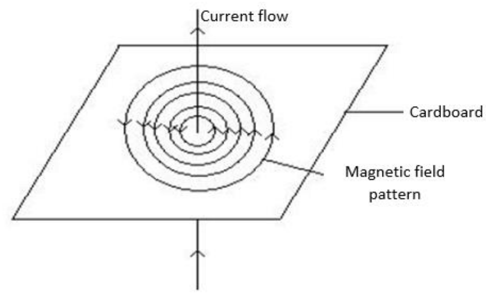
ELECTRICITY AND MAGNETISM

Magnetic effect of an electric current

Magnetic flux pattern due to a current in a long straight wire

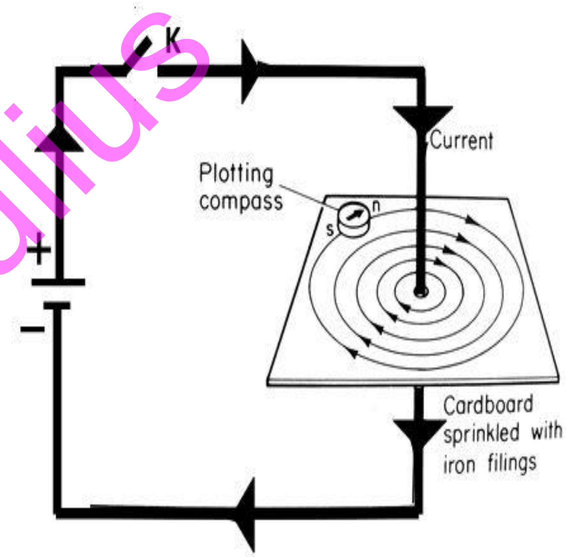
- ✓ A magnetic field is always set up around a conductor carrying current.
- ✓ This field will cause the iron fillings to arrange themselves in concentric circles around the wire, indicating that the field lines are circles around the wire.
- ✓ The direction of the field depends on the direction of flow of current in the wire *(see diagram >>>)*



- ✓ The direction of these field lines can be found by using
  - **(i)** plotting compass
  - **(ii)** right hand Grip rule
  - **(iii)** Maxwell's screw

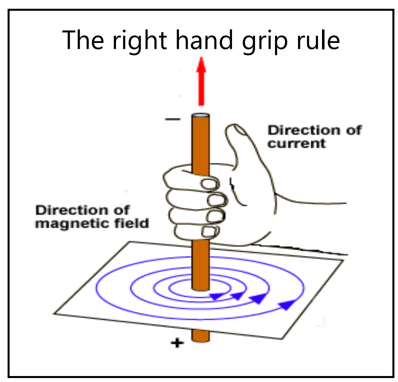
Plotting compass

- A fine layer of iron fillings is sprinkled on the cardboard
- The switch K is closed and current flows in the coil of wires
- The cardboard tapped gently.
- The fillings set in series of concentric circles about the wire as center.
- A small plotting compass placed on the card indicates the direction of the flux.
- If the current is reversed by changing over the battery connections, the compass needle will swing round and point in the opposite direction, but the pattern of the flux remain unchanged. (*This indicates that only the direction of the field lines changes when current reverses)*



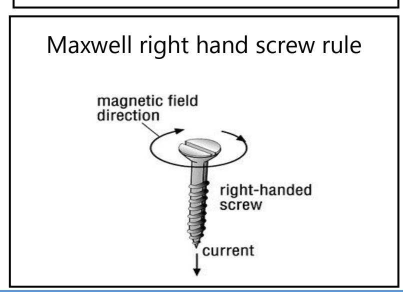
Right hand grip rule

If a conductor is grasped in the right hand, with the ***thumb pointing in the direction of current, then the direction of the fingers will give the direction of the magnetic flux***.

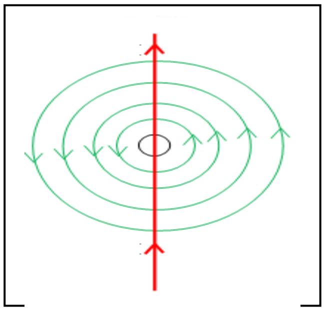
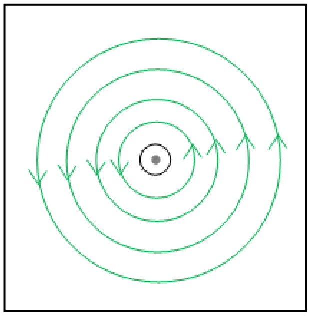
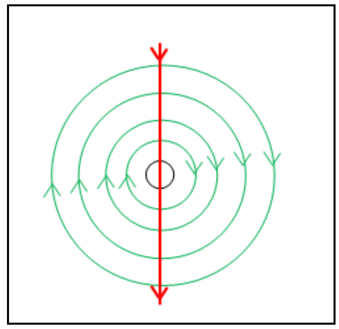
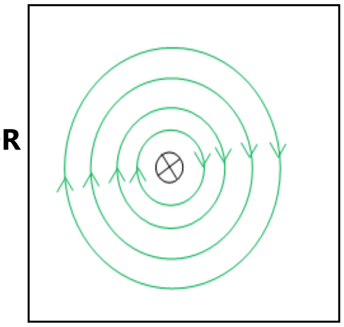


Maxwell's right hand screw rule

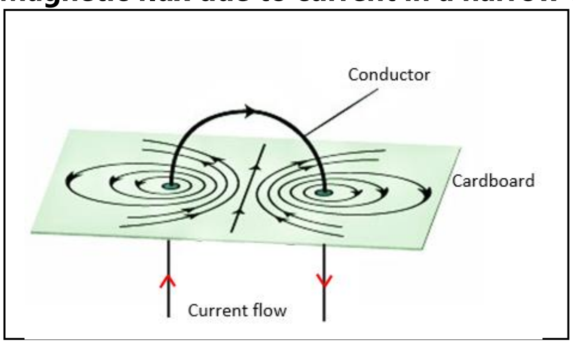
Imagine a screw being screwed along the wire in the direction of the current. ***Then the direction of rotation of the screw as it enters gives the direction of magnetic field***.



Magnetic field pattern due to a long isolated conductor carrying current

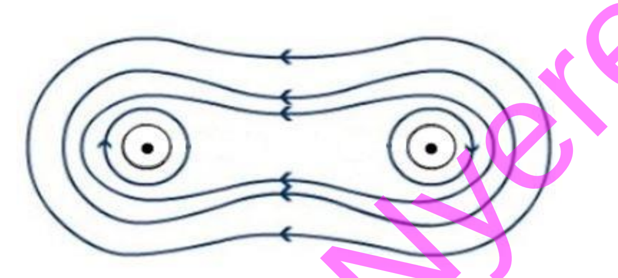
Current out of the page	Current into the page
 **OR** 	 **OR** 

Magnetic flux due to current in a narrow circular coil

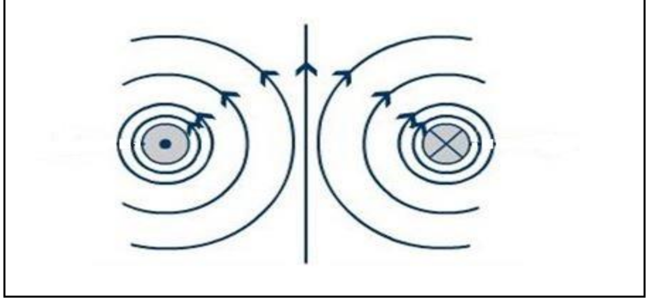


Magnetic field patterns for two straight wires

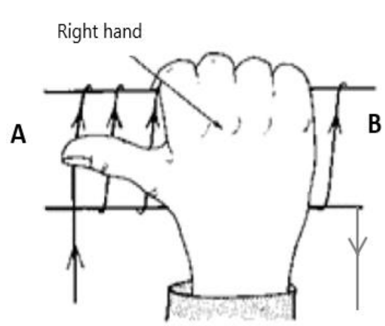
(a). Carrying current in the same direction



(b). Carrying current in the opposite direction



Right hand grip rule and the solenoid

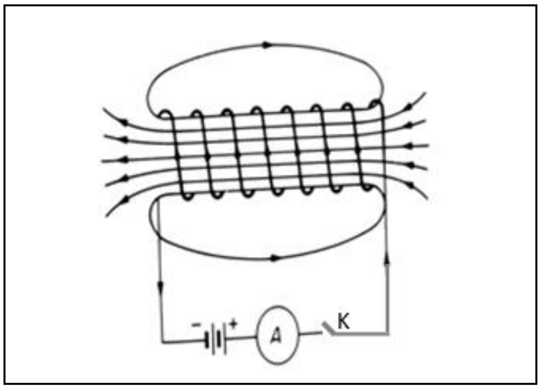


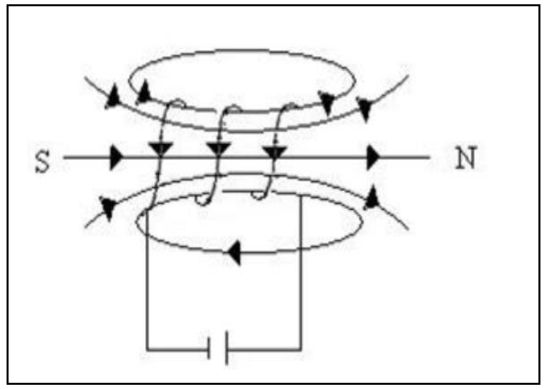
In order to determine the polarity at the ends of a solenoid when current flows through it, the right hand can as well be used but this time considering the folding of the fingers of the right hand to take the direction of current around the windings of the coil and then the thumb will be North Pole

*From the figure on the left, then side **A will be North Pole while B is South Pole***

The magnetic field lines will then flow from the north pole of the solenoid to the south pole of the solenoid as illustrated below

Magnetic flux in a solenoid





Electromagnets

- ✓ An electromagnet is a current carrying coil of wire that acts as a magnet.
- ✓ Electromagnets therefore are current carrying coil of wire that act as a magnet
- ✓ When soft iron is placed inside a solenoid it will be strongly magnetized when the current is flowing. However when no current is flowing it loses its magnetism. This property of iron is used whenever strong temporally electromagnets are needed.
- ✓ On the other hand when steal is used, instead of iron, relatively weaker electromagnet is formed, but unlike iron steel retains its magnetism, even when no current is flowing in the solenoid.

The strength of the field of an electromagnet can be increased by;

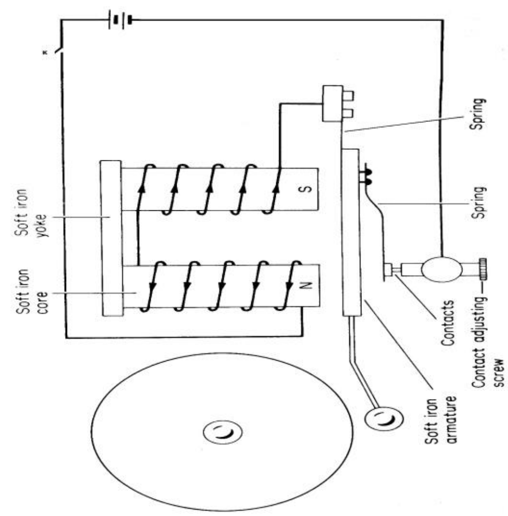
1) Increasing the magnitude of the current.
2) Increasing the number of turns of the coil.
3) Placing an iron core inside the solenoid/coil.
4) Increase the surface area / length of the electromagnets.
5) Using soft iron instead of steel.

Applications of electromagnets

1.Electric bell, **2.** Telephone system (microphone)**,**
3.Moving coil loud speakers **4.** Electric motors**,**
5.Galvanometers. **6.** Voltmeters.
7.Ammeters
8. For lifting magnetic materials in industries

Electric Bell

- ✓ An electric bell consists of a hummer, a gong soft iron armature, contact adjusting screw, a bell push which is the switch, steel spring and an electromagnet which is made of two coils wound in opposite direction on two iron cores.
- ✓ When the current flows in the circuit, it causes iron core to be electro magnetized.
- ✓ It attracts the soft iron armature and the circuit breaks at the contact point causing the electromagnet to lose its magnetism.
- ✓ The spring of steel which holds the armature back so that the points are in contact again, thus the process is repeated with the continued striking of the gong by the hummer.

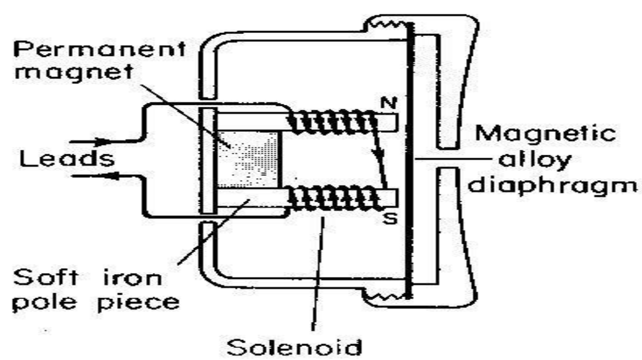


Mode of action

- ✓ When the current is switched on, the soft iron cores are magnetized such that their adjacent ends acquire opposite polarities.
- ✓ The soft iron armature is then attracted and moves towards the electromagnet. This causes the harmer to hit the gong producing sound.
- ✓ As the armature moves towards the electromagnet, the circuit is broken at the contact and as a result the electromagnet loses its magnetism, hence the spring pulls the armature back, and contact is made again.
- ✓ This process is repeated on and on, and the armature together with the harmer vibrates to and fro thus producing a continuous sound.

Telephone receiver

- ✓ It consists of an electromagnet made up of soft iron and a permanent magnet which attracts the diaphragm and keeps it under tension.

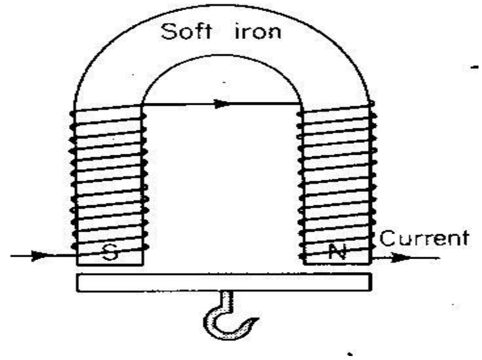


Mode of working

- ✓ When a person speaks at the mouth piece, the sound energy is converted to electrical energy which has the same frequency as the original sound.
- ✓ This electrical energy is transmitted through cables to the telephone receiver.
- ✓ This electric current now entering the receiver magnetizes the electromagnet to varying strengths, depending on the frequency of the sound energy.
- ✓ This causes the diaphragm to experience a varying magnetic force and therefore it is set to vibrate with the frequency of the original sound, producing exactly similar sound as the original.

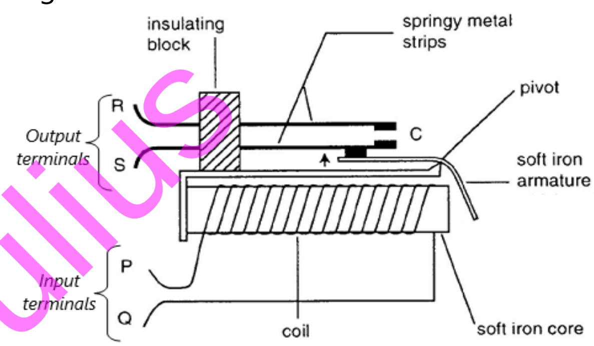
Lifting Magnetic Materials in Industries

- ✓ When current passes through the coil, a strong but temporary magnetism is induced on the soft iron magnetic material.
- ✓ This attracts the magnetic material of the load lifter
- ✓ The magnetism is lost when current is switched off and gained when the current is switched on.



Magnetic relay switch

- The magnetic relay is a switching device, which uses an electromagnet.
- It uses a small current in the primary circuit *(input circuit)* to control a larger current in the secondary circuit *(output circuit)*
- It has two or more completely separate circuits. *(Input circuit at terminals P and Q. Output circuits at R and S)*.
- The primary and secondary circuits have no direct or electrical contact with each other



Mode of working of a relay switch

- When the current flows in the coil from the input circuit the soft iron core becomes magnetized and attracts one end of the armature.
- The armature rocks at its pivot and closes the contact at C in the output circuit.

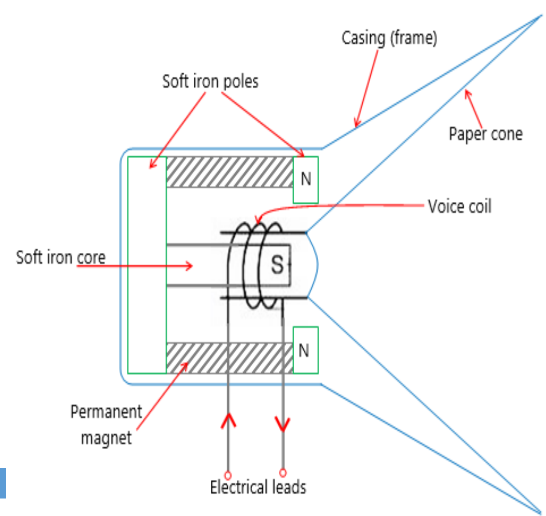
Note

When the primary circuit is switched off, the soft iron core ceases to be an electromagnet and as a result the armature is no longer attracted and returns to its original position.
The top gets lowered and the contact now opens at C and the current in the secondary circuit is switched off.

The moving coil loudspeaker

- A loudspeaker is a device that converts electrical energy to sound energy
- The loud speaker works on the principal that a force is exerted on the coil that is in the magnetic field causing it to move and hence moving the coil and the paper cone that produces sound waves

Structure: It consists of the cylindrical coil placed in soft iron core which is attached to a permanent magnet.



Working of a loud speaker

- Varying current flows thru the terminal into the coil which is in a magnetic field.
- The coil experiences a varying force which causes it and the paper cone to vibrate to and fro.
- This sets the air in contact with it into vibration hence setting up a sound wave which follows the same pattern as the original electrical signal.

Energy changes in a loudspeaker

Electrical energy ⟶ *kinetic energy* ⟶ *sound energy*

Force on a conductor carrying current in a magnetic field

- ✓ Experiments have shown that a current carrying conductor (wire), placed in a magnetic field experiences some force due to the field provided the magnetic field lines are not parallel to the wire.
- ✓ The magnitude (size) of this force depends on (*factors determining the magnitude of force on current carrying conductor*);

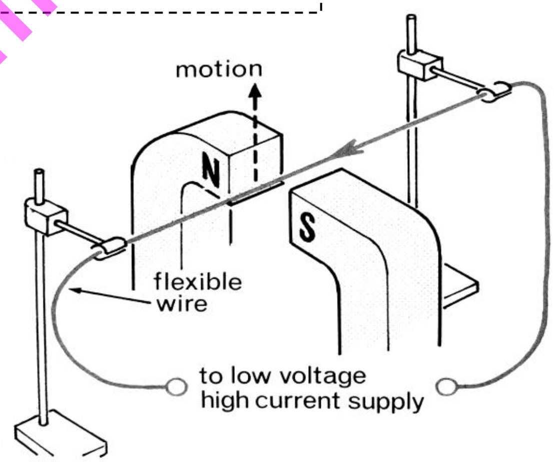
1) The strength of the magnetic field.
2) The size of the current in the wire.
3) The length of the wire

$$F = BIl;$$

B = magnetic field strength
I = Current through the conductor
l = Length of the conductor

Demonstration

- In the figure above, the flexible wire is loosely supported in the strong magnetic field of two permanent magnet.
- When the switch is pressed, current flows in the wire which jumps up as shown.
- If either the direction of the current or the direction of the field is reversed, the wire moves downwards.



Fleming's left hand rule

The direction of this force experienced by a wire (conductor) carrying current in a magnetic field can be determined (predicted) by **Fleming's Left hand rule**

It states that if the first three fingers of the left hand are held at right angles to each other so that the middle finger points in the direction of Current and the first finger points in the direction of field, the thumb will point in the direction of force.

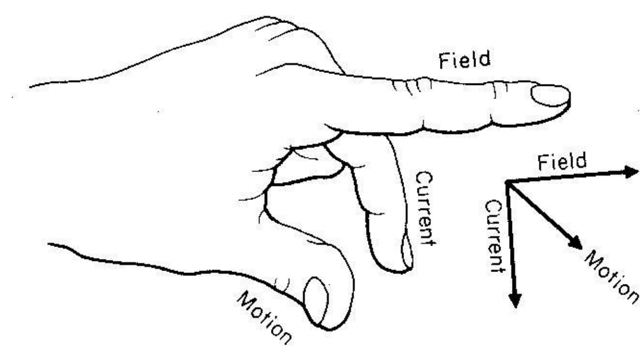
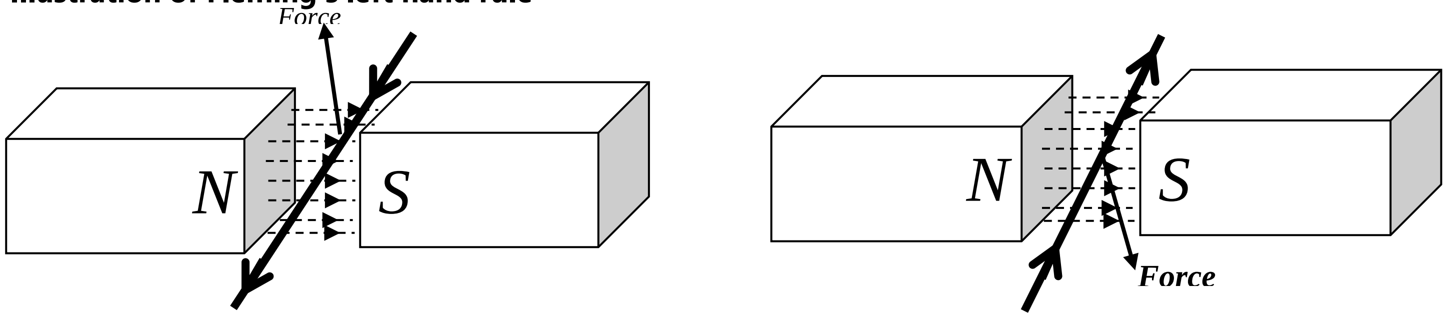
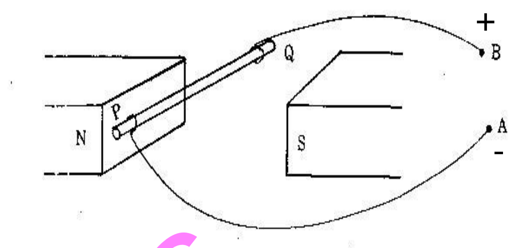


Illustration of Fleming's left hand rule

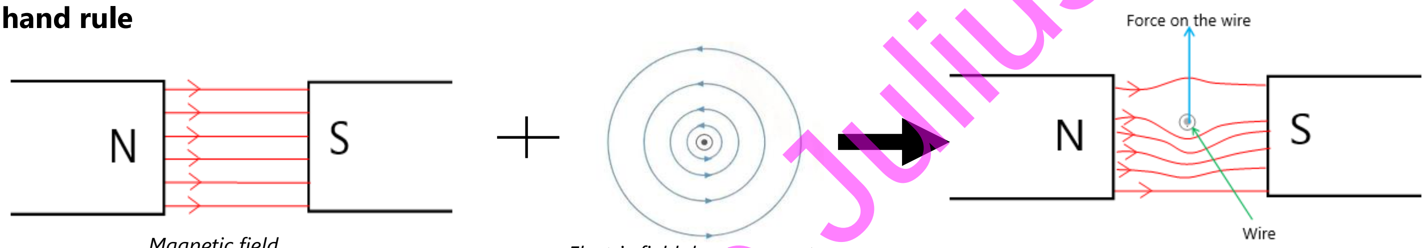


✓ When current flows through the wire, the wire jumps upwards as shown. (*see diagram on the right*)

✓ If their direction of current or magnetic field is reversed the wire moves down wards



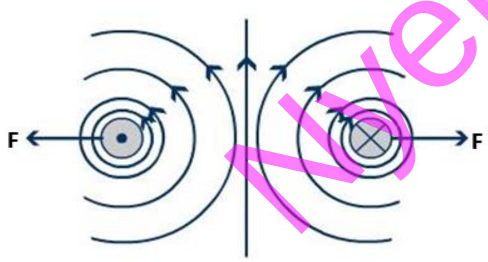
Interaction of magnetic and electric fields for Fleming's right hand rule



Magnetic field   *Electric field due to current out of the paper*   *Resulting force on the conductor*

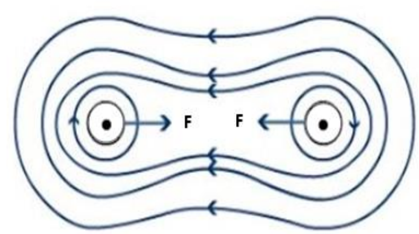
Force between two parallel conductors carrying current

(a) In the opposite direction



The forces on the wires repel each other.

(b) In the same direction



The forces on the wires attract each other

Factors affecting magnitude of force on a current carrying conductor

The magnitude (size) of force on a current carrying conductor is directly proportional to

(1) Magnitude of current in the wire. (*Increasing amount of current increases the size of force*)

(2) Field strength of the magnet. (*Using a stronger magnet increases the size of force*)

(3) The length of the conductor. (*increasing the length increases the size of force*)

N.B: *The effect of the magnetic field on a current carrying conductor is referred to as* ***motor effect***.

Application of the motor effect

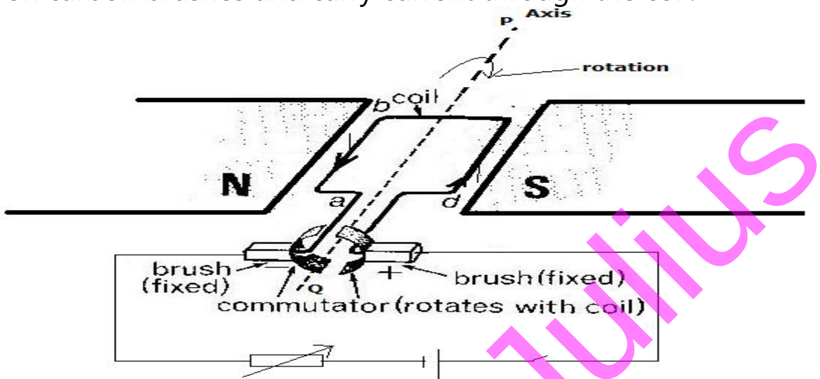
(1) Simple D.C. motor
(2) Moving coil galvanometer
(3) Moving coil loud speaker.

The simple electric motor (D.C Motor)

- A D.C. motor is a machine which transfers electrical energy into mechanical energy.

Structure: It consists of a rectangular coil ABCD which can rotate about affixed axis PQ in a magnetic field provided by the permanent magnet.

- The two ends of the coil are soldered to two halves of a copper split rings (*also called commutator*), pressing lightly on carbon brushes and carry current through the coil.



Mode of working of a motor

- When current is passed through the coil, the side of the coil **ab** experience an upward force while **cd** experiences a downward force.
- The two forces form a couple and therefore the coil rotates in a clockwise direction about the axis **PQ**
- When the coil reaches the vertical position, the brushes loose contact with the commutators and no current flows through the coil
- The coil continues past the vertical position because of its initial momentum
- This causes the brushes to change contact with the commutators, thereby reversing the direction of current in the coil. Hence the coil continues to rotate in the same direction.

N.B: *The direction current through the coil changes whenever the coil is in vertical position but the direction of current (e.m.f) in the external circuit never changes.*

Energy Losses in a practical motor

(1) Energy loss due to Eddy currents
(2) Energy loss due to friction between the carbon brushes and the commutators
(3) Energy loss due to resistance in the windings. This results in heat generated
(4) Energy loss due to magnetic reversals (*also called Hysteresis*)

How to increase the efficiency of a motor

(1) Laminating the core to reduce eddy currents
(2) Lubrication the spaces between the brushes and the commutators
(3) Using thick copper wires of low resistance for winding the coil
(4) Using a core made of soft iron which has low hysteresis
(5) Increasing the number of turns of the coil

Applications of electric motors

(i) Electric fans
(ii) Washing machines
(iii) Hair driers
(iv) Power drills
(v) Refrigerators
(vi) Radio cassettes

Back e.m.f in an electric motor

- ✓ When an electric motor is running, it also acts as a dynamo and sets up a small e.m.f that flows in the reverse direction, called **back e.m.f**.
- ✓ Back e.m.f there opposes the e.m.f applied to rotate the motor
- ✓ The Net e.m.f $E_{net} = E - E_b$ *Where* E = *applied e.m.f and* E_b = *back e.m.f*

The resulting Current $I = \dfrac{E - E_b}{R}$, *Where R is the* resistance *of the coil*

Example

A D.C motor has amerteure resistance 6.0Ω. If it draws a current of 15A when supplied with a p.d of 240V. Calculate the;

(a) The power input in the motor
(b) Power wasted in the windings
(c) Efficiency of the motor

Solution

(a) Power in put, $P_{in} = \mathrm{IE} = 15 \times 240 = 3600\mathrm{W}$

(b) Power wasted, $P_w = I^2R = 15^2 \times 6 = 1350W$

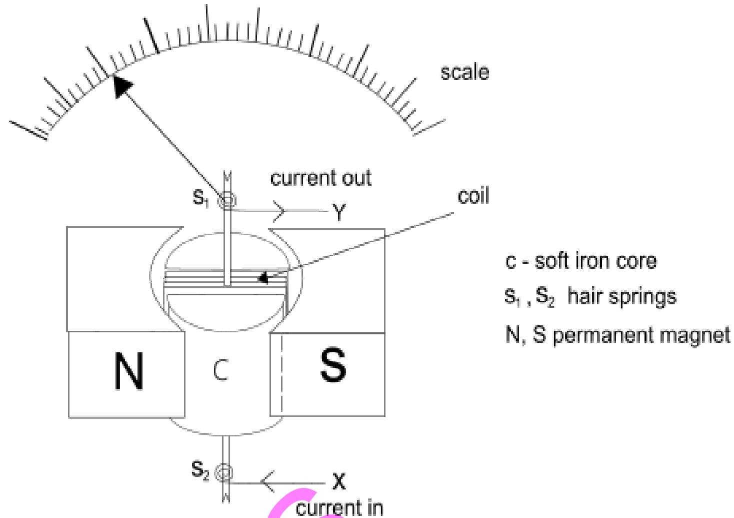
(c) Useful power $P_{out} = P_{in} - P_w = 2250W$

$$efficiency(\eta) = \frac{P_{out}}{P_{in}} \times 100\% = \frac{2250}{3600} \times 100\% = 62.5\%$$

The Moving Coil Galvanometer

A moving coil galvanometer is a device that is used to detect small current or small p.d or detect flow of electric charge

Structure



- Consist of a fine insulated copper wire wound on a soft iron or light aluminum frame.
- The frame is pivoted on bearings.
- The coil is connected to the pointer which moves over the linear scale when it turns.

Mode of working of moving coil galvanometer

- The current to be measured is fed in at X and out Y.
- The vertical side of the coil experience equal and opposite forces which constitute a couple.
- The couple then turns the coil until when its magnitude balance with tension in the spring.
- The position of a coil is then the measure of current through.
- This current is read off on the position of the pointer on the scale

Note:

(i) *A coil put is put in soft iron cylinder so as to concentrate the magnetic flux and make the magnetic flux density is constant. This results in force on the sides of the coil to be proportional to current.*

(ii) <u>A sensitive galvanometer</u> is one which can detect very small currents

How to increase the sensitivity of a moving coil galvanometer

(i) Increasing the number of turns of the coil
(ii) Using a stronger magnet. (*To provide strong magnetic field)*
(iii) Using weak hairy springs
(iv) Using a coil of large area
(v) Suspending the coil so that it can rotate freely

Advantage of moving coil Galvanometer

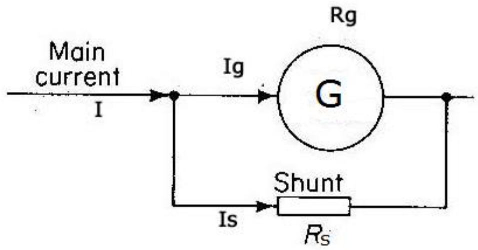
(i) It is very sensitive
(ii) It has fairly low resistance
(iii) It has a uniform scale
(iv) It can be made to measure different ranges of current and voltages
(v) External field around the galvanometer has no influence because of the strong magnetic field between the magnets and the soft iron.

Disadvantages of moving coil galvanometer

(i) Can only measure D.C current (cannot measure A.C)
(ii) The strength of the permanent magnet reduces with time thus causing errors in measurement

Conversion of Galvanometer to ammeter

To convert a galvanometer to ammeter, a low value resistor called a **shunt** is connected in parallel with the galvanometer



$>> I = I_g + I_s \quad \Rightarrow I_s = I - I_g$

$>> \text{also p.d across } G = \text{p.d across Shunt}$

$$I_g \times R_g = I_s \times R_s$$

Basic points to note

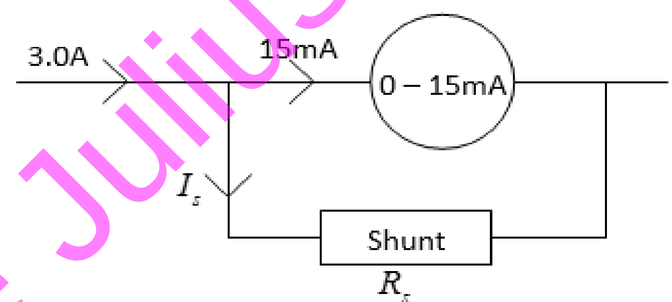
(1) Most of the current will pass through the shunt and just a small fraction will pass through the galvanometer (*to prevent damage of the coil of galvanometer*)

(2) The p.d across the galvanometer is equal to the p.d across the shunt

(3) The current through the shunt is greater than the current through the galvanometer

Example:

A moving coil galvanometer has a resistance of 5.0Ω and gives a full scale deflection ***(f.s.d)*** when a current of 15.0mA flows through it. Find the value of the resistance necessary to convert the galvanometer into an ammeter reading up to 3A: **Solution**



$I = 3.0A, \; I_g = 15\times10^{-3} A$

$\Leftrightarrow I_s = 3 - 15\times10^{-3} = 2.985A$

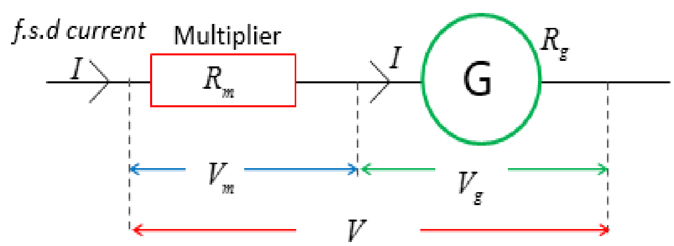
$\text{p.d across } G = \text{p.d across Shunt}$

$$15\times10^{-3}\times 5 = 2.985\times R_s$$

$$\Rightarrow R_s = 0.025\Omega$$

Conversion of Galvanometer to voltmeter

To convert a galvanometer to voltmeter, a high value resistor called a **Multiplier/robin** is connected in series with the galvanometer



$>> V = V_g + V_m \quad \Rightarrow V_m = V - V_g$

$>> \text{also p.d across Galvanometer} = I_g \times R_g$

$>> \text{and p.d across Multiplier} = I_m \times R_m$

Basic points to note

(1) The multiplier and galvanometer are in series

(2) The current through the multiplier and the galvanometer are the same

(3) The p.d across the multiplier and the galvanometer are the same

Example:

A galvanometer reads 2.5mA at f.s.d and has a resistance of 2.0Ω. How can the galvanometer be adopted to a voltmeter to read a maximum voltage of 15.0V at f.s.d

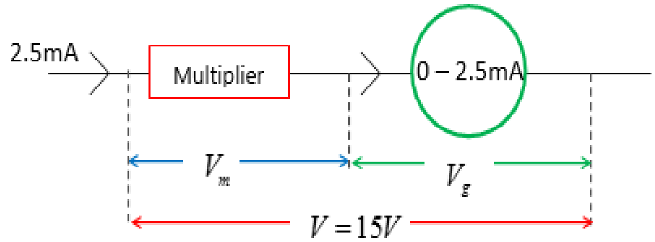
Solution

$From \;\; V = V_g + V_m$

$\Rightarrow 15 = \left(2.5\times10^{-3}\times2\right) + \left(2.5\times10^{-3}\times R_m\right)$

$\therefore R_m \;=\; 5998\Omega$

Thus the by connecting a 5998Ω resistor in series with galvanometer, it will work as a voltmeter to measure maximum voltage of 15.0V



Questions:

1) A galvanometer has a resistance of 20 ohms and gives the f.s.d of 200m

(a) What is the voltage a cross the galvanometer

(b) What resistance (shunt) must be connected across the galvanometer for it to read 10 A

(*Ans: 4.0v, R_s = 0.41 Ω*)

2) A galvanometer of resistance 12Ω reads 200mA at f.s.d. What resistance must be connected in series with it in order to read 8V? (*Ans: = 28Ω*)

3) A current of 25mA passes through the galvanometer of resistance 10Ω.How can the galvanometer be adopted;

(a) To a voltmeter in order to read 10V at f.s.d.

(b) To ammeter to read 5A at f.s.d

4) A galvanometer has a coil of resistance 8 Ω and gives a full-scale deflection when a current of 0.5 mA is supplied. Calculate the resistance that can be used to convert it into an ammeter measuring up to 5 A.

ELECTROMAGNETIC INDUCTION

- An e.m.f is always induced in a coil placed in a magnetic field whenever the flux (field lines) through the coil changes
- If such a coil is connected to a closed circuit, the induced e.m.f causes current to flow in the circuit. This effect is called *electromagnetic induction.*
- ***Electromagnetic induction*** is therefore the effect of producing electric current due to changing magnetic field in the coil (conductor).
- The direction of the induced current (e.m.f) is determined using Lenz's law

Factors affecting the magnitude of the induced e.m.f above

(i) The number of turns of the coil
(ii) The strength of the magnetic field
(iii) The area of the coil
(iv) The resistance of the coil
(v) The rate of change of flux through the coil

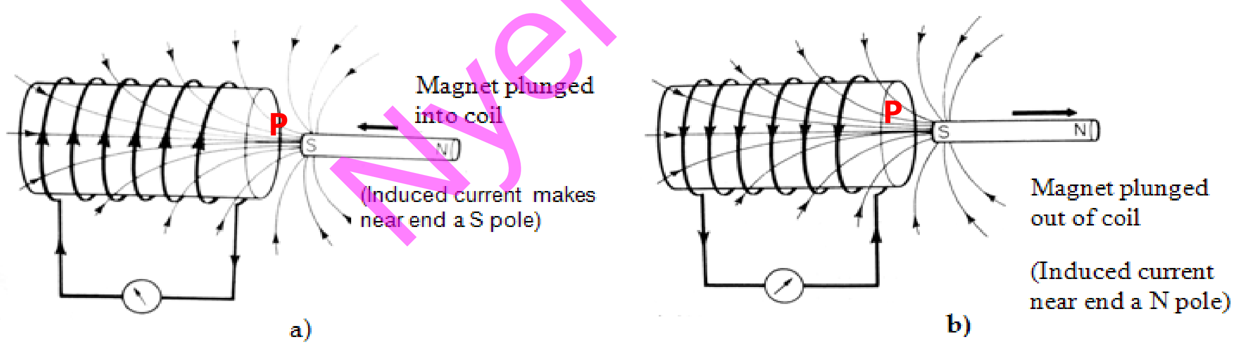
Laws of electromagnetic induction: There are two laws of electromagnetic induction, namely *Lenz's law* and *Faraday's law*

Faraday's law of electromagnetic induction

Whenever there is a change in the magnetic flux linked with a circuit, an e.m.f is induced. The strength of which is proportional to the rate of change of the flux linked with the circuit.

Lenz's law: states that the direction of the induced current (e.m.f) is always in such a way to oppose the change producing it.

Illustration of Lenz's law



In fig. (a): The south pole of the bar magnet is approaching the solenoid at **P**.
The induced current in the coil therefore must flow in such a way that the end **P** of the solenoid behaves as a **south pole** in order to oppose *(or repel)* the incoming south pole of the bar magnet

In fig. (b): The south pole of the bar magnet is being withdrawn from end of the solenoid at **P**.
The induced current in the coil therefore must flow in such a way that the end **P** of the solenoid attracts the **south pole** of the bar magnet in order to oppose the removal of magnet. Therefore end P of the solenoid becomes a **North Pole.**

Fleming's Right Hand rule (dynamo rule)

If the first finger, second finger and the thumb right hand are placed at right angles to each other with the First finger pointing in the direction of the Field and the thumb in the direction of the Motion of the wire, then the second finger will point in the direction of the induced Current.

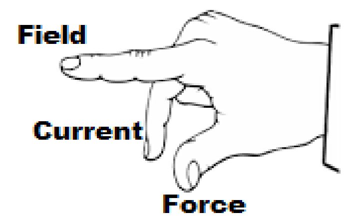
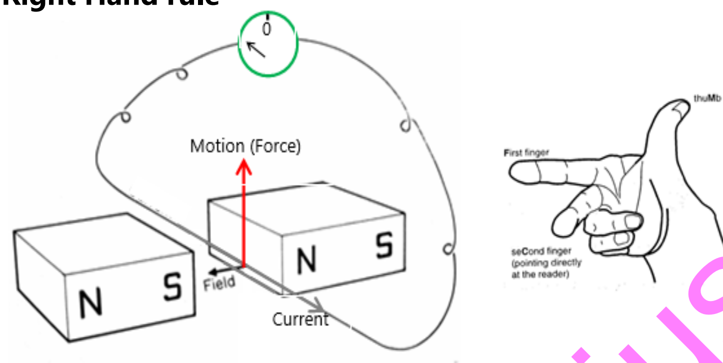


Illustration of Fleming's Right Hand rule



- ✓ When the wire is moved upwards, induced current in the wire flows downwards (*anticlockwise*) and the galvanometer deflects in one direction
- ✓ When the wire is moved downwards, the induced current in the wire flows upwards (*clockwise)* and the galvanometer deflects in the opposite direction.
- ✓ When the wire is left stationary, no current is induced in the wire and the galvanometer shows no deflection.
- ✓ Also when the wire is moved parallel with *(or along)* the field lines no current is induced in the wire and the galvanometer shows no deflection.
- ✓ The first two observations above are also obtained when the wire is stationary but the magnets are moved up or down

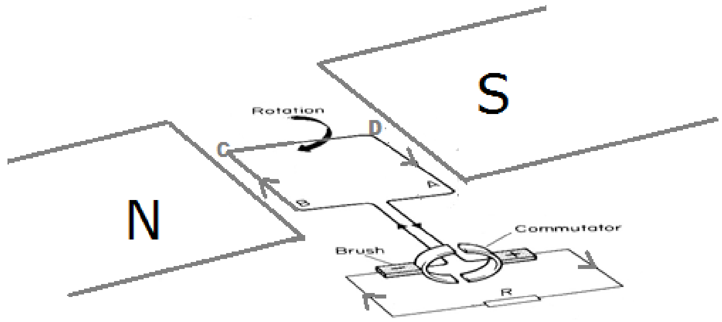
Generators (Dynamos)

- This is a device that converts mechanical energy to electric energy
- Generators are sometimes referred to as dynamos.
- There are two types of generators, namely *a.c generator* and *d.c generator*

The simple d.c generator

Structure:

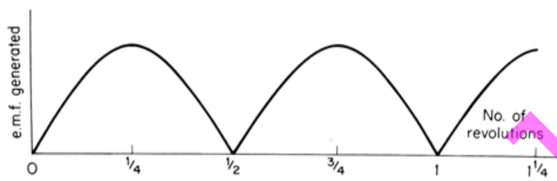
- ✓ It consists of a rectangular coil of wire which is rotated in a magnetic field between the poles of a permanent magnet called a field magnet
- ✓ The ends of the coil are connected to two ends of split slip rings (commutators) which press lightly onto the carbon brushes from which current is tapped/obtained.



Mode of action

- ✓ When the coil rotates, its sides cut the magnetic field and therefore current is induced in the coil.
- ✓ By application of Fleming's Right Hand rule, the current flows in a clockwise direction
- ✓ The brushes change contact from one commutator to another when the coil is in the vertical position.
- ✓ In this position, the e.m.f induced in the coil reverses and so one brush always positive and other negative, thus current always flows in one direction in the external circuit.

The graph of the e.m.f produced by the d.c generator



Note:

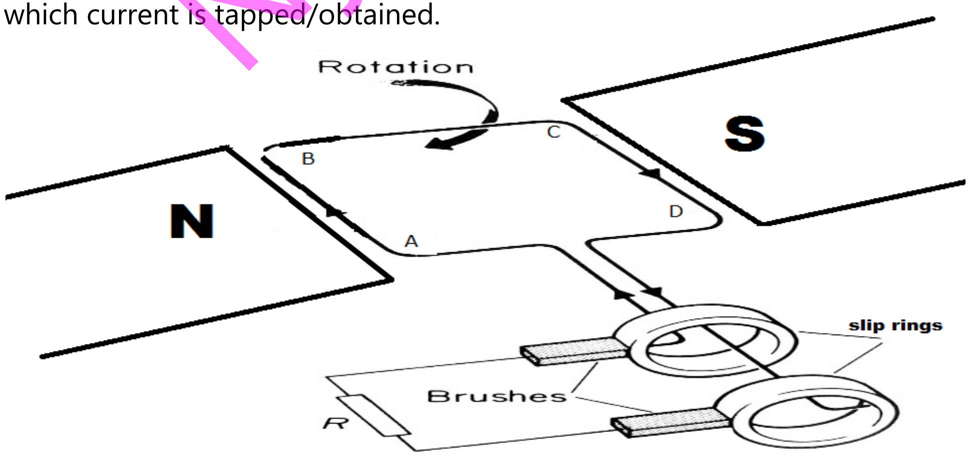
(a) The e.m.f generated is zero when the coil is in vertical position.

(b) The e.m.f generated is maximum when the coil is in horizontal position

The simple a.c generator

Structure:

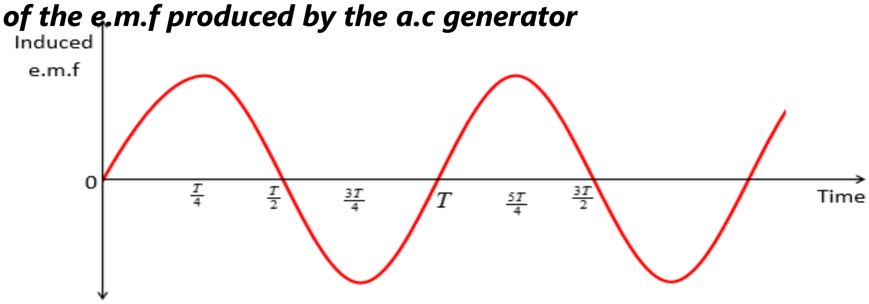
- ✓ It consists of a rectangular coil of wire which is rotated in a magnetic field between the poles of a permanent magnet called a field magnet
- ✓ The ends of the coil are connected to two ends of slip rings which press lightly onto the carbon brushes from which current is tapped/obtained.



Mode of working

- ✓ When the coil rotates, its sides cut the magnetic field and therefore current is induced in the coil.
- ✓ By application of Fleming's Right Hand rule, the current flows in a clockwise direction
- ✓ The induced current is tapped from the slip rings by the carbon brushes to the load R.
- ✓ The e.m.f/current reverses every half rotation of the coil as it passes the vertical

The graph of the e.m.f produced by the a.c generator



Factors that determine the magnitude of the induced e.m.f in the generator coil

The e.m.f generated from a transformer can be increase by;

(1) Using a stronger magnet/increasing the strength of the magnetic field
(2) Increasing the number of turns of the coil
(3) Increasing the area/length of the coil
(4) Increasing the speed of rotation of the coil(rate at which the flux changes)
(5) Winding the coil on a soft iron core

Functions of the parts of the generator

Part of the generator	**Function**
The permanent (field) magnet	to provide a strong magnetic field through which the coil rotates in
Armature or coil	It brings about electromagnetic induction in the coil. Armature is the moving part of the generator
Slip rings (and commutators)	contacts from which current or e.m.f is tapped
Carbon brushes	transmit current between the moving part and the external circuit of the generator

MUTUAL INDUCTION AND SELF-INDUCTION

Mutual Induction: Is the process by which an e.m.f is generated in a coil as a result of changing magnetic flux in the neighboring coil.

Mutual induction is applied in the working of a transformer

Self-induction: Is the process by which an e.m.f is generated in a coil as a result of changing magnetic flux within the same coil

The change in the magnetic flux can be achieved by;

(i) Switching on and off current (e.m.f) in a coil

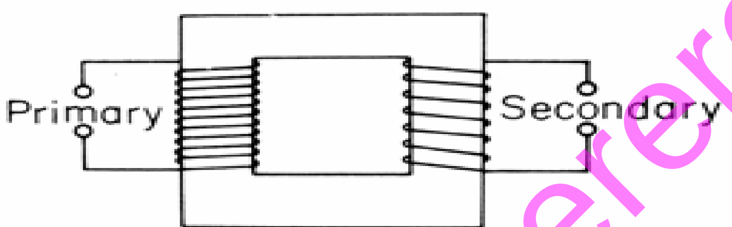
(ii) Using an alternating current

Transformer

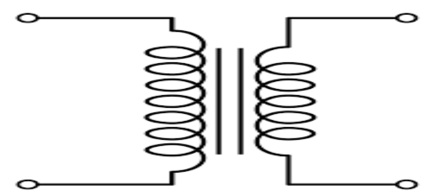
- ✓ A transformer is a device which steps up or down the voltage of an alternating current.
- ✓ A transformer is therefore used to change a.c voltage from one value to another
- ✓ A transformer only works on alternating current (a.c)

Construction

- ✓ A transformer consists of two coils, namely; the *primary* and the *secondary* coils, wound around the soft iron core
- ✓ The two coils are not connected electrically but are linked together magnetically
- ✓ The soft iron pieces insulated from each other to reduce heat loses.



Structure of a transformer



Symbol for transformer in electric circuits

The principle of working of a transformer

- ✓ When a.c is fed into the primary coil, an alternating magnetic flux is set up in the soft iron core
- ✓ The changing magnetic flux in the soft iron then induces a changing voltage in the secondary coil.
- ✓ Thus causes and alternating current to flow in the secondary coil

Factors that determine the magnitude of the induced e.m.f

The size of the e.m.f induced is proportional to:

1) The number of turns on the secondary coil.
2) The rate at which flux (field) in the core changes.

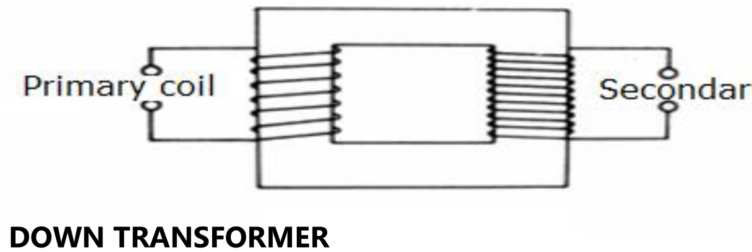
Types of transformers; there are two types

(a) Step up transformer

(b) Step down transformer

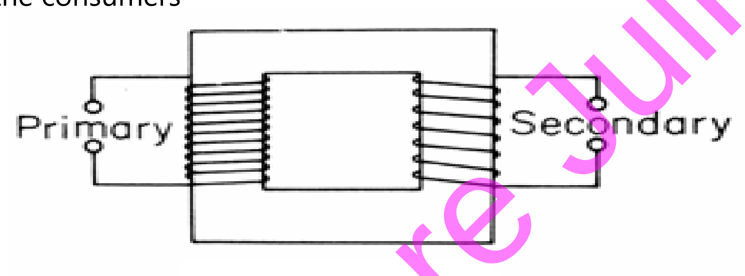
STEP UP TRANSFORMER

- ✓ Is the transformer in which the number of turns in the secondary coil is greater than those in the primary coil.
- ✓ It therefore increases voltage; the secondary (output) voltage is greater than the primary (input) voltage
- ✓ Step up transformers are normally put/used at the power generation stations and transmission stations to raise the generated voltage to a high value for transmission



STEP DOWN TRANSFORMER

- ✓ Is the transformer in which the number of turns in the primary coil is greater than those in the secondary coil.
- ✓ It therefore reduces voltage; the primary (input) voltage is greater than the secondary (output) voltage
- ✓ Step up transformers are normally put near consumers with electric appliances to lower the voltage for safe use by the consumers



Ideal Transformer

- ✓ In an ideal transformer, there are no energy losses.
- ✓ The efficiency of such a transformer is 100%

The following relationships hold;

$$\frac{secondary\,output\,voltage(Vs)}{primary\,input\,voltage(Vp)} = \frac{number\,of\,turns\,on\,secondary(Ns)}{number\,of\,turns\,on\,primary(Np)}$$

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \quad \text{Or} \quad \frac{V_s}{N_s} = \frac{V_p}{N_p}$$ *This is referred to as turn ratio of a transformer*

Since an ideal transformer is 100% efficient, the power in the primary coil (input power) is equal to the power in the secondary coil (output power)

Power in the secondary coil = Power in the primary coil

$$I_sV_s = I_pV_p \qquad \Rightarrow \frac{I_s}{I_p} = \frac{V_p}{V_s}$$

Example:

1. A transformer with 1200turns in its primary coil is used to step down an alternating voltage from 240V to 12V. Calculate the number of turns in the secondary coil.
   Ans: 60turns
2. A 240 V mains transformer has 1000turns in the primary. Find the number of turns in the secondary if it is used to supply a 12V, 24W. *Ans: 50 turns*
3. A transformer has twice as many turns in the secondary as in the primary coil. The a.c in put the primary coil is 110V. Find the output voltage. *Ans: 220V*

Efficiency of a transformer

Defined as the ratio of power output to power input expressed as a percentage

$$\text{Efficiency }(\eta) = \frac{\text{Power output}}{\text{Power input}} \times 100\%$$

$$\Rightarrow \eta = \frac{I_s V_s}{I_p V_p} \times 100\%$$

KEY NOTE

Power output = $I_s V_s$ *{occurs in the secondary coil}*

Power input = $I_p V_p$ *{occurs in the primary coil}*

Energy losses in a practical transformer

In practical transformers, energy loses usually occur in the following ways:

1. **Resistance of windings (coils).** The current flowing through the coil will generate heat due to resistance in the copper wires (I^2R)
2. **Eddy currents**: The alternating magnetic flux also induces small current in the soft iron core .this current is referred to as Eddy currents.
3. **Leakage of field lines (flux leakage)**. The field lines due to the current in the primary coils may not all link with the secondary coil.
4. **Hysteresis:** this is energy loss as a result of repeated reversal of magnetic field lines

N.B: *In practice no transformer is 100% efficient. The power loss in the transformer due to the resistance (R) in the coils is calculated from* $P_{lost} = I^2R$

How to minimize energy losses in a practical transformer

Type of energy loss	**How its minimized**
Loss due to Resistance of windings (coils).	Using thick copper wires with low resistance
Loss due to Eddy currents:	Laminating the cores so that current doesn't flow across them
Loss due to flux leakage	Designing the core so that the coils are close to each other (Using **E**-shaped core)
Loss due to Hysteresis	Using a metal of low hysteresis like soft iron

Examples

1. A transformer is designed to operate at 240V mains and deliver 9.0V. The current drawn from the main supply is 1.0A. If the transformer is 90% efficient, calculate;
   (i) The maximum output current *Ans: 24A*
   (ii) The power loss: *Ans: 24W*

2. Electric power is generated at 11Kv. Transformers are used to raise the voltage to 440kv for transmission over large distances using cables. The output of the transformers is 19.8 Mw and they are 90% efficient. Find;
   (i) The input current to the transformer.
   (ii) The output current to the cables.

Solution: $V_p = 11\times10^3 V, \; V_s = 440\times10^3 V, \; Pout = 19.8\times10^6 W, \; \eta = 90\%$

(i) $$From \;\; \eta = \frac{P_{out}}{P_{in}}\times100\% \;\Leftrightarrow\; \frac{90}{100} = \frac{19.8\times10^6}{P_{in}} \quad \therefore P_{in} = 22.0\times10^6 W$$

$$Also \;\; P_{in} = I_p V_p \;\Rightarrow\; I_p = 2000A$$

(ii) $$From \;\; P_{out} = I_s V_s \;\Rightarrow\; I_s = 45A$$

3. A transformer of efficiency 80% is connected to 240V a.c. supply to operate a heater of resistance 240Ω. If the current flowing in the primary circuit is 5A,
   (i) Calculate the potential difference (p.d) across the heater.
   (ii) If the transformer is cooled by oil of specific heat capacity 2100 J kg^{-1} K^{-1} and the temperature of the oil rises by 20^{0}C in 3 minutes, find the mass of the oil in the transformer

Solution: $V_p = 240V, \;\; \eta = 90\%, \; I_p = 5.0A$,

$$\text{Using } \eta = \frac{P_{out}}{P_{in}}\times100\% \;\Rightarrow \eta = \frac{P_{out}}{I_p V_p}\times100\%$$

(i) $$\therefore P_{out} = 960W$$

$$recall: \; P_{out} = \frac{V_s^2}{R}, \; and \; R = 240\Omega \;\Leftrightarrow thus \; V_s = 480V$$

(ii) $$Electric\ energy\ due\ to\ resistance = Heat\ energy\ absorbed\ by\ the\ Oil$$

$$P_{out}\times time = mc\Delta\theta \quad \Rightarrow m = 4.1kg$$

Advantages of a.c over d.c. transmission

1) a.c can be easily and cheaply changed from one voltage to another by a transformer with very little loss of energy.
2) Since the a.c. is transmitted at very high voltage, it follows that the cables carry small current. These thinner cables can be used with high voltage transmission.
3) a.c is more suitable for heating than d.c.
4) a.c is easier and cheaper to generate than d.c

Disadvantages of a.c over d.c

(i) a.c cannot be used to charge a battery.
(ii) a.c cannot be used in electroplating.
(iii) a.c cannot be used in electrolysis.

Exercise on transformer

1. A transformer has 200 turns in the primary coil. Calculate the number of turns in the secondary coil if 240V is to be stepped up to 415V.

2. A 240 V main transformer has 1000 turns in primary and **N** turns in the secondary. If used to supply energy to a bulb rated 12V 60W.

(i) How many turns are there in the secondary coil?

(ii) What is the efficiency of the transformer if the current drawn from the 240 V supply is 290mA?

(Ans: 86.2%)

3. A transformer designed to step down voltage from 240 V to 12 V has 3 000 turns in the primary and is 75% efficient.

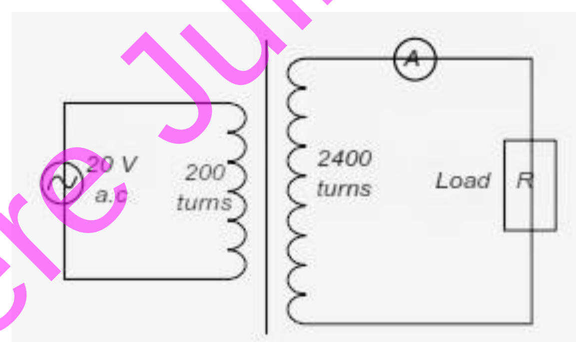
(i) Find the number of turns in the secondary.

(ii) Find the current in the primary when the secondary is connected to a 20Ω electric bulb.

(Ans: 40mA)

4. The figure below is a transformer connected in a circuit.

(a) Identify the type transformer used in the connection



(b) Calculate;

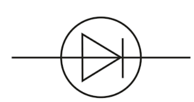
(i) the potential difference across the load R

(ii) the ammeter reading if the resistance of the load is 400Ω

(iii) the power output of the transformer

(c) What will be the ammeter reading, if the ac input voltage is changed to 20 V dc? Explain your answer.

Rectification

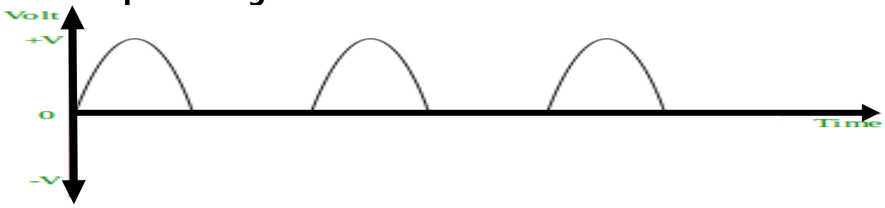
- ✓ This is the process of converting an alternating current (a.c) to direct current (d.c)
- ✓ Rectification is done using a device called rectifier /diode
- ✓ A rectifier/diode is device that permits current to flow only in one direction;
- ✓ There are two types of rectifiers/diodes
- ✓ *Semiconductor diode* and *vacuum tube rectifiers/ diodes*  *circuit symbol*

Types of rectification

There are two types of rectification, namely; half-wave rectification and full-wave rectification

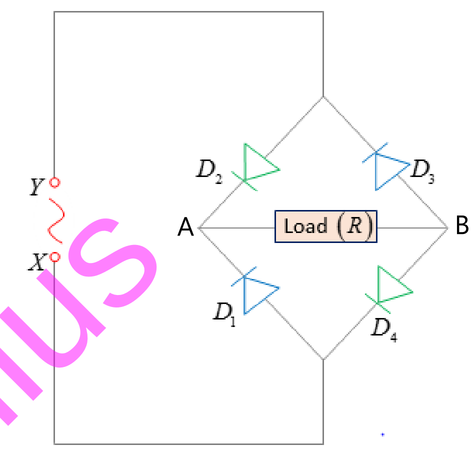
***Half-wave rectification*:** which is done using a single diode/rectifier

The out-put voltage for half-wave rectification



Full-wave rectification: which is done using four semiconductor diodes

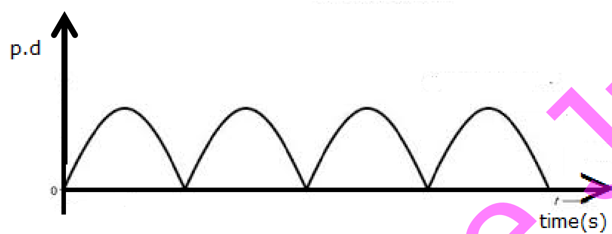
Circuit diagram for full-wave rectification



<u>How full-wave rectification is achieved in the above circuit</u>

- ✓ When the terminal **X** is positive, current flows through diodes D_1, the load **R**, diode D_3 back to **Y**.
- ✓ When the terminal **Y** is positive, current flows through diodes D_2, the load **R**, diode D_4 back to **X**.
- ✓ As a result the current through the load is always in one direction i.e. from **A** to **B**

The out-put voltage for full-wave rectification



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