

NATURAL SCIENCE SOLUTION

Accelerating Academic Skills



Summary Notes (edexcel A2 Physics unit-4)

Topics:

1. Circular Motion
2. Momentum
3. Electricity
4. Capacitor
5. Magnetic Field
6. Particle Physics

“Knowing the path is good but not enough, walking the path with determination leads to destiny”

Uniform Circular Motion

Uniform Circular Motion:

A particle moves in a circular path at constant speed V .

- ✓ Speed V , of the particle remains the same, but due to change in direction velocity keeps changing (V_1 and V_2 are velocities). Fig (a).

Important Terms:

1. Angular Displacement:

It is the angle subtended at the centre in the given interval of time. The displacement is measured in radian (rad). Fig (b).

2. Arc length and angular displacement:

The arc length s in a circle of radius r can be found by using

$$s = r \theta \text{ (The angle } \theta \text{ must be in radian).}$$

One radian is the angle subtended at the centre of a circle by an arc whose length is equal to that of the radius of the circle. Fig (c).

For one complete cycle; $2\pi \text{ rad} = 360^\circ$ or $\pi \text{ rad} = 180^\circ$

It follows that, $1 \text{ radian} = \frac{180^\circ}{\pi}$

3. Angular velocity:

Rate of change of angular displacement. Or angular displacement per unit time.

$$\omega = \frac{\theta}{t}, \text{ it is measured in rad s}^{-1}$$

If particle completes one cycle then $t = T$ and $\theta = 2\pi$, the angular velocity can be found by,

$$\omega = \frac{2\pi}{T}$$

Note: $T = \frac{1}{f}$ where, f is the frequency. The angular velocity then can be written as;

$$\omega = 2\pi f$$

The angular velocity is also known as angular frequency.

4. Linear Speed/Tangential velocity, v

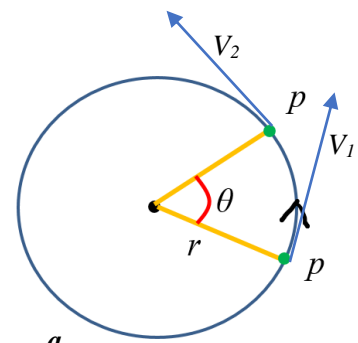
The velocity of a particle moving in circle is constantly changing because of the change in the direction.

The speed however, is constant and can be calculated. $V = \frac{s}{t}$

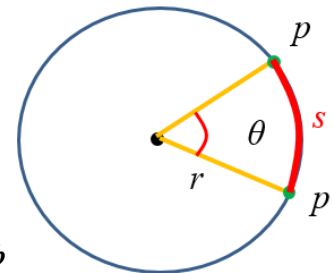
If we rearrange the top equation by replacing $s = r \theta$ and $\theta = \omega t$. We have an **important relation between the angular velocity and the linear velocity.**

$$V = r \omega$$

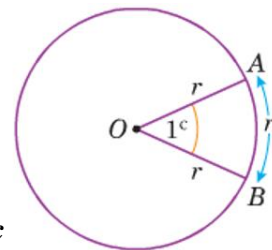
Note: particles moving along a same radial line have same angular but different instantaneous velocities



a



b



c

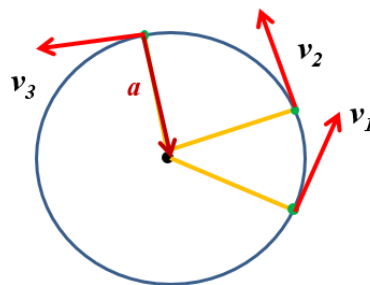
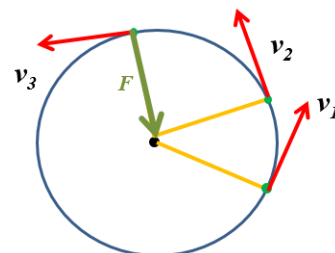
Centripetal Force:

The **direction** of velocity of a particle moving in circle is constantly changing. Fig (a). Which means **there must be some force** acting on the particle which is causing the change in the direction. This force is called **Centripetal Force**.

The centripetal force and is provided by a number of things:

- For a satellite orbiting the Earth it is provided by gravitational attraction.
- For a car driving around a roundabout it is provided by the friction between the wheels and the road.
- For a ball on a string being swung in a circle it is provided by the tension in the string.

- ✓ The **Centripetal Force** always acts **towards the centre** of the circular path.
- ✓ According to **Newton's second law** if there is a net force there must be acceleration...
- ✓ The acceleration due to velocity vector change is called centripetal acceleration a .
- ✓ The **Centripetal acceleration** also acts parallel to the force or **towards the centre** of the circular path.



The required centripetal force depends on three factors.

- Mass m of the moving object.
- Speed/velocity v of the moving object.
- Radius r of the circular path.

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

The centripetal acceleration is given by the equation. $a = \frac{v^2}{r}$

The centripetal force and acceleration in terms of angular velocity;

$$F = mr\omega^2 \quad \text{and} \quad a = r\omega^2$$

Special cases of centripetal force:

Remember, The centripetal force is the **resultant** of forces acting along the direction of central line (**towards the centre of the circular path**).

Case-1 (Conical pendulum):

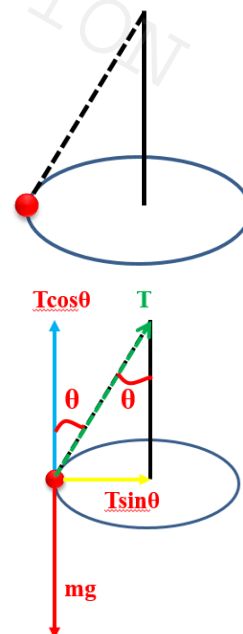
After resolving tension into its components.

Along the vertical direction; $T \cos \theta = mg$

Along the horizontal direction; $T \sin \theta = \frac{mv^2}{r}$

Combining the above two equations;

$$\tan \theta = \frac{v^2}{rg}$$



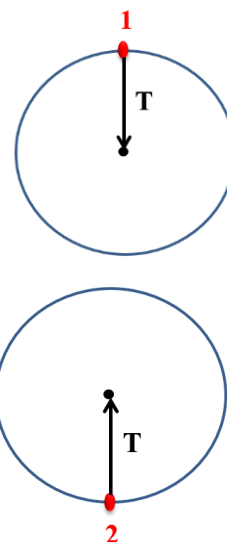
Case-2 (Pendulum in a vertical circle):

At position 1, tension in the string along with the weight (mg) provides the required centripetal force.

$$T + mg = \frac{mv^2}{r}$$

At position 2, the required centripetal force is the resultant of tension and the weight (mg).

$$T - mg = \frac{mv^2}{r}$$



Momentum in two dimension and Collisions

Momentum in two dimension:

Collisions in a straight line or in one dimension are rare.

Majority of collisions are two dimensional, i.e. either *before* or *after* the collision, the *particles move making some angles with the x-axis or with the y-axis.*

Important:

Velocities/momentums are *resolved into their components* to apply the *momentum conservation law.*

In the diagram there are components of velocities V_1 and V_2 after collision.

Applying law of conservation of momentum along x-axis (horizontally);

$$m_1 u_1 = m_1 V_1 \cos \theta_1 + m_2 V_2 \cos \theta_2$$

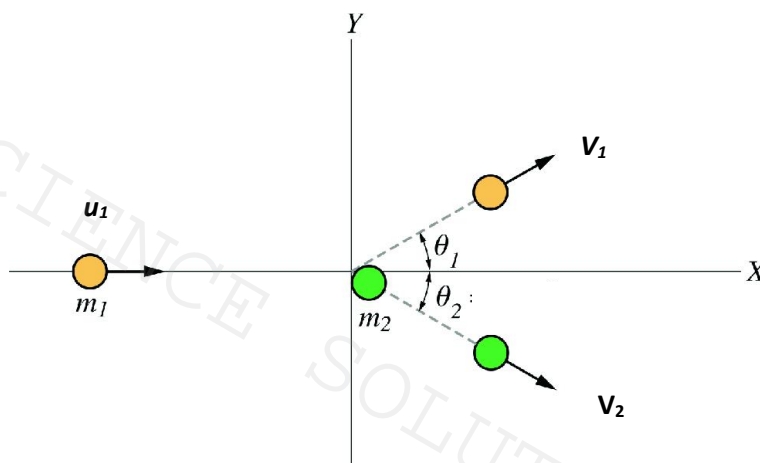
Applying law of conservation of momentum along y-axis (vertically);

$$0 = m_1 V_1 \sin \theta_1 - m_2 V_2 \sin \theta_2$$

Note:

There is only horizontal momentum before collision, no vertical momentum.

If a particle is initially making some angle before collision, then we will have initial horizontal and vertical momentums.



Types of collisions:

1. Elastic (Perfectly Elastic) collision:

- The collision in which *momentum is conserved*.
- The collision in which *total K.E is conserved*.
- They are *rare*.
- Collision caused by the *Non-Contact forces* are elastic.

2. Inelastic collision:

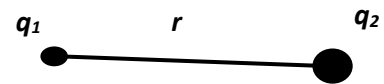
- The collision in which *momentum is conserved*.
- The collision in which *total K.E is not conserved*.
- The loss of K.E converts into *other forms of energy*.
- Collision caused by the *Contact forces* are elastic.

- ✓ *Momentum is always conserved in all collisions.*
- ✓ *Law of conservation of energy holds in inelastic collision. It is because decrease in K.E is equal to increase in heat and sound energy.*
- ✓ *Explosion is an example of inelastic collision. It is because K.E is increased.*

Coulomb's Law and Electric Fields

Coulomb's Law:

The *electrostatic force (Coulomb's force)* between two charges is *directly proportional* to the *product of magnitudes* of the charges and *inversely proportional* to the *square of the distance* between the charges.



$$F = \frac{Kq_1q_2}{r^2}$$

Where, **K** is called **Coulomb's constant** which depends upon *permittivity* of the medium between the two charges.

- *The capability of a medium to permit electric fields is called permittivity of the medium.*

If the medium between the two charges is **Free Space/Vacuum** then **K = 8.98 X10⁹ Nm⁻²c²**.

The value is found by the equation;

$$K = \frac{1}{4\pi\epsilon_0}$$

Where, ϵ_0 is the *permittivity of the free space/vacuum*. ($\epsilon_0 = 8.85 \times 10^{-12} \text{ m}^2\text{C}^2\text{N}^{-1}$).

The coulomb's law for free space/vacuum can also be written as;

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$$

✓ *The electrostatic force between two charges can be positive or negative.*

- * If the two charges are positive, $(+q_1)(+q_2) = +q_1q_2$ A positive force means the charges repel.
- * If the two charges are negative, $(-q_1)(-q_2) = +q_1q_2$ A positive force means the charges repel.
- * If one is negative and one is positive, $(-q_1)(+q_2) = -q_1q_2$ A negative force means the charges attract.

Electric field:

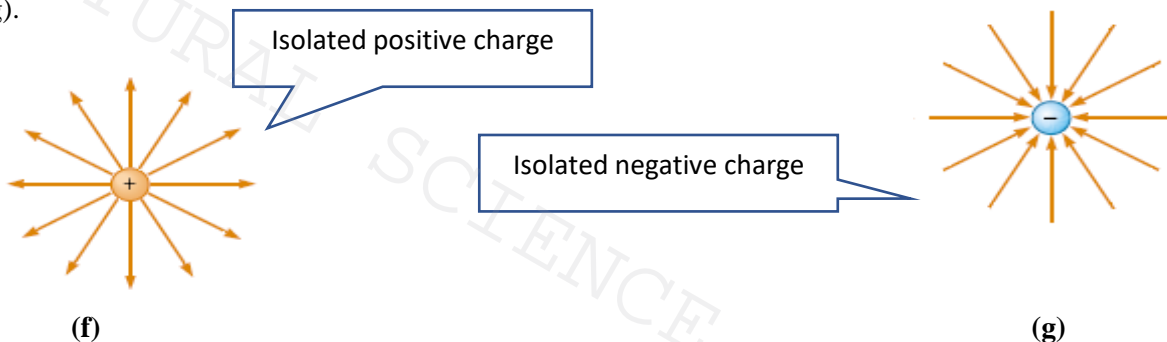
It is a *region around a charge* in which *another charge experiences an electric force*.

➤ *The electric field causes the charge to accelerate.*

Electric field Lines:

The electric field region is modelled as field lines or lines of force.

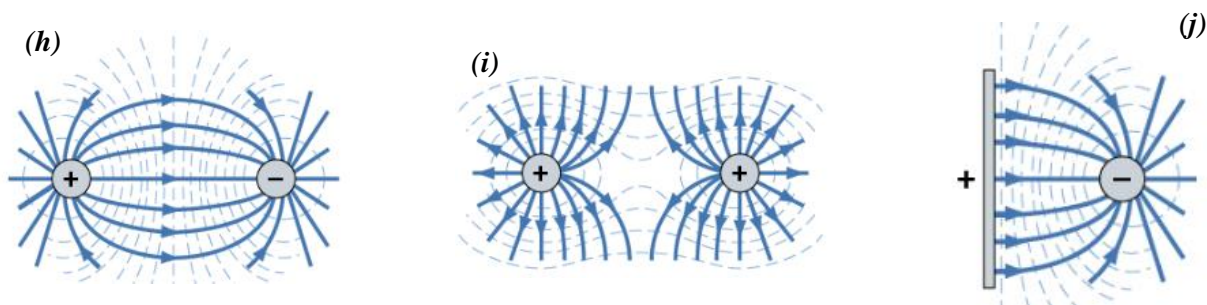
- ✓ For an isolated positive charge the field lines start at the charge and go out to infinity (Fig. f).
- ✓ For an isolated negative charge the field lines end at the centre of a mass and tail back from infinity (Fig. g).



- * *The electric field become more spread out the further from the charge, which means the field is getting weaker as you go further away from the charge.*
- * *The electric field lines are in fact path along which the second charge moves.*

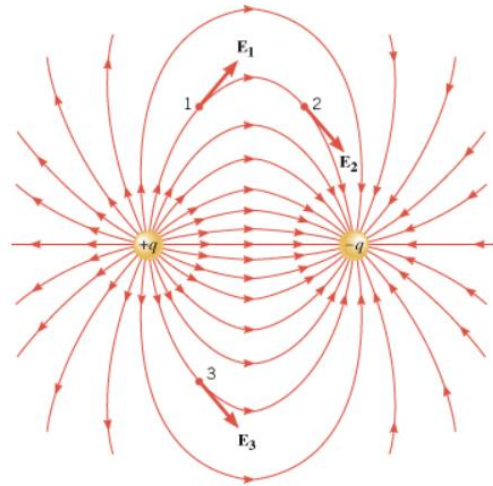
More configuration:

1. Electric field lines between a positive and a negative charge (Fig. h).
2. Electric field lines between two positive charges (Fig. i).
3. Electric field lines between a negative charge and a positive charged plate (Fig. j).



Electric field Lines:

- ✓ Field lines are directed away *from the positive electric charge and towards the negative electric charge.*
- ✓ Electric field lines are *continuous curves* in a charge-free region.
- ✓ Electric field is a *vector*.
- ✓ *Tangent* to any point of field lines give the *direction of the electric field* at that point (*note the directions at point 1, 2, and 3*).
- ✓ The field lines are *perpendicular to the surface* of the charge. That's why they are called *radial field*.
- ✓ Electric field lines *never cross each other*.



Electric field strength:

The electric field strength E at a point P due to a charge Q is the force experienced by per coulomb of charge (fig k).

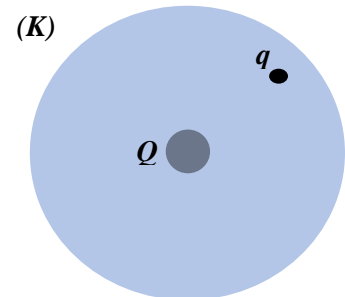
$$E = \frac{F}{q}$$

It is measured in NC^{-1}

Note: q is the charge moving/entering into the field of the charge Q .

If a be the acceleration of charge; $ma = Eq$

$$a = \frac{Eq}{m}$$



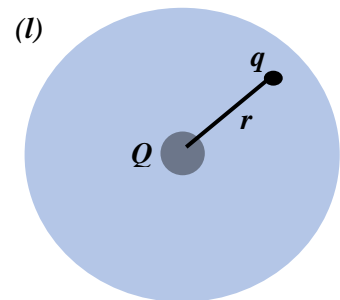
The electric field strength E at a distance r from a charge Q (Fig. l) can be found by using the formula.

$$E = \frac{KQ}{r^2}$$

Where, K is called **Coulomb's constant**. ($K = 8.98 \times 10^9 \text{ Nm}^{-2}\text{c}^2$)

Note: Q is the charge causing the electric field.

- ✓ All the electric fields so far we discussed (fig. f to l) are non-uniform electric field.



Electric Potential, V:

The work done per unit charge against the field to move a positive point charge from infinity to that point.



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

$$V = \frac{KQ}{r}$$

- ✓ The value will be positive when work is done against the field (when like charges are repelling).
- ✓ The value will be negative when work is done by the field (when opposite charges attract).
- ✓ In both cases the potential at infinity is zero. Electric potential is a scalar quantity.

Electric Potential is measured in Joules per Coulomb, $J C^{-1}$

Electric Potential Difference ΔV :

If a charge q moves in an electric field of charge Q ;

The electric potential difference is the work done/Energy per unit charge which can be written as;

$$\Delta V = \frac{W}{q}$$

The energy gained by the charge q is given by the equation;

$$E = q\Delta V$$

Uniform Fields:

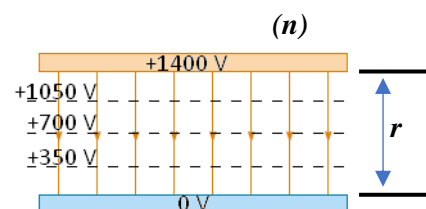
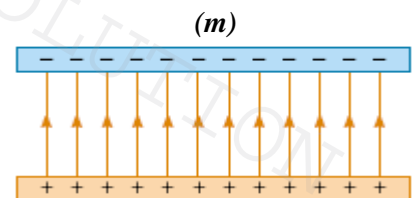
- The electric field between two charged metal/conducting plates is considered to be uniform (fig. *m*).
- The field lines are parallel in a uniform field.
- Between two such plates the field lines leave the positive plate and enter the negative plate.

Potential V between the two plates varies with the distance r (fig. *n*).

Electric field between the two charged metal/conducting plates is given by the equation;

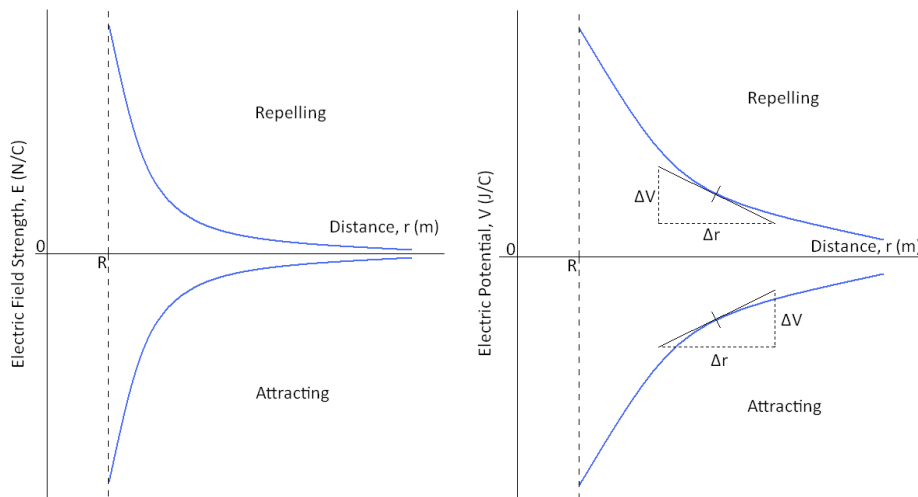
$$E = \frac{\Delta V}{\Delta r}$$

Electric Field Strength can be measured in Volts per metre, $V m^{-1}$



Important graphs:

The following graphs show how electric field strength **E** and electric potential **V** vary with distance **r** from the centre of a charged sphere. In both cases **R** is the radius of the sphere.



- The gradient of the electric potential graph gives the electric field strength at that point.

$$\text{gradient} = \frac{\Delta V}{\Delta r}$$

* *The gradient is the electric field strength **E** at that point.*

Electric and Gravitational Fields Comparison

	<i>Gravitational Field</i>	<i>Electric Field</i>
<i>Constant of proportionality</i>	G	$K = \frac{1}{4\pi\epsilon_0}$
<i>Equation for force</i>	$F = -\frac{Gm_1m_2}{r^2}$ newton (N) Vector	$F = \frac{1}{4\pi\epsilon_0} \frac{Q_1Q_2}{r^2}$ newton (N) Vector
<i>Nature of force</i>	Attractive only	Like charges repel Different charges attract
<i>Definition of field strength</i>	Force per unit mass	Force per unit charge
<i>Field strength in radial field</i>	$g = -\frac{GM}{r^2}$ newtons per kilogram (N/kg) Vector	$E = \frac{Q}{4\pi\epsilon_0 r^2}$ newtons per Coulomb (N/C) Vector
<i>Definition of potential</i>	The work done in bringing a unit mass from infinity to the point in the field	The work done in bringing a unit charge from infinity to the point in the field
<i>Potential</i>	$V = -\frac{GM}{r}$ Joules per kilogram (J/kg) Scalar	$V = \frac{Q}{4\pi\epsilon_0 r}$ Joules per Coulomb (J/C) Scalar

Capacitors

Capacitors

A capacitor is an electronic component that can store electrical charge so the electrical energy, and then release it.



The charge that is stored by the capacitor is due to the potential difference across the plates.

$$Q \propto V$$

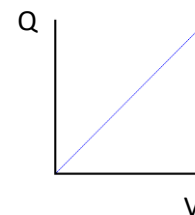
The charge than can be found by using;

$$Q = CV$$

Where the C is capacitance of the capacitor measured in CV^{-1} ($CV^{-1} = \text{farad/F}$).

* The charge stored per unit volt is called the capacitance of the capacitor.

- ✓ Q-V graph is a straight line passing through origin.
- ✓ The gradient of the graph gives capacitance.



Energy stored in a capacitor:

Work is done to store charge in a capacitor, the work is stored as energy is the capacitor. The soterd energy canbe found by using the equation;

$$E = \frac{1}{2} QV$$

* The area under Q-V graph is the energy stored.

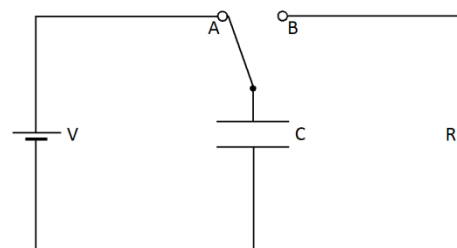
Using the equation $Q = CV$, the stored energy can also be found as;

$$E = \frac{1}{2} CV^2 \text{ and } E = \frac{1}{2} \frac{Q^2}{C}$$

- ✓ When a capacitor is connected to a battery is sends out electrons to one of the plates, this becomes negatively charged. The same amount of electrons move from the second plate and enter the battery, leaving the plate positively charged. The capacitor is now storing a charge or is 'charged'.
- ✓ If the charged capacitor is disconnected from the battery and connected to a lamp it will give out the stored charge or will 'discharge'. The electrons on the negative plate move through the circuit and onto the positive plate. The plates now have no charge on them. The energy stored by the capacitor is transferred to the bulb whilst the electrons move (whilst a current flows).

Charging and discharging a capacitor:

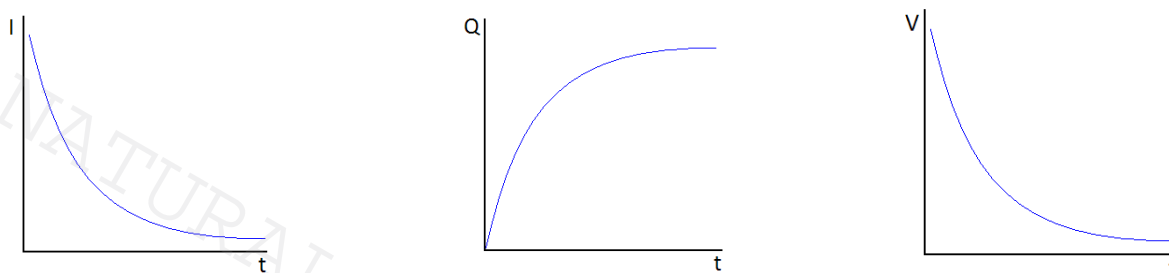
In the circuit a capacitor can be charged by the battery if the switch is moved to position A. It can then be discharged through a resistor by moving the switch to position B.



Charging A capacitor:

When the switch is moved to A the lower plate gets electron this leaves the lower plate negatively charged and the upper plate positively charged. In result an electric field is build up between the plates.

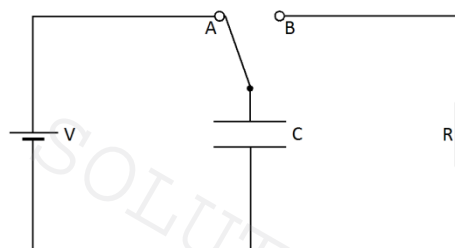
- ✓ **Current:** As the capacitor starts charging, the amount of charge increases quickly at the beginning because a large current is flowing. As the current drops the rate at which the charge increases also drops. A maximum charge is reached.
- ✓ **Charge:** As the capacitor starts charging, the amount of charge increases quickly at the beginning because a large current is flowing. As the current drops the rate at which the charge increases also drops. A maximum charge is reached.
- ✓ **Potential difference (Voltage):** As the capacitor starts charging, the voltage increases quickly at the beginning because a large current is flowing. As the current drops the rate at which the voltage increases also drops. A maximum voltage is reached.



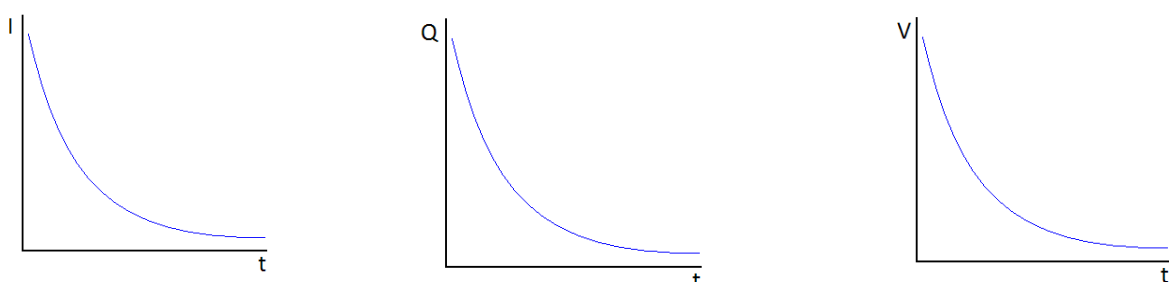
* *Charging of a capacitor is an exponential process.*

Discharging the capacitor and Time constant:

When the switch is moved to B, the electrons on the negative plate repel each other and move back into the circuit. Eventually both plates lose their charge and the electric field between them disappears.



- ✓ **Current:** As the capacitor starts discharging, there is initially a large current as the electrons leave the negative plate. As the number of electrons on the negative plate falls the current fall at a slower rate. When no more electrons move in the circuit the current drops to zero.
- ✓ **Charge:** As the capacitor starts discharging, the amount of charge decreases quickly at the beginning because a large current is flowing. As the current drops the rate at which the charge decreases also drops.
- ✓ **Potential difference (Voltage):** As the capacitor starts discharging, the voltage decreases quickly at the beginning because a large current is flowing. As the current drops the rate at which the voltage decreases also drops.



* *Discharging of a capacitor is an exponential process or exponential decay.*

- * In order to delay the discharging process we should use a capacitor of a larger capacitance, it means it can hold more charge, this means it will take longer to discharge.
- * We can also use a large resistance, the larger resistance means it is harder to move the electrons around the circuit, this also means it will take longer to discharge.

The amount of charge Q remains in the capacitor after time t can be found by using the following equation.

$$Q = Q_0 e^{-t/RC}$$

The equation is called the decay equation for charge where;

t is the time that has elapsed since discharge began

Q is the remaining charge

Q_0 is the initial (or starting) charge

R is the resistance through which the capacitor is discharging

C is the capacitance of the capacitor

- ✓ The term RC is called the **time constant**, it is the **time taken for the charge or p.d. of a capacitor to fall to 37% of the initial value.** OR the **time taken for the charge or p.d. of a capacitor to fall by 63% of the initial value.** It is given by the equation:

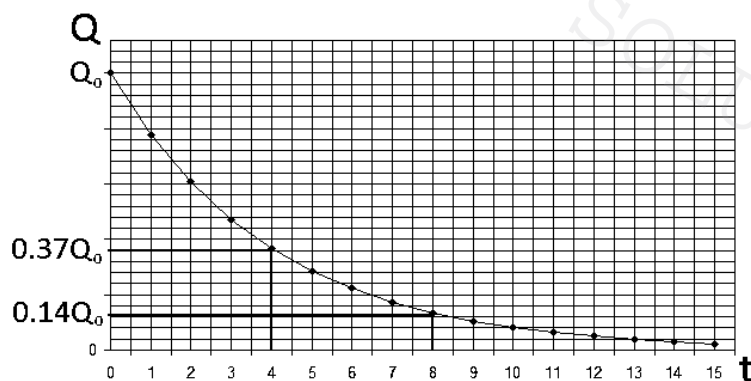
$$\tau = RC$$

- ✓ 5τ is the time considered for a capacitor to discharge completely.

The other decay equations (for the current and the voltage) are given as;

$$V = V_0 e^{-t/RC} \qquad I = I_0 e^{-t/RC}$$

- ✓ The $Q-t$, $V-t$, and $I-t$ graphs are exponential decay graphs as mentioned in discharging process.



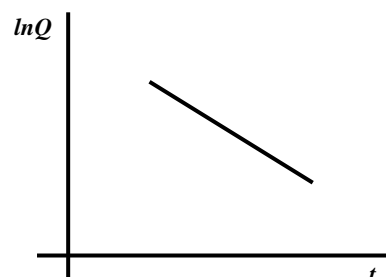
- ✓ In this case the **time constant τ** is 4 seconds. The capacitor will take 20s to discharge completely.

The exponential equations of the charge, Voltage and current can be rearranged in the form of $y = mx + c$ as follows;

$$\ln Q = -\frac{1}{RC} t + \ln Q_0$$

The graph of $\ln Q$ against t is a straight line with negative gradient.

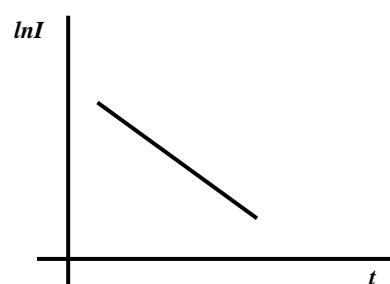
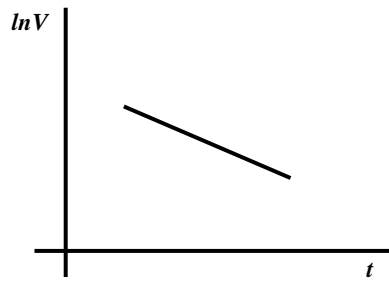
The gradient of the line is $-\frac{1}{RC}$ and the y-intercept is $\ln Q_0$



The similar equations for the voltage and the current can be written as;

$$\ln V = -\frac{1}{RC} t + \ln V_0$$

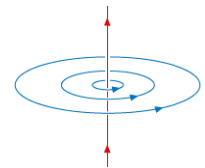
$$\ln I = -\frac{1}{RC} t + \ln I_0$$



Magnetic Field of Current Carrying Wire and Coil

Current and magnetic field:

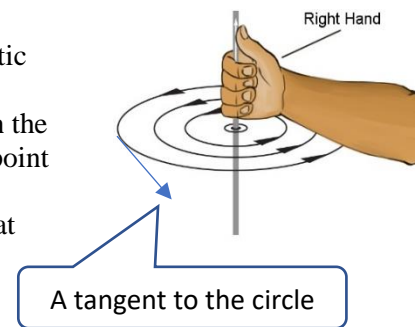
- ✓ Current causes a magnetic field.



Magnetic field of a current carrying straight wire:

When a current flows through a straight wire it creates a magnetic field in the form of concentric circles. The circles spaced away from each other.

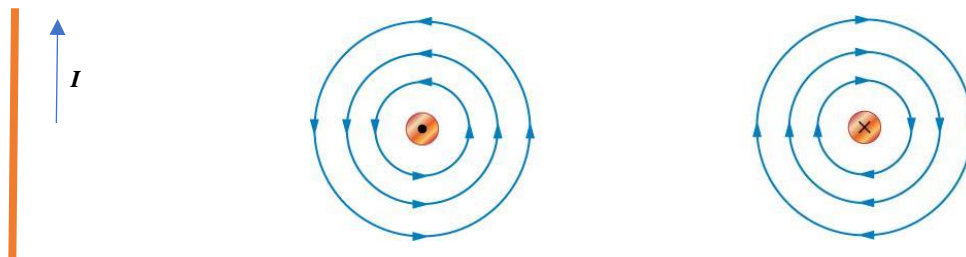
- ✓ The Right Hand Grip Rule is used to show the direction of the magnetic field.
- ✓ If we imagine holding wire in our right hand such that **the thumb** is in the direction of the **conventional current (positive current)**, **the fingers** point the **direction of the field lines**.
- ✓ A **tangent** to the circle represents direction of the magnetic field at that point.



Current flow representation in a wire:

Consider current is flowing upward through a wire as shown in figure. The flow of current can be represent in the form of dot-cross model as follows.

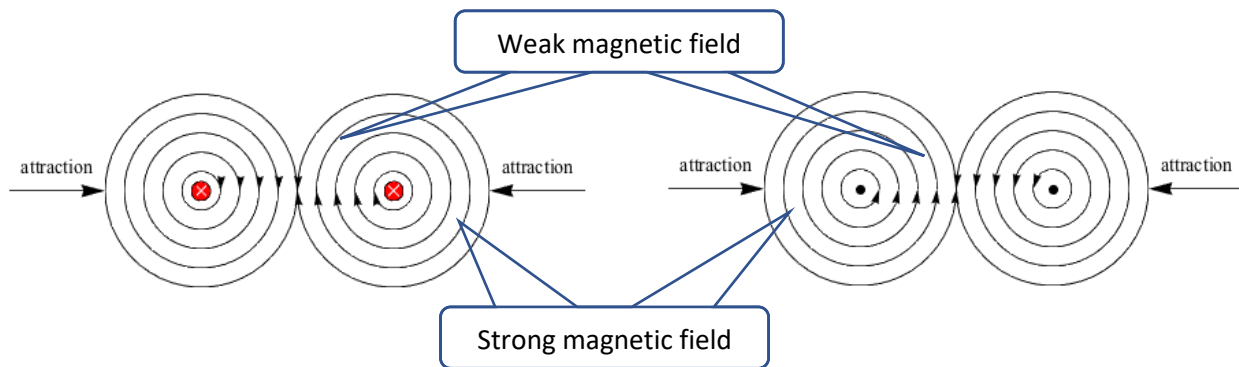
- ✓ If the wire is viewed from the top. **The dot** is used to show the flow of current out of the page. The magnetic fields are in the form of anticlockwise circles spaced away from each other.
- ✓ If the wire is viewed from the bottom. **The cross** is used to show the flow of current going into the page. The magnetic fields are in the form of clockwise circles spaced away from each other.



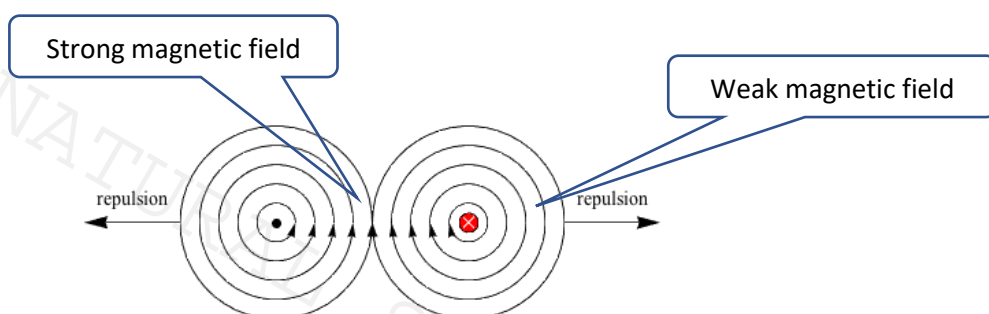
Force between two parallel current carrying conductors:

Force between **two parallel conductors** in which current is flowing depends upon the direction of the current. They either **attract or repel** each other.

- ✓ Two parallel conductors in which current flow in same direction attract each other. It is because net magnetic field between the two conductors is weaker than the magnetic field of outer region.



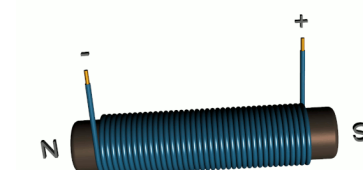
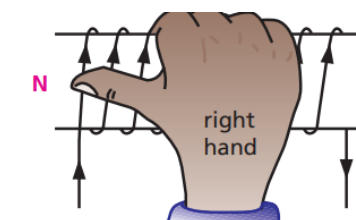
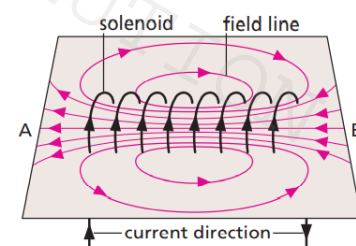
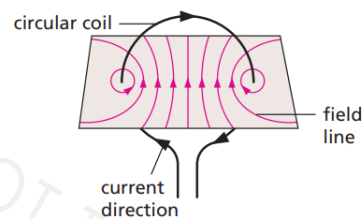
- ✓ Two parallel conductors in which current flow in opposite direction repel each other. It is because net magnetic field between the two conductors is stronger than the magnetic field of outer region.



Magnetic field of a circular coil/one loop of a wire:

The face of the coil behaves as a north and as south pole of a magnet. The right-hand rule again gives the direction of the field at any point.

- ✓ If the current in a coil is flowing **clockwise** the face you are looking at is **south face** and vice versa.
- ✓ At the centre of the coil the **field lines are straight and at right angles to the plane of the coil**.



Magnetic field of a solenoid:

A solenoid is a long cylindrical coil. It produces a field similar to that of a bar magnet.

- ✓ The direction of the magnetic field can be found by using the right hand grip rule.
- ✓ One end of the coil is the north face and the other end is the south face.
- ✓ If a soft iron rod is inserted into the solenoid the rod becomes a magnet. Such magnet is called electromagnet.

The strength of an electromagnet increases if

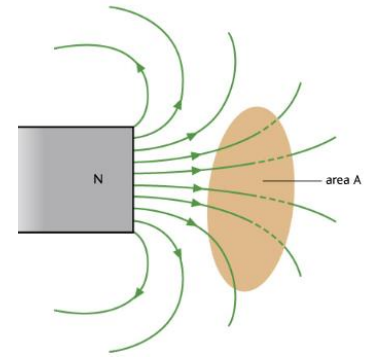
- the current in the coil increases,
- the number of turns on the coil increases,
- the poles are moved closer together.

Magnetic Flux and Flux Density

Magnetic Flux:

Number of magnetic field lines passing through an area, denoted by ϕ (phi) measured in weber (Web). OR

The amount of magnetic field lines within a loop or coil.



Magnetic Flux Density/Magnetic field strength:

Magnetic flux per unit area is called magnetic flux density or Magnetic field strength denoted by **B**.

$$B = \frac{\phi}{A}$$

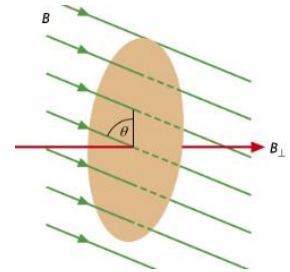
The SI unit of **B** is webm^{-2} which is called tesla (T) { $T = \text{webm}^{-2}$ }

From the above equation the magnetic flux can be found as; $\phi = BA$.

The above formula is used if **A** is perpendicular to the magnetic field.

If area **A** is making some angle with the magnetic field **B**.

$$\phi = BA \sin \theta$$



Flux Linkage:

Flux linked with one coil is defined as; $\phi = BA$

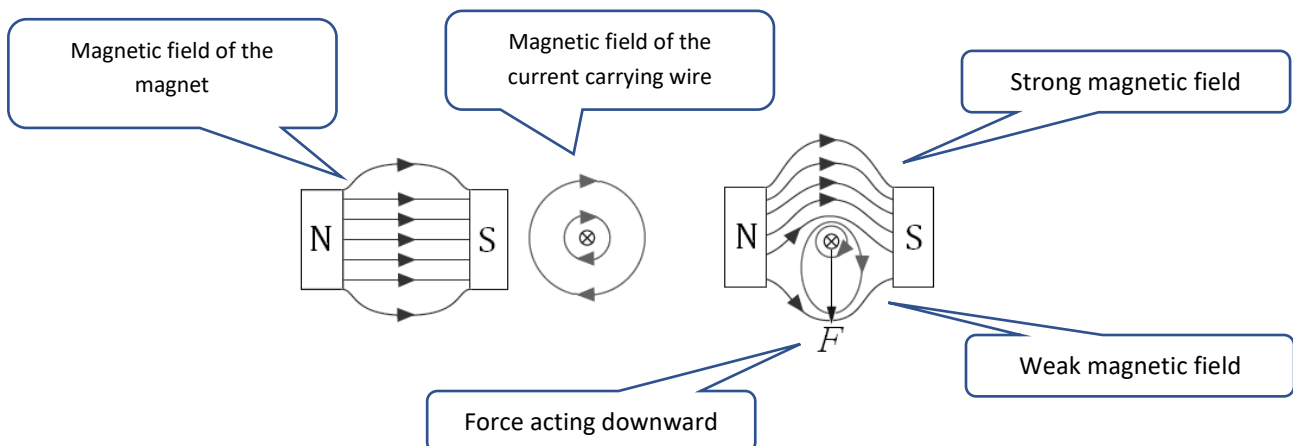
If there are **N** turns the total amount of flux linked with the **N** turns is called flux linkage is defined as;

$$N\phi = BAN$$

Force on a Current Carrying Wire

Force on a current carrying wire:

When a (conventional) current flows through the wire placed in a magnetic field, it experiences a force due to the net magnetic field of the magnet and the wire.

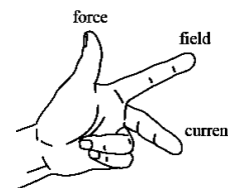


- ✓ *The magnetic field lines above are more compact than below. This forces the wire downwards.*
- ✓ The direction of the force can be determined by using *Flaming's left hand rule*.

Flaming Left Hand Rule:

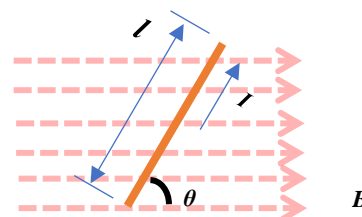
This rule links the *magnetic field*, *conventional current* and *directions of the force* which are all at right angles to each other.

- ✓ Your first finger points from North to South (in the direction of the magnetic field).
- ✓ Your middle finger points from positive to negative or in the direction of the current flow.
- ✓ Your thumb points in the direction of the force or direction of the motion of the conductor.



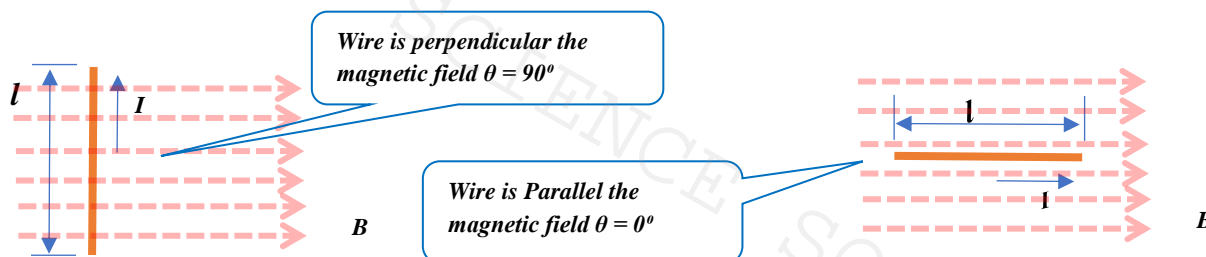
Strength of the force:

If a current carrying wire of length l is placed in a magnetic field of strength B making at an angle θ with the magnetic field, the force acting on the wire can be found by using;



$$F = BIl \sin\theta$$

- ✓ If the wire is *perpendicular* ($\theta = 90^\circ$) to the magnetic field the force will be maximum. $F = BIl$
- ✓ If the wire is *parallel* to the magnetic field the force will be zero. $F = 0$



Motor Effect/ Rotating Coil in a Magnetic Field:

If a *current carrying coil* is placed in a magnetic field then the *force acting* on the coil causes the *coil to rotate*.

If we have a rectangle of wire that has an area of A and we place it in a magnetic field of flux density B , we have seen that the amount of flux flowing through the wire depends on the angle θ between it and the flux lines.

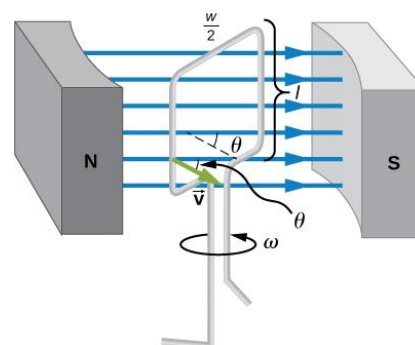
The flux linkage at an angle θ from the perpendicular to the magnetic field is given by: $N\Phi = BAN\cos\theta$

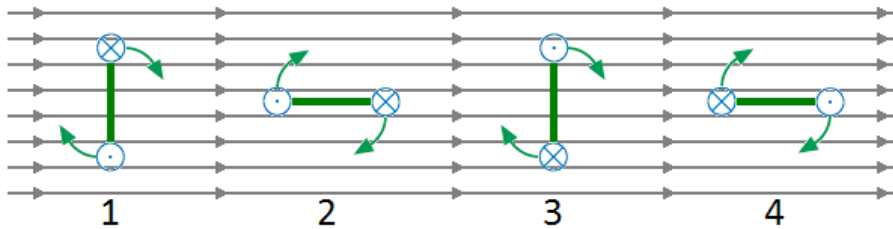
The angular speed is given by $\omega = \frac{\theta}{t}$.

The flux linkage is then written as; $N\Phi = BAN\cos(\omega t)$

When $t = 0$ the wire is perpendicular to the field so there is a maximum amount of flux.

Complete cycle of the coil is shown in the figure below;





At 1 the flux linkage is a maximum in one direction. There is the lowest rate of change at this point.

At 2 the flux linkage is zero. There is the biggest rate of change at this point

At 3 the flux linkage is maximum but in the opposite direction. The lowest rate of change occurs here too.

At 4 the flux linkage is zero. There is the biggest rate of change at the point too but in the opposite direction.

Force on a moving charge in a magnetic field:

If a charge q enters in a magnetic field of strength B with velocity v and it makes an angle θ with the magnetic field, the force acting on the moving charge can be found by using;

$$F = Bqv \sin\theta$$

- ✓ If the wire is *perpendicular* ($\theta = 90^\circ$) to the magnetic field the force will be maximum. $F = Bqv$

- ✓ If the wire is *parallel* to the magnetic field the force will be zero. $F = 0$

- ✓ The direction of the *force* can be determined by using *Flaming's left hand rule*.

1. Your first finger points from North to South (in the direction of the magnetic field).
2. Your middle finger points from positive to negative or in the direction of the current flow.
3. Your thumb points in the direction of the force acting on the moving charge.

- ✓ The *force* acting on the charge in the 2nd diagram is *upward*.

- ✓ If the charge moves *perpendicularly* to the **magnetic field**, the magnetic force on the moving charge *acts as a centripetal force*. The charge then moves along a *circular path* of radius r .

$$Bqv = \frac{mv^2}{r} \quad \text{OR} \quad Bq = \frac{mv}{r}$$

- ✓ The above equation can be rearrange to make r as a subject of the equation to find the *radius* of the circular path.

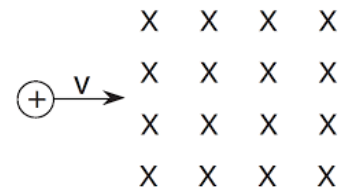
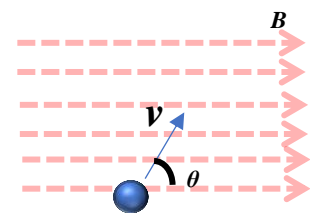
$$r = \frac{mv}{Bq}$$

Less curvature, large radius.

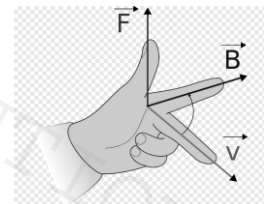
More curvature, small radius.

From the above equation it is evident that radius of the circular path;

1. Directly proportional to the *mass* (m) of the charged particle.
2. Directly proportional to the *speed* (v) of the charged particle.
3. Inversely proportional to the *strength of the magnetic field* (B).
4. Inversely proportional to the *amount of the charge* (q).



Magnetic field into the page



Electromagnetic Induction (EMI)

Electromagnetic Induction:

If a wire/coil placed in a magnetic field moves, an e.m.f is induced which cause a current in the wire/coil.

There are two possibilities to induce e.m.f. across the ends of a conducting wire:

- 1) Move the wire through a magnetic field or 2) Move a magnet through a coil of the wire

- ✓ In both cases magnetic field lines and wires are **cutting through each other**. We say that the wire is cutting through the magnetic field lines (although it is fair to say that the field lines are cutting through the wire).
- ✓ If the **conductor is part of a complete circuit** a current will be induced through it as well as an e.m.f. across it.

Faraday's Law of Induction:

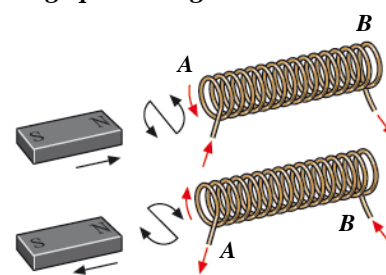
The magnitude of the e.m.f. E induced in a conductor equals the rate of change of flux linkages or the rate at which the conductor cuts a magnetic flux.

$$E = \frac{N\Delta\Phi}{\Delta t}$$

Lenz's Law:

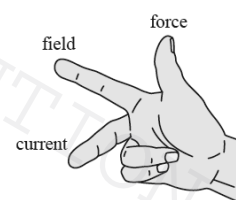
The direction of the e.m.f. induced in a conductor is such that it opposes the change producing it.

- ✓ When we **push** the North Pole of a magnet the induced current in the solenoid flows to make the **end A** of the coil as a North Pole to **repel the magnet**.
- ✓ When we **pull** the North Pole out of the solenoid the induced current flows to make the **end A** as a South Pole to **attract the magnet**.



Fleming's Right Hand Rule/Direction of the induces e.m.f:

- ✓ Your first finger points in the direction of the field from North to South.
- ✓ Your thumb points in the direction the wire is moved.
- ✓ Your middle finger points in the direction of the conventional current.



Transformers

Transformer:

It is a device to increase or decrease the voltage/current using electromagnetic induction.

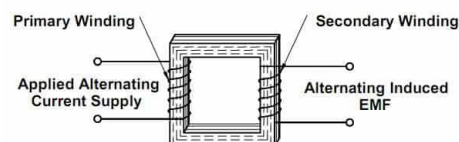
Working Principle:

An A.C current flows through the primary coil which creates an alternating magnetic field. The field lines cut through the turns of wire on the secondary coil. This induces an e.m.f. (voltage) and a current in the second coil.

There are two types of transformers:

1. Step Up:

- The voltage in the secondary coil is larger than the voltage in the primary coil.
- The current in the secondary coil is smaller than the current in the primary coil.



There will be more turns of wire on the secondary coil meaning more flux linkage. $N_s > N_p$

2. Step Down

The voltage in the secondary coil is smaller than the voltage in the primary coil.

The current in the secondary coil is larger than the current in the primary coil.

There will be fewer turns of wire on the secondary coil meaning less flux linkage. $N_p > N_s$

The voltage V_p , current I_p , and the number of turns N_p in the **primary coil** is linked to the voltage V_s , current I_s , and the number of turns N_s in the **secondary coil** by the following equations:

$$\frac{N_s}{N_p} = \frac{V_s}{V_p} \quad ; \quad \frac{N_s}{N_p} = \frac{I_p}{I_s} \quad ; \quad \frac{V_s}{V_p} = \frac{I_p}{I_s}$$

Nuclear and Particle Physics

In Search of Fundamental Particles:

- ✓ Till 19th century atom was supposed to be a fundamental and indivisible particle from which everything else is constructed.
- ✓ 1857 W. Crooks discovered electron as one of the fundamental particle.
- ✓ 1897 J.J Thomson found the e/m ratio for electron.
- ✓ Later positive rays discovered and gave proof of existence of protons.
- ✓ Chadwick discovered Neutron in his artificial radioactive experiment.

Structure of an Atom:

After discovery of the three fundamental particles of that time;

Constituent	Charge (C)	Mass (kg)
Proton	1.6×10^{-19}	1.673×10^{-27}
Neutron	0	1.675×10^{-27}
Electron	-1.6×10^{-19}	9.11×10^{-31}

- ✓ J.J Thomson gave his Plum Pudding model for atom.
- ✓ Rutherford performed scattering of alpha particle from a gold foil and gave his model for structure of atom.
- ✓ Niels Bohr refined the model giving idea about existence of fixed energy level.

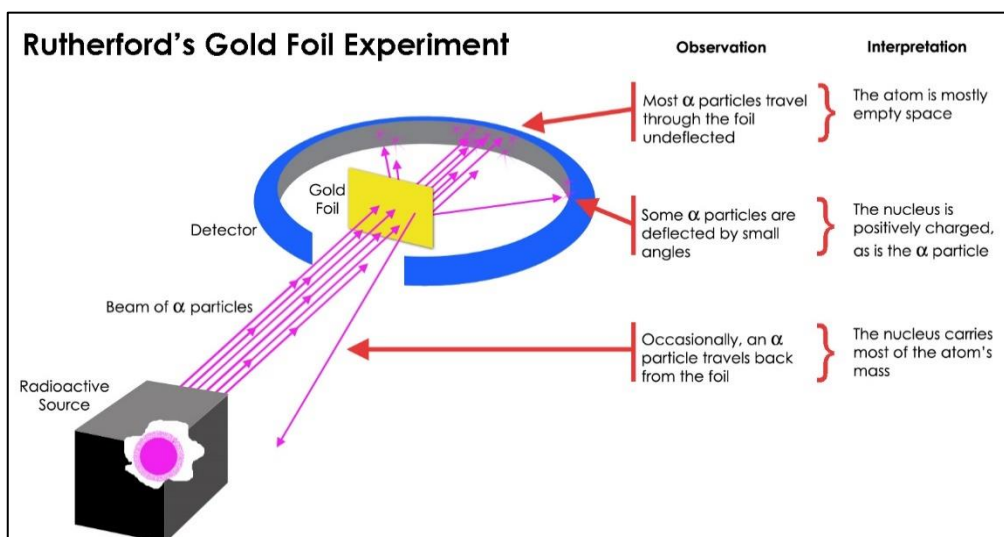
Alpha scattering experiment:

In 1911, **Rutherford** and co-workers **Hans Geiger** and **Ernest Marsden** initiated a series of ground-breaking experiments that would completely change the accepted model of the atom.

- ✓ They bombarded very thin sheets of gold foil with fast moving alpha particles.
- ✓ Alpha particles, a type of natural radioactive particle, are positively charged particles with a mass about four times that of a hydrogen atom.

Observation and conclusion:

1. **Most** of the α particles **passed straight** through the gold foil, which showed that **atoms are mostly empty space**.
2. **Some** of the α particles were **deflected at various angles** hence the **positive charge** in an atom is **not uniformly distributed**. The positive charge in an atom is **concentrated** in a **very small volume**.
3. **Very few** α particles were **bounced back** from the gold foil, so the **volume** occupied by the **positively charged** particles in an atom is **very small** as compared to the **total volume** of an atom.



Note: Nucleus has positive charge *was not valid assumption* from the above observation.

Nuclear Notation:

- ✓ Collectively *protons* and *neutrons* are called *Nucleons*.
- ✓ Number of protons is called *proton number* or *charge number* denoted by *Z*.
- ✓ Number of protons + number of neutrons is called *Mass number* or *nucleon number* denoted by *A*.

If X is a nucleus of an element, we write the following notation to represent the nucleus; $\frac{A}{Z}X$.

Where $A = Z + n$ {n = number of neutrons}.

Isotopes:

Isotopes are atoms of same element with same atomic number but different mass number. Or atoms of same element with same protons number but different nucleons number.

${}^1_1\text{H}$	${}^2_1\text{H}$	${}^3_1\text{H}$
Hydrogen-1/Protium	Hydrogen-2/Deuterium	Hydrogen-3/Tritium
electrons = 1 protons = 1 neutron = 0	electrons = 1 protons = 1 neutron = 1	electrons = 1 protons = 1 neutron = 2

Three Important Isotopes:

There are three Isotopes of Hydrogen.

Interesting Facts:

- * If we shrunk the Solar System so that the Sun was the size of a gold nucleus the furthest electron would be twice the distance to Pluto.

If the nucleus was a full stop it would be 25 m to the first electron shell, 100m to the second and 225m to the third.

Mass-Energy Conservation

Mass-Energy Equation:

According to Einstein energy E linked *the rest mass* of a particle as follows:

$$E = mc^2$$

Where c is the speed of light ($c = 3 \times 10^8 \text{ ms}^{-2}$).

✓ So whether you have mass or energy you still have the same amount.
The law of conservation of energy can now be referred to as the conservation of mass-energy.

The total mass-energy before is equal to the total mass-energy after.

Mass Energy associated with 1 Kg of mass: $9 \times 10^{16} \text{ J} = 5.63 \times 10^{35} \text{ eV}$. {eV = electronvolt}

Mass Energy associated with mass of one electron: $8.199 \times 10^{-14} \text{ J} = 0.51 \text{ MeV}$.

Photon:

Photon is a discrete energy packet of electromagnetic wave.

The energy carried by a photon is given by the equation: $E = hf$

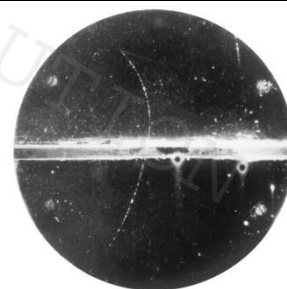
Where h is the *Planck's constant*: $h = 6.625 \times 10^{-34} \text{ Js}$, and f is the frequency of the *photon* (electromagnetic wave).

Since $c = f\lambda$ we can also write the above equation as: $E = \frac{hc}{\lambda}$

Particles and Antiparticles

Positron/Antielectron/positive electron:

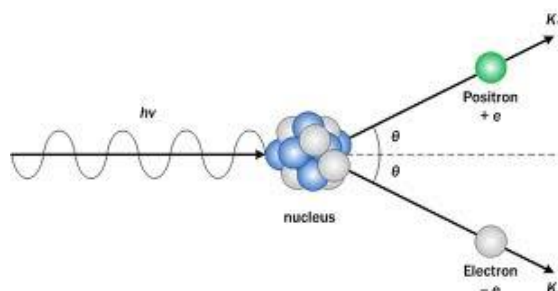
- ✓ In 1932, *Caltech physicist Carl Anderson* discovered *the positron* (A *positive electron*, a particle of same mass but opposite charge of that of electron).
- ✓ *Positron* was the *first* particle of *antimatter* to be identified.
- ✓ Anderson had not set out to hunt *antimatter*.
- ✓ He had built a *cloud chamber* to determine the composition of *cosmic rays*, *high-energy particles* that rain down from space.



Pair Production:

If an attempt is made to stop a photon of energy E (generally absorption in nucleus) a pair of *particle and antiparticle* produced.

- ✓ In order to *conserve momentum*, the produced pair always moves in *opposite direction*.
- ✓ The energy E of the *absorbed photon* must be *greater* than the *double of the rest mass energy* of the photon.



$$E > \text{mass energy of } e^- + \text{mass energy of } e^+$$

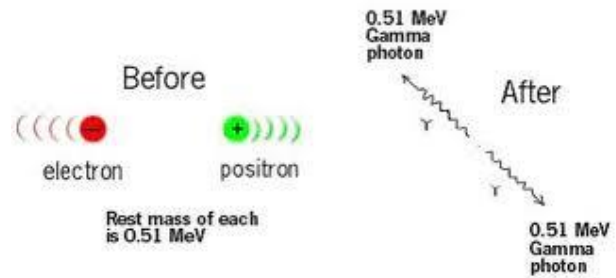
- * **Pair production** is in consequence of **mass-energy conservation** in which **energy of a photon** is converting into **mass (particle and antiparticle)**.

Annihilation:

When a **pair of particle and antiparticle** collides they **annihilate** each other in result **two photons** are produced which move in **opposite direction produced**.

- ✓ In order to **conserve momentum**, the produced **photons** always move in **opposite direction**.

- * **Annihilation** is in consequence of **mass-energy conservation** in which **mass of particle and an antiparticle** is converting into **energy**.



Electron Beams:

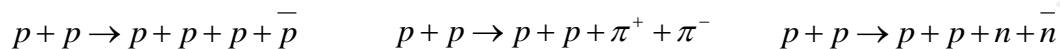
- ✓ Electron can be emitted by **gaining enough energy** simply through **heating of the metal**.
- ✓ The release of electrons from the surface of metal as it is heated is known as **Thermionic Emission**.
- ✓ Once electrons emitted they find themselves in an **electric field** that **accelerates** these electrons.
- ✓ At **sufficient high P.D** the emitted electrons then move as **beam of fast moving electrons**.
- ✓ The **kinetic energy gained** by an electron under **p.d** of **V** is $E_k = eV$.
- ✓ The **electron beam** is **deflected** by a **magnetic field**.

Particle accelerators:

- ✓ A **beam** of particles is **accelerated** inside a tubes (**straight or circular**) and allow to collide at **very high speed (very high energy)**.
- ✓ **High energy** is necessary because at **lower energies** the particles just **bounce off** each other keeping their internal secrets.
- ✓ If we collide particles hard enough they will **breakup**, ravelling their structure.
- ✓ In most cases **additional particles** are created from the **energy** of the collision

At CERN **protons** are accelerated and fired into each other. If they have enough kinetic energy when they collide **particle-antiparticle pair** may be created from the energy.

The following are examples of the reactions that have occurred:



- * In all the above reaction, we can see that the **conservation laws** of particle physics are **obeyed**.

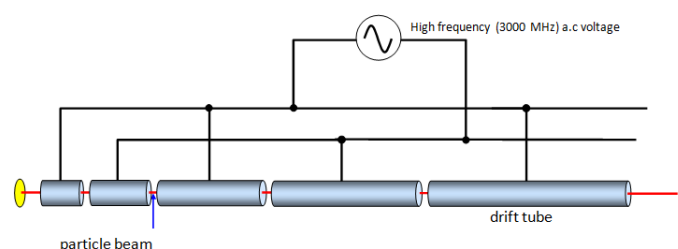
There are two types of particle accelerators.

1. Linear accelerator
2. Circular accelerators.

Linear accelerators (LINAC):

A linear accelerator (linac) is a type of particle accelerator in which charged particles/electron are accelerated in a straight line.

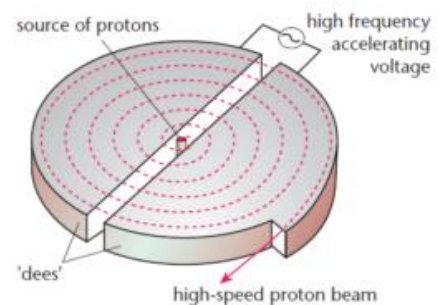
It consist of drift tubes of increasing length.



- ✓ Electrons are emitted through thermionic emission, which are then accelerated towards the first drift tube because of their negative potential and drift tube's positive potential.
- ✓ When electrons come inside the tube, at that moment radio frequency (RF) source shifts its polarity.
- ✓ First drift tube then becomes negatively charged and second drift tube positively charged.
- ✓ Electrons come outside of the tube because of its inertia and at that moment they are pushed with the first drift tube and attracted by the second one in the same direction.
- ✓ As electrons are accelerating, their velocity becomes bigger and they travel a longer distance in the same time.
- ✓ That is the reason why drift tubes must be longer as electrons come closer to target; because of their greater velocity.
- ✓ If the very great velocity is needed, because of long drift tubes and a big number of drift tubes, linac must be very long.

Circular accelerators (Cyclotron):

- ✓ The first major component of a cyclotron consists of two hollow metal parts/containers each resembles as a shape letter D.
- ✓ The two parts of the cyclotron are known as dees.
- ✓ At any one time, one dee in the cyclotron is given appositve potential and the other negative.
- ✓ The dees are connected to a source of high frequency alternating voltage so that the polarity on both dees changes back and forth many times per second.
- ✓ The second major component of a cyclotron is a large magnet that is situated above and below the dees.
- ✓ The presence of the magnet means that any charged particles moving within the dees will travel in circular path.
- ✓ The electric field causes the charge particle to accelerate and gain energy.
- ✓ The magnetic field causes the magnetic force acts as a centripetal force due to which the charge particle moves along a circular path.



Cyclotron frequency:

The frequency of the voltage is set so that particles make one circuit during a single cycle of the voltage. To achieve this condition, the frequency must be set to particle's cyclotron frequency.

$$f = \frac{qB}{2\pi m}$$

Where,

B is the magnetic field strength

q is the electric charge of the particle

m is the relativistic mass of the charged particle

Note: In a magnetic field, if a charge q of mass m moves with velocity v in circular path of radius r then;

$$r = \frac{mv}{Bq} = \frac{p}{Bq}$$

- ✓ At *slow speed* the radius of the path is proportional the momentum of the charge.
- ✓ When the speed of the particle *approaches to the speed of light*, relativistic effect need to be accounted for.
- ✓ In particular, at such speed the particle's *mass increases*, which would also *alter its momentum*.

- ✓ The overall effect of *increasing mass* is that a particle increasing speed would travel along an *outwardly spiralling path*.

An important unit of mass and conversion:

To measure the energy of sub atomic particles electron volt (eV) is used.

The atomic mass unit (u) is the unit use to measure the atomic masses.

$$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$$

Constituent	Charge (C)	Mass (u)
Proton	1.6×10^{-19}	1
Neutron	0	1
Electron	-1.6×10^{-19}	1/1836

Since energy and mass are related by the equation $\Delta E = \Delta mc^2$

We can also have *mass unit* which are measured of E/c^2 , such as MeV/c^2 and GeV/c^2

$$1 \text{ u} = 931.5 \text{ MeV}$$

The Four Forces

The Four Forces:

- ✓ All the known forces in the universe can be grouped into *four basic types*.
- ✓ In order of *increasing strength* these are;

❖ Gravitation:

- In the subatomic realm (fundamental interaction b/w particles) it is of no importance at all.
- The gravitational force b/w two protons just touching their surface is about 10^{-38} of the strong force

❖ The weak nuclear force:

- Responsible for nuclear beta decay and other similar decay processes involving fundamental particles Electromagnetism.
- The weak force b/w two binding protons is about 10^{-7} of the strong force.
- It does not play a major role in the binding of nuclei.
- Its range is smaller than 1fm.

❖ The Electromagnetic force/Electromagnetism:

- Play important role in the structure and interaction of fundamental decay.
- The EM force b/w two binding protons is about 10^{-2} of the strong force
- Due to shielding generally diminishes.
- But within the nucleus can act cumulatively because there is no shielding, therefore can compete with the strong force in determining the stability of the nucleus.

❖ Strong nuclear force:

- Responsible for the binding of nuclei.
- Most of the fundamental particles decay through strong force.
- It's a short range force i.e. can't act more than 1fm.
- Some particles such as electron (Leptons) do not feel this force at all.

Standard Model

Twelve fundamental particles:

- ✓ After discovery of many particles a theory about matter was developed known as *Standard Model*.
- ✓ The current theory, which identifies *12 fundamental particles* from which all matter is made of.
- ✓ After probing inside the two nucleons the idea that *proton* and *neutron* as fundamental particles has been *overturned*.
- ✓ *Proton* and *Neutron* are composed of *three particles* known as *Quarks*.
- ✓ The *electron* so far survived as being *fundamental particle*.
- ✓ *Electron (e)* along with its *two partners Muon (μ)* and *Tauon (τ)* forms a family of fundamental particles called *LEPTON*.
- ✓ Each of the *three lepton* also have other three particles associated with them called *neutrino*.
 1. *Electron neutrino* ν_e , 2. *Muon neutrino* ν_μ 3. *Tauon neutrino* ν_τ

Note: *electron, muon, and tau* are always emitted with their *associated neutrino*.

- ✓ The table on the left shows the *six leptons*. For every lepton there is *anti-lepton*.

Lepton Family:

Leptons	Symbol	Charge	Anti-Leptons	Symbol	Charge
<i>Electron</i>	e^{-1}	-1	<i>Anti-electron/Positron</i>	e^{+1}	+1
<i>Electron neutrino</i>	ν_e	0	<i>Anti-electron neutrino</i>	$\bar{\nu}_e$	0
<i>Muon</i>	μ^{-1}	-1	<i>Anti-muon</i>	$\bar{\mu}$	+1
<i>Muon neutrino</i>	ν_μ	0	<i>Anti-muon neutrino</i>	$\bar{\nu}_\mu$	0
<i>Tauon</i>	τ^{-1}	-1	<i>Anti-tauon</i>	$\bar{\tau}$	+1
<i>Tauon neutrino</i>	ν_τ	0	<i>Anti-tauon neutrino</i>	$\bar{\nu}_\tau$	0

- * The *fundamental particles* from which *proton, neutron* (and some other particles) are made. There are six type of *Quarks*.

Quark Family:

Quark	Symbol	Charge	Anti-Quark	Symbol	Charge
<i>Up</i>	u	$+(2/3)e$	<i>Anti-up</i>	\bar{u}	$-(2/3)e$
<i>Down</i>	d	$-(1/3)e$	<i>Anti-down</i>	\bar{d}	$+(1/3)e$
<i>Strange</i>	s	$-(1/3)e$	<i>Anti-strange</i>	\bar{s}	$+(1/3)e$
<i>Charm</i>	c	$+(2/3)e$	<i>Anti-charm</i>	\bar{c}	$-(2/3)e$
<i>Bottom</i>	b	$-(1/3)e$	<i>Anti-bottom</i>	\bar{b}	$+(1/3)e$
<i>Top</i>	t	$+(2/3)e$	<i>Anti-top</i>	\bar{t}	$-(2/3)e$

- ✓ *Protons* and *neutrons* are composed of two *lightest quarks* (up and down).
- ✓ The heavier quarks are found in more exotic particles.
- ✓ Quarks can undergo interactions via *strong nuclear force*.

You will not be asked about the last three quarks.

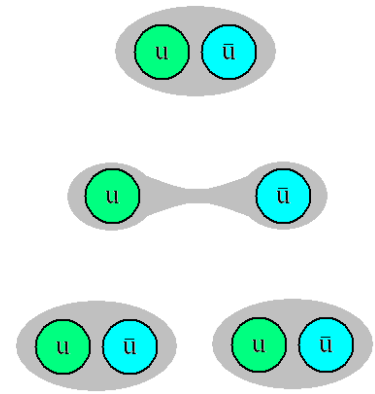
- Protons composed of two u and one d quark; [*quark composition is uud*].
- Neutron composed of two d and one u quark; [*quark composition is ddu*].
- Anti-Protons composed of two anti-up and one anti-down quark; [*quark composition is $\bar{u} \bar{u} \bar{d}$*].
- Neutron composed of two d and one u quark; [*quark composition is $\bar{d} \bar{d} \bar{u}$*].

The quark composition tells us about the *charge on the particle*.

- ✓ *Charge on a proton:* $+(2/3)e + (2/3)e - (1/3)e = +1e$
- ✓ *Charge on a neutron:* $-(1/3)e - (1/3)e + (2/3)e = 0$

The Lone Quark?

- * *Quarks never appear on their own/isolated state.*
- ✓ The energy required to pull two quarks apart is so massive that according to $E = mc^2$ the used energy is enough to make two new particles.
- ✓ A quark and an antiquark are created, another example of pair production.
- ✓ A particle named a *neutral pion* (π^0) is made from an *up* quark and an *anti-up* quark.
- ✓ Moving these apart creates *another up* quark and an *anti-up quark*.
- ✓ We now have two pairs of quarks.
- ✓ Trying to separate two quarks made *two more quarks*.



Particles classification: Particles which can be obtained in an isolated state are categorized as;

Hadrons – Heavy and made from quarks.

Leptons – Light and not made from smaller particles.

Hadrons

- ✓ Hadrons are *not fundamental particles* they are all made from smaller particles, *quarks*.
- ✓ The properties of a hadron are due to the combined properties of the quarks that it is made from.
- ✓ There are two categories of Hadrons: *Baryons* and *Mesons*.

Baryons Made from three quarks.

Proton	Charge (Q)	Baryon Number (B)	Strangeness (S)
u	$+\frac{2}{3}$	$+\frac{1}{3}$	0
u	$+\frac{2}{3}$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}$	$+\frac{1}{3}$	0
P	+1	+1	0

Neutron	Charge (Q)	Baryon Number (B)	Strangeness (S)
d	$-\frac{1}{3}$	$+\frac{1}{3}$	0
u	$+\frac{2}{3}$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}$	$+\frac{1}{3}$	0
n	0	+1	0

* *The proton is the only stable hadron, all others eventually decay into a proton.*

Mesons Made from a quark and an antiquark

Pion Plus	Charge (Q)	Baryon Number (B)	Strangeness (S)
u	$+\frac{2}{3}$	$+\frac{1}{3}$	0
\bar{d}	$+\frac{1}{3}$	$-\frac{1}{3}$	0
π^+	+1	0	0

Pion Minus	Charge (Q)	Baryon Number (B)	Strangeness (S)
\bar{u}	$-\frac{2}{3}$	$-\frac{1}{3}$	0
d	$-\frac{1}{3}$	$+\frac{1}{3}$	0
π^-	-1	0	0

Pion Zero	Charge (Q)	Baryon Number (B)	Strangeness (S)
U	$+\frac{2}{3}$	$+\frac{1}{3}$	0
\bar{u}	$-\frac{2}{3}$	$-\frac{1}{3}$	0
π^0	0	0	0

Pion Zero	Charge (Q)	Baryon Number (B)	Strangeness (S)
d	$-\frac{1}{3}$	$+\frac{1}{3}$	0
\bar{d}	$+\frac{1}{3}$	$-\frac{1}{3}$	0
π^0	0	0	0

Kaon Plus	Charge (Q)	Baryon Number (B)	Strangeness (S)
U	$+\frac{2}{3}$	$+\frac{1}{3}$	0
\bar{s}	$+\frac{1}{3}$	$-\frac{1}{3}$	+1
K⁺	+1	0	+1

Kaon Minus	Charge (Q)	Baryon Number (B)	Strangeness (S)
\bar{u}	$-\frac{2}{3}$	$-\frac{1}{3}$	0
s	$-\frac{1}{3}$	$+\frac{1}{3}$	-1
K⁻	-1	0	-1

Kaon Zero	Charge (Q)	Baryon Number (B)	Strangeness (S)
D	$-\frac{1}{3}$	$+\frac{1}{3}$	0
\bar{s}	$+\frac{1}{3}$	$-\frac{1}{3}$	+1
K⁰	0	0	+1

Anti-Kaon Zero	Charge (Q)	Baryon Number (B)	Strangeness (S)
\bar{d}	$+\frac{1}{3}$	$-\frac{1}{3}$	0
s	$-\frac{1}{3}$	$+\frac{1}{3}$	-1
\bar{K}^0	0	0	-1

Anti-Hadrons

- ✓ Anti-hadrons are made from the opposite quarks as their Hadron counterparts, for example a proton is made from the quark combination uud and an antiproton is made from the combination $\bar{u}\bar{u}\bar{d}$
- ✓ We can see that a π^+ and a π^- are particle and antiparticle of each other.

Anti Proton	Charge (Q)	Baryon Number (B)	Strangeness (S)
\bar{u}	$-\frac{2}{3}$	$-\frac{1}{3}$	0
\bar{u}	$-\frac{2}{3}$	$-\frac{1}{3}$	0
\bar{d}	$+\frac{1}{3}$	$-\frac{1}{3}$	0
\bar{p}	-1	-1	0

Anti Neutron	Charge (Q)	Baryon Number (B)	Strangeness (S)
\bar{d}	$+\frac{1}{3}$	$-\frac{1}{3}$	0
\bar{u}	$-\frac{2}{3}$	$-\frac{1}{3}$	0
\bar{d}	$+\frac{1}{3}$	$-\frac{1}{3}$	0
\bar{n}	0	-1	0

- * **You need to know all the quark combination shown on this page as they may ask you to recite any of them.**

Particles interaction

Reactions Conservation properties:

For *interaction/reaction* to be possible in addition to *mass/energy/momentum* and *charge conservation*;

- ✓ *Lepton* and *Baryon number* must be conserved.

Baryon Number (B): The baryon number is one third of the difference between the number of quarks and the number of anti-quarks within a system.

- ✓ Baryons are assigned a baryon number $B = +1$.
- ✓ Anti-baryons are assigned a baryon number $B = -1$
- ✓ All non-baryons are assigned the baryon number $B = 0$

Lepton Number (L):

- ✓ A lepton is assign a lepton number $L = +1$, for an antilepton; $L = -1$.
- ✓ For hadrons lepton number is zero, $L = 0$.

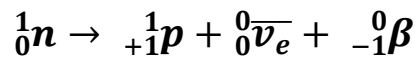
Strangeness (S):

If a *strange quark* is involved then we also check the *conservation of strangeness*, the strangeness of *strange quark* s is -1 ($S = -1$) and strangeness of *anti-strange quark* \bar{s} is $+1$ ($S = +1$)

Some important Decay and Interactions:

1. β^{-1} Decay:

A neutron decays into a proton by decaying β^{-1} particle as follows;



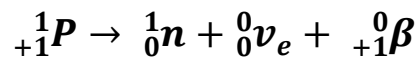
Checking the validity:

$$\begin{array}{l} \text{Q: } 0 \rightarrow +1 + 0 + -1 \quad 0 \rightarrow 0 \quad (\text{charge is conserved}) \\ \text{B: } +1 \rightarrow +1 + 0 + 0 \quad +1 \rightarrow +1 \quad (\text{Baryon number is conserved}) \\ \text{L: } 0 \rightarrow 0 - 1 + 1 \quad 0 \rightarrow 0 \quad (\text{Lepton number is conserved}) \end{array}$$

Charge, Baryon number, and Lepton number is conserved. The decay is valid

2. β^{+1} Decay:

A proton decays into a neutron by decaying β^{+1} particle as follows;



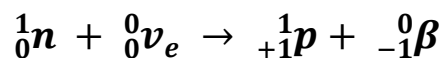
Checking the validity:

$$\begin{array}{l} \text{Q: } +1 \rightarrow 0 + 0 + 1 \quad +1 \rightarrow +1 \quad (\text{charge is conserved}) \\ \text{B: } +1 \rightarrow +1 + 0 + 0 \quad +1 \rightarrow +1 \quad (\text{Baryon number is conserved}) \\ \text{L: } 0 \rightarrow 0 + 1 - 1 \quad 0 \rightarrow 0 \quad (\text{Lepton number is conserved}) \end{array}$$

Charge, Baryon number, and Lepton number is conserved. The decay is valid

3. A neutron-neutrino interaction:

A neutron interacts with an electron neutrino and turns into a proton along with emission of β^{-1} particle as follows;



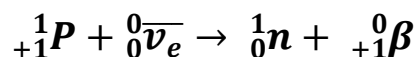
Checking the validity:

$$\begin{array}{l} \text{Q: } 0 + 0 \rightarrow +1 + -1 \quad 0 \rightarrow 0 \quad (\text{charge is conserved}) \\ \text{B: } +1 + 0 \rightarrow +1 + 0 \quad +1 \rightarrow +1 \quad (\text{Baryon number is conserved}) \\ \text{L: } 0 + 1 \rightarrow 0 + 1 \quad +1 \rightarrow +1 \quad (\text{Lepton number is conserved}) \end{array}$$

Charge, Baryon number, and Lepton number is conserved. The interaction is valid

4. A neutron-neutrino interaction:

A proton interacts with an anti-electron neutrino and turns into a neutron along with emission of β^{+1} particle as follows;



Checking the validity:

$$\begin{array}{l} \text{Q:} \quad +1 + 0 \rightarrow 0 + 1 \quad \quad +1 \rightarrow +1 \quad (\text{charge is conserved}) \\ \text{B:} \quad +1 + 0 \rightarrow +1 + 0 \quad \quad +1 \rightarrow +1 \quad (\text{Baryon number is conserved}) \\ \text{L:} \quad 0 + -1 \rightarrow 0 - 1 \quad \quad -1 \rightarrow -1 \quad (\text{Lepton number is conserved}) \end{array}$$

Charge, Baryon number, and Lepton number is conserved. The decay is valid

Exchange Particles/Bosons

The process by which the forces interact has been modelled as an *exchange* of other *non-material* particle called **Boson**.

- ✓ Each of the interactions/forces has its own *exchange particles*.

Interaction/Force	Exchange Particle			What is acts upon
Strong Nuclear	Gluons between quarks	Pions between Baryons		Nucleons (Hadrons)
Electromagnetic	Virtual Photon			Charged particles
Weak Nuclear	W ⁺	W ⁻	Z ⁰	All particles
Gravitational	Graviton			Particles with masses

* *In fact Bosons are carrier of these forces*

ALL THE BEST