PHYSICS

CHAPTER 3 ELECTROMAGNETIC INDUCTION

<u>Induced *e.m.f* in a solenoid – An Experiment</u>

Materials required: barmagnet, solenoid, galvanometer

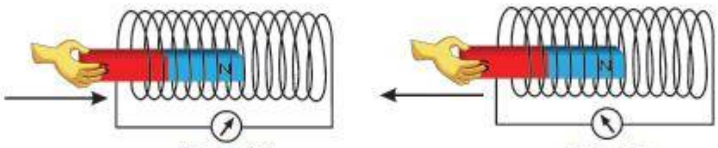


Fig 3.1 (a) Fig 3.1 (b)

Inference

Sl. No.	Experimental procedure	Observation (Galvanometer needle)	
		Deflects/ does not deflect	Direction to the left/ to the right
1	The magnet is stationary near the solenoid	Doesn't deflect	No direction
2	North pole of the magnet is moved into the solenoid	Deflects	Right
3	The magnet is stationary inside the solenoid	Doesn't deflect	No direction
4	The magnet is moved out of the solenoid.	Deflects	Left
5	The south pole of the magnet is moved into the solenoid	Deflects	Left
6	Magnet and solenoid are moved in the same direction at the same speed	Doesn't deflect	No direction
7	The solenoid is moved keeping the magnet stationary	Deflects	Left/ Right

Note:

- **When ever there is relative motion between barmagnet and solenoid happens, a current is induced(developed) in the solenoid, i.e galvanometer deflects.**
- **When both magnet and solenoid are stationary with respect to each other there is no induced current in the solenoid, i.e galvanometer does not deflect.**

Experiment	Deflection of the galvanometer needle	
	increases	decreases
Number of turns increased	Increases	
Strong magnet is used	Increases	
Magnet/solenoid moves with greater speed.	Increases	

Note:

- **Factors which influence the current induced in a solenoid are**
  - **Number of turns**
  - **Strength of barmagnet**
  - **Relative speed of barmagnet or solenoid**

Q) how will you increase the *e.m.f* induced in a solenoid?

Ans) by increasing the number of turns of the solenoid, by increasing the strength of barmagnet, by increasing the relative speed of barmagent or solenoid

Note: galvanometer is used to understand the presence of current and its direction in a conductor. It cannot measure the amount of current. It is connected series to a circuit.

<u>Electromagnetic Induction</u>

> *Whenever there is a change in the magnetic flux linked with a coil, an emf is induced in the coil. This phenomenon is electro-magnetic induction.*

Michael Faraday

(1791-1867)

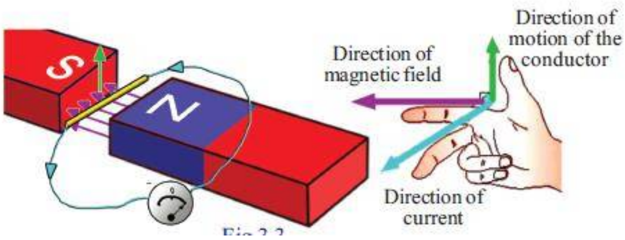
The direction of induced e.m.f is given by Fleming's Right Hand Rule also known as generator rule

Note: factors on which direction of induced current depends

- **Direction of magnetic field**
- **Direction of motion of the conductor**
- **Relative motion of the conductor and magnet.**

<u>Fleming's Right Hand Rule</u>

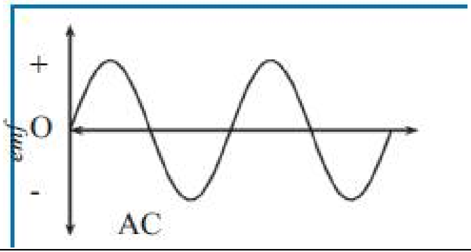
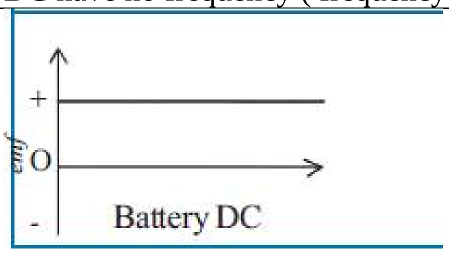
> *Imagine a conductor moving perpendicular to a magnetic field. Stretch the forefinger, middle finger and the thumb of the right hand in mutually perpendicular directions. If the fore finger represents the direction of the magnetic field, and the thumb represents the direction of motion of the conductor, then, the middle finger represents the direction of the induced current.*



- **Induced e.m.f is always AC**

Alternating Current (AC) and Direct current (DC)

> *A current that flows only in one direction continuously is a direct current (DC). Current that changes direction at regular intervals of time, is an alternating current (AC).*

Alternating Current	Direct Current
The direction of current changes continuously	The direction of current is same (unidirectional current)
Value is varying with respect to time	Value of current is constant with respect to time
Produced by AC generators	Produced by DC generators, batteries, galvanic cells
AC has frequency	DC have no frequency (frequency = 0)
	

Application of Electromagnetic Induction

- **Generators**
- **Moving coil microphone**
- **Transformer**
- **Inductors**

GENERATOR

- **Generator is a device which convert mechanical energy into electrical energy**
- **It will produce both AC and DC by using AC generators and DC generators**

AC GENERATOR

Structure

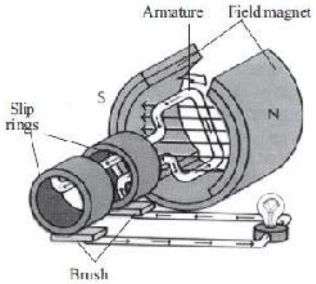


Fig. 3.5 (a)

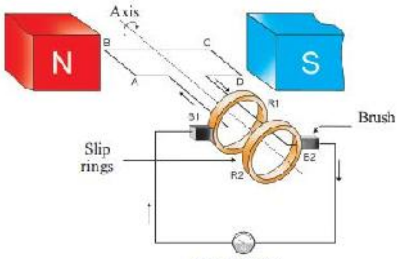


Fig. 3.5 (b)

N,S – field magnet
ABCD- armature coil
R_1, R_2 – slip rings
B_1, B_2 brushes

Parts of AC generator

Field magnet

The magnet that creates magnetic flux in the generator

Armature

An arrangement of insulated conducting wire wound on a soft iron core. This can be made to rotate about an axis.

Slip rings

Metal rings which are welded together with the armature coil. They rotate along with the armature on the same axis of rotation as the armature

Brushes

They are arrangements which always make contact with the slip rings. Current flows through them to the external circuits.

Working

When the armature coil rotates between the field magnets it will cuts magnetic flux and an e.m.f is induced in the armature coil by electromagnetic induction. This e.m.f will flow to the external circuits through slip rings and brushes.

For one complete rotation the direction of induced current will changes twice

Graph

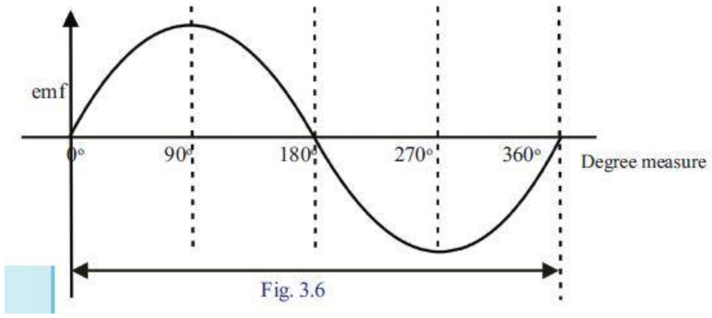
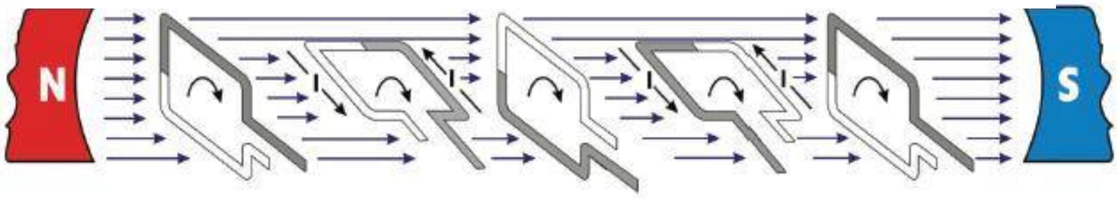


Fig. 3.6

0^0 90^0 180^0 270^0 360^0



	Time				
	0	**T/4**	**T/2**	**¾ T**	**T**
Angle of rotation of the armature.	0^0	90^0	180^0	270^0	360^0
Rate of change of flux.	0	maximum	0	**maximum**	**0**
Induced emf in volts V.	0	maximum	0	**maximum**	**0**

Q) what are the instants at which maximum e.m.f is obtained in the armature coil

Ans) when armature rotates at 90^0, 270^0

Q) what are the instants at which minimum e.m.f is obtained in the armature coil

Ans) when armature rotates at 0^0, 180^0, 360^0

Period T

The time taken by the armature coil for a full rotation is called the period, T. Time taken for half rotation (180°) is T/2.

Q) when an armature rotates 360 turns in 1 minute calculate its time period.

Time period T = $\frac{time\ taken}{number\ of\ complete\ rotations}$

$= \frac{60s}{360}$

=1/4

Note:

- **The frequency of electricity generated in India is 50Hz**
- **50Hz means the armature completes 50 rotations in 1 second**
- **The direction of current changes 100 times (50Hz)**
- **In order to overcome this practical difficulty, the number of rotations is reduced by increasing the number of armature coils and increasing the number of pole pieces**

DC GENERATORS

Structure

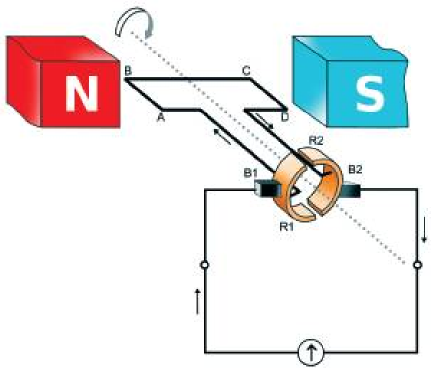


Fig. 3.7 (a)

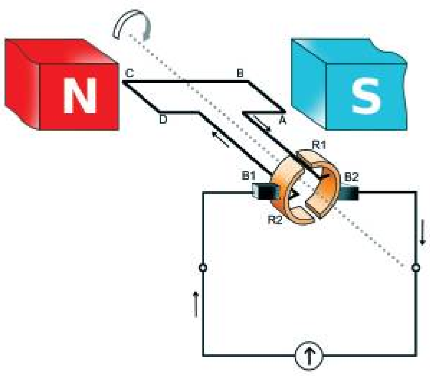


Fig. 3.7 (b)

N,S – field magnet

ABCD- armature coil

R_1, R_2 – split rings

B_1, B_2 brushes

Working

When ever armature coil rotates between field magnet an e.m.f is induced in the armature coil by electromagnetic induction. After every half rotation the brushes B1 comes into contact with armature part moving upward and B2 comes into contact with armature coil moves downwards. So, the direction of current is same in each half rotation. Thus, split ring commutator will help to convert AC into DC

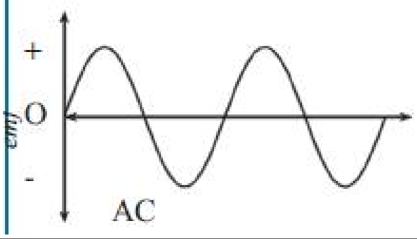
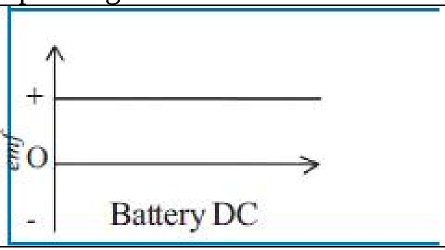
Note:

- **By using split ring commutator, we can convert an AC generator into DC generator**

Q) what are the similarities between AC generator and DC generator?

AC generator	DC generator
Permanent magnetic field is used	Permanent magnetic field is used
Armature coil rotates (rotor)	Armature coil rotates (rotor)
Brushes are used	Brushes are used
Working principle is electromagnetic induction	Working principle is electromagnetic induction
Mechanical energy is converted into electrical energy	Mechanical energy is converted into electrical energy

Q) what are the differences between AC and DC generators?

AC Generator	DC Generator
Alternating current is produced	Direct current is produced
Slip rings are used	Split rings are used
	
Varying e.m.f is produced	Constant e.m.f is produced
The direction of current is reversed every half rotation	The direction of current is same

Q) what are the similarities and differences between DC Generators and DC Motors?

DC Generator	DC Motor
Similarities	
Permanent magnetic field	Permanent magnetic field
Armature coil rotates	Armature coil rotates
Split rings are used	Split rings are used
Brushes are used	Brushes are used
Differences	
Mechanical energy is converted into electrical energy	Electrical energy converted into mechanical energy
Flemings right hand is used	Flemings left hand is used
Works based on the principle of electromagnetic induction	Works based on motor principle

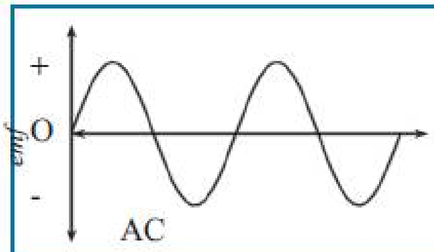
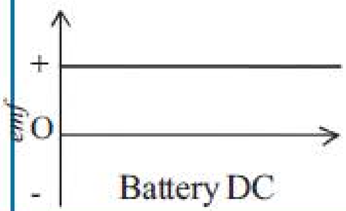
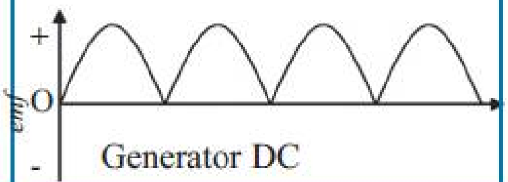
	• Direction changes continuously • **emf increases and decreases**
	• **Direction is same (unidirectional)** • **emf is constant**
	• **Direction is same (unidirectional)** • emf increases and decreases.

Table 3.5

Mutual Induction

Consider two coils of wire kept side by side. When the strength or direction of the current in one coil changes, the magnetic flux around it changes. As a result, an emf is induced in the secondary coil. This phenomenon is the mutual induction

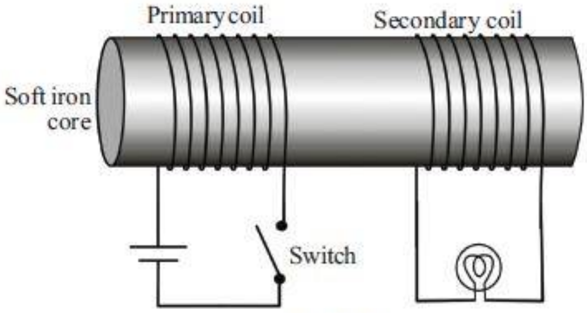


Fig. 3.8

When the switch is put ON and OFF only at that instant bulb will glow. Because the current is varying and varying magnetic flux will cause mutual induction

When the switch is still in ON position the bulb will not glow because DC is used here so current is constant, constant magnetic field is produced hence there is no mutual induction

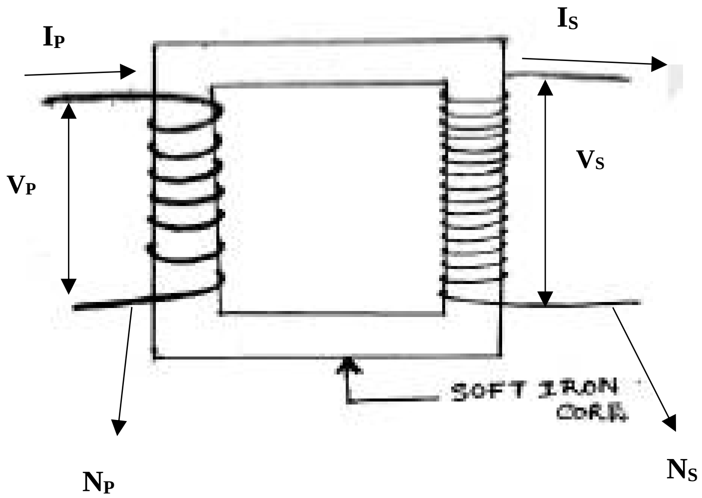
When it is replaced by an AC source bulb will glow continuously, because varying magnetic flux will cause mutual induction

The coil into which we give current for the production of magnetic field is the primary coil and the coil in which induced emf is generated is the secondary coil.

Transformer

- It is a device works on the principle of mutual induction
- Transformer will not work on DC it will works only in AC
- It used to increase or decrease the AC voltage / current
- There are two types of transformers step-up and step-down transformers.

Structure



V_P – voltage in the primary / input

V_s- voltage in the secondary/ output

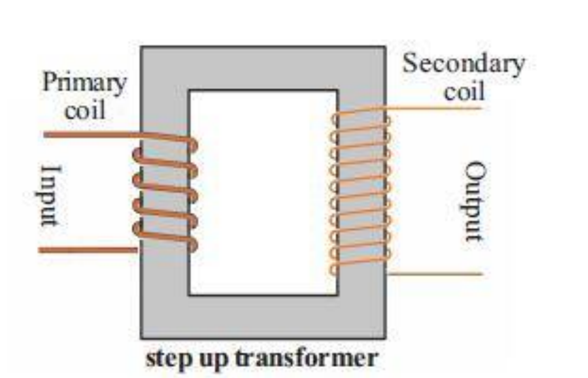
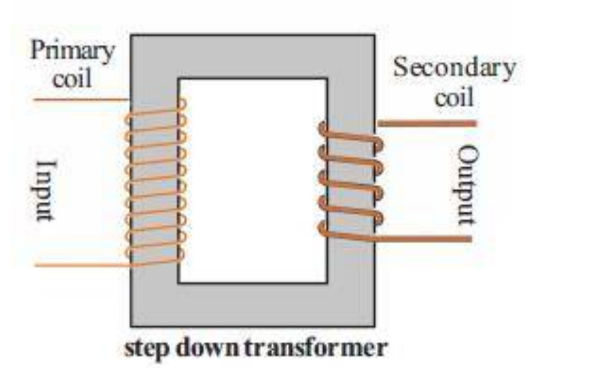
N_s- number of turns in the secondary

N_P- number of turns in the primary

I_P- current in the primary

I_s – current in the secondary

Step Up and Step-Down transformers

STEP UP TRANSFORMER	STEP DOWN TRANSFORMER
	
It is used to increase the voltage in the secondary coil Vs > Vp	It is used to decrease the voltage in the secondary coil Vp > Vs
Number of turns in the secondary is more $\frac{N_S}{N_P} > 1$	Number of turns in the primary is more $\frac{N_S}{N_P} < 1$
Current in the primary coil is higher Ip > Is	Current in the secondary coil is higher Ip < Is
Thick copper wires are used in primary	Thick copper wires are used in secondary

Note: thick copper wires are used in a transformer where current flow is higher so it may be led to the melting of wire, in order to reduce this the thickness of the coil increased.

Transformer Equation

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} = \frac{I_P}{I_S}$$

Power developed in a transformer

Power, P = Voltage × current

Power in primary, $P_P = V_P \times I_P$

Power in Secondary, $P_S = V_S \times I_S$

In a transformer,

Power in the primary = Power in the secondary

That is,

$$V_P \times I_P = V_S \times I_S$$

$$\therefore \frac{I_P}{I_S} = \frac{V_S}{V_P}$$

For a lossless transformer/ ideal transformer, power in primary = power in secondary

In a step up transformer the voltage in the secondary coil is more and the current is less. But in a step down transformer the secondary voltage is less and the current is more.

Self-Induction

The change in magnetic flux due to the flow of an AC in a solenoid will generate a back emf in the same solenoid in a direction opposite to that applied to it. This phenomenon is known as the self induction.

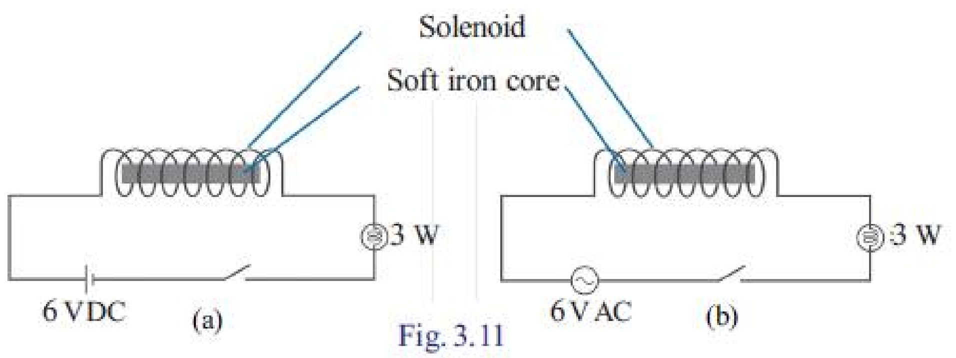


Fig. 3.11

Note:

- **When both the switches are getting ON a varying magnetic field is developed around the coil in fig(b) because of AC, a back emf is induced in it due to self-induction, the resultant voltage across the bulb decreases hence brightness of the bulb decreases**
- **In fig (a) a DC source is used, there is no self-induction in DC circuit so brightness of the bulb is maximum**
- **When a soft iron core is inserted into the solenoid the magnetic flux linked with the coil also increases hence back emf become large it will further reduces the glow of bulb**

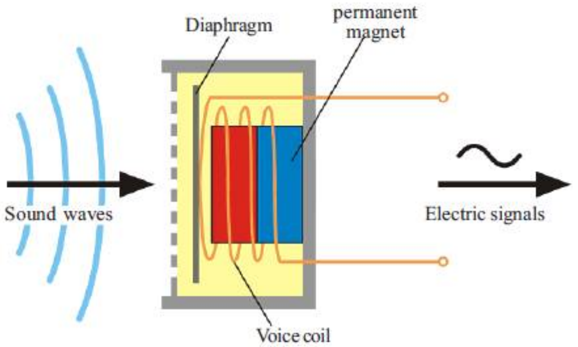
Inductor

Inductors are coils used to oppose the changes in electric current in a circuit. They are used to reduce current in a circuit to the desired value without loss of power

- **Inductors are widely used in AC circuits because they can control the amount of current in AC circuit without any power loss**
- **The advantage of inductor over resistor is that it will not have any energy loss in the form of heat while in resistors it will have power loss in the form of heat.**
- **Inductors are not used in DC because it will act as resistor in DC have energy loss**

Moving Coil Microphone

Structure



Moving Coil Microphone

The working of Moving coil microphone

The voice coil is situated in a magnetic field. The diaphragm connected to the voice coil vibrates in accordance with the sound waves falling on it. As a result, electrical signals corresponding to the sound waves are generated in the voice coil. In the microphone, mechanical energy is converted into electrical energy.

- **The weak electrical signal from microphone is strengthened by using Amplifier**
- **The amplified signal is fed to loud speaker**

Power Transmission and Distribution

- **In India power is generated at power station in 11KV (11000V)**
- **When it is transmitted to distant places there is a loss of energy in the form of heat.**

Q) How will you reduce the transmission loss?

Ans)

- **by increasing the voltage up to 220KV the current flowing through the conductor is minimised hence, by joule's law ($H = I^2Rt$) heat loss can be reduced**
- **by increasing the thickness of the conductor**

Q) if the current is reduced to half, how much will be the reduction in heat?

Ans) $I = I/2$ so heat, $H = (I/2)^2Rt = I^2Rt/4 = H/4$

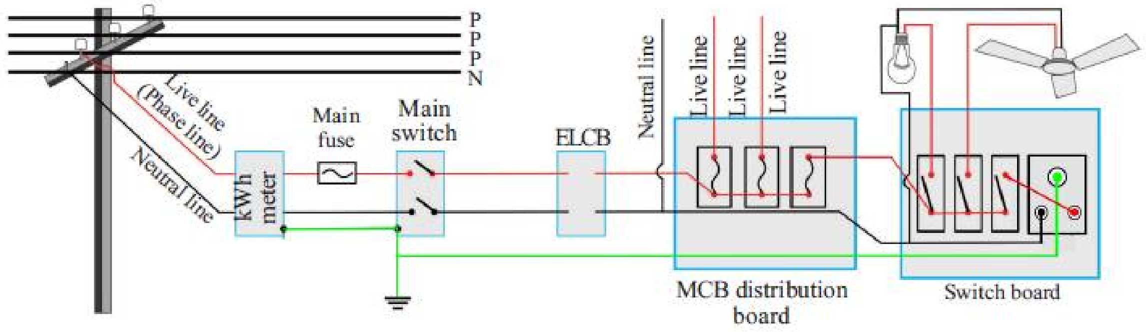
Heat is reduced by four times

Note:

- **in power stations step up transformers are used**

- in distribution transformer step down transformers are used
- in substations step down transformers are used
- the voltage between a phase line / live line and neutral line is 230V
- the voltage between a phase line / live line and earth is 230V
- the voltage between a phase line / live line and another phase line is 400V
- the voltage between a neutral line and earth is 0V
- a man standing on the earth touches the phase line will get electric shock
- a man standing on the earth touches a neutral line will not get electrocuted
- for a household electrification at least two lines are needed one is phase line and other is neutral line

<u>**Household Electrification**</u>



- electrical line first reaches to the device kWh meter/ watt hour meter/ energy meter
- earth line starts from kWh meter
- watt hour meter is used to measure the amount of electrical energy consumption
- fuse wire is connected with phase line in series.
- Main switch will control/ regulate the current flowing into the household circuit
- Red colour- phase line, Green colour- earth line, Black colour- neutral line
- The earth wire is connected with E pin in the three-pin plug socket
- All the devices in household circuits are connected in parallel

Q) what are the advantages of connecting the devices in parallel?

- Ans) we can control each device individually by using switches
- In parallel connection all the devices will get required voltage
- The effective resistance of the circuit is minimum hence the heat loss is also minimum
- Any damage/ failure of one device will not affect the entire circuit
- Devices will work according to their marked power

<u>**Watt Hour Meter**</u>

Watt – hour meter is a device that is used to measure electrical energy. Electrical energy is measured using the unit kilowatt hour. This is also known as a unit.

1 unit electrical energy = 1 kWh

The commercial unit of electrical energy is kilowatt hour (kWh). A device of power 1000 watt (1 kW), when used for one hour (1h), consumes one unit of electrical energy (1 kWh)

Watt hour meter

$$\text{Energy in kilowatt hour} = \frac{\text{Power in watt} \times \text{time in hour}}{1000}$$

<u>Safety Measures in Household Electrification</u>

1. **Safety Fuse**

   During the entire time of the passing of current through a circuit, a small amount of heat is generated in the fuse wire. But this heat will be transmitted to the surroundings. When the current that flows into the circuit exceeds the permissible limit, the heat generated becomes excessive. Since more heat is generated in unit time than the heat transmitted, the fuse wire melts.

2. **MCB (Miniature Circuit Breaker)**

   MCB is a device that is used in the place of a fuse wire branch circuits. MCB automatically breaks the circuit whenever there is an excess flow of current due to short circuit or overloading. After rectifying the circuit we can switch on the MCB and make the circuit as it was. MCB works making use of heating and magnetic effects of electricity.

3. **ELCB (Earth Leakage Circuit Breaker)**

   ELCB helps to break the circuit automatically whenever there is a current leak due to insulation failure or any other reason. Hence a person touching the electric circuit or a device does not get an electric shock. Nowadays RCCB, which ensures more safety than ELCB is made use of.

MCB ELCB

RCCB

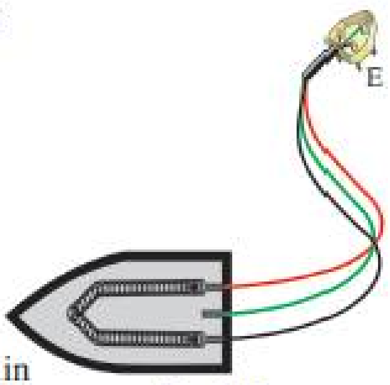


Fig. 3.16

4. Three Pin Plug and Earthing

Earthing for better safety

Symbol

The pin E of a three pin plug comes into contact with the earth line. This pin is now connected to the body of the appliance. If at all the body comes into contact with an electric connection, electricity flows to the earth through the earth wire. The flow of current to the earth through a circuit of low resistance increases the current. As a result heat generated in the fuse wire increases and the circuit gets broken. This ensures the safety of instrument and the person handling it. The length and thickness of the earth pin is more than that of the other pins. Since the length is more, when the three pin is introduced into the socket, the earth pin comes into contact with the circuit first. When the three pin is pulled out of the socket, the earth pin will be the last to break the contact. Hence complete safety is ensured by the three pin plug. Since thick copper wire is used as the earth wire, a path of low resistance is created. Electricity can easily flow to the earth through this path.

- **Rectifier convert AC into DC. It is a diode and will conduct current in only one direction**
- **Devices works in AC are TV, Fan, Mixie, bulb**
- **Devices works in DC are calculator, watch, torch, toys**

<u>Electric Shock</u>

Electric shock occurs when we touch bare wires or cable with damaged insulation or when lightning strikes. Severe injuries may occur when current flows through our body.

Precautions

- Never handle electric equipments or operate switches when the hands are wet.
- Insert plug pins into socket and withdraw them only after switching off.
- Do not operate devices of high power using ordinary sockets.
- Wear rubber footwear while operating electric devices.
- Do not touch the interior parts of the cable TV adapters. Ensure that there is an insulated cap for the adapters.
- Do not fly kites near electric lines.
- Do not use table fan to dry hair.
- Ensure that there are no tall buildings or tall trees near electric lines.
- Ensure that the main switch and ELCB are switched off when maintenance work is being carried out at home.

Precautions during some Special Circumstances

- During lightning, avoid doing any work that will bring you in contact with electric circuits. (There is a posssiblity of excess current in the circuit during lightning)
- Disconnect the plugs from the socket whenever there is a chance of lightning.
- During rain and wind, electric lines are likely to touch the ground. This may cause danger. We have to be cautious on such occasions.
- If water enters home due to floods or other reasons, disconnect electric connections. Reconnect it only after ensuring that the main switch and the switch board are perfectly dry.

First aid to be given in the case of electric shock

After removing the electric connection do the following:

- **Raise the temperature of the body by massaging**
- **Give artificial respiration**
- **Massage the muscles and bring back them to the original condition**
- **Start first aid for the functioning of heart (apply pressure on the chest)**
- **Call medical team, inform police or CHC or take the person to the nearest hospital**

Saving electricity is equivalent to generating electricity so don't waste it

KSEB Ltd.