTRICAL CIRCUITS
IV Characteristics



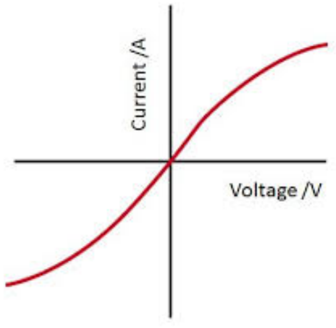
Metallic Conductor At Constant Temperature



- Straight line through origin

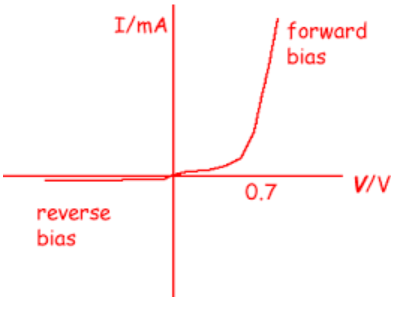
- Gradient = $\frac{1}{v} = \frac{1}{R}$
- It refers to ohm's law
- Gradient constant, resistance constant.

Filament Lamp

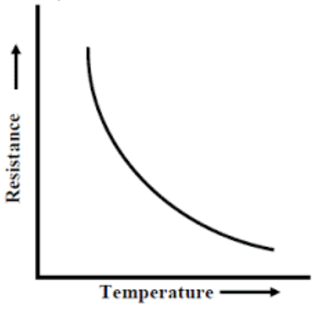


- As p.d increases, current increases but it is not a potential relationship.
- As p.d increases, current increases but resistance decreases because gradient decreases.

Semi-Conductor Diode



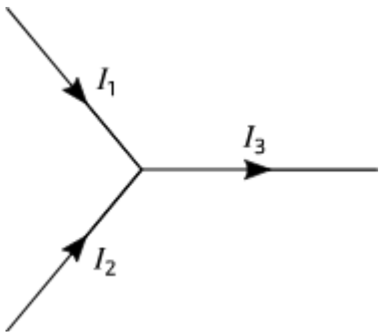
Temperature Characteristics of a Thermistor



KIRCHOFF'S LAWS

Kirchoff's First Law

The electric sum of the current and the junction is 0.



If current entering the function is positive, then the current leaving the junction is negative.

$I_1 + (-I_2) + (-I_3) = 0$

$I_1 = I_2 + I_3$

Note: This law is based on the conservation of charge i.e. total charge entering junction = total charge leaving junction.

Kirchoff's Second Law

In any closed loop the algebraic sum of the emf's is equal to the algebraic sum of the products of current and resistance (i.e. the algebraic sum of the p.d)

$$\sum E = \sum(IR)$$
$$\sum E = \sum v$$

Note: This law is based n the conservation of energy.

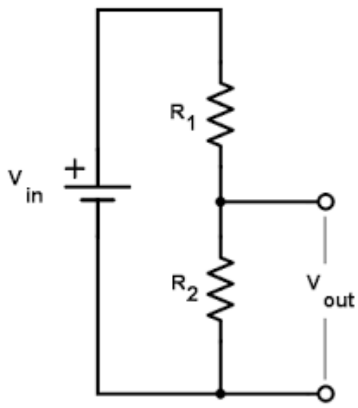
RESISTORS IN SERIES

Total resistance $R = R_1 + R_2 + R_3$

RESISTORS IN PARALLEL

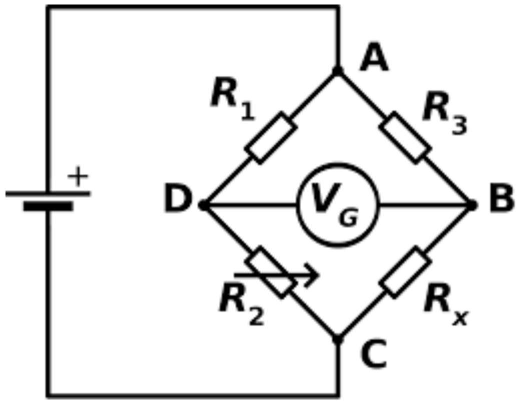
Total resistance, $R = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

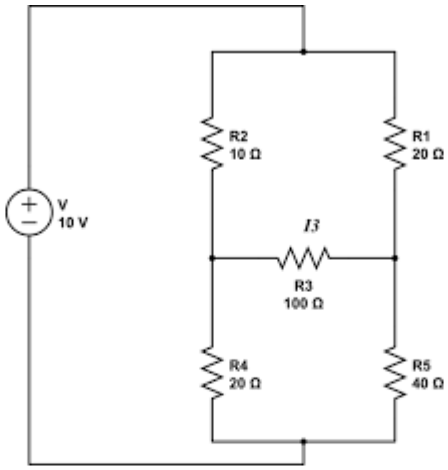
POTENTIAL DIVIDER



$V_{out} = (\frac{R_2}{R_1 + R_2}) V_{in}$

WHEATSTONE BRIDGE





The Wheatstone bridge maybe considered as two potential dividers connected in parallel.

The bridge is said to be balanced when there is no deflection in the galvanometer, no current flows between X and Y, potential at X equals potential at Y.

At balance.

Potential at X = Potential at Y

At balance: $\frac{P}{Q} = \frac{R}{S}$

The Wheatstone bridge is used to compose resistances.

MAGNETIC FIELDS

A magnetic field is defined as any region where a force is experienced eg. the region near a permanent magnet or near a current carrying conductor.
The magnetic field is rep. by magnetic field line whose direction at point gives the direction of the field at that point.
The direction of a field at that point is taken as the direction of the force exerted on a free north pole placed at that point.

Note:

- The field pattern near permanent magnet
- Magnetic forces
- Smaller separation, greater the force

ELECTROMAGNETISM
Force on an current carrying conductor
Th force exerted on a long straight current carrying conductor placed in a magnetic field other its own depends on :

1. The magnitude of the current through the conductor
2. The length of the conductor
3. Angle between conductor and the field
4. The strength of the magnetic field which is called the magnetic flux density, B

MAGNETIC FLUX DENSITY, B

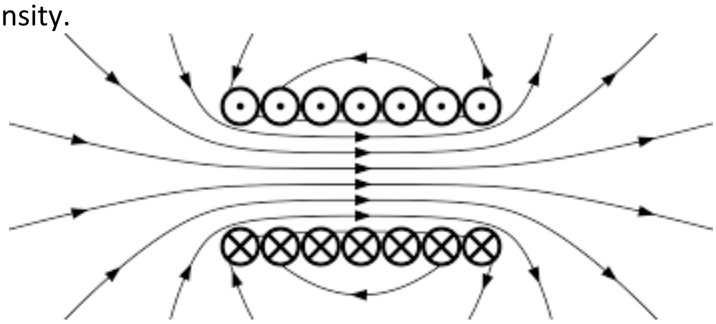
The magnetic flux density of a magnetic field is defined as the force per unit current exerted on a current carrying conductor which is perpendicular to the magnetic field.

$$B = \frac{F}{IL}$$

Notes: The S.I units of magnetic flux density is the Tesla (T)
Definition: The tesla is he magnetic flux density of a field which exerts a force of 1N per unit length, per unit current on a current carrying conductor which is perpendicular to the magnetic field.

$$1T = 1Nm^{-1} A^{-1}$$

The number of field lines per unit cross sectional area is a measure of the magnetic flux density.



FORCE ON A CHARGE MOVING THROUGH A MAGNETIC FIELD

Consider a particle with a charge Q moving with a speed, v at an angle θ to a uniform magnetic flux density B.

F = BQv sin θ

When v = 0 F = 0

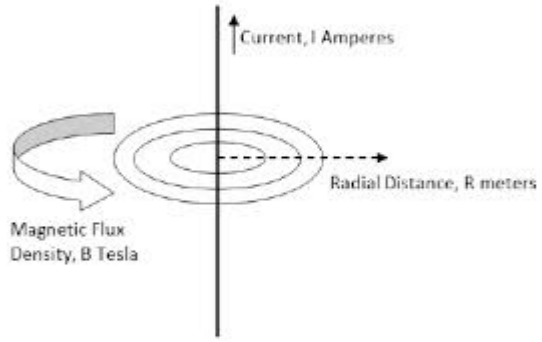
When θ = 0 or π F = 0

When Θ = $\frac{\pi}{2}$ f = BQv (i.e. max force)

Direction of force predicted using Flemings left hand law.

MAGNETIC FIELD PATTERNS AROUND CURRENT CARRYING CONDUCTOR

1. Long Straight Conductor



Direction of field determined using

1. Flemings right hand grip rule
2. Right hand screw rule

Magnetic flux density at a perpendicular distance, a from the conductor is given by:

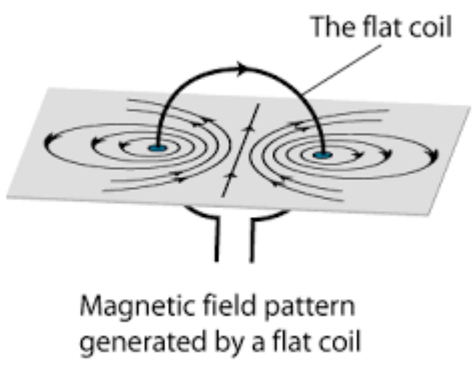
$$B = \frac{\mu_0 I}{2\pi_0}$$

I – current (A)

a – perpendicular distance from the conductor (m)

μ_0 – permeability of free space

2. Flat Circular Coil

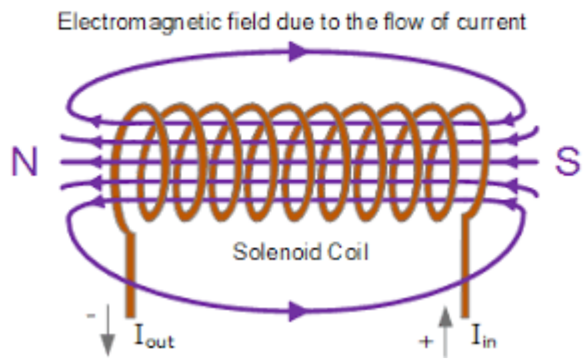


Magnetic flux density at the center of the coil

B = $\frac{\mu_0 NI}{2r}$

I – current in the coil(A)
N – number of turns in the coil
r – radius of the coil (m)
μ_0 – permeability of free space $4\pi \times 10^{-4}$ Hm^{-1}
The direction of the field is predicted using the righthand grip rule.

3. Solenoid



Magnetic flux along the axis of the solenoid

B = $\mu_c n I$

I – current in the solenoid

n – number of turns per unit length of the solenoid

μ_0 – permeability of free space $4\pi \times 10^{-7}$ Hm^{-1}

Direction of magnetic field may be determined using the righthand grip rule.
Inside the solenoid, the field is from south to north.

FORCES BETWEEN CURRENT CARRYING CONDUCTORS

Two current carrying conductors are placed in each other magnetic field may exert mutual forces on each other.
Consider two infinitely parallel conductor with separation. A carrying current, I_1 and I_2 respectively in a vacuum.

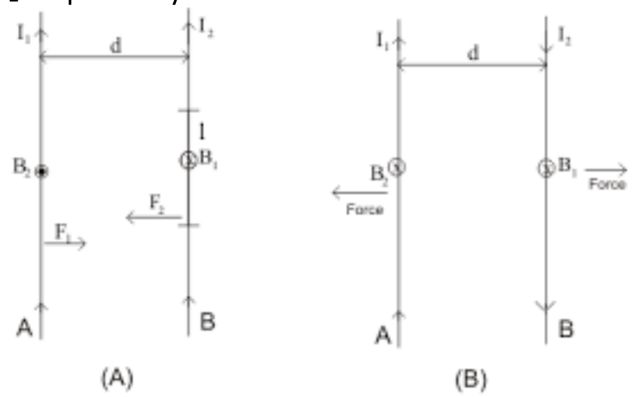
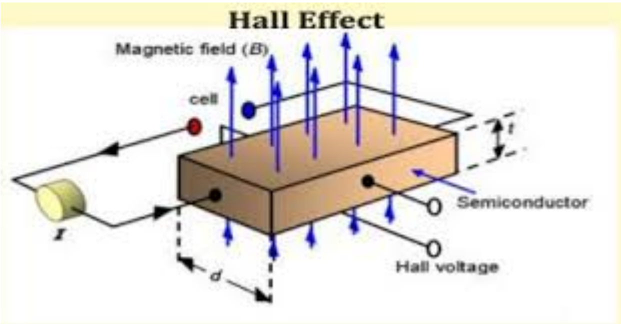


Figure 5. Current carrying wires exerts force on each other

Fx = Fy
Forces are mutual forces
Currents are in the same direction, mutual forces of attraction.
If currents are in opposite direction, mutual forces of repulsion.

THE HALL EFFECT
Consider a conducting material placed in the magnetic field of flux density, B whose direction is perpendicular to that of the current that flows in the material. A flow of electrons with drift velocity, v constitutes the electric current, I.



By F.L.H.R the electrons experience a downward force F_B. this causes a build up of negative charge on side Y while a positive charge is left on side X.
A point is therefore created between X and Y which opposes the motion of the charges, since the electric force and magnetic force are opposite in direction. The build up of charge continues until the p.d becomes so large that it prevents any further increases, this max p.d is called the half voltage, V_H.
When the hall voltage has been established.

$F_e = F_B$

$QE = B\,Qv$

$E = \frac{VH}{ø} \rightarrow \frac{VH}{d} = Bv$

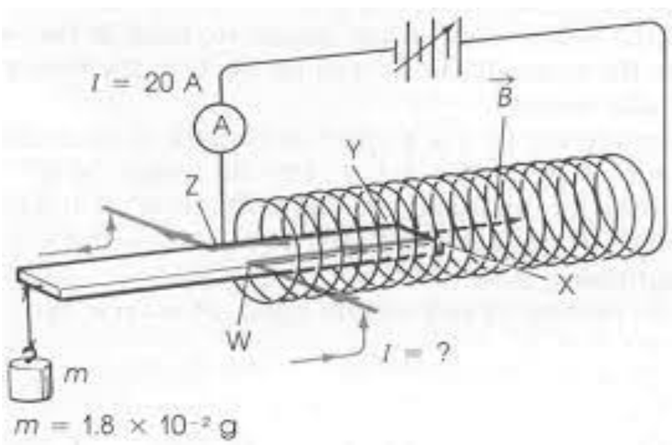
$V_H = Bvd$

$V = \frac{I}{n\,Ac} \rightarrow V_H = B\left(\frac{I}{n\,Ac}\right) d$

$A = td \rightarrow V_H = \frac{BI\not{d}}{nt\not{d}e}$

$V_H = \frac{BI}{net}$

Current Balance

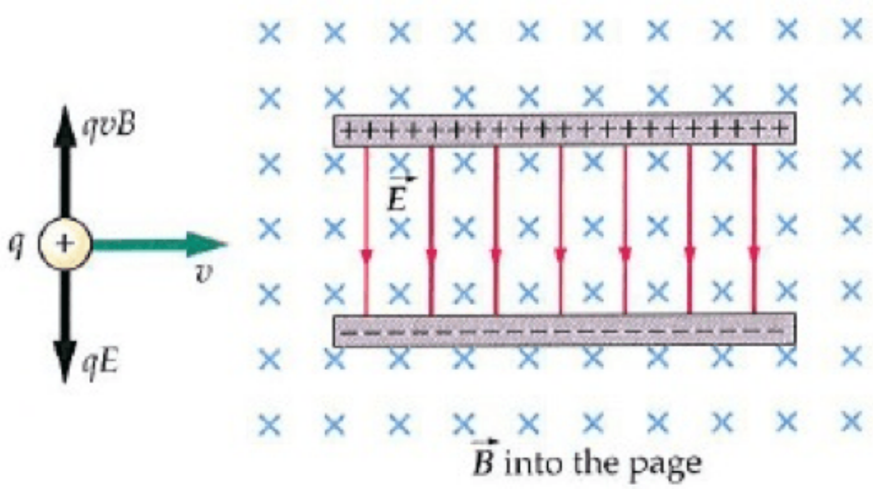


When balanced:

$mg = BIL$

$B = \frac{mg}{IL}$

Crossed Fields



$F_B = F_E$

$BQv = EQ$

$v = \frac{E}{B}$

NB – mass of particle is ignored

- this apparatus can be used as a velocity selector. The required value can be adjusted by altering the values E + B.

Velocity which are greater than $\frac{E}{B}$ would have a greater magnetic force ($F_B > F_E$) and would therefore be deflected downwards and vice versa.

ELECTROMAGNETIC INDUCTION

MAGNETIC FLUX, Ø

Definition: The magnetic flux through a small plain surface is the product of the flux density normal to the surface and the area of the surface.

$$Ø = BA$$

Notes: The S.I unit of magnetic flux is the Weber (Wb)

Definition: The Weber is the magnetic flux through a $1m^2$ area perpendicular to a magnetic field of flux density on Testa

$$1Wb = 1 Tm^2$$

FLUX LINKAGE

If a coil has more than 1 term, then the flux through the whole coil is the sum of the individual fluxes through each term. This is called a flux linkage and is defined as the product of the number of terns N and he flux through 1 turn Ø.

Flux Linkage = NØ

= NBA cos Θ

LAWS OF ELECTROMAGNETIC INDUCTION

1. Faraday's Law

   The magnitude of the emf induced in a conductor is directly proportional o the rate of change of flux linkage as the rate of cutting of magnetic flux.

2. Lenz's Law

   The direction of the induced emf is such that it opposes the flux change causing it and does oppose it if an induced current flow.

Notes: E = $\frac{-d(NØ)}{dt}$

The direction of induced current is given by Fleming's Right-Hand Rule.

Examples:

1. Emf induced in a straight conductor

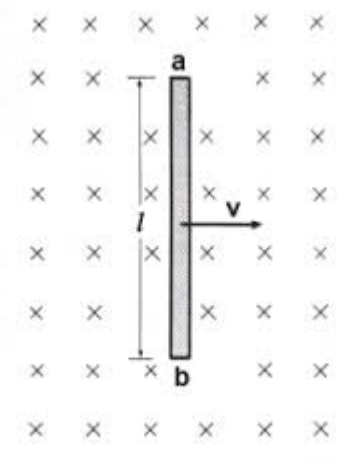


Fig. 4

In 1s the distance covered = v

→ in 1s the area swept ΔA = Lv

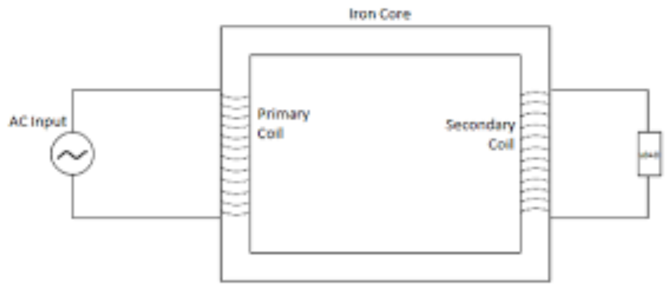
$$\frac{\Delta A}{\Delta t} = Lv$$

Therefore, E = BLx

TRANSFORMERS

The transformer uses the principle of mutual induction to produce a large alternating emf from a small one or vice versa.

Mutual induction is the process in which a change in current in one circuit produces a changing magnetic field and induces an emf in the 2nd circuit, not connected to the 1st.



Schematic Diagram of Simple Transformer

$$\frac{Vs}{Vp} = \frac{Ip}{Is}$$

$$\frac{Ns}{Np} = \frac{Vs}{Vp} = \frac{Ip}{Is}$$

For the step up transformer: Ns > Np, Vs > Vp, Is< Ip

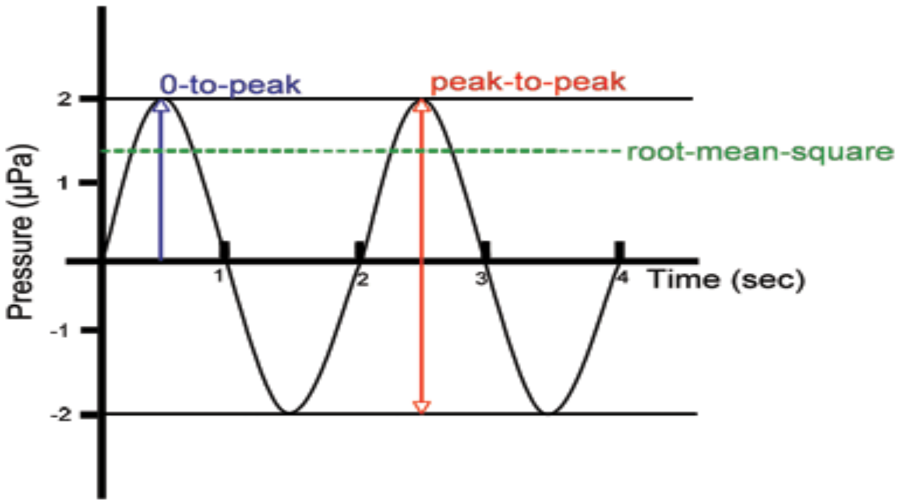
For the step down transformer: Ns < Np, Vs < Vp, Is > Ip

POWER LOSES IN A TRANSFORMER

POWER LOSS	DESIGN FEATURE TO REDUCEPOWER LOSS
Power dissipated in the circuit resistant in primary secondary coils. Power Loss $P = I^2R$ I – current in coil R – resistance of coil	The coil which carries the larger current is round with thicker core and reduce the resistance of the coil therefore power loss reduced = P =
The coil is magnetically linked with the primary coil and therefore a current is induced in the core called an eddy current. This cause heat to be lost.	The core is laminated, and each section is separated by a thin layer of insulation. This increases the resistance of the core and significantly reduces the eddy current.
Power, $P = I^2R$	

MODULE 2: AC Theory and Electronics

Alternating Currents



General equation for AC
$x = x_0 \sin \omega t$

Frequency = one of cycles in one second = $\frac{1}{T}$ [Hz]

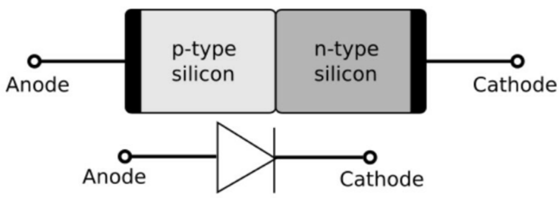
$V_{rms} = \frac{V_0}{\sqrt{2}}$ [root mean square Voltage]

$P_{rms} = I_{rms} . V_{rms}$

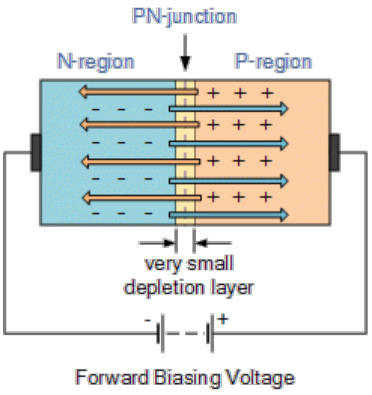
$I_{rms} = \frac{I_0}{\sqrt{2}}$ [root mean square Current]

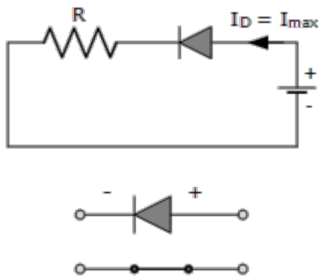
NB: The r.m.s. value of an ac current is equivalent to that value of a dc current which would dissipate power at the same rate in a given resistor.

p-n Junction Diode

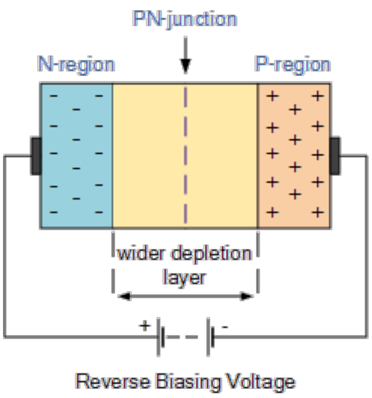


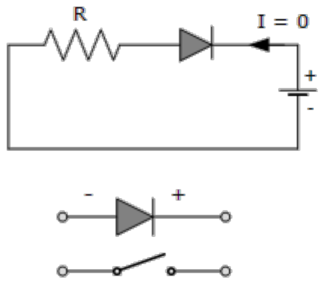
A p−n junction. The circuit symbol is shown: the triangle corresponds to the p side.





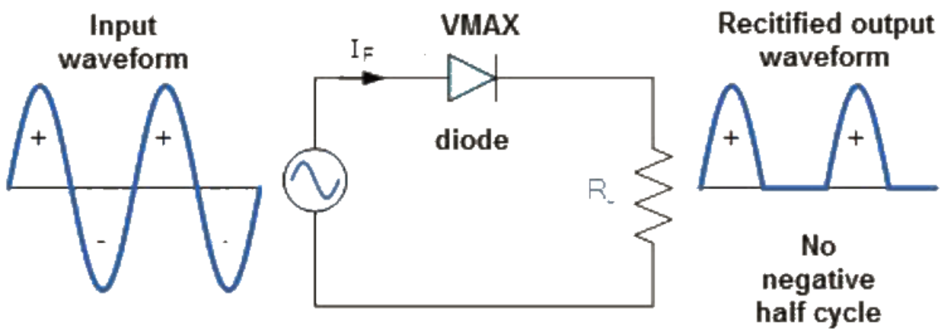
Why



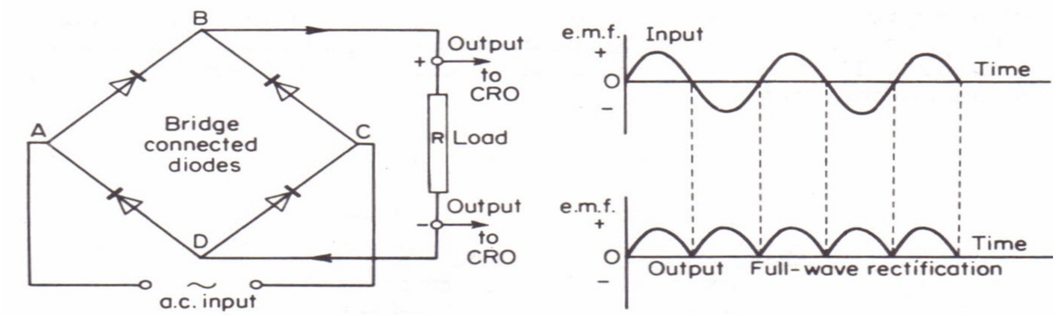


Why ?

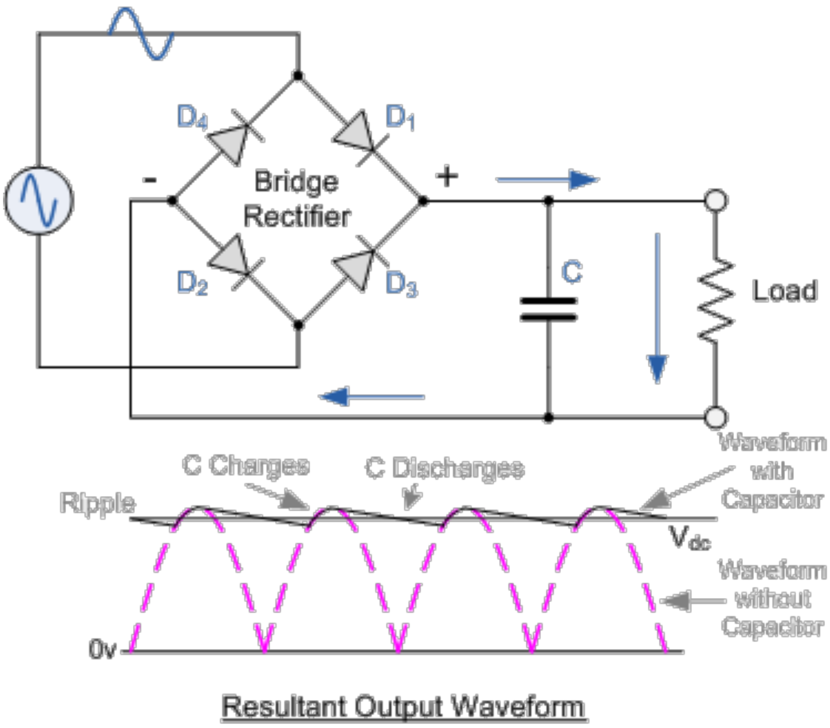
Half wave rectification



Full wave rectification



Smoothening



Transducers

Transducers are devices that transform energy from one form to another.

Input transducers - most input transducers (sensors) vary their **resistance** and this can be used directly in some circuits but it is usually converted to an electrical signal in the form of a voltage. Examples of input transducers are:

Photocells microphones thermistors LDR Thermocouple

Output transducers - Convert an electrical signal to another quantity. Examples of output transducers are:

Speakers motors lights

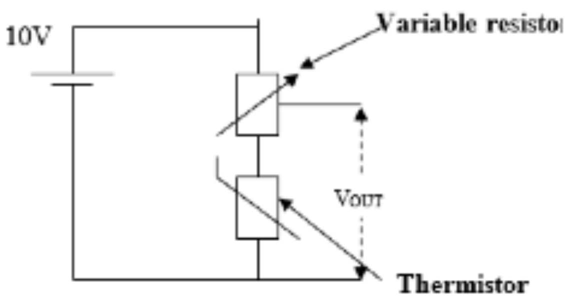
Certain transducers change their **resistance** as a result of an **environmental factor** such as temperature, moisture, light intensity etc. These devices can be used as part of a **voltage divider** circuit to **switch on** an electric circuit.

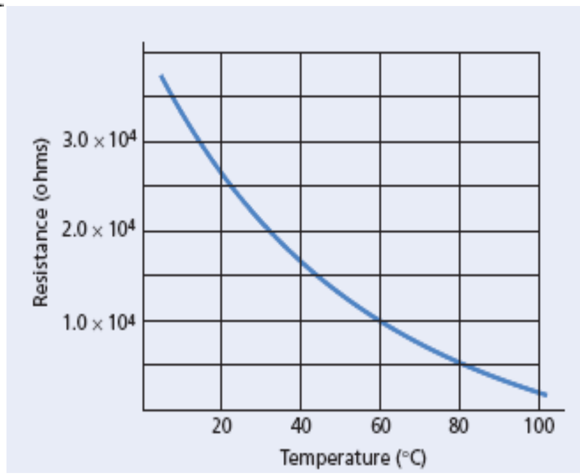
Thermistor

A thermistor is a device that changes its resistance according to the temperature of the surroundings. A thermistor ((TDR – temperature dependant resistor) can be used to turn on and off the cooling unit in a fridge or a central heating unit within a house.

Example.1

A thermistor has the temperature-resistance characteristic shown in the below curve. It is placed in a circuit containing a voltage divider.

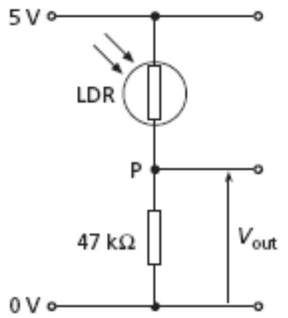


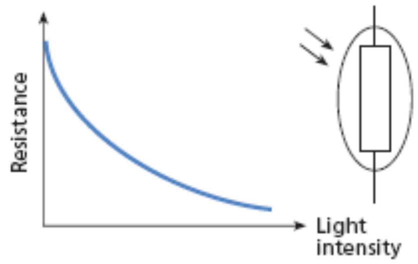


LDR

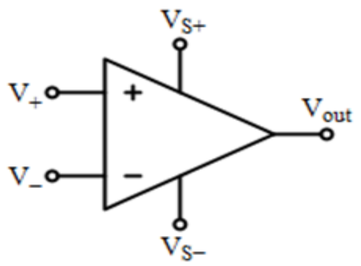
A light-dependent resistor (LDR) is a semiconductor device that has a resistance which decreases with the amount of light falling on it. Light-dependent resistors can be used to turn on street lights when the ambient lighting drops at sunset. They can also be used a part of a light meter circuit.

A light dependant resistor (LDR) can also be used in place of a TDR as a component within a voltage divider circuit.





Operational Amplifiers



- V_+ : non-inverting input
- V_- : inverting input
- V_{out} : output
- V_{S+} : positive power supply
- V_{S-} : negative power supply

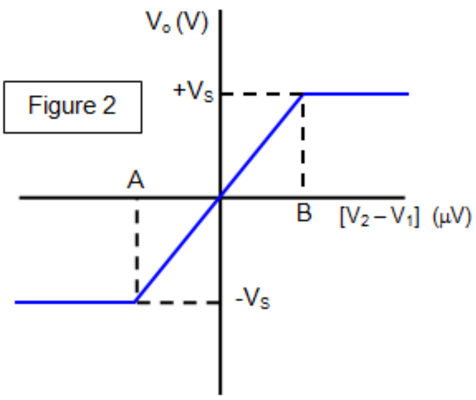
Properties of an ideal op amp

- An infinite open loop gain
- An infinite input impedance
- Zero output impedance

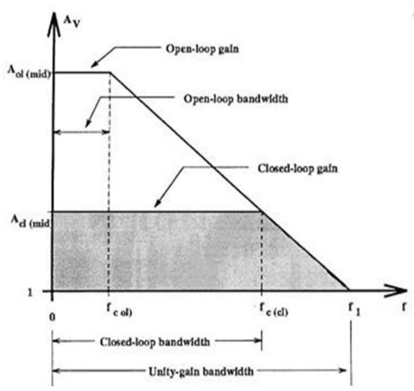
Rules that apply to Op amps:

- Gain, A = $\frac{V_{out}}{V_{in}}$
- $-V_s \leq V_{out} \leq V_s$, else Op amp is said to be saturated.
- To avoid saturation: $V_{in} = \frac{\pm V_s}{A}$

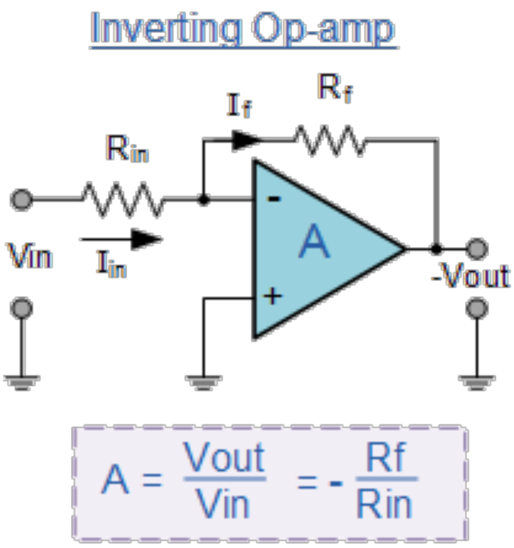
Figure 2

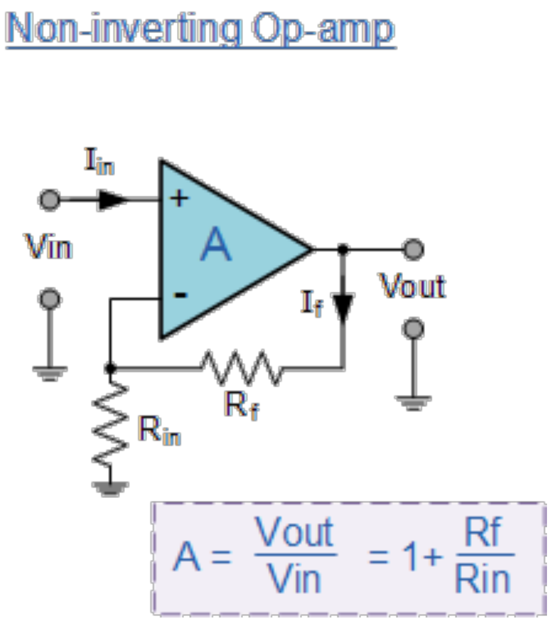


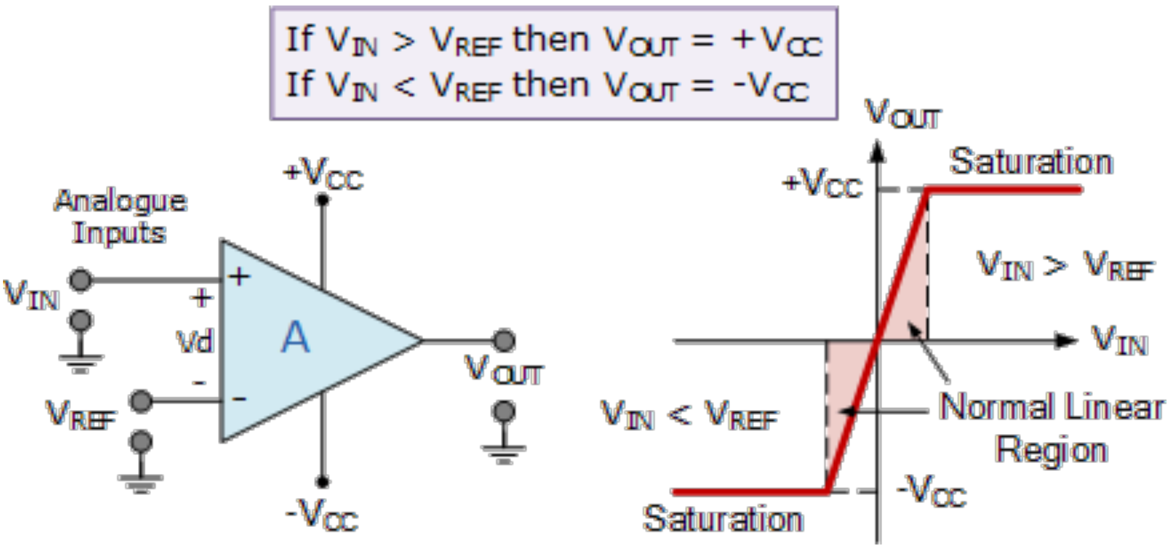
Gain versus Bandwidth
Applying feedback will reduce the gain but increase the bandwidth.



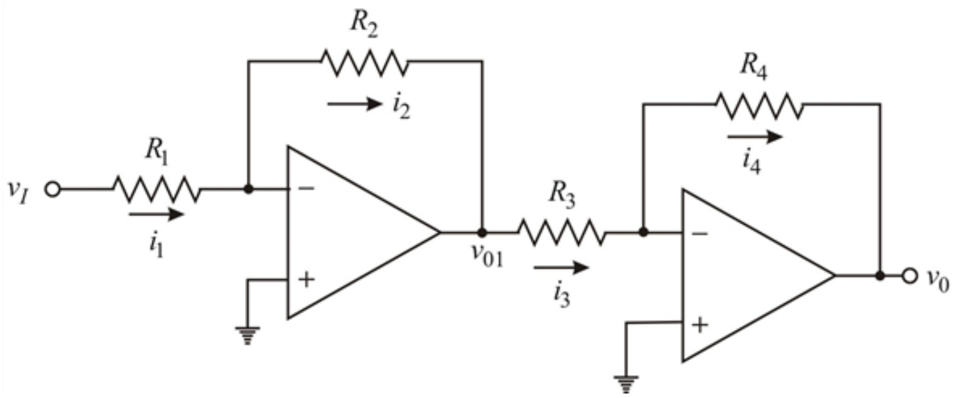
Types of Op amps





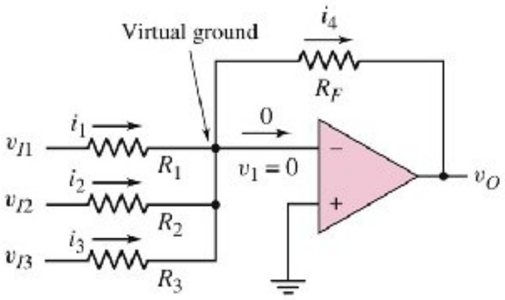


Cascaded Op amps:



GAIN = product

Summing Amplifiers



Similarly,

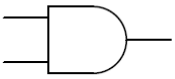
Using KCL at the input node

$$i_1 + i_2 + i_3 - i_4 - 0 = 0$$

Output voltage

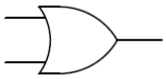
$$V_0 = -R_F\left(\frac{V_{i1}}{R_1} + \frac{V_{i2}}{R_2} + \frac{V_{i3}}{R_3}\right)$$

Logic Gates



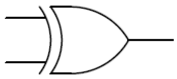
AND

A	B	Output
0	0	0
0	1	0
1	0	0
1	1	1



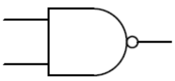
OR

A	B	Output
0	0	0
0	1	1
1	0	1
1	1	1



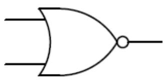
XOR

A	B	Output
0	0	0
0	1	1
1	0	1
1	1	0



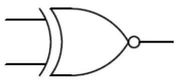
NAND

A	B	Output
0	0	1
0	1	1
1	0	1
1	1	0



NOR

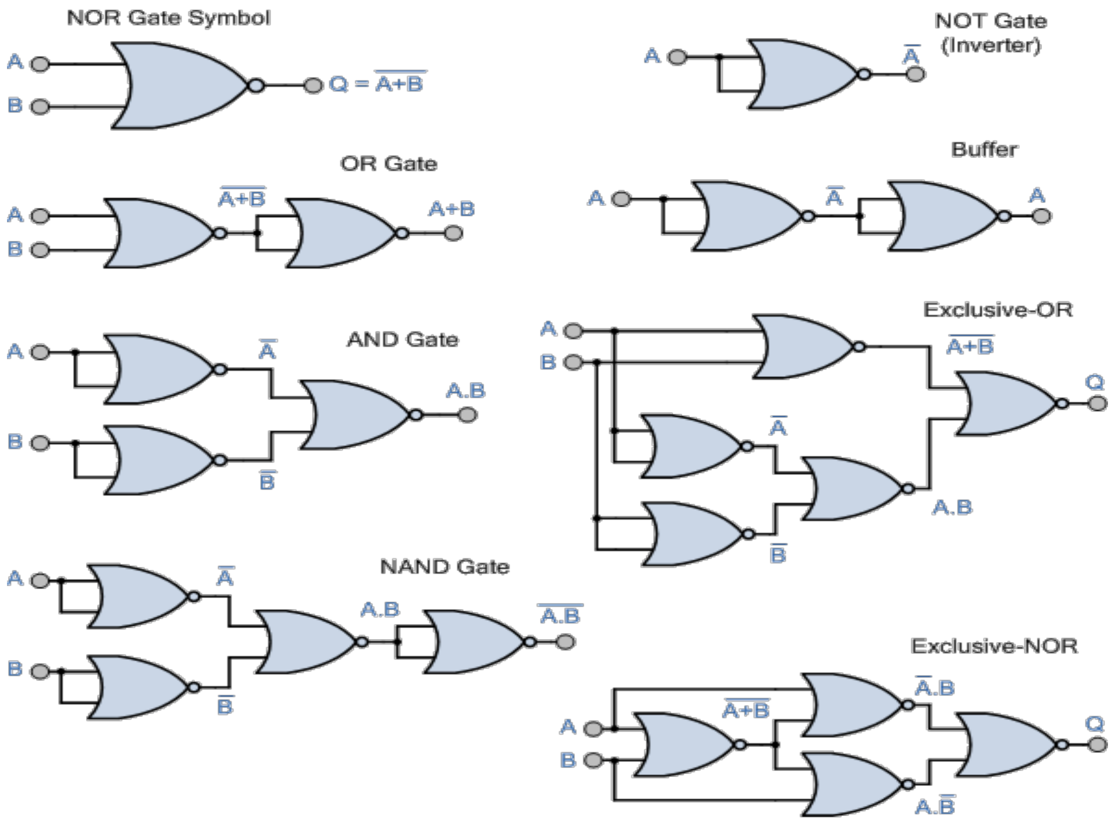
A	B	Output
0	0	1
0	1	0
1	0	0
1	1	0



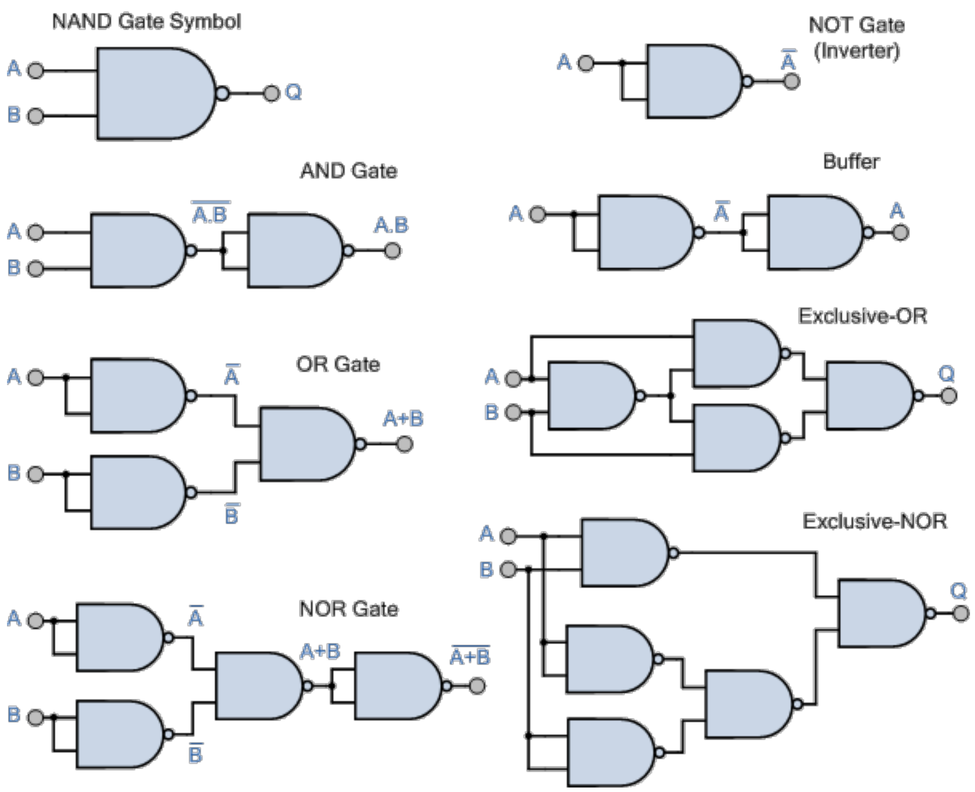
XNOR

A	B	Output
0	0	1
0	1	0
1	0	0
1	1	1

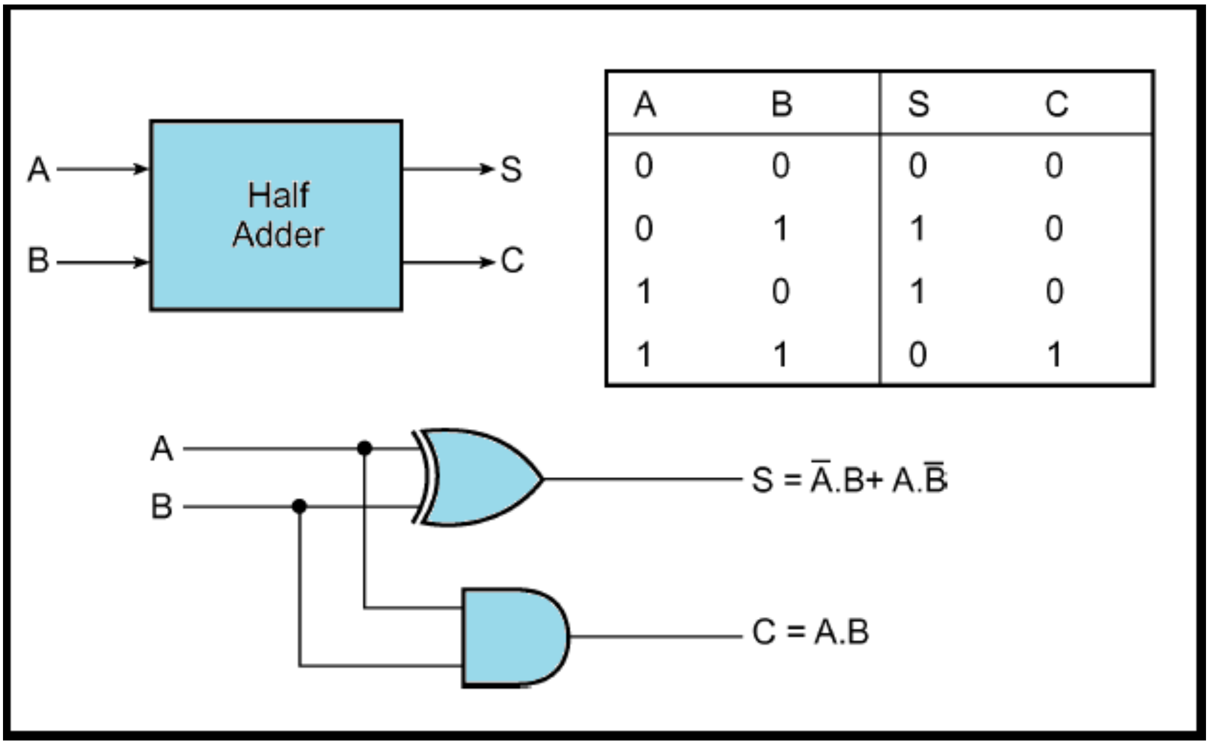
NOR's only



NANDs only

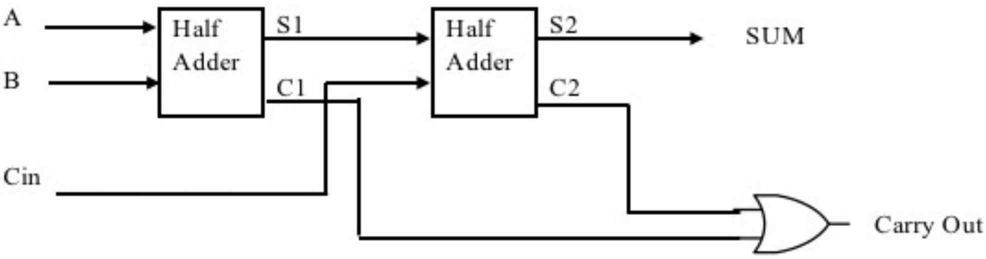


Half adders



A	B	S	C
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

Full Adder



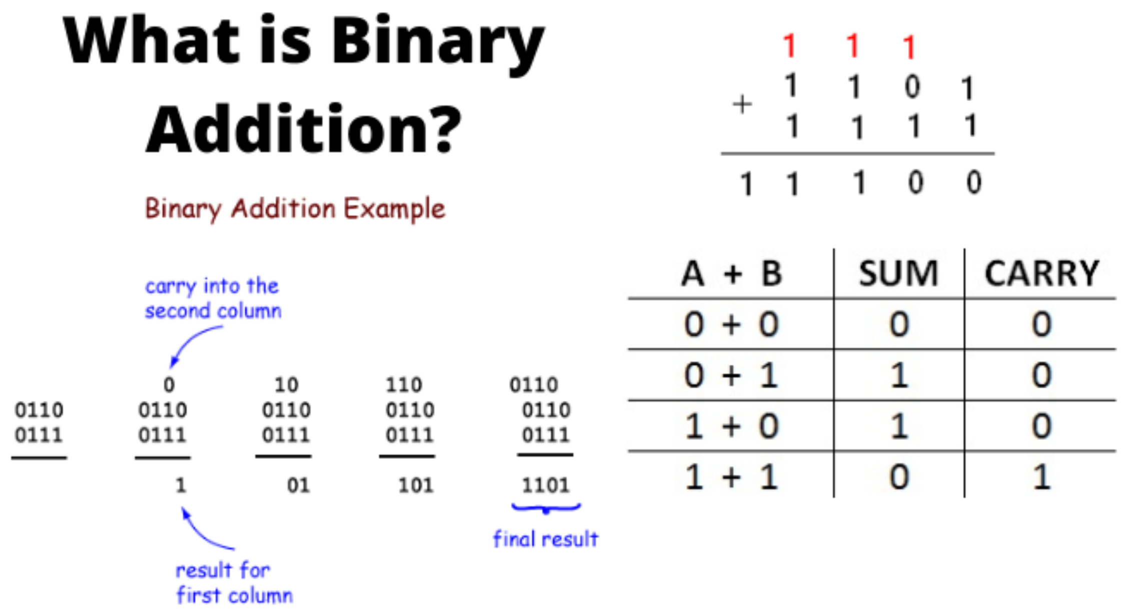
For this circuit

A	B	Cin	S1	C1	S2	C2	SUM	Carry Out
0	0	0						
0	0	1						
0	1	0						
0	1	1						
1	0	0						
1	0	1						
1	1	0						
1	1	1						

For a full adder

A	B	Cin	SUM	Carry Out
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

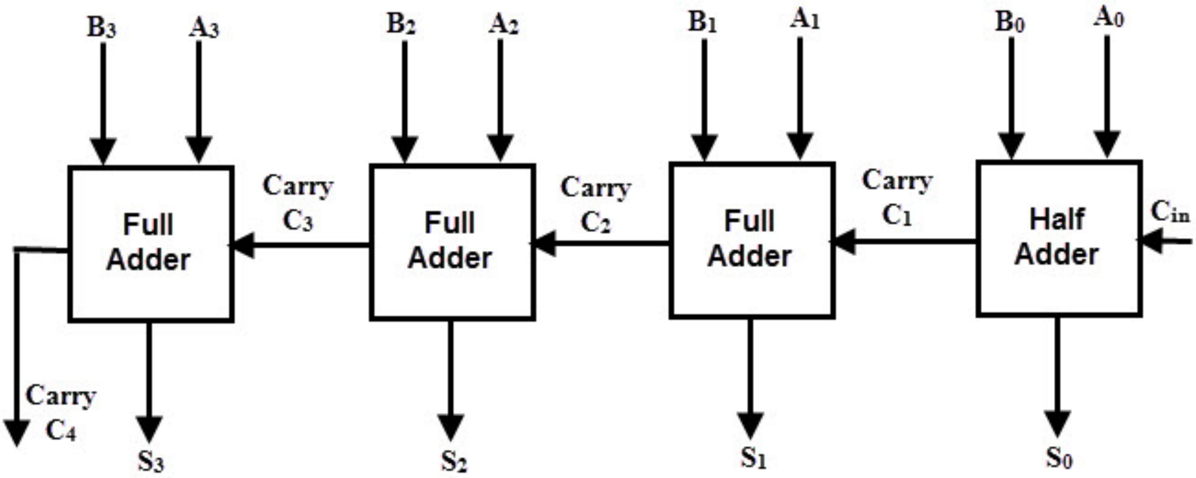
Binary addition



Adder Chip

An adder chip for above binary addition would comprise of :

- 1 half adder
- 3 Full adders



Flip flops

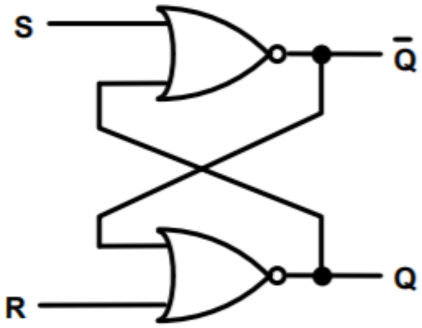


Figure 4.1 SR NOR Latch

S	R	Q	$\bar{Q}$
0	0	Q	$\bar{Q}$
0	1	0	1
1	0	1	0
1	1	0	0

Table 4.1 SR NOR Latch Truth Table

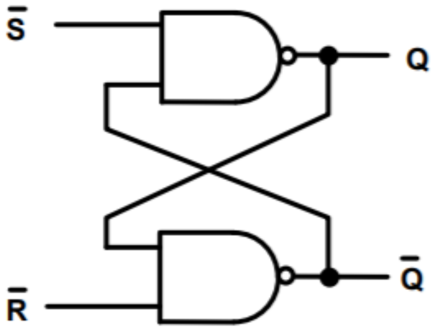
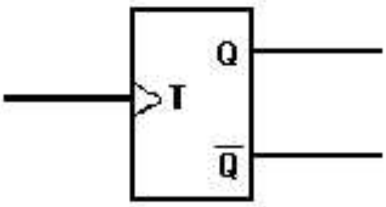


Figure 4.2 SR NAND Latch

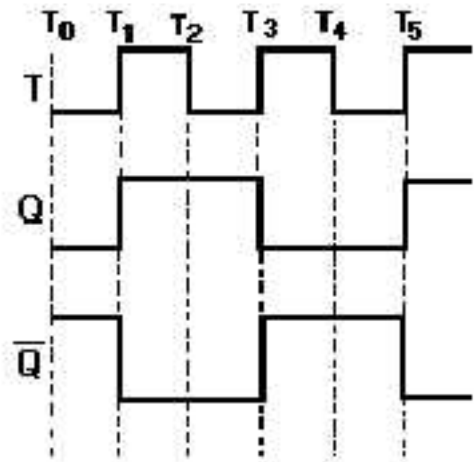
$\bar{S}$	$\bar{R}$	Q	$\bar{Q}$
1	1	Q	$\bar{Q}$
0	1	1	0
1	0	0	1
0	0	1	1

Table 4.2 SR NAND Latch Truth Table

T-Type



A

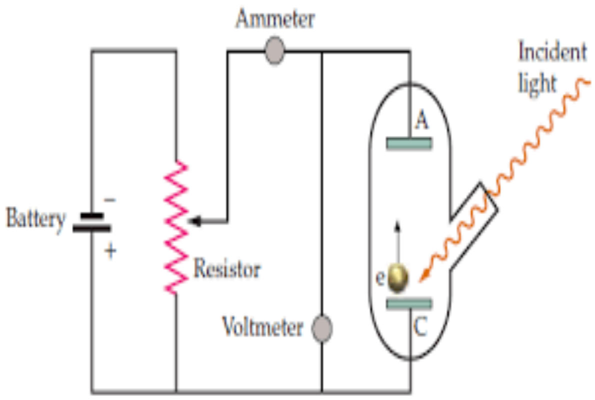


B

MODULE 3: Atomic and Nuclear Physics

The Photoelectric Effect

Heisuch Hertz, in 1887, was the first to observe the photoelectric effect during experiments with a spark-gap generator (an early form of a radio receiver). The photoelectric effect was viewed as the process at which light can be used to push electrons, freeing them from the surface of the solid. The ejected electros were called photoelectrons.

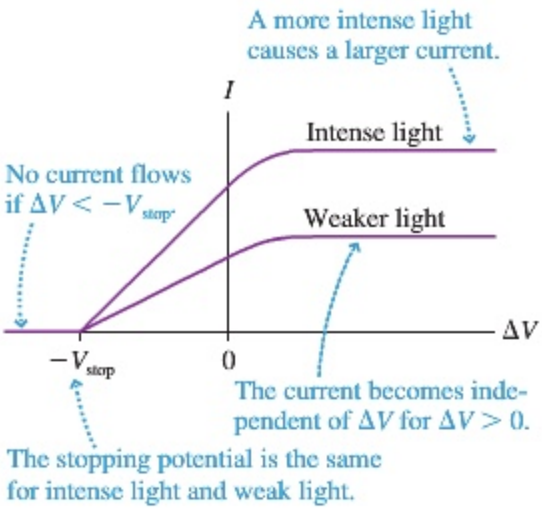


An assistant of the Hertz performed the definitive study on the photoelectric effect. He used metal surfaces that were first cleaned and then held under a vacuum, housed in an evacuated glass tube with a second metal plate mounted at the opposite end. This tube is called a photo cell.

The photo cell was then connected to the circuit shown above and then illuminated with light of different frequencies and intensities (colour). Electrons were knocked out of the metal and these photoelectrons moved freely through the vacuum, to the second plate, before returning to the original plate.

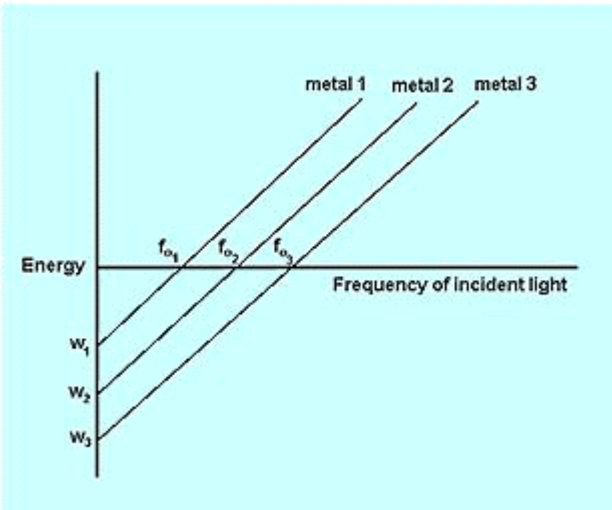
The microammeter measured the small **photocurrent** generated. This value represented the rate at which photoelectrons were leaving the surface of the photoemissive material.

There is a potential difference that is set up between the second plate and the negative terminal of the power supply, causing the photo electrons to be pushed back to the photoemissive material. By increasing the potential difference, the more energetic electrons are further pushed back and this results in a decrease of the photocurrent reading in the microammeter. A further increase in the potential gives a microammeter reading of zero, which indicates that no electrons are being emitted from the material. This potential is known as the **stopping potential**, $\mathbf{V_s}$



This potential is the measure of the maximum kinetic energy, K_{max}, of the emitted electrons.
W = QV
$K_{max} = eV_s$
$V_s = \frac{K_{max}}{e}$
Lenard also found hat the intensity of the incident light had no effect on the maximum kinetic energy of the photoelectrons, but more photoelectrons were emitted (note: photocurrent vs voltage graph)
Robert Millikan, later discovered that the frequency of light had a direct effect on the maximum kinetic energy of the photoelectrons and that frequencies below a particular cut off value, called the **Threshold Frequency** would not eject any photoelectrons.

The following graph highlights some of Millikan's observations.



NB: For all photoemissive materials, their slope is the same and it is equal to Plank's constant (6.33×10^{-34} Js).

It was also discovered that the photoelectrons were instantaneously ejected from the surface of the photoemissive material, regardless of the intensity of the incident light.

These observations troubled the physics world at that time and this period was called the **Classical Physics Era.**

Modem Physics Era

These problems brought about what we know today as modem physics and who else but Albert Einstein was the physicist responsible for shepherding the new era.

In 1905, he realized that light was not behaving as waves but as tiny particles which he later called photons. Einstein developed on the work of max Plank and suggested that the energy of each photon was proportional to the frequency of the incident radiation, i.e. E = hf (E = energy of photon, h = Plank, f = frequency).

Classical (wave)

1. $\uparrow I \neq \uparrow E_k$
2. $\uparrow f = \uparrow E_k$
3. e^- left instantly
4. $\uparrow I = \uparrow$ no. of photoelectrons

Modern

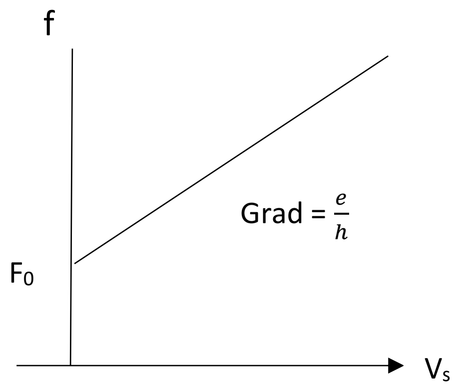
1. Photons make up waves
   E = hf
   (light = particle and wave)

Einstein summarized the entire process by the following formula:

$E_{k\,max} = h\,(f - f_0)$
$E_{k\,max} = hf - hf_0$
$E_{k\,max} = E - hf_0$
$E = E_{k\,max} + hf_0$
$E = \phi + E_{k\,max}$

In the above equation, E represents the energy of the incident photons which is the energy required for the electrons to be free from their bonds and $E_{k\,max}$ represents the maximum kinetic energy of the leaving photoelectron

NB: E = hf
$\phi = hf_0$
$E_{k\,max} = eV_s$



$E = \phi + E_{k\,max}$

$\div hf = hf_0 + eV_s$

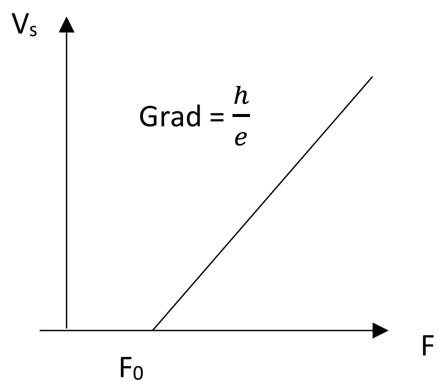
$f = f_0 + \frac{e}{h} V_s$

$f = \frac{e}{h} V_s + f_0$

↓ ↓ ↓ ↓

Y = m x + c

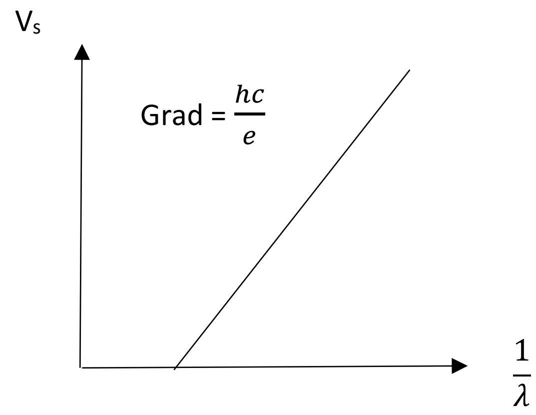
Also we can have:



$eV_s = hf - hf_0$

$V_s = \frac{h}{e} f - \frac{h}{e} f_0$

Y = mx + c



(for light) c = fλ

$f = \frac{c}{\lambda}$

$V_s = \frac{h}{e} f - \frac{h}{e} f_0$

$V_s = \frac{hc}{e} (\frac{1}{\lambda}) - \frac{hc}{e\lambda_0}$

Wave Particle Duality

To explain some aspects of light behavior such as diffraction and interference, light is described as having wave properties, but for aspects such as the photoelectric effect, we describe light as having particle properties. Therefore, light exhibits wave – particle duality. (both wave and particle properties).

Wav- particle duality is not confined to light only, every object exhibits wave- particle duality (all objects from electrons to footballs). The behavior of relatively large objects is dominated by particle behavior although they exhibit wave properties.

De Broglie's

In 1923, Lewis De Broglie predicted that since light exhibited both wave and particle behavior, particles should also have both wave and particle behavior.

He proposed that all particles have a wavelength given by $\lambda = \frac{h}{p}$

$E = mc^2$…….1

E = hf……….2

$mc^2 = hf$

$mc^2 = h (\frac{c}{\lambda})$

$mc = \frac{h}{\lambda}$

since mc = momentum

$\rho = \frac{h}{\lambda}$

$\lambda = \frac{h}{\rho}$

His predictions was shown to be true when beams of electrons and neutrons were directed at crystals an diffraction patterns were obtained. This is evidence of wav properties of these particles. Everything has wavelength, but the wave properties of matter are only observable for very small objects.

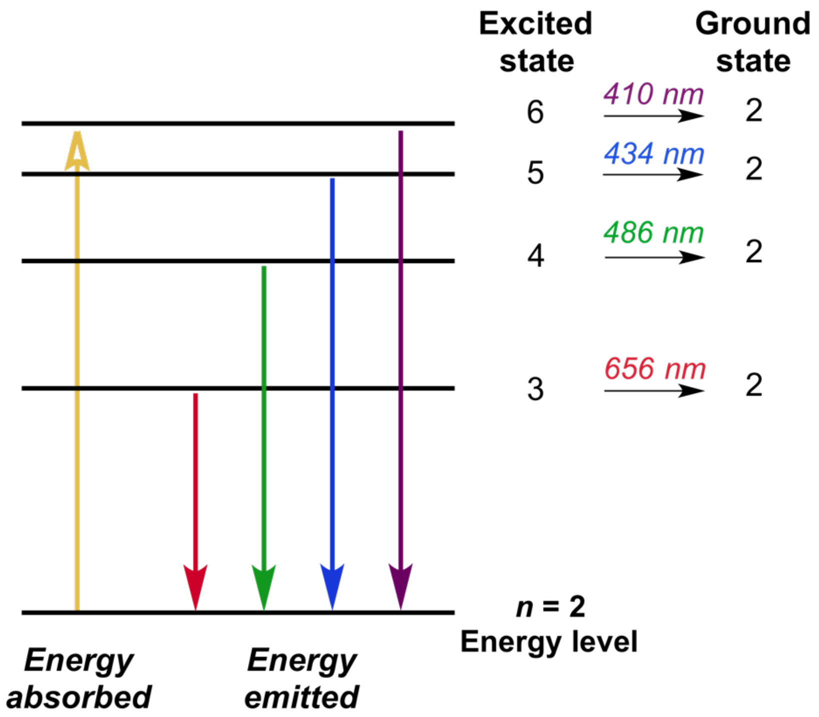
If we work the wavelength of a moving football, we would observe that its wavelength is far too small to be observed.

Line Spectra

The line spectrum (of Hydrogen) provides evidence for the particle nature of EMR. The line spectrum represents an emission spectrum or an absorption spectrum consisting of separate, isolated lines. Each line represents a discrete energy or frequency.

Specific wavelengths of light are absorbed or emitted from hydrogen. This implies that there are discrete energy levels that the electrons are moving between. The energy of light of the transition corresponds to the difference in energy between two of these levels.

The hydrogen absorption spectrum and emission spectrum may look as follows:



Emission lines refer to the fact that glowing hot gas emits lines of light, whereas absorption lines refer to the tendency of cool atmospheric gas to absorb the same lines of light.

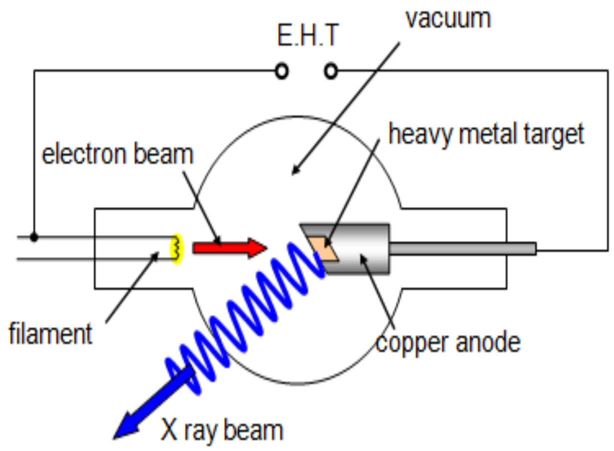
NB: *When light passes through gas in atmosphere, some of the light at particular wavelengths is scattered, resulting in darker bands.*

X-Rays
Production of X-Rays

A modern form of an x- ray tube is shown below. A focused beam of electrons is accelerated towards the target during the half cycles that is positive with respect to the filament.

On collision, the electrons decelerate rapidly, and x-rays are produced.
Over 99% of the kinetic energy of the electrons goes into producing heat.

The **target is a high melting point metal** such as Tungsten or molybdenum, embedded in a **copper rod**, the purpose of which is to conduct heat away from the target. The rod is cooled by **circulating oil** through it or by the use of **cooling fans.**



The intensity of an x- ray beam increases with the **number of electrons** hitting the target and therefore with **filament current.** It is also increased by **increasing the p.d** across the tube because it **increases the energy** with which the electrons hit the target and so makes more energy available for x- ray production. The penetrating power or quality of x -ray **increases with the p.d** across the tube. X- rays with low penetrating power are called hard x- rays.

Question
Calculate the wavelength of the most energetic x- rays produced by a tube operating at 1×10^5 V.
NB: The most energetic x- rays are those produced by electrons which lose all their kinetic energy on impact.

Step 1: Calculate the $E_{k\,max}$ on impact

$$W = QV$$
$$E_{k\,max} = eV$$
$$= (1.6 \times 10^{-19})(1 \times 10^{5})$$
$$= 1.6 \times 10^{-14} \text{ J}$$

*The energy of the most energetic x- rays is 1.6×10^{-14} J
Therefore maximum E_k lost = 1.6×10^{-14} J

Step 2: Use E = $\frac{hc}{\lambda}$ to calculate λ

$$E = \frac{hc}{\lambda}$$

$$1.6 \times 10^{-14} = \frac{(6.6 \times 10^{-34})(3 \times 10^{8})}{\lambda}$$

$$\lambda = 1.24 \times 10^{-11} \text{ m}$$

Properties of X-rays

- They travel in straight lines at a velocity of light
- They cannot be deflected by electric or magnetic fields
- They penetrate matter and is least with materials of high density
- They can be reflected and diffracted
- They cannot be focused on lens

The following properties are **used to detect x- rays:**

- They ionize gases through which they pass
- They affect photographic film
- They can produce fluorescence
- They can produce photoelectric emissions

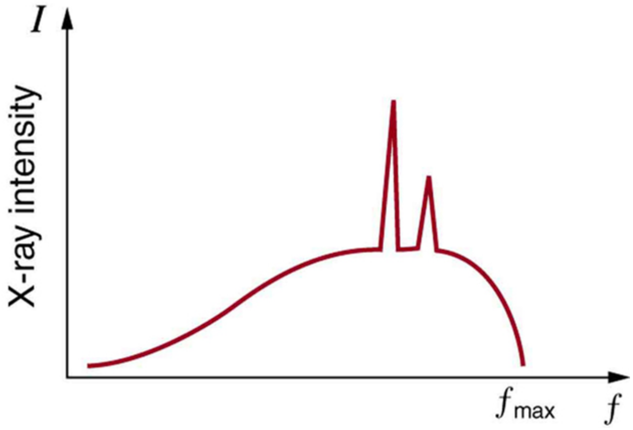
Uses of X- rays

- They are used in medicine to locate bone fractures or destroy cancer cells.
- They are used to locate internal imperfections in welded joints and castings.

X- rays Emission Spectrum

A typical x- ray spectrum has two distinct components:

1. A **background of continuous radiation,** the minimum wavelength of which depends on the operating voltage of the tube that is on the energy of a bombarding electrons
2. **Very intense emissions** at a few discrete wavelengths. These wavelengths are characteristic of the target material and are dependent on the operating voltage.



The continuous background is produced by electrons colliding with the target and being decelerated. The energy of the emitted x- ray quantum is equal to the energy lost in the deceleration. An electron may lose any fraction of its energy in this process. **The most energetic x- rays (those whose wavelengths is λ_{min}) are a result of bombarding electrons losing all their energy at once.**

Since the energy of the electrons depends on the operating voltage, so too does $\lambda_{min.}$
λ_{min} is inversely proportional to the voltage of the operating supply.
X- rays with longer wavelengths are the results of electrons losing less than their total energy.

The line spectrum is the result of **electron transitions** within the atoms of the target material. The electrons which bombard the target are **very energetic** and are capable of knocking electrons out of **deep- lying energy levels** of the target atoms. N outer electron may then fall in the **vacancy created** in its atom and I doing so, causes a **high energy quantum** of EMR i.e. an x-ray to be emitted.

The frequency of the x- ray is given by E = hf where E is the **difference in energy of the levels involved.** Since the energy level are characteristic of the target atoms, so to are the x-rays produced in this way.

The essential difference between transitions which gives rise to x- rays and those which give rise to **visible light** is that the x- ray transitions involves **deep- lying energy levels** while **optical transitions** do not.

X- ray Absorption

A monochromatic beam of x- rays of intensity I_0 is incident on a thickness, x of some absorber. The intensity, I of the emergent beam is given by $I = I_0 e^{-\mu x}$ where μ is a constant for a given material and wavelength.

Radioactivity

Radioactivity is the spontaneous decay of a radioactive element.

Three types of radioactive emissions are:

- Alpha
- Beta
- Gamma

An alpha particle is a helium atom ${}^{4}_{2}He$ with a charge of +2
Beta is a fast- moving electron, ${}^{0}_{-1}e$
Gamma is a ray of energy

Equation of a Radioactive Decay

If an element undergoes alpha decay:
${}^{a}_{b}X \rightarrow {}^{a-4}_{b-2}Y$ + ${}^{4}_{2}He$
If an element undergoes beta decay:
${}^{a}_{b}X \rightarrow {}_{b+1}{}^{a}Y$ + ${}^{0}_{-1}e$

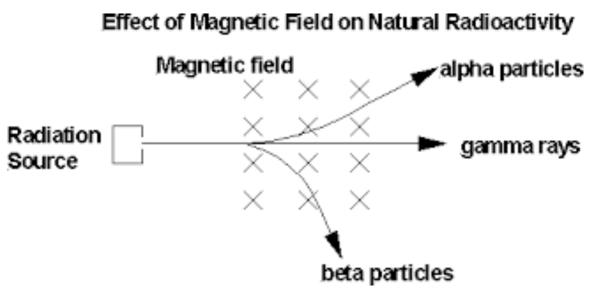
If it undergoes gamma decay:
${}^{a}_{b}X \rightarrow {}^{a}_{b}X^{*}$ + Gamma ray
$\downarrow$
(loss energy)

Example:
Write the equation for the following reaction:
- a uranium atom loses 2 alphas and 3 beta

${}^{235}_{92}U \rightarrow {}^{227}_{91}X$ + 2 ${}^{4}_{2}He$ + 3 ${}_{-1}^{0}e$

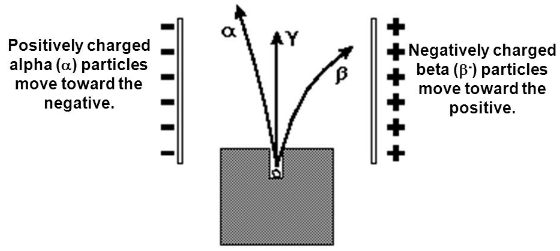
Properties of α β and γ

Magnetic field



NB: Fleming's Left Hand rule is used to explain the direction of the force exerted on alpha and beta particles. Also, that the direction of current is that of a **positive charge.**

Electric Field

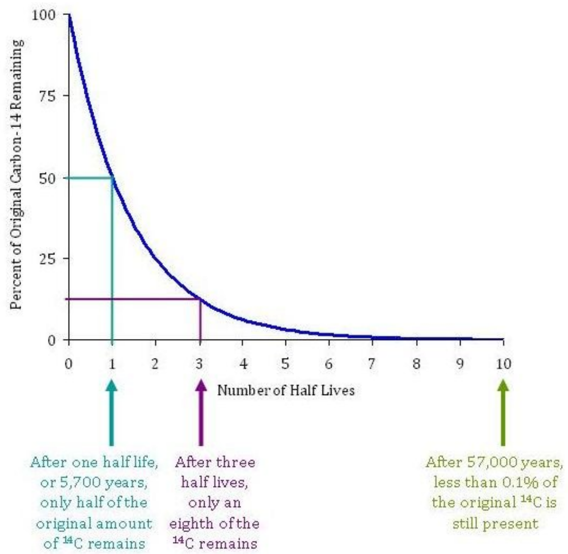


Uses Of Radioactive Elements /Isotopes
Radioactive elements are used in the following ways:

- Carbon -14 dating
- As a tracer to find cancer cells
- In the production of pacemakers
- In the treatment of cancer
- To determine cracks in steel structures

Decay Curve

Radioactive decay is the **disintegration** of an unstable radioactive element. It is a **spontaneous** process and cannot be sped up or slowed down.
The decay curve for a radioactive element has the following general shape:-



Radioactive decay follows an **exponential** function and is defined by the following relationship:
$\frac{dN}{dt} \propto -N$ where λ – decay constant; N – number of nuclei present
$\frac{dN}{dt} = -\lambda N$

The rate of change of nuclei is also called the activity of the element, A. the S.I unit is Bq which is the number of disintegrations per second.

$A = \frac{dN}{dt}$

$A = -\lambda N$

By using the equation (differential equation) $\frac{dN}{dt} = -\lambda N$, we can obtain an expression for N in terms of t.

$\frac{dN}{dt} = -\lambda N \quad \int \frac{1}{N} \, . \, dN = \int -\lambda \, dt$

$In\ N = -\lambda t + c$

$@t = 0, N = N_0$

$In\ N_0 = -\lambda (0) + c$

$C = In\ N_0$

Therefore $In\ N = -\lambda t + In\ N_0$

$In\ (\frac{N}{N_0}) = -\lambda t$

$\frac{N}{N_0} = e^{-\lambda t}$

$N = N_0 e^{-\lambda t}$

Since $A = -\lambda N \rightarrow A_0 = -\lambda N_0$

Therefore $A = A_0 e^{-\lambda t}$

Half- Life

The half-life of radioactive element is the time taken for half of the present nuclei to decay.

An expression for half- life can be obtained using $N = N_0 e^{-\lambda t}$ and when $t = T_{\frac{1}{2}}$, $N = \frac{N_0}{2}$.

$N = N_0 e^{-\lambda t}$

$\frac{N_0}{2} = N_0 e^{-\lambda t ½}$

~~$In\ N_0$~~ $- In\ 2 =$ ~~$In\ N_0$~~ $- \lambda t_{\frac{1}{2}}$ ~~$In\ e$~~

$- In\ 2 = -\lambda T_{\frac{1}{2}}$

$T_{\frac{1}{2}} = \frac{In 2}{\lambda}$

Experiment To Determine Half- Life

If the half- life of a substance is short enough for its activity to decrease by a measurable amount in a reasonable time, its half- life may be determined directly by monitoring its activity as a function of time. i.e. $A = A_0 e^{-\lambda t}$

If the half- life is extremely small, then the following method can be used:

- Determine the background count rate
- Open the clips and squeeze the bottle. This forces the radon to the cell
- Close the clips, whereby isolating the radon
- Immediately after closing the clips, start the scalar and the stopwatch.

- Count for 10 s and during the next 10 s interval, reset the counter and record the previous count
- Repeat step 5 and continue for 5 mins
- Use $R = R_0 e^{-\lambda t}$ where R is the count rate.