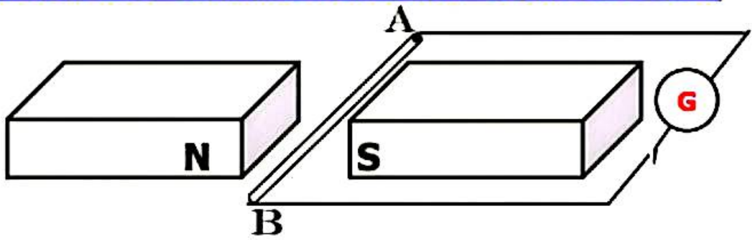
5. ELECTROMAGNETIC INDUCTION

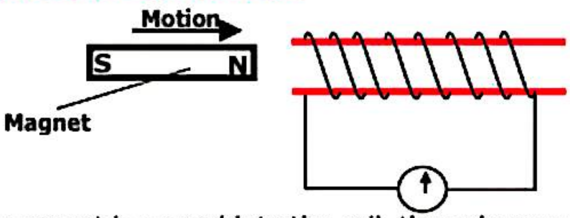
This is a phenomenon where a changing magnetic field induces an electric current.

INDUCING EMF ON A STRAIGHT CONDUCTOR



When the conductor **AB** is moved vertically downward,it cuts across the magnetic field lines and hence a current is induced making the galvanometer deflects in one direction, when the conductor is moved upwards the galvanometer deflects in the opposite direction.
When the conductor is held stationery, there is no effect on the galvanometer since there is no motion between the conductor and the magnetic field.
The magnitude of the induced current increases as the angle θ at which the conductor cuts the fieldincreases. Current is maximum when $\theta = 90^0$.
At $\theta = 0^0$ the conductor is moving parallel with the magnetic field and there is no current induced. If the conductor is held stationary and the magnet is moved now; the result are the same as above.

INDUCING EMF IN A COIL



When the magnet is moved into the coil, the galvanometer deflects in one direction, when it is moved out the galvanometer deflects in the opposite direction.
The same observations are made when the magnet is held stationary and the coil moved towards it.
When there is no motion between the coil and the magnet, there is no deflection.

Factors affecting the magnitude of induced EMF

(i) ***Speed of the relative motion***~The higher the speed the higher the EMF.

(ii) ***Strength of the magnet***~The stronger the magnet the higher the E.M.F

(iii) ***The number of turns on the coil***~The more the number of turns of coils the higher the E.M.F.

All these are summed up in ***Faraday's***law of electromagnetic inductionwhich states that.
"The magnitude of the induced e.m.f is directly proportional to the rate of change of magnetic flux linkage".

To determine the direction of an induced current.

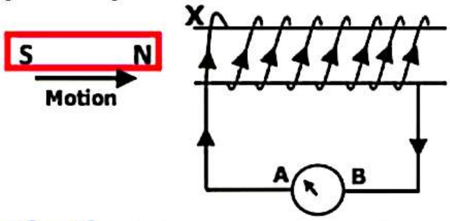
The direction in which the induced currentcan be determined in two ways:

(i) Lenz's law
(ii) Flemings right hand rule

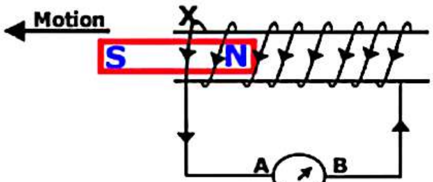
LENZ'S LAW

It states that *"The induced current flows in such a direction as to oppose the magnetic effect producing it.*

Consider a magnet being moved in to a coil.



When the *north pole* of the magnet is moved towards the coil, a current is induced in the coiland the pointer deflects towards **A** showing that the induced current flows from **B** to **A**. The induced current forms an electromagnet in the coil with a *north pole* at the end **X** in accordance withLenz's law hence coil opposes (repels) the *north pole* of the magnet. When now, the *north pole* of the magnet is moved away from the coil, the pointer deflects towards**B**showing that the current flows from **A** to **B**.



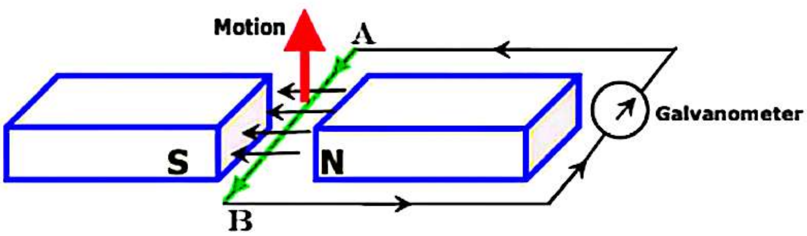
In this case the induced current in the coil flows in such a way that a *south pole*is formed at the end **X** in accordance with Lenz's law. The *south pole* of the coil attracts the *north pole* of magnet and thus opposing the movement of the magnet.

(i) FLEMING'S RIGHT HAND RULE

This is a rule used to determine the direction of the induced current given the direction of motion and that of the magnetic field.

It states that *"If the thumb and the first two fingers of the right hand are held mutually at right angles with the First finger pointing in the direction of the Field, the thuMb pointing in the direction of Motion, then the seCond finger points in the direction of the induced Current".*

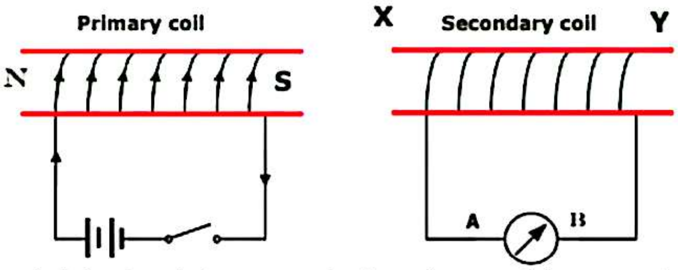
First .... Field
ThuMb .... Motion
SeCond........................... Current



When the conductor **AB** is moved upwards the current moves from **A** towards **B** using Fleming's right hand rule

MUTUAL INDUCTION

Mutual inductance occurs when a changing current in one coil induces a current in another placed close to it.
The first coil is called the primary coil while the second is called the secondary coil.
The changing magnetic flux in the primary coil links with the secondary coil and hence induces an e.m.f in it.
Consider two coils one connected to a battery source (primary coil) and the other one connected to a galvanometer.



When the switch is closed,the current in the primary coil increases from zero to maximum within a very short time causing the magnetic flux in the primary coil linking with the secondary coil to increase from zero to maximum in the same time interval and hence inducing and e.m.f in the secondary coil.

The end **X** will be a ***south pole*** and **Y** a ***north pole*** in accordance with Lenz's law. The current in the secondary coilflows in an anticlockwise direction hence the galvanometer deflects towards **B**.

However, it deflects and then come back to zero immediately since the induced e.m.f exists only when the magnetic flux in the primary coil is changing.

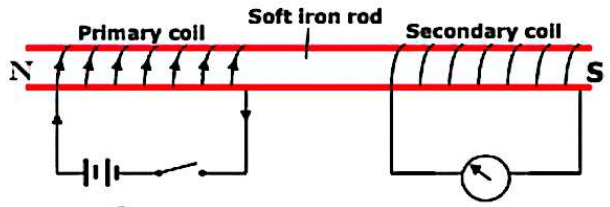
When the switch is now opened the galvanometer deflects towards **A** and then falls back to zero. The current in the primary takes a very short time to fall from maximum value to zero. Magnetic flux in the primary linking with the secondary coil also falls to zero inducing and e.m.f in the secondary coil.

The end **X** will now be a *north pole* and **Y** a *south pole* in accordance with Lenz's law hence the current is flowing in a clockwise direction in the secondary coil.

NOTE: ***The induced e.m.f in the secondary coil is much high when the current in the primary is switched off than when switched on because current in the circuit takes a much shorter time to die off than build up.***

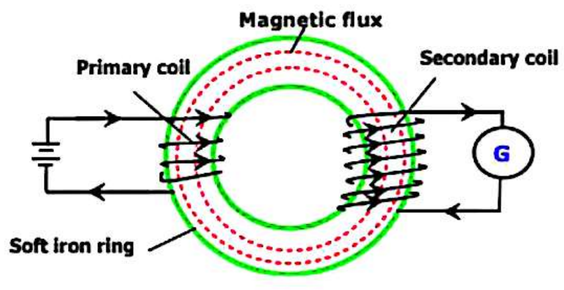
The e.m.f is induced in each turn of the secondary coil since the magnetic flux of the primary coil links with each. The total induced e.m.f is the sum of e.m.f induced in the individual turns, hence the more the number of turns in the secondary coil, the higher the ***e.m.f*** induced

The induced ***e.m.f*** in the secondary coil is highly increased if both the primary coil and the secondary coil are wound on the same soft iron rod because the soft iron concentrates the magnetic flux in both coils.



The induced ***e.m.f*** can even be increased further by winding both primary and secondary coils on the same soft iron ***ring***.

The ring enables the magnetic flux of the primary to form concentric loops within it, thus reaching the secondary coil.



Applications of electromagnetic induction

It is applied mainly in

i) ***Transformers***

ii) ***Moving coil microphone***

iii) ***Induction coil***

1. TRANSFORMERS

A transformer is a device that transfers electrical energy from one circuit to another by mutual inductance. It consists of a primary coil where an alternating current is fed and a secondary coil forming the output. The coils are wound on a common soft iron core.

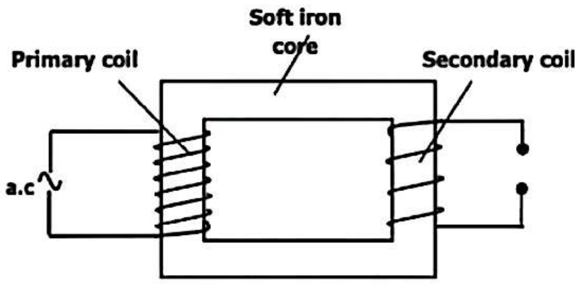
Since the induced e.m.f in the secondary coil depends on the number of turns, two kinds of transformers can be obtained; ie

i) *Step – up transformer*
ii) *Step down transformer*

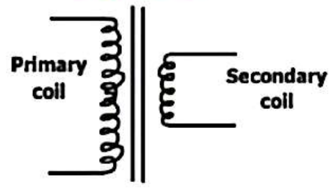
NOTE: A transformer can only work with an **(a.c)** voltage. The **a.c** in the primary coil produces achanging magnetic flux which links with the secondary coil. This in-turn induces an alternating e.m.f in the secondary coil.
If direct current (**dc**) is used it would burn out the transformer.

STEP–DOWN TRANSFORMER

It has more turns in the primary coil (**N_P**) than in the secondary coils (**N_s**)



SYMBOL



Turn Ratio $n = \dfrac{\text{Secondary turns}}{\text{Primary turns}}$

$$n = \frac{N_s}{N_p}$$

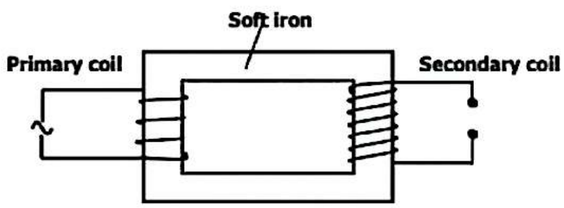
Since the secondary coils are less than the primary coils, the inducedvoltagein the secondary **V_s**issmaller than the primary voltage

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

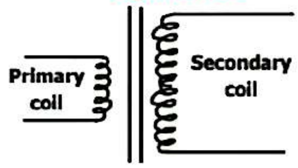
Step-down transformer is used to change voltage from a higher value to a lower value.They are used where a low output voltage is required and a higher current eg welding machine, lighting and other general consumption.
Since **Power = VI**
Then, when voltage reduces current increases.

STEP–UP TRANSFORMERS

They have more turns in the secondary coil **N_S** than in the primary coil **N_P**.
The secondary voltage is greater than primary voltage.



SYMBOL



The transformer changes a smaller voltage to a higher value.
They are used where high output voltage but smaller current is required eg in transmission lines, x-ray tubes etc.
Voltage is usually stepped – up for transmission to minimize the current to be carried by the long cables that have high resistance. **V = IR**
If a high current is transmitted, then most of the electrical energy will be lost, in the form of heat energy on the way. Hence the less the current, the less the power loss.

Power loss = I^2R

EQUATIONS RELATED TO TRANSFORMERS.

Since **Power = VI**
Then
Power input = Primary voltage x Primary current

$= V_P \times I_P$

Power output= $V_s \times I_s$

$$\text{Efficiency} = \frac{\text{Power output}}{\text{Power input}} \times 100$$

$$\text{Efficiency} = \frac{V_s \times I_s}{V_p \times I_p} \times 100$$

For an ideal transformer (ie no energy loss) the efficiency is 100% thus
$V_P \times I_P = V_S \times I_S$

$$\frac{I_p}{I_s} = \frac{V_s}{V_p}$$

But $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

Hence also $\frac{I_p}{I_s} = \frac{N_s}{N_p}$

NOTE: *This formula with current applies only when the efficiency of the transformer is 100%*

EXAMPLES

1. A transformer is designed to step-up the mains of **240V** to **1000V**. if the primary coil has **1500** turns, find the number of secondary coil turns
2. A transformer connected to **240V** mains power supply has **480** turns in the primary coil has **36** turns in the secondary coil. Calculate the voltage in the secondary coil
3. A transformer is used to provide a p.d of **100kV** to an X-ray tube from a **250V** a.c mains supply. A current of **0.01A** flows in the X-ray tube and the transformer is **100%** efficient. Calculate
   i) Current in the primary coil. ***(4A)***
   ii) Ratio of number of secondary turns to primary

4. A student designed a transformer to supply a current of **10A** at a Pd of **60V** to a motor from an a.c mains supply of **240V**. If the efficiency of the transformer is **80%** Calculate
   i) The power input. ***(750W)***
   ii) The current in the primary coil. ***(3.125A)***
5. A transformer supplies a current of **3.6A** at a potential difference of **20V** to a motor from an a.c mains supply of **240V**. If the efficiency of the transformer is **50%**,calculate
   a) Power supplied to the transformer ***(144W)***
   b) Current in the primary coil. ***(0.6A)***

ENERGY LOSSES IN A TRANSFORMER

Energy in a transformer is lost in four main ways;-

i) *Flux leakage*

This is the magnetic fluxfrom the primary coil that fails to link with the secondary coil. This reduces ***e.m.f*** induced in the secondary.

Flux leakage is reduced by efficient design of the transformers to ensure maximum flux linkage ie by winding the secondary coil on top of the primary coil or wounding the two coils next to each other on a common core.

ii) *Copper losses (Resistance of coils)*

This is heat generated in the coils due to the resistance of the wire making up the coil. Thisheat leads to power loss. Power loss = I^2R.

To reduce copper losses, thick copper wires are used in the secondary coils of a step-down transformer and the primary coils of step-up transformers to reduce this heating effect.

iii) *Eddy currents*

This is a current that flow in the soft iron core. The alternating magnetic flux in the soft iron core cuts the very own soft iron core; inducing an **e.m.f** in it.This **e.m.f** sets up **eddy currents** that generates heat.
This effect reduces the power transfer to the secondary coil.

Eddy currents can be minimized by laminating the core ie made of thin sheets of insulated soft iron plates. The current induced in each place is small and hence minimum heating effect.

iv) *Hysteresis loss.*

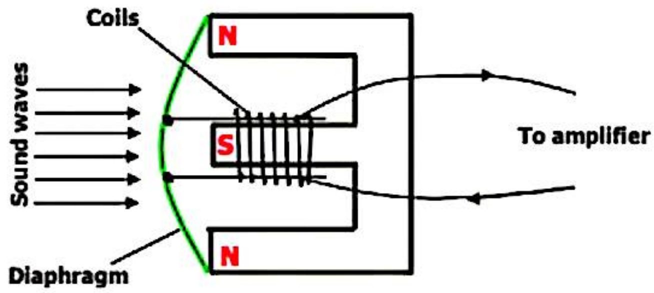
Hysteresis is the loss of energy as the iron core is heated by being repeatedly magnetized and demagnetized.

Hysteresis can be minimized by using a soft iron core, which is easily magnetized and demagnetized.

Note: Practically despite all the above measures taken to eliminate heat loss, it is still generated in any transformer. The heat generated in small transformers used in domestic appliances eg T.V, Radio etc is low and therefore air is sufficient to cool them.

However heat generated in larger transformers in powers station and along mains transmitting lines is cooled by oil, which ***does not evaporate easily.***

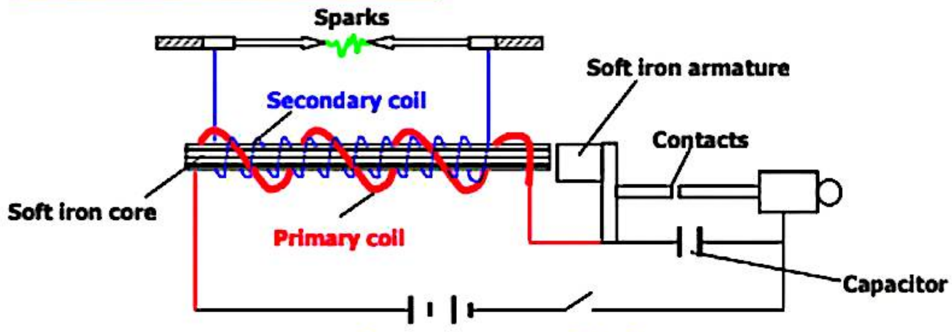
2. MOVING COIL MICROPHONE



A moving coil microphone has a light coil situated in a strong magnetic field of a cylindrical pot magnet and connected to a diaphragm. Sound waves from a source set the diaphragm into vibrations causing the coil to move **to** and **fro,** thus cutting the magnetic field. A varying e.m.f is induced in the coil which in turn sets up a varying current in the coil.

The current has the same frequency as the sound wave of the source. An amplifier is used to increased the amplitude of this current before being fed to the loud speaker to be converted back to sound.

3. THE INDUCTION COIL



It consists of a primary coil of ***few turns*** of ***thick*** copper wirewound on the same soft iron core with secondary coils of ***many turns*** of ***thin*** copper wire.

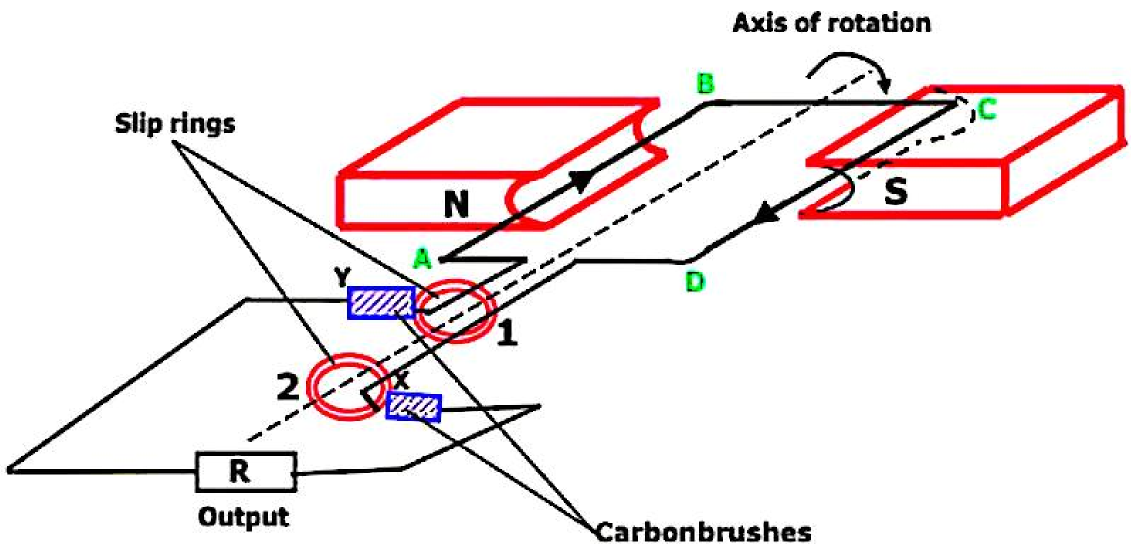
The primary coil is connected to a **dc** of low voltage.

- *When the switch is closed, the soft iron core becomes magnetized and attracts the soft iron armature.*
- *This opens the contacts and cuts offthe primary current rapidly reducing the magnetic field to zero.*
- *This in turn induces a large* **e.m.f** *in the secondary coil by mutual induction and Sparks jumps across the gap btn the ends of the secondary coil.*
- *The sparks are used to ignite petrol air mixture in a car engineand the process repeats itself*

NOTE: ***A capacitor is connected across the contacts to minimize the sparking.***

ALTERNATING CURRENT (A.C) GENERATOR.

A generator is a device that converts mechanical energy to electrical energy.



It consists of two slip rings **1** and **2**, two carbon brushes **X** and **Y**, a permanent magnet and a coil.The current enters and leaves the coil thru the brushes which press against the slip rings.

The brushes are made of carbon because it is <u>slippery to offer lubrication</u> and a <u>good conductor of electricity</u>.

As the coil rotates its sides cuts the magnetic flux and therefore a current is induced in it.

Applying Fleming right hand rule, the current flows in the direction

A – B – C–D.

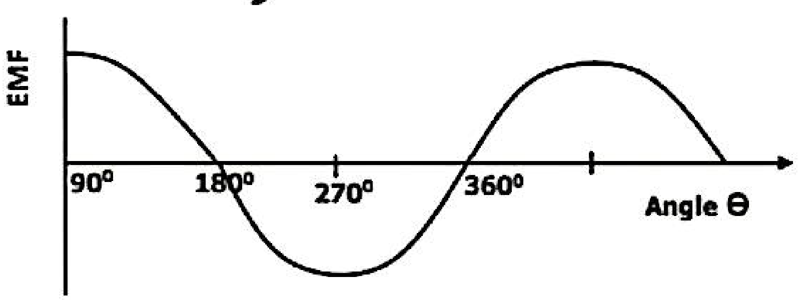
This current flows thru slip-ring **2** and brush **X** then brush **Y** and slip ring **1** then completes the circuit.

Brush **X** is thus positive terminal while **Y** is negative. As the coil rotates from the horizontal to the vertical position the angle at which the sides of the coil cut the magnetic field reduces from **90^0** to **0^0**.As a result the induced **E.m.f** reduces from maximum to zero.

In vertical position side**AB** and **CD** are parallel to the coil,hence no e.m.f is induced.

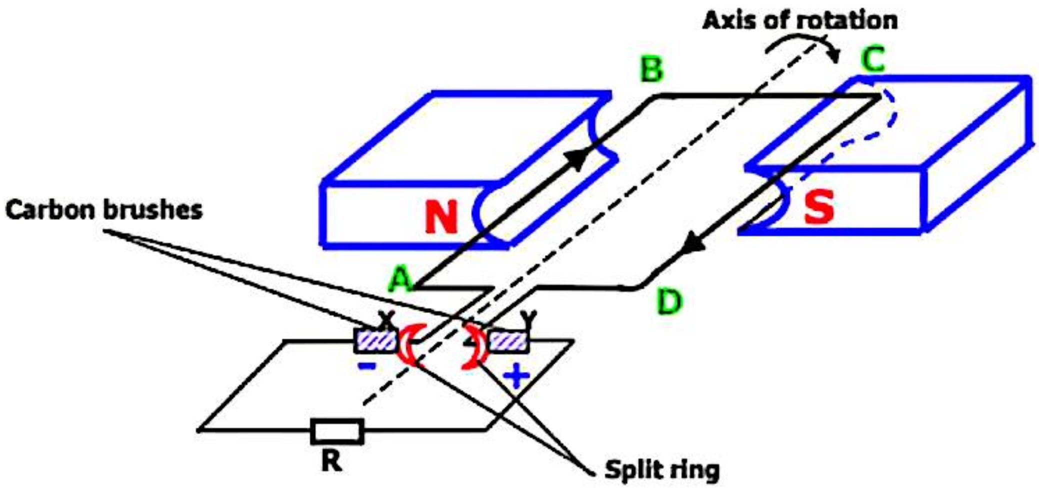
When the coil rotates past the vertical position, side **AB** moves downwards as side **CD** moves upwards, the direction of the current thru the wire reverses and it moves through ***D – C – B – A***.Brush **Y** is now positive and brush **X** is negative.

The graph of ***e.m.f*** induced against the **angle Θ**as the coil rotates is a sinusoidal.At **90^0** the ***e.m.f*** induced is max^m



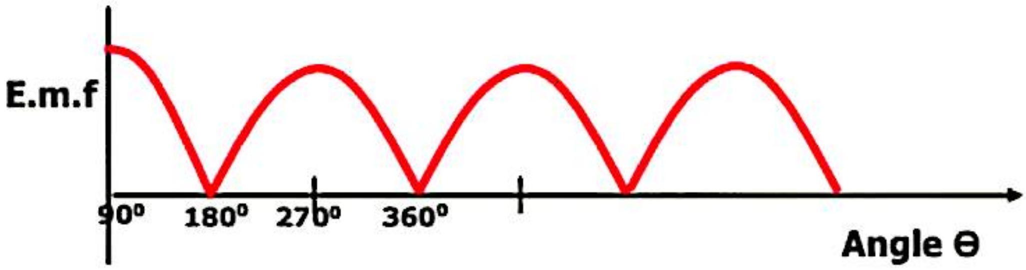
DIRECT CURRENT (D.C) GENERATOR.

Itconsists of a permanent magnet, two carbon brushes and a split ring.



As the coil rotates in clockwise direction from the horizontal position into the vertical position, the ***e.m.f*** induced decreases from max to zero,applying Fleming's right hand rule, the current flows in the direction ***A – B – C – D***. Brush **Y** is positive and **X** is negative. When the coil goes into the vertical position, no***e.m.f*** is induced.The brushes touch the gaps within the commutator. When the vertical position is passed the split rings exchange the brushes and hence the direction of the current does not change.

The graph of ***e.m.f*** induced against the **angle Θ** as the coil rotates is a as follows



NOTE : The diff btn an AC and a DC generator is that an AC has two ***slip*** rings while a DC has a ***split*** ring.

The induced **e.m.f** or current for both **AC** and **DC** generator depends on:

- **(i)** ***Speed of rotation***~ the faster the speed the higher the current.
- **(ii)** ***No of turns of the coil*** ~ the more the turns the higher the current.
- **(iii)** ***Strength of the magnetic field***~ the stronger the magnet the higher the current.