Syllabus

UNIT-I ELECTRICAL FUNDAMENTALS

1.1 Nature of Electricity, Charge, free electrons, Electric current, Electric potential and potential difference, Electric current, Electrical Energy, Electrical power and their unit.

1.2 Resistance: Definition, Unit, Laws of resistance, conductivity and resistivity, Effect of temperature on resistance, Temperature coefficient of resistance, Types of resistance & their applications, Color coding of resistance.

1.3 Inductors and capacitors with their wattage consideration.

1.4 Factors affecting capacitance of a capacitor. Capacitors in series and parallel.

UNIT-II DC CIRCUITS AND THEOREMS

2.1 Ohm's law and its verification.

2.2 Kirchhoff's current law and Kirchhoff's voltage law.

2.3 Star – Delta connections.

2.4 Voltage and current source, symbol and graphical representation, characteristics of ideal and practical sources.

2.5 Mesh and Loop analysis

2.6 Thevenin's theorem, Norton's theorem, Superposition Theorem, Maximum Power Transfer Theorem.

UNIT-III AC CIRCUITS

3.1 AC Fundamentals: Cycle, frequency, time period, amplitude, difference between AC and DC, instantaneous value, average value, r.m.s. value, maximum value, form factor and peak factor.

3.2 Concept of conductance, susceptance, admittance, impedance and concept of inductive and capacitive reactance

3.3 RL-RC Circuits

3.4 Introduction to series and parallel resonance and its conditions

3.5 Power in pure resistance, inductance and capacitance, power in combined RLC circuits.

3.6 Power factor, active and reactive power: Definition and their significance.

UNIT-IV ELECTRO MAGNETIC CIRCUIT

4.1 Concept of electro-magnetic field produced by flow of electric current, magnetic circuit, concept of magneto-motive force (MMF), flux, reluctance, permeability, analogy between electric and magnetic circuit.

4.2 Faraday's laws of electro-magnetic induction, principles of self and mutual induction, self and mutually induced emf.

4.3 Energy stored in an inductor, series and parallel combination of inductors.

UNIT-V BATTERIES

5.1 Basic idea of primary and secondary cells.

5.2 Construction, working principle and applications of Lead-Acid, Nickel-Cadmium, Li-Ion batteries.

5.3 Series and parallel connections of batteries.

5.4 Introduction to maintenance of free batteries.

5.5 Disposal of batteries

5.6 General idea of solar cells, solar panels and their applications.

PRACTICE EXERCISES

1. Familiarization of measuring instruments viz voltmeter, ammeter, CRO, Wattmeter and multi-meter and other accessories.
2. To measure (very low) resistance of an ammeter and (very high) resistance of a voltmeter
3. To verify Ohm's law by drawing a graph between voltage and current.
4. To observe change in resistance of a bulb in hot and cold conditions, using voltmeter and ammeter.
5. To determine the value of resistance using colour coding method.
6. Verification of Kirchhoff's Current and Voltage Laws in a DC circuit on bread board.
7. Verification of Thevenin's theorem.
8. Verification of Norton's theorem.
9. Verification of Superposition theorem.
10. Verification of Maximum Power theorem.
11. Alternating voltage applied to resistance and inductance, resistance and capacitance in series.
12. To find the voltage current relationship in a single phase R-L circuits and draw their impedance triangles.

13. To find the voltage current relationship in a single R-C Series circuits, and draw their impedance triangles.
14. Measurement of power and power factor in a single phase R,L,C. circuit
15. Calculation of active and reactive powers in the circuit.
16. To test a lead - acid storage battery and measure its specific gravity.
17. Care and maintenance of lead-acid battery.
18. Visit to a nearby Power Station.

1 ELECTRICAL FUNDAMENTALS

1.1 NATURE OF ELECTRICITY

Electricity is flow of electrons. Each substance in this universe has large number of atoms. Each atom has equal number of electrons and protons. Thus the atom is electrically neutral. It has no charge on it. Protons are immobile while electrons revolve around the nucleons in different orbits. Some of the electrons can leave their orbit and become free to move. These free electrons always try to have uniform concentration. Movement of free electrons is electricity. It is a form of energy which causes flow of current in a closed circuit by movement of free electrons.

Difference between A.C and D.C

In a closed electrical circuit, electric current is the flow of free electrons. There are two types of electric current *i.e.* Direct current (D.C) and Alternating current (A.C).

1. **Direct Current (d.c.):** A direct current has the following characteristics :
   (*i*) It flows in one direction only.
   (*ii*) It always flows from the + ve terminal to – ve terminal of the supply.
   (*iii*) It may or may not have constant value and thus direct current may be :
      (*a*) Steady D.C.
      (*b*) Pulsating D.C.

A direct current which has constant magnitude is called steady D.C. A graph of steady D.C. is drawn between current (along Y-axis) and time along X-axis. This graph is a straight line parallel to X -axis as shown in figure 1.1.

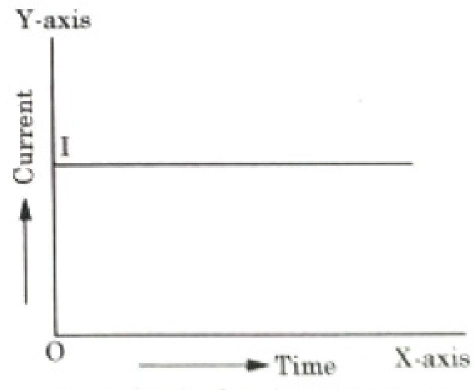


Fig. 1.1: Steady Direct Current

A direct current which changes in magnitude with the passage of time but flows in the same direction in the circuit is called pulsating direct current. A pulsating D.C. is shown in figure 1.2(*a*), (*b*)

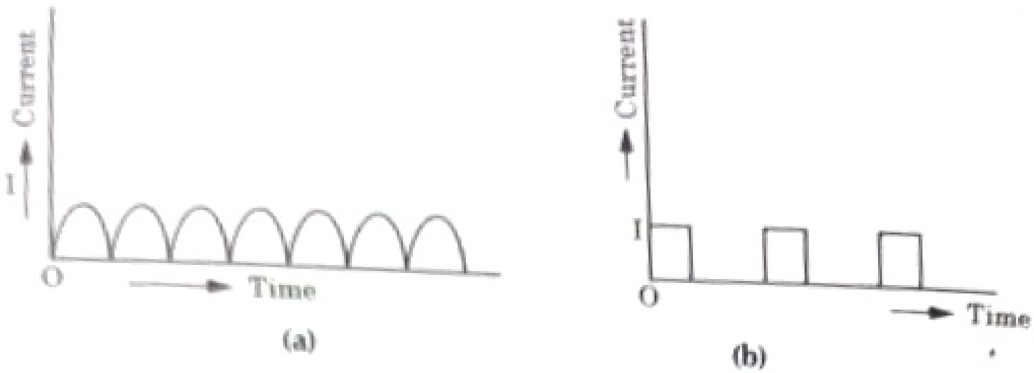


Fig. 1.2: Pulsating D.C.

Unless specifically mentioned, D.C. means steady direct current. D.C. is supplied by cells, batteries and D.C. generators. A circuit in which Direct Current flows is called D.C. circuit.

2. **Alternating Current:** An alternating current has the following characteristics :
   (*i*) It changes its direction periodically.
   (*ii*) It also changes it's magnitude with time.

An alternating current is shown in figure 1.3.

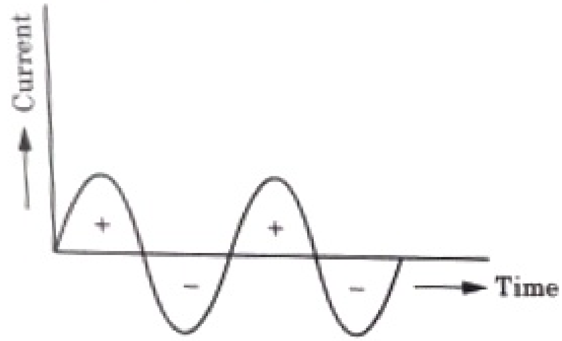


Fig 1.3: Alternating Current

A.C. is supplied by A.C. Generator (Alternator) and oscillator. A circuit in which Alternating Current flows is called A.C. circuit.

1.2 CHARGE

Nature of Electricity: Every matter contains two basic particles i.e. electrons and protons. The arrangement of these two particles in the matter determines it's electrical properties. Under normal conditions, a body does not exhibit any electrical property because number of electrons is equal to number of protons making an atom electrically neutral.

If some electrons are removed from a neutral body, deficiency of electrons is created. As a result number of protons becomes more than the number of electrons. Now the body attains a positive charge.

Thus, when electrons are detached from a body, it becomes deficient of electrons and is called positively charged body or positive ion.

On the other hand, if electrons are supplied to neutral body, then total negative charge becomes more than total positive charge. As a result, a body no longer remains neutral and attains a negative charge.

Thus, a negatively charged body has more number of electrons than it's normal share.

A charged body contains either excess or lesser number of electrons than it's normal state.

A body is said to be positively charged if it has deficiency of electrons and it is said to be negatively charged if it has excess of electrons.

Unit: Practical, Unit of Charge is "Coulomb".

Charge on 1 electron = -1.6×10^{-19} Coulomb.

$$1 \text{ Coulomb} = \frac{1}{1.6 \times 10^{-19}} = 6.28 \times 10^{18} \text{ electrons.}$$

Similar charges repel each other.

Opposite charges attract each other.

$+ \leftarrow$ Repel each other $\rightarrow +$, $- \leftarrow$ Repel each other $\rightarrow -$, $+ \rightarrow$ attract each other $\leftarrow -$, $- \rightarrow$ attract each other $+$

Free Electron: Electrons present in the atomic structure of an atom rotate around the nucleus in different shells /orbits. Number of electrons in an orbit depends upon the formulae $2n^2$ where n is number of orbit.

Thus an atom will have

$$2.1^2 = 2 \text{ electrons in first orbit}$$
$$2.2^2 = 8 \text{ electrons in second orbit}$$
$$2.3^2 = 18 \text{ electrons in third orbit}$$

and so on

The last orbit which is also known as valance orbit cannot have more than 8 electrons. These electrons are called Valance Electrons. These electrons are loosely bound to the nucleus.

When an atom gains heat energy at room temperature, the valance electrons leave the parent atom and become free to move in the atomic structure of the material. These electrons are called **Free electrons** and their movement constitutes flow of current when a voltage is applied to it.

Potential: Potential at a point is work done to bring a unit charge from infinity to that point.

$$V = \frac{W}{q} \quad \text{where V is the potential in volts}$$

W is work done in Joules

q is charge in coulombs

Electric potential is 1 volt, if 1 joule of work is done in moving 1 coulomb charge. It is a scalar quantity.

Potential Difference: Potential difference [illegible] between them. When two points having some potential difference are connected through a conductor, there is flow of electrons between them. Flow is from a higher potential to the lower potential. This flow of electrons due to potential difference between two points constitutes flow of current. Current will continue to flow between the two points as long as there is a potential difference. It is measured in volts.

Electric Current: When an electric potential difference or voltage is applied across a metal conductor, then electrons in the outer most orbit get detached from the nucleus. These free electrons start moving towards the positive terminal of battery. These moving electrons constitute the electric current.

Thus, electric current may be defined as the moving stream of electrons flowing in an electric circuit.

Conventional Current: Earlier it was believed that some matter flows when a potential difference or voltage is applied across a conductor, and this matter flows from higher potential to lower potential *i.e.* positive terminal of battery to negative terminal. This conventional direction of flow of current is still in use and its direction is opposite to the direction of flow of electrons. Thus, conventional direction of flow of current is from +ve terminal to –ve terminal of the source through external circuit.

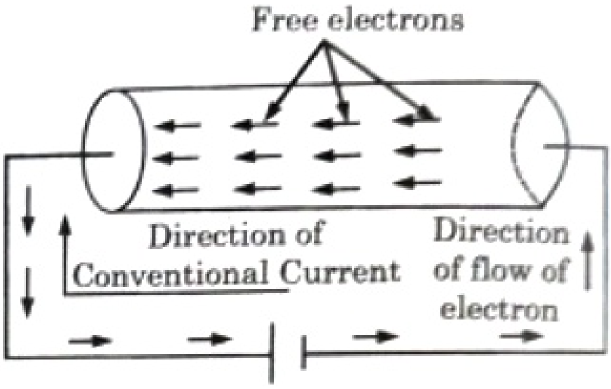


Fig. 1.4

The magnitude of current in any conductor is rate of flow of charge.

i.e. current = charge/time

or $$I = Q/t \quad \text{...(1.1)}$$

Unit: The unit of current is ampere.

As $$I = Q/t$$

as unit of charge is Coulomb and unit of time is Sec

$\therefore$ Unit current may also be Coulomb/sec

If $$Q = 1 \text{ Coulomb}, t = 1 \text{ sec}$$

then $$I = 1 \text{ C/S} = 1\text{A}$$

So, one ampere current is said to flow through a conductor if one Coulomb of charge flows through it in one second.

As $$1\text{Coulomb} = \text{Charge of } 628 \times 10^{16} \text{ electrons}$$

* Why the direction of electron is opposite to Electric Current?

Electric current is the rate of flow of charge. The direction of current is shown by the direction of flow of positive charge. This can be achieved by moving Negative charge (electron) opposite to the direction of current. So, electrons flow from –ve to +ve terminal of the source of supply.

∴ One ampere of current is said to flow through a wire if at any section 628×10^{16} electrons pass through that section in one second.

Electrical Energy: The capacity of an electrical machine to do work is called electrical energy.

or

The total amount of work done in moving the electrons in an electric circuit is called **electrical energy.**

Its symbol is E.

i.e. Electrical energy = Total work done in an electrical circuit.

It is measured by the product of electric power and time *i.e.*

$$\textbf{Electrical energy} = \textbf{Electric power} \times \textbf{time}$$

$$\mathbf{E} = (\mathbf{P}) \times t$$

$$\mathbf{E} = \mathbf{VI} \times t \qquad [\because\ P = VI]$$

$$\therefore \quad \textbf{Electrical energy} = \mathbf{VI}t$$

Units of electrical energy :

The basic unit of electrical energy is joule or watt-sec.

One joule (or watt-sec.) of energy is expended if 1 ampere current passes through 1 ohm resistance for 1 second.

$$1 \text{ Joule} = 1 \text{ volt} \times 1 \text{ amp.} \times 1 \text{ sec.}$$
$$= 1 \text{ watt- sec.}$$

The joule or watt-sec. is a very small unit of electrical energy for practical purposes. In practice, for measurement of electrical energy, bigger units watt-hour and kilowatt hour (kWh) are used.

$$1 \text{ watt } hr. = 1 \text{ watt} \times 1 \text{ hr.}$$

1 kilowatt hr. (kWh) : This is the commercial unit for the measurement of electrical energy.

One kWh of electrical energy is expended if 1 kW (1000 watts) of power is supplied for 1 hour.

$$1 \text{ kWh} = 1 \text{ kW} \times 1 \text{ hr.}$$
$$= 1000 \text{ watts} \times 3600 \text{ sec.}$$
$$= 3.6 \times 10^6 \text{ watts-sec}$$

$$1 \text{ unit} = \text{watts} \times \frac{\text{hours}}{1000}$$

Example 1.1. What is the filament resistance of 100-watt, 230V lamp?

Solution. Rated power, P = 100 watts

Rated voltage, V = 230 volts

Let R ohms be the resistance of the filament.

Example 1.13. The hot resistance of an electric iron is 117.56 Ω. Find out the wattage of the iron, if it draws 1.956 A from the supply mains

Solution. $\because$ $P = I^2 R$

$\therefore$ $P = (1.956)^2 \times 117.56$

or $P = 449.78$ W or say = **450 W** **Ans.**

Example 1.14. What is the power rating of an electric lamp with a filament resistance of 220 ohms when the potential across its terminals is 220 volts?

Solution. Filament Resistance = 220 ohms.

Terminal Voltage = 220 volts.

We know, Power = $\dfrac{V^2}{R}$

Putting the values in the formulae we get

$$P = \frac{220 \times 220}{220}$$

Power Rating (P) = **220 W** **Ans.**

1.3 RESISTANCE

1.3.1 Laws of Resistance

The property of a conductor which opposes the flow of electric current through it is known as resistance. It is denoted by R and its unit of measurement is ohm represented by Ω (omega). The instrument that measures resistance is known as an ohmmeter. Good conductors have small resistances and insulators have large resistances.

1. **Factors Affecting Resistance:** The resistance of a conductor depends on four factors :
   - (*a*) **Material:** For example, Silver is a better conductor than Copper.
   - (*b*) **Length:** The longer the wire, higher is the resistance. $(R \propto L)$ ...(1.5)
   - (*c*) **Cross Sectional Area:** The thicker the wire, the smaller is the resistance and vice versa $\left(R \propto \frac{1}{a}\right)$ ...(1.6)
   - (*d*) **Temperature:** Most of the materials have higher resistance at higher temperature. $(R \propto T)$

(**Note:** In some materials – notably Carbon and Electrolytes the resistance decreases as the temperature rises).

2. **Laws of Resistance:** Laws of resistance for any conducting materials are:

From equations (1.5) and (1.6)

conductor *i.e.* $R \propto \frac{1}{a}$.

So $$R \propto \frac{1}{a}$$

or $$R = \frac{\rho l}{a}$$

where ρ is known as the resistivity or specific resistance of the material. It is defined as ance of a specimen of the conducting material whose length is one unit and area of cr on is one square unit. If length is in metres and area of cross-section is in square metres t nit of resistivity is ohm-metre.

$\because$ $$R = \frac{\rho l}{a}$$

or $$\rho = \frac{R \times a}{l}$$

e l is in metres (m)

a is in square metres (m^2)

R is in ohms (Ω)

So $$\rho = \frac{R(\text{ohm}) \times a(m^2)}{l(m)}$$

$\therefore$ the unit of ρ is ohm-m.

It's value at 20^0C for copper is about 1.732×10^{-8} Ω-m and for aluminium is ab $\times 10^{-8}$ Ω-m.

3. **Units of Resistance:** The unit of resistance is the ohm (Symbol Ω). A material ha tance of one ohm when a current of one ampere flows through it on application of a volt e volt. For larger and smaller resistance value we use:

$\frac{1}{1000}$ ohms = 1 milli ohm, which is abbreviated as 1 m $\Omega = 10^{-3}\Omega$

$\frac{1}{1,000,000}$ ohm = 1 micro-ohm, which is abbreviated to 1 $\mu\Omega = 10^{-6}\,\Omega$

1000 ohms = 1 kilo ohm, which is abbreviated as 1 K$\Omega = 10^3\,\Omega$

1,000,000 ohm = 1mega ohm. which is abbreviated to 1 M$\Omega = 10^6\,\Omega$

To measure resistance value up to 10 MΩ, a meter known as ohm-meter is used.

For measurement of insulation resistances greater than about 10 MΩ, a special instrum d a meggar is used.

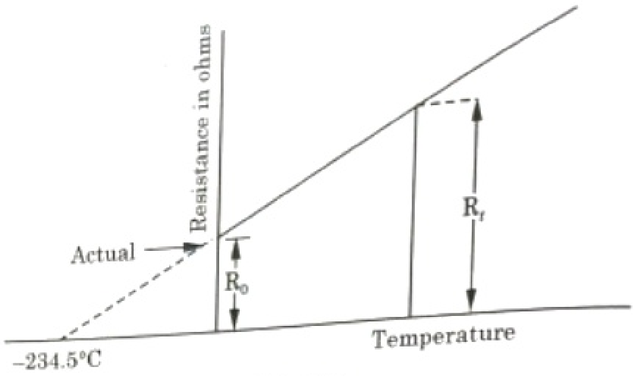


Fig. 1.8

However, in actual practice, the curve departs (point A) from the straight line path at very low temperatures.

1.3.5 Temperature Co-efficient of Resistance

Consider a conductor having resistance R_0 at 0^{0C} and R_t at t^0C. It has been found that in the normal range of temperatures, the increase in resistance (*i.e.*, $R_t - R_0$)

(*i*) is directly proportional to the initial resistance, *i.e.*, $R_t - R_0 \propto R_0$ ...(*i*)

(*ii*) is directly proportional to the rise in temperature, *i.e.*, $R_t - R_0 \propto t$ ...(*ii*)

(*iii*) depends upon the nature of material.

Combining the (*i*) and (*ii*), we get

$$R_t - R_0 \propto R_0 t$$

or

$$R_t - R_0 = \alpha_0 R_0 t$$

where α_0 is a constant and is called temperature co-efficient of resistance at 0^0 C. Its value depends upon the nature of material and temperature.

Rearranging equation (*iii*), we get,

$$R_t = R_0 (1 + \alpha_0 t)$$

Definition of α_0. From equation (*iii*) we get,

$$\alpha_0 = \frac{R_t - R_0}{R_0 \times t}$$

= increase in resistance/ohm original resistance /^{0}C rise in temperature

Hence **temperature co-efficient of resistance** of material is the increase in resistance per unit resistance per ^{0}C rise in temperature.

The unit of α is /^{0}C. Copper has a temperature co-efficient of resistance of 0.00426/^{0}C.

The following points may be noted carefully:

(*i*) Those substances (e.g., pure metals) whose resistance increases with rise in temperature are said to have positive temperature co-efficient of resistance. On the other hand, those

Fig. 1.11 shows a metal film resistor. The helical grooves have not been shown

Fig. 1.11: Metal Film Resistor

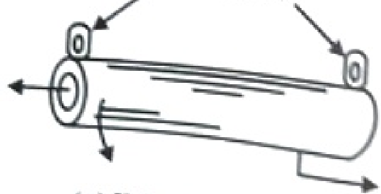
(*d*) **Wire wound resistors.** As is clear from name, wire wound resistors ar winding a high resistance on an insulating former. Commonly used resistance Nichrome, Eureka, alloys of silver and Nickel.

Nichrome is an alloy of Nickel and Chromium while Eureka is an alloy of C Nickel. The wire must be annealed before it is used for making a resistor. It must temperature co-efficient of resistance and low hygroscopicity. Choice of wire also dep its resistivity and value of resistance required.

One end of winding wire is welded on a cap and a calculated length of wire is wour the core. Other end of wire is soldered to a metallic cap at the other end.

These resistors suffer from high frequency effects of winding, mechanical vibrat shocks. High frequency effects can be reduced by using Bifilar winding as shown in while fig. 1.12(*a*) (*b*), show wire wound resistance.

These resistors can have high wattage up to 10 watts. These are commonly used i supplies, multimeter, bridge circuits, radios, communication system. T.V. sets and a applications requiring high power dissipation.



(*a*) **Wire wound resistor**

(*b*) **Ceramic Type Wire Wound Resistor**

Fig. 1.12

Fig. 1.13 : Bifilar Winding

2. **Variable Resistors:** Variable resistors are used to select a suitable value of resistance ny circuit. It can be changed from zero value to the maximum value of resistance. Basically it a resistive material to make the resistor and a movable wiper which makes contact with the stor to change value of resistance.

On the basis their application variable resistors are classified as :

(*i*) General purpose variable resistors

(*ii*) Precision value variable resistors

On the basis of resistance material used, variable resistors are classified as :

(*i*) Wire wound resistors (*ii*) Carbon resistors (*iii*) Cermets.

(*i*) **Wire wound variable resistors :** Wire wound variable resistors are made of nichrome, ıstantan, Eureka or any other high resistivity material wire. The wire is wound over an ulated former. The former may be in form of a circle or an arc. A shaft is used to move a ving contact on the resistance wire. Position of moving contact decides the resistance available ween the terminals of the variable resistor.

A variable wire wound resistor is shown in Fig. 1.14. These can be classified as

(*i*) Single turn resistors (*ii*) Multi turn resistors

(*iii*) Ganged resistors.

Change in resistance may follow linear law, logarithmic law, square law, sine law or cosine law.

Typical specification of a wire wound resistor are :

Resistance law	: Linear
Value	: 10 Ω to 1000 Ω
Tolerance	: ± 5%
Power rating	: 10W
Temperature co-efficient	: 100 ppm/°C
Stability	: 50,000 Maximum.

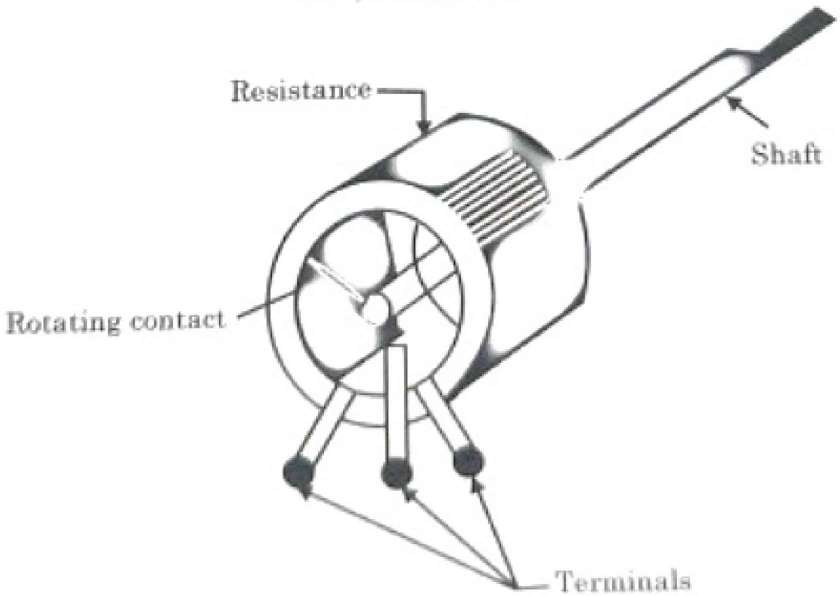


Fig. 1.14: Wire Wound Variable Resistors

4. **Non Linear Resistor:** Non linear resistor can be divided into three categories :

(*i*) Thermistor

(*ii*) Voltage Dependent Resistor (VDR)

(*iii*) Light Dependent Resistor (LDR).

(*i*) **Thermistors :** The word thermistor is derived from 'Thermal resistors'. As can be sensed from its name it's resistance depends upon the temperature of operation.

Thermistor uses a semi-conductor which behaves like a resistor. Its resistance depends upon the quantity of heat supplied to it. (Temperature of a body depends upon the heat supplied). It has negative temperature co-efficient of resistance. Hence it's resistance decreases with rise in temperature. Change in resistance value may be as large as 5% per degree centigrade change in temperature. Hence it is highly sensitive to temperature.

Thermistors are used in precision measurement and control of temperature in the range of 50°C to 100°C.

Construction : Thermistors are composed of sintered mixture of metallic oxides such as NiO, Mn_2O_3 and Co_2O_3. Thermistors may be in the following forms [as shown in Fig. 1.16 (*a*, *b* & *c*)].

(*a*) Disc form.

(*b*) Bead form.

(*c*) Probe form.

A thermistor in bead form is smallest in size can have diameter of 0.015 mm. These can be sealed in the tips of solid glass tube for easy installation. Glass probes have a diameter of about 2.5 mm and a length varying from 6 mm to 50 mm. Discs can be made by pressing material under high pressure into cylindrical flat shapes with diameter ranging from 2.5 mm to 25 mm.

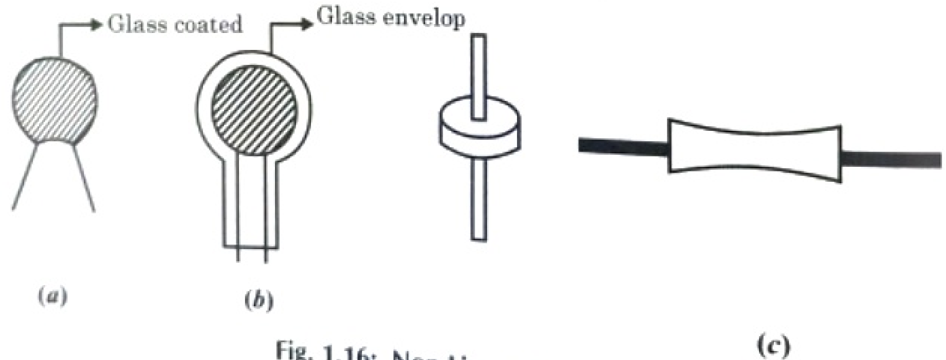


Fig. 1.16: Non Linear Resistors

Applications of Thermistors : Thermistors are used in following applications :

(*i*) Thermistors are used for accurate temperature measurement.

(*ii*) Thermistors are used for temperature compensation over a wide temperature range.

(*iii*) Measurement of power at high frequency.

(*iv*) Measurement of thermal conductivity.

(*v*) Thermal relay.

(*vi*) Temperature actuated control ckts.

Specifications of Thermistors : Specifications of Thermistors are:

(*a*) Resistance at room temperature 25 °C

(*b*) Switch temperature

(*c*) Max. voltage at 55 °C

(*d*) Temperature co-efficient of resistance

(*e*) Dissipation factor

(*f*) Temperature range.

(*ii*) Voltage Dependent Resistor (VDR) : Resistance of a VDR depends upon the applied voltage. Thus a VDR can also be called as voltage sensitive resistor. Depending upon the nature of change in resistance value VDR can be classified as

(*a*) Symmetrical varistors.

(*b*) Non-symmetrical varistors.

(*a*) Symmetrical Varistors : Resistance of symmetrical varistors varies equally for both positive and negative voltage changes. Such varistors have similar VI characteristics in both directions.

A mixture of silicon carbide grains, clay and graphite is either pressed or extruded in to desired shape. The VDR disc or rod is metalised and leads are soldered to it. Then it is provided with PVC or epoxy coating.

Working voltage of VDR depends upon it's thickness and composition of mixture. It can vary from 50 V to 10000 Volts.

(*b*) Non symmetrical varistors : Non symmetrical or Asymmetrical varistors have different values of resistance for positive and negative voltages. Their property is similar to that of a diode. Their resistance in one direction is different to the resistance in other direction.

Plate or disc type copper oxide varistors use a pure copper plate. A layer of cuprous oxide is formed on the plate by oxidation. Silver or gold electrodes are formed by evaporation of silver or gold on hard cuprous oxide layer.

Applications : These are used in :

(*a*) Protection against surges,

(*b*) Sensing element in voltage stabilizers.

(*c*) For increasing sensitivity of measuring instruments.

Specifications : The main specifications of varistors are :

(*a*) Max. continuous voltage

(*b*) Maximum Energy

(*c*) Maximum non-repetitive surge current.

(*d*) Typical capacitance.

$$5\% \text{ of } 8.6\ \Omega = \frac{8.6 \times 5}{100} = 0.43\ \Omega$$

The resistance should lie somewhere between the values (8.6– 0.43) Ω and (8.6+ 0.43) 8.17 Ω and 9.03 Ω.

Manufacturing of Resistor: Manufacturing of resistor involves following steps :

(*i*) Preparation of base/substrate

(*ii*) Preparation of resistance element

(*iii*) Providing of terminal

(*iv*) Providing of preventive coating

(*v*) Marking of rating of resistor.

(*i*) **Preparation of Substrate:** The resistance element coating of the resistive element provided on an insulating substrate. Materials commonly used as base material are glass, cera and derivatives of plastic. Some combinations of these materials are also used to improve characteristics of resistors. The base material should be able to bear the working temperature resistor. It's mechanical strength should also be good. It should not absorb moisture Thermal expansion of base material should match with co-efficient of resistance, otherwise it will result formation of cracks or warpings on the resistor.

(*ii*) **Preparation of resistance element:** Materials based as resistance elements generally metal alloys of carbon and graphite. Binders are also used. Wire used in resistors generally made of Nickel Copper, Nickel Chromium and alloy of Nickel Chromium-Aluminium Temp. co-efficient of resistance of such material must be low so that resistance value does not change appreciably due to rise in temp.

Resistance element can be in form of film or slug. Base is covered with a film or conducting coating for providing terminals.

(*iii*) **Providing of terminals :** A resistor is connected in a circuit using two terminals, wire leads metallic lugs and metallic furriles are used for this purpose. Axial or radial lead configuration is used. Welding, soldering or pressing is done to form terminals.

(*iv*) **Providing of preventive coating :** Resistance element is protected against mechanical forces and atmospheric conditions by using preventive coating. The resistor can withstand higher temperature by using a proper coating on it. Materials used for preventive coating are generally cement (mixed with a binder) viterous, enamel or silicon.

(*v*) **Marking of rating on resistor :** Resistance value is marked on the resistor by either using colour coding or printing the value on the body of the resistor. Tolerance is also marked on it.

Specifications: Specification for Fixed Precision Resistors

General requirements and Methods of Test.

IS– 9437 (Part I) 1979

Rated resistance : Preferred values as per IS 842 : 1965

Tolerance on rated resistance ± 0.01, ± 0.025, ± 0.05, ± 0.1, ± 0.25% or 10 milliohm.

Rated dissipation at ambient 70°C

0.086, 0.125, 0.25, 0.05, 1.0 and 2.0 W

Limiting element voltage 75 ; 100, 150, 200, 250, 300, 360, 500, 600 and 750 V dc or ac r.m.s.

Stability classes 0.25, 0.1 and 0.05%.

Insulation resistance 1000 Megohm minimum

Tests

(*i*) Solderability

(*ii*) Temperature rise

(*iii*) Temperature characteristics of resistance

Specification for Fixed resistors : General purpose, power

Part I General requirements and methods of tests :

IS : 8909 (Part I) 1978.

Ratings

Rated resistance: as per preferred values.

Tolerance on rated resistance 5% and 10%.

Rated dissipation

Limiting element voltage

100, 150, 200, 250, 350, 500, 750, 1000, 1250, 1500, 1750, 2000, 2500, 2750, 3
3500 V.

Types of tests : Similar to last ones.

Specifications for Variable Resistors

IS : 8872 (Part I) 1977

General requirements and Methods of Tests,

There are the following types of variable resistors :

Variable resistance – Precision

Variable resistance General purpose

Variable resistance preset.

Resistance laws

Common variable resistance laws are as follows :

(*a*) **Linear law :** Resistance v/s Mechanical position curve is a straight lin

(*b*) **Logarithmic law :** Resistance v/s Forward mechanical position is a l

(*c*) **Reversed logarithmic law :** The curve of resistance v/s reversed m
curve follows reversed logarithmic law.

1. **On the basis of nature of value :**
   (*i*) Fixed value capacitor (*ii*) Variable capacitor

In fixed value capacitors value of capacitance is constant and cannot be changed whereas in variable capacitors value of capacitance can be changed by adjusting some parameters of the capacitor.

2. **On the basis of dielectric material used.** On this basis capacitors are of following types :
   (*i*) Paper capacitor (*ii*) Ceramic capacitor
   (*iii*) Mica capacitor (*iv*) Air capacitor
   (*v*) Glass capacitor etc. (*vi*) Oil filled capacitor.

3. **On the basis of polarization. The capacitors are of three types:**
   (*i*) Polarized capacitor. (*ii*) Semi-polarized capacitor.
   (*iii*) Non-Polarized capacitor.

FIXED VALUE CAPACITORS CONSTRUCTION AND APPLICATIONS

I. Paper Capacitors

(*a*) Impregnated Paper Capacitors: Paper capacitors are general purpose capacitors. These are constructed by rolling paper between metal electrodes. Kraft or linen paper of 7.5 microns to 25 microns thickness is used. Thickness of aluminium foil is 22.5 microns. Normally two paper sheets are used instead of single sheet to avoid the possibility of short circuit, if single paper contains metal impurities. The effect of pin holes in paper is to reduce effective dielectric constant, break down strength and power factor. Impregnation of paper with mineral oil fills these viods and improves it's stability. After rolling, ends are sprayed with copper so that lug or extended foil type connections can be taken out. Protective coating is applied and capacitance value is printed on the capacitor. Fig. 1.22 shows the constructional details of impregnated paper capacitor.

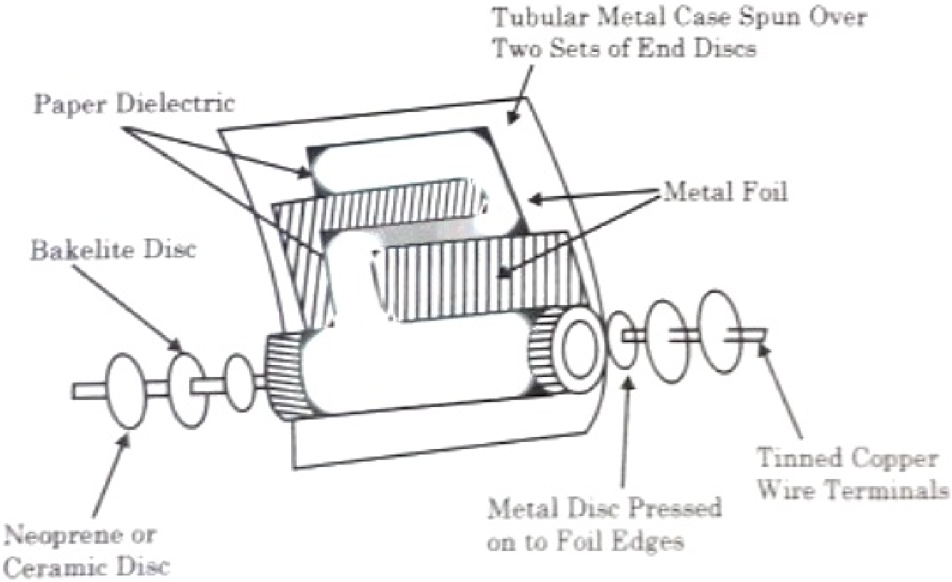


Fig. 1.22: Construction of impregnated paper capacitor

(*i*) **Low Loss Low Permittivity.** Steatite is used as dielectric in this type of capacitors. Steatite is first ground into fine powder, then it is compressed, the impurities are removed by heating the powder to a temp of about 900°C.

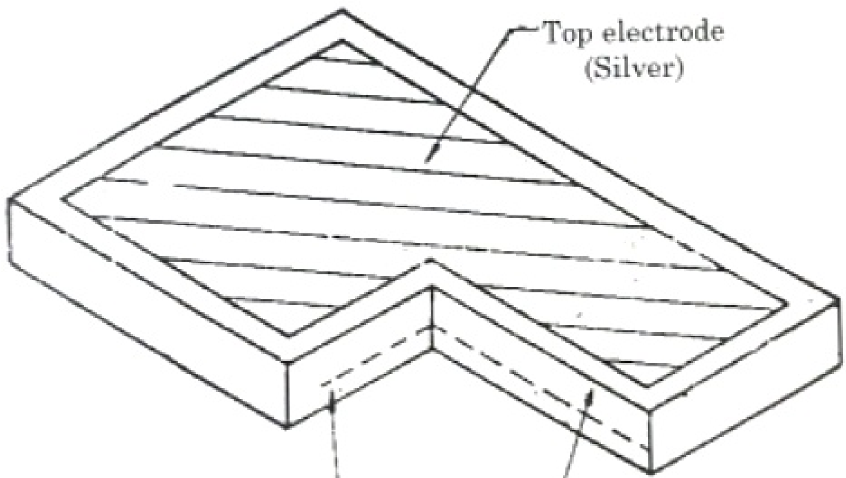
It is again ground and heated to about 1300°C. Both sides of it are metallised by thin plate or film. Leads are soldered to the metalised layer and are brought out.

Different shapes of these capacitors such as disc, tublar or rectangular shaped Capacitors are available. The body is covered with insulated laquer.

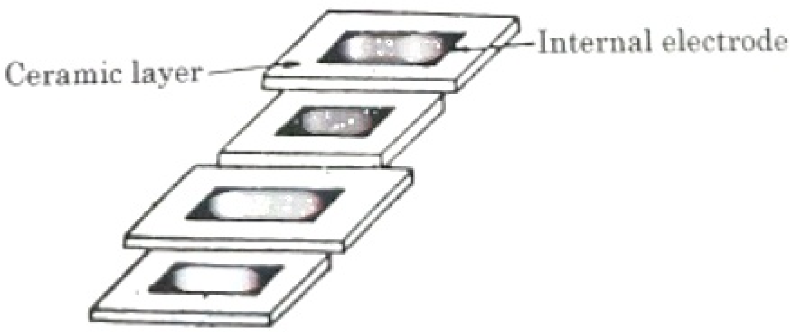
These capacitor are used for applications requiring temperature compensation. These are also used for by passing.

(*ii*) **High permittivity type :** High permittivity ceramic material such as Barium Titanate $BaTiO_3$ is used as dielectric material in this type of capacitors. Their capacitance is generally high while their size is relatively low, capacitance of these capacitors does not change appreciably with temperature. These capacitors are used as general purpose capacitors for coupling and decoupling.

(*iii*) **Multilayer Ceramic Capacitors :** Fig. 1.28 shows the constructional details of multilayer ceramic capacitor.

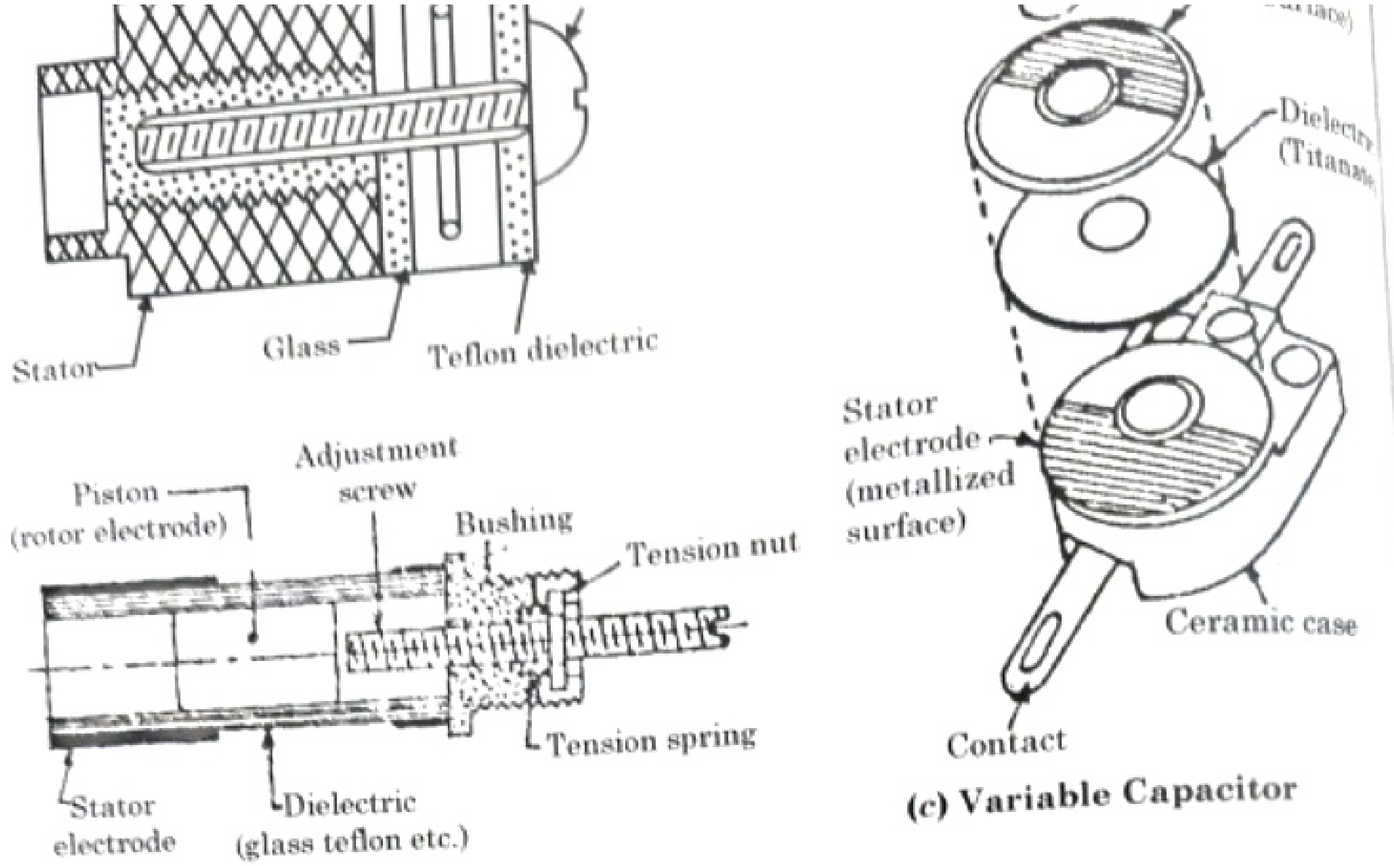


(*a*)



(*b*)

Fig. 1.28: Chip and Multilayer ceramic capacitor



(c) Variable Capacitor

Fig. 1.30

In case of concentric type, a long metallic screw having silvered outside surface sum in ceramic tube which is silvered on outside. The capacitance variation follows linearity. The available upto 10 pf. Their construction is shown in Fig. 1.30(*c*)

3. Glass variable capacitor: It has a glass tube. Outer surface of tube is coated conducting material. This constitutes the stator. A threaded rod is inserted from other end o It works as rotor. Effective area of the plates changes with inward/outward movement of th Straps and clamps embedded in the metallisation on outside surface of tube are used tc connections. Brushes in the intimate contact with threaded rod on piston is also used tc contacts. These capacitors are manufactured in 5 pf to 30 pf values. The temperature co-e is 100 pm/°C.

Applications: These capacitors are used is circuits requiring precise varial capacitance.

4. Mica variable capacitors: These capacitors are also known as mica comp variable capacitors. It has two non ferrous metallic conducting plates. A thin film of provided between these metallic plates. This forms the basic capacitor. A number of su capacitors are stacked to form the variable capacitor. A ceramic container contains stack basic capacitors.

2 D.C. CIRCUITS AND THEOREMS

INTRODUCTION TO D.C. CIRCUITS

Electric Current: *The quantity of electricity passing through an electric circuit is called electric current or simply current.*

Electric current may be defined as 'The flow of electrons in one direction along any path or through any circuit.

Unit of Electric Current: Electric current is measured in amperes.

One ampere *current is said to flow through a conductor if one coulomb of electricity is passing through any section of conductor in one second i.e.,*

$$1 \text{ ampere } = \frac{1 \text{ coulomb}}{1 \text{ sec}}$$

$$= 1 \text{ coulomb/sec.}$$

For example : If 4 coulombs of electricity is flowing through any section of wire in 2 seconds, then electric current I is given by

$$\text{Current I } = \frac{4}{2} = 2 \text{ coulomb/sec} = 2 \text{ Amperes.}$$

The meter used for measuring current is called ammeter. The smaller units of current are milli ampere and micro ampere.

$$1 \text{ milli ampere } = \frac{1}{1000} \text{ Ampere} = 10^{-3} \text{ A}$$

which is in short written as mA.

$$1 \text{ micro ampere } = \frac{1}{1,000,000} = \frac{1}{10^6} \text{ Ampere} = 10^{-6} \text{ A}$$

which is in short written as μA.

The meters used for measuring milliamperes is called milli ammeters. The meters used for measuring micro amperes is called micro-ammeters.

Characteristics of Direct Current

In a closed circuit, an electric current is the flow of electrons. There are two types of electric current-Direct current (D.C) and Alternating current (A.C).

Direct Current: A direct current has the following characteristics :

The ratio of the potential difference (V) between any two points of a circuit to the current (I) flowing through it is constant, provided that physical conditions, namely temperature, pressure etc., remain constant. The constant is usually denoted by resistance (R) of circuit.

Hence, $\frac{V}{I} = R$, where V = voltage between two points

I = current flowing

R = the resistance of the conductor and its unit is ohm (Ω)

For calculating purpose, this can be written as under.

(*a*) $I = \frac{V}{R} = \frac{\text{Voltage}}{\text{Resistance of the circuit}}$

(*b*) $V = I.R = \text{Current} \times \text{Resistance}$

(*c*) $R = \frac{V}{I} = \frac{\text{Applied voltage}}{\text{Current in the circuit}}$

2.1.1 Conditions for Ohm's Law

(1) Ohm's law can be applied either to the entire circuit or a part of a circuit.

(2) When Ohm's law is applied to a part circuit, part resistance and the potential across the part resistance should be used.

(3) The Ohm's law can be applied to DC as well as AC circuits. However in case of AC circuits impedance Z, is used in place of resistance R *i.e.*,

$$I = \frac{V}{Z} = \frac{\text{Applied voltage}}{\text{Impedance of the circuit}}$$

2.1.2 Limitations of Ohm's Law

Ohm's Law is not applicable to certain circuits under the following conditions. :

(1) For Arc lamps and insulator

(2) For electronic valves

(3) For metals which are heated by current to a high temperature.

(4) For gas filled tubes, in which ions are generated with the passage of current.

2.1.3 Experimental Verification of Ohm's Law

The circuit diagram for the verification of Ohm's Law is shown in fig. 2.3. A conductor having resistance R is connected in series with an ammeter A, battery B, rheostat R_h and key K. The voltmeter is connected across the resistance to measure the potential difference.

The ammeter measures the current through the resistance R. The purpose of rheostat is to change the circuit resistance and hence current. Key K is to make or break the circuit.

2.2.4 Comparison of Series and Parallel Circuits

Series Circuit	Parallel Circuit
1. There is only one path for the current to flow.	1. There are as many paths of current as the resistances are connected in parallel.
2. Total resistance is equal to the sum of its individual resistances *i.e.* $R = R_1 + R_2 + R_3 + \ldots R_n$	2. The reciprocal of the total resistance is equal to the reciprocal of the sum of individual resistances *i.e.* $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_n}$
3. The current passing through all the resistances will be the same and equal to the main current.	3. The current passing through each resistance is different (if not equal). Greater the resistance, lesser the current flowing through it.
4. The voltage in a series circuit is divided across each resistance according to the value of resistance. Greater the value of resistance, greater will be the voltage drop across it.	4. The voltage across each resistance connected in parallel is the same.
5. The total voltage applied is equal to the sum of the voltage drops in individual resistances, *i.e.* $V = V_1 + V_2 + V_3 + \ldots$	5. The total current of the circuit is equal to the sum of all the currents flowing through various branches connected in parallel, *i.e.* $I = I_1 + I_2 + I_3 + \ldots$
6. The total resistance is more than the highest value resistance connected in the series circuit.	6. The total resistance is less than the minimum value of resistance connected in the parallel circuit.

2.3 SOURCE AND IT'S INTERNAL RESISTANCE

A source supplies power to a load. Fig. 2.16 shows connection of a load to a source. Source of electrical energy may be a d.c. source or an a.c. source. Examples of d.c. sources are : Cells, batteries, D.C. Generators and power supplies. Examples of a.c. source are alternators, oscillators and signal generators.

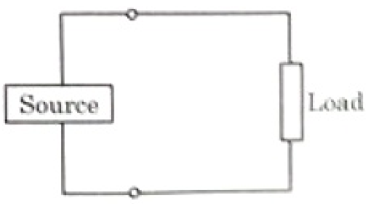


Fig. 2.16

2.3.3 Characteristics of an Ideal Voltage Source

Ideal voltage source characteristics is a graph between terminal voltage of source and load impedance/current drawn from the source.

As detailed in article 2.3.2 the terminal voltage of an ideal voltage source remains constant irrespective of load impedance or current supplied by it.

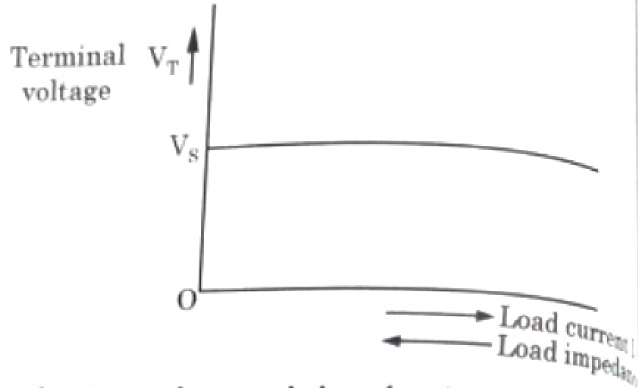


Fig. 2.20 : Characteristics of an ideal voltage source

Fig. 2.20 shows characteristics of an ideal voltage source.

2.3.4 Practical Voltage Source

Ideal conditions do not exist. However it can be made as near to ideal situation as poss
Practically no voltage source can have a constant value of terminal voltage. If it could be possi
then it would be able to supply infinite amount of power at short circuit (zero load impeda
infinite load current). However the concept of ideal voltage source is helpful to understan
practical voltage source.

Practically, a voltage source may be considered as an ideal voltage source having sm
internal resistance in series with it; as shown in fig. 2.21.

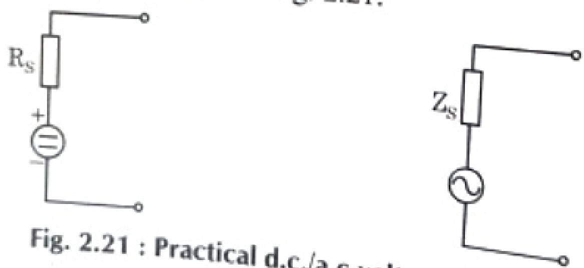


Fig. 2.21 : Practical d.c./a.c voltage source

Let us consider two examples

Example 2.16. Consider a 6 volt source having an impedance of 1 ohm; connected to a variable load of 1 to 9Ω. Calculate load voltage and %age change in load voltage when RL changes from 1Ω to 9Ω.

Solution.

$$V_S = 6\text{ V}, R_S = 1\Omega$$

(*i*) When

$$R_L = 1\Omega,\ I = \frac{V_S}{R_s + R_L} = \frac{6}{1+1} = 3\text{ A}$$

$$V_L = \text{voltage across load} = 3 \times 1 = 3\text{ volts.}$$

$$I = \frac{V}{R_1 + R_2}$$

V_{Th} = voltage between terminals A, B = IR_2

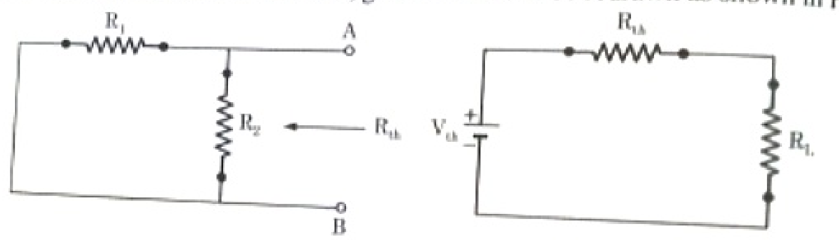
or
$$V_{Th} = \left(\frac{V}{R_1 + R_2}\right) \times R_2$$

Step II : Finding Thevenin's equivalent resistance

The Thevenin equivalent resistance is the resistance between the terminals AB while looking into the circuit with the conditions

(*a*) Load R_L is removed.

(*b*) Voltage source is short circuit or replaced by internal resistance and current source removed from the circuit. Therefore, given circuit can be redrawn as shown in Fig. 2.65.



(*a*) (*b*)

Fig. 2.65

$$R_{Th} = \frac{R_1 \times R_2}{R_1 + R_2}$$

Thus the value of the R_{Th} is determined. Once the value of V_{Th} and R_{Th} are known, then the current through load resistance R_L is determined by connecting the load resistance. R_L between terminals A and B as shown in Fig. 2.65(*b*).

$$I_L = \frac{V_{Th}}{R_1 + R_L} = \frac{V_{th}}{R_{th} + R_L}$$

Example 2.33. Calculate the current in AB using Thevenin's theorem for the circuit as shown in Fig. 2.66.

Solution. For calculating the value of current through AB *i.e.* through 10Ω resistance, we have to find V_{Th} and R_{Th}.

For V_{Th}, remove load *i.e.* 10Ω resistance, now circuit becomes as shown in Fig. 2.67.

Total resistance $= 15 + 3 + 2 + 5$
$= 25\Omega$

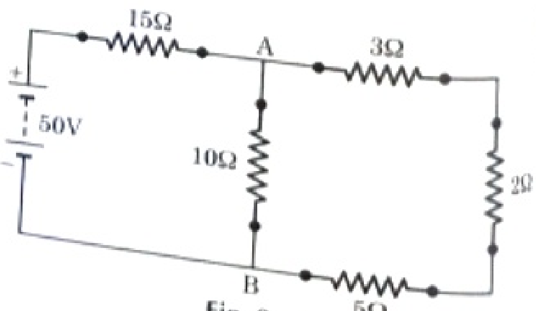


Fig. 2.66

$$\therefore \quad I_{CD} = \frac{\quad}{6+10} = \frac{\quad}{16} = 1.25 \text{ A}$$

Let us verify the result by using Norton's Theorem

$$R_i = R_{Th} = 6\Omega$$

Remove load from C and D and short these terminals

$$\therefore \quad I_{SC} = \frac{50}{15}$$

$$= 3.333 \text{ A}$$

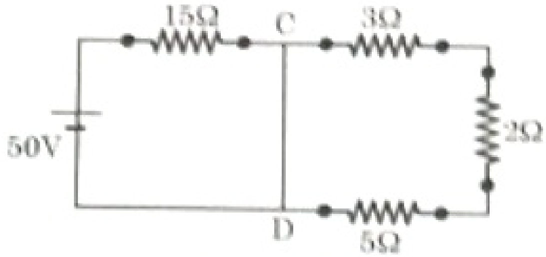


Fig. 2.92

Refer Fig. 2.93

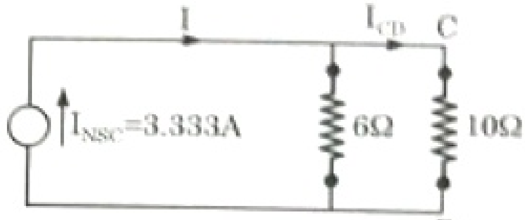


Fig. 2.93

$$V_{CD} = 3.333 \times \frac{6 \times 10}{6+10}$$

or

$$V_{CD} = 3.333 \times \frac{60}{16}$$

$$= 12.5 \text{ volts}$$

$$\therefore \quad I_{CD} = \frac{12.5}{10} = 1.25 \text{ A} \quad \textbf{Ans.}$$

SUPERPOSITION THEOREM

This theorem states that if many voltage sources or current sources are acting simultaneously linear network, then resultant current in any branch is the algebraic sum of the currents that d flow through it, when each source acting alone, replacing all other emf sources by their ıal resistances and keeping the terminals open, form where current source has been removed.

Procedure

i) Mark the direction of currents in various sections of the network I_1, I_2 I_3.

ii) Now consider only one source of emp say E_1. Redraw the circuit and determine the current in those section as I_1, I_2 and I_3 respectively.

iii) Now consider the second source E_2 and short circuit E_1 and redraw the circuit.

iv) Again determine the current I_1'', I_2'' and I_3'' By superposition theorem, the actual flow of current in various sections can be determined by superimposing the current, i.e.,

$$I_1 = I_1' - I_1''$$

$$I_2 = I_2' - I_2''$$

$$I_3 = I_3' - I_3''$$

If the load resistance changes, terminal voltage of source remains unchanged (if the R_S/R_L remains negligibly small)

Such a voltage source is a said to be a Good voltage source. Although it is not an ideal voltage source.

Ideal Voltage Source

In an ideal voltage source the terminal voltage of sources remains unchanged irrespective of the load connected to it or the current supplied by it. It is possible if source resistance (In case of a.c. source, it is source impedance) is zero.

Practical Voltage Source

Ideal conditions do not exist. However it can be made as near to ideal situation as possible. Practically no voltage source can have a constant value of terminal voltage. If it could be possible then it would be able to supply infinite amount of power at short circuit (zero load impedance, infinite load current). However the concept of ideal voltage source is helpful to understand practical voltage source.

Practically, a voltage source may be considered as an ideal voltage source having small internal resistance in series with it.

Current Source

A current source is similar to a voltage source. It can also supply current to a load connected to it. If there is a constant current source, it should supply a constant current to a load connected to it. The current supplied should not change, when load connected to it changes.

Ideally it should supply a constant current I_s even on infinite load i.e. when output terminals are open circuited. In such a situation power supplied by source $I^2 R_L$ will be infinite as the load connected to source is infinite. This is impossible. No practical source can supply infinite power. A practical current source should have high value of Z_S.

Any source supplying a load can work as a voltage source or as a current source depending upon the ratio of load impedance Z_S to source impedance, Z_L.

If ratio $\dfrac{Z_S}{Z_L}$ is small, the source works as a voltage source.

If ratio $\dfrac{Z_S}{Z_L}$ is high, the source works as a current source.

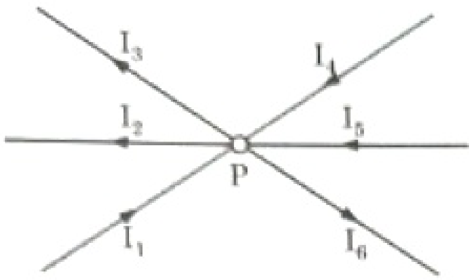
Given source can be represented either as a voltage source or as a current source under open circuit conditions, short circuit conditions or load conditions.

Thus a voltage source can be converted into an equivalent current source and vice-versa.

Kirchoff's Laws

Some complicated circuits cannot be simplified into a simple series or simple parallel or series-parallel circuit and cannot be solved simply by applying Ohm's law. Such circuits may be solved by applying Kirchhoff's laws.

ents meeting at a point (or junction) is zero or the sum of incoming currents towards any point ual to the sum of outgoing currents leaving that point. If I_1, I_2, I_3, I_4, I_5 and I_6 are the currents



ting at junction P, flowing in the directions of arrow heads marked on them (see Fig.) taking ming currents as positive and outgoing **Fig.** currents as negative, according to Kirchhoff's law (KCL).

$$I_1 - I_2 - I_3 + I_4 + I_5 - I_6 = 0$$

or

$$I_1 + I_4 + I_5 = I_2 + I_3 + I_6$$

Kirchhoff's Second Law or Voltage Law (KVL) or Mesh Law

According to this law in any closed electrical circuit or mesh, the algebraic sum of emfs ng in that circuit or mesh is equal to the algebraic sum of the products of the currents and stances in the circuit.

Application of Kirchhoff's Law in Circuit Solutions

While applying Kirchhoff's second law, the question of algebraic signs may be troublesome resistive drops in a mesh due to current flowing in clockwise direction must be taken as itive drops.

The resistive drops in a mesh due to current flowing in counter-clockwise direction must be en as negative drops.

Similarly the battery *emf* causing current to flow in clockwise direction in a mesh must be en as positive *emf* and the battery *emf* causing current of flow in counter-clockwise direction in esh must be taken as negative *emf.*

Simplification of Circuit Using Star-Delta Transformation

There are certain circuits which cannot be simplified by merely series and parallel circuit es. For simple and easy solution of such circuits, conversion of delta connected elements into r and vice versa is required. It is carried out in such a manner that the two circuits are ctrically equivalent *i.e.* resistance between the corresponding terminals is same. The methods transformation from delta to star and vice-versa is described below:

3 A.C. CIRCUIT

A circuit in which current flows only in one direction is called direct current and the sup system is commonly known as D.C. supply system.

Another supply system in which current varies in magnitude and direction periodically is cal an alternating current and commonly known as AC supply system. Therefore, an alternating curren that current which flows once in one direction and then in the reverse direction.

3.1 CONCEPT OF ALTERNATING VOLTAGE AND CURRENT

When a current carrying coil is placed in a magnetic field, an *e.m.f.* is induced in it accordin to Faraday's laws of Electromagnetic induction. The magnitude of this induced *e.m.f.* depend upon the rate of change of flux linking with the coil.

When the direction of magnetic field or coil is reversed, the direction of induced emf. in the coil is also reversed. When magnitude of flux cut by conductor is changing, then there is change in magnitude of induced e.m.f. Therefore nature of current in the load also changes.

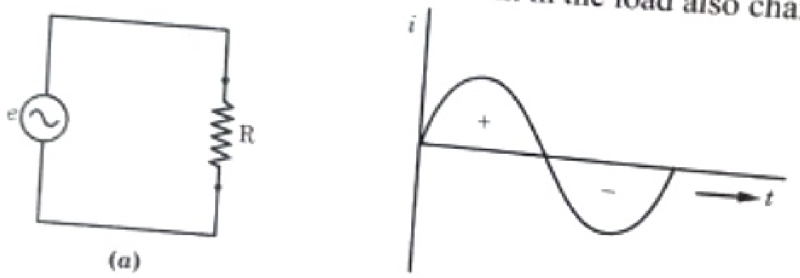


Fig. 3.1

For the generation of A.C., the machine is designed so as to generate alternating *e.m.f.* When such type of changing nature *e.m.f.* is applied across a load similar changing nature of current will flow through it.

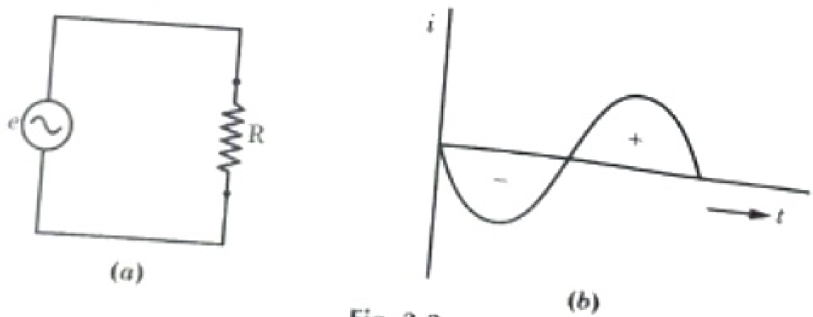


Fig. 3.2

3.2 EQUATION OF ALTERNATING E.M.F. (VOLTAGE)

An alternating *e.m.f.* can be generated in a coil by rotating it in an uniform magnetic field at constant speed. It is now desired to find the equation of this alternating *e.m.f.* in order to understand the performance of an a.c. circuit.

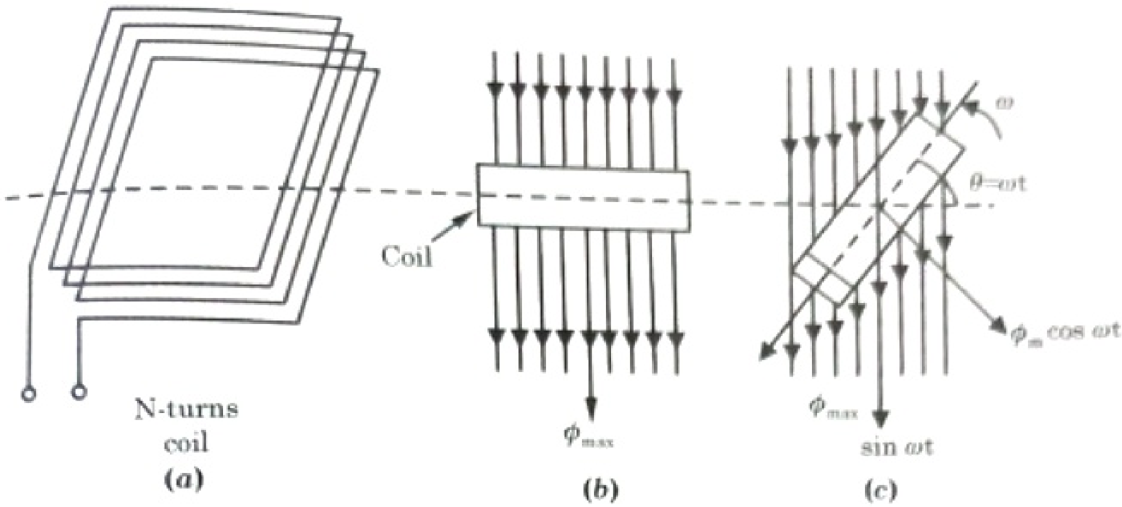


Fig. 3.3: Coil and Coil linking flux

Consider a coil of N-turns rotating in an uniform magnetic field in the anti-clockwise direction with an angular velocity of ω radians per second as shown in fig. 3.3. Let the time be measured from the instant when the plane of the coil coincides with *x*-axis. In this position maximum flux is linking the coil. As the rotates, flux linking with it changes and *e.m.f.* is induced in it. Let the coil turn through an angle θ in time t seconds, clearly $\theta = \omega t$.

In this position of the coil, maximum flux acting vertically down-wards can be resolved into two components *i.e.*

(*i*) Component $\phi_{max} \sin \omega t$ parallel to the plane of the coil. This component induces no *e.m.f.* as it is parallel to the plane of the coil and a coil moving parallel to flux has no change of flux linking with it.

(*ii*) Component $\phi_{max} \cos \omega t$ perpendiculars to the plane of coil. This component induces *e.m.f.* in the coil.

flux linkages at this instant

= Number or turns × flux linking

$= N \times \phi_{max} \cos \omega t$

According to Faraday's laws of electromagnetic induction, *e.m.f.* induced in a coil is equal to the rate of change of magnetic flux linkaging with the coil. Therefore, *e.m.f.* (*e*) induced in the coil at this instant is given by

$$e = -\frac{d}{dt}\text{(flux linkages)} \quad \ldots(3.1)$$

$$= -\frac{d}{dt}(N\,\phi_{max}\cos\omega t)$$

$$= -N\phi_{max}\frac{d}{dt}(\cos\omega t)$$

$$= -\,N\phi_{max}\,\omega\,(-\sin\omega t)$$

$$\therefore \quad e = N\omega\phi_{max}\sin\omega t. \quad \ldots(3.2)$$

The value of instantaneous *e.m.f.* (e) will be maximum when $\sin\omega t = 1$ or $\omega t = 90°$. Let us denote this maximum value by E_{max}.

$$\therefore \quad E_{max} = N\,\omega\phi_{max}$$

Putting this value of E_{max} in equation $N\,\omega\,\phi_{max}\sin\omega\,t$ we get

$$e = E_{max}\sin\omega t$$

or

$$e = E_{max}\sin\theta \quad \ldots(3.3)$$

This is the equation of the alternating *e.m.f.* induced in the coil. It is clear from the equation that instantaneous *e.m.f.* varies as the sine function of time angle. A current i flows through the circuit when voltage of e volts is applied.

The equation for the sinusoidal current is given by

$$i = I_{max}\sin\theta$$

$$i = I_{max}\sin\omega t \quad \ldots(3.4)$$

3.3 DIFFERENCE BETWEEN AC AND DC

Alternating Current (A.C.)	Direct Current (D.C.)
(1) It changes its direction 50 times per second, hence its frequency is 50 Hz.	It does not change its direction.
(2) It can be easily transmitted from one place to other.	It is difficult to transmit and is more expensive.
(3) It can be converted into to D.C. easily.	It can be converted into ac by using inverter.
(4) Its magnitude can be varied with choke without dissipation of energy.	Its magnitude can be varied by resistance in which energy is dissipated in the form of heat.
(5) It produces heat when passed through a resistance.	It also produces heat.
(6) A.C. source has two terminals and current flow + ve to – ve terminal periodically	D.C. source has also two terminals, marked + ve and – ve terminals and current always flows + ve to – ve through the load.

If the alternating voltage be represented by $e = E_m \sin \omega t$, then the projection of OA on th
axis at any instant gives the instantaneous value of the voltage.

$$OM = OA \sin \omega t$$

$$e = OA \sin \omega t$$

or

$$e = E_m \sin \omega t$$

A line OA can be made to represent alternating voltage or current, if it satisfies the followi
conditions.

(i) Its length should be equal to the maximum value of sinusoidal alternating voltage to suitable scale.

(ii) It should be in the horizontal position at the same instant when the alternating quanti is zero and increasing positively.

(iii) Its angular velocity (ω) should be such that it completes one revolution in the sam time as taken by the alternating quantity to complete one cycle.

PHASE

The phase of an alternating quantity (current or voltage) at any particular instant is define he fractional part of a cycle through which the quantity has advanced from selected origin.

In practice, we are more concerned with the phase difference between the two alternatin antities.

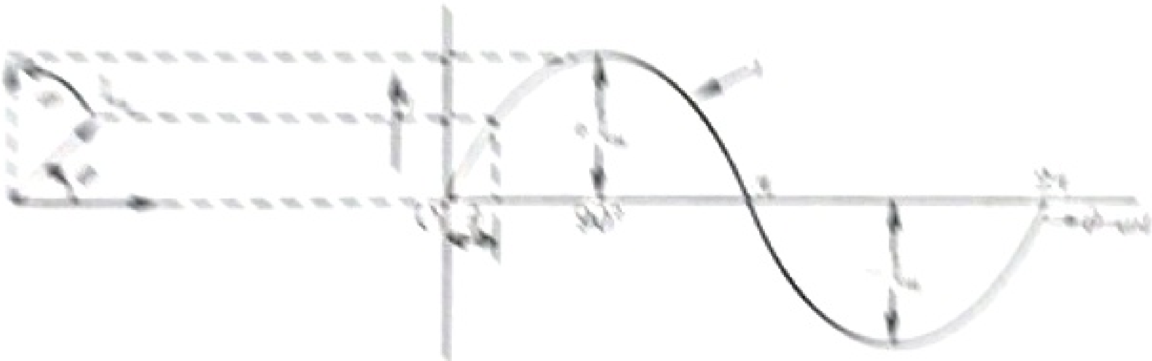


Fig. 3.16

PHASE DIFFERENCE

When two alternating quantities of the same frequency have their values zero and maximum different instants, they are said to have a phase difference.

Consider an a.c. circuit in which current i lags behind the voltage e by $\varphi°$. Then we say that phase difference between voltage and current is $\varphi°$.

Their equations are, $\quad e = E_{max} \sin \omega t$

$$i = I_{max} \sin (\omega t - \varphi)$$

(we could also take two voltages or two currents)

Instantaneous power, $p = ei$

$$= E_m \sin \omega t . I_m . \sin(\omega t - \pi/2)$$
$$= -E_m I_m \sin \omega t . \cos \omega t$$
$$= -\frac{E_m I_m}{2} . \sin 2\omega t$$

$\therefore$ Average power, P = Average of p over one cycle

$$= \frac{1}{2\pi}\int_0^{2\pi} -\frac{E_m I_m}{2} . \sin 2\omega t d(\omega t) = 0$$

Hence power consumed in a pure inductive circuit is zero.

Power Curve: From the power curve diagram it is clear that the average power in a half cycle is zero, as the negative and positive loop area under power curve is the same. Fig. 3.22 shows the power curve for a pure inductive circuit. During the first quarter cycle (90°) the power is supplied by the source that is stored in the magnetic field set up around the coil. In the next quarter cycle (*i.e.*, 90°), the magnetic field collapses and the power stored in the field is returned to the source. This process is repeated in each and every half cycle. Hence no power is consumed in a pure inductive circuit.

3.8 ALTERNATING VOLTAGE APPLIED TO PURE CAPACITANCE

If two conductor plates are separated by an insulating medium which may be air, a capacitor is formed. The insulating medium is called dielectric. A capacitor blocks the flow of D.C. completely. However A.C. can pass through it. A capacitor blocks the flow of D.C. completely. However A.C. can pass through it. A capacitor shown in fig. 3.23 is connected across a sinusoidal varying voltage given by.

$$e = E_m \sin \omega t \quad \ldots (1)$$

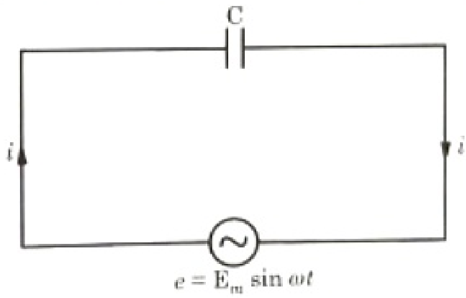


Fig. 3.23

Let C be the capacitance of this capacitor in farads.

The charge on the capacitor at any instant.

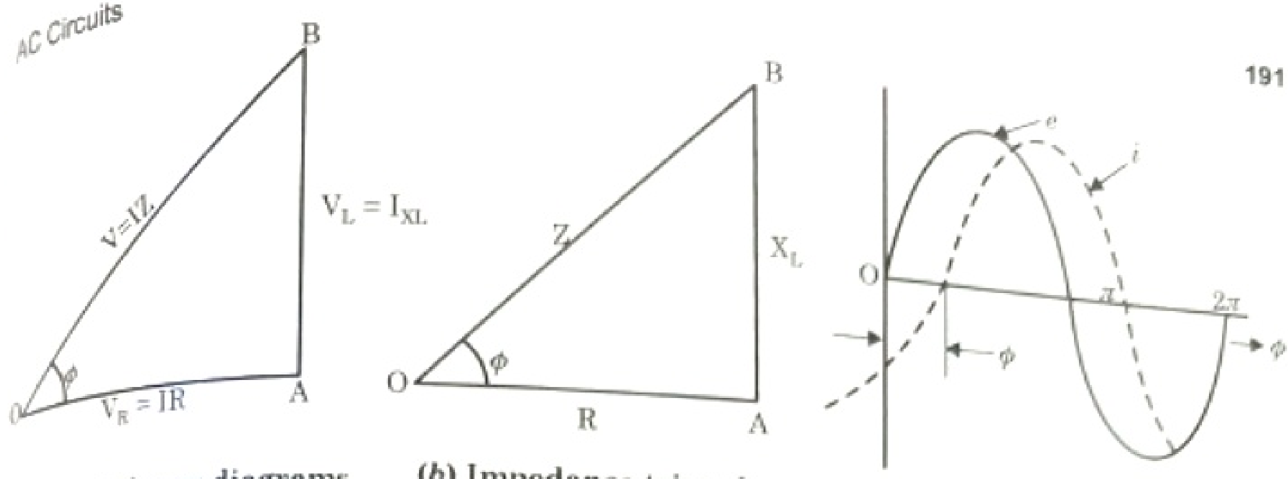
$$q = c.e = CE_m \sin \omega t$$
$$[\because e = E_m \sin \omega t]$$

The capacitor current $i = \frac{dq}{dt}$ (Rate of change of charge)

$$\therefore \quad i = \frac{dq}{dt} = \frac{d}{dt}[CE_m \sin \omega t]$$
$$= CE_m \omega \cos \omega t.$$

or

$$i = CE_m \omega \sin(\omega t + 90°) \quad \ldots (2) \quad [\because \cos\omega t = \sin(\omega t + 90°)]$$



(a) Phasor diagrams (b) Impedance triangle (c) Wave diagram

Fig. 3.29

Thus a right angle triangle whose base represents circuit resistance, perpendicular, represents reactance and hypotenuse represents circuit impedance is called in impedance triangle.

The concept of impedance triangle is useful since it enable us to calculate:

(i) The impedance of the circuit $Z = \sqrt{R^2 + X^2}$

(ii) The power factor of the circuit $\cos\phi = R/Z$

(iii) Phase angle, $\phi = \tan^{-1} X/R$

(iv) Whether current leads or lags the voltage.

It is always helpful to draw the impedance triangle while analysing an a.c. circuit.

PHASE AND PHASE ANGLE

Phase of an alternating current means the fraction of the time period of alternating current that has elapsed since the current last passed through the zero position of reference.

The phase angle of any quantity means the angle which the vector representing the quantity makes with the reference line to be taken at zero degree or radian. It is represented by ϕ.

Phase angle ϕ is positive if the circuit has resistance and inductance or it is an inductive circuit. Phase angle is negative if the circuit is capacitive.

3.12 R-C SERIES CIRCUIT

The Fig. 3.30(a) shows a simple circuit pure resistance R ohms and a pure capacitance in C series.

A voltage of r.m.s. value E is applied across the combination. Let the current flowing through the circuit be I amperes.

Let E_R be the voltage across R and E_C is the voltage across capacitor C. The circuit can be shown by drawing the phasor diagram. [Fig. 3.30(b)].

i) Power factor = $\frac{\quad}{EI}$ = $\frac{\text{...power}}{\text{Apparent power}}$

r example, in a resistor, the current and voltage are in phase *i.e.*, $\phi = 0°$. Therefore, power f a pure resistive circuit is $\cos 0° = 1$. Similarly, phase difference between voltage and in a pure inductive or capacitive circuit is 90°. Hence power factor of pure L or C circuit is is is the reason that power consumed by pure L or C is zero. For a circuit having R, L and rying proportions, the value of power factor will lie between 0 to 1. It may be noted that actor can never have a value greater than 1.

It is a usual practice to attach the word 'lagging' or leading with the numerical value of power factor to signify whether the current lags or leads the voltage. Thus if a circuit has a p.f. 0.6 and the current lags the voltage, we generally write p.f. as 0.6 lagging.

) Sometimes power factor is expressed as a percentage. Thus, 0.8 lagging power factor may be expressed as 80%.

Disadvantages of Low Power Factor

wer consumed in a single phase circuit

$$P = E\,I\cos\phi \qquad \ldots(i)$$

$$I = \frac{P}{E\cos\phi} \qquad \ldots(ii)$$

om equations (*i*) and (*ii*) we see that for a fixed value of power and voltage, the load are inversely proportional to the power factor. Lower the power factor, higher is the and vice versa. The higher current results in the following disadvantages.

Larger Conductor Size: To transmit or distribute a fixed amount of power at a fixed voltage at low power factor, the conductor will have to carry large amount of current which will necessitate a larger conductor size.

Larger Copper Losses: Due to more current carried by the conductors, I^2R losses are increased which results in poor efficiency of transmission or distribution.

Poor Voltage Regulation: Due to low power factor and increased currents, the voltage drop in transformers, alternators and transmission lines is more which again results in poor voltage regulation.

Large kVA Rating of the Equipment: The output power of electrical machines e.g. alternators and transformers is always rated in apparent power *i.e.*, kVA

$$\text{Because kVA} = \frac{kW}{\cos\phi}$$

Thus, we see that the rating of the equipment is inversely proportional to the power... At low power factor, the value of kVA will increase. Therefore, at low power factor, equip... of higher kVA has to be installed which will increase the size and cost of the equipment.

3.15.2 Causes of Low Power Factor

The following are the main causes of low power factor.

1. Transformers and chokes are the inductive devices which cause the current ... behind the voltage *i.e.*, they operate at a lagging power factor. However, at ... loads, the magnetising current does not affect too much, but at low loads or light ... the magnetising current has notable effect and lowers the power factor.
2. The motors which are used in industry are mostly induction motors having ind... loads, which have low power factor. Normally the power factor of induction mo... vary from 0.8 to 0.85 when operating at full load and 0.3 to 0.5 when running li... *i.e.*, at small loads.
3. Arc lamps, heating furnaces (Induction and arc furnaces) also operate at a low po... factor (lagging).

3.15.3 Advantages of Improved Power Factor

When the power factor of the system is improved, then the current flowing through whi... the system decreases for the same load. A decrease in current required has following advantag...

1. Small conductor size.
2. Small copper losses, better efficiency.
3. Less voltage drop, better regulation.
4. For the same kW out put, smaller kVA rating of the equipment.

Example 3.30. A single phase 220 volts, 50 Hz, motor takes supply current of 50 amper... a power factor 0.5 lagging. The motor power factor has been improved to 0.9 laggin... connecting a condenser in parallel. Calculate the capacitance of the capacitor required.

Solution. Applied voltage, $E = 220$ volts

Current taken from supply, $I = 50$ A

Supply frequency, $f = 50$ Hz

Power factor of the motor $\cos\phi_1 = 0.5$ (lagging)

$\therefore \quad \phi_1 = \cos^{-1} 0.5 = 60°$

Active component of current, $I_a = I\cos\phi = 50 \times 0.5 = 25\text{A}$

Since load on the motor is constant.

The active component of current remains the same.

4 ELECTROMAGNETIC CIRCUITS

4.1 CONCEPT OF ELECTROSTATICS

A basic property of some elementary particles of matter is that they develop electric influence. This property is known as electric charge. A charge can be positive or negative. Electric charge can not exist on its own, it always requires a mass to exist. But electric monopole is possible *i.e.* positive and negative charges can exist independently e.g. an electron carries negative charge on it. It can remain stable or can move from one place to another and it has different effects in both the cases. The behaviour of stationary charge is different from that of moving charge. The effects of electric charge at rest is studied under electrostatics. So **the branch of science associated with the study of effects of stationary charges is called Electrostatics.**

Electric charge is the **property of matter due to which, it exhibits electric, magnetic and electromagnetic effects.**

Electric charge is a fundamental property of matter. It has the following properties.

(*i*) Electric charge is quantised **i.e.** it occurs only in the integral multiples of a basic and smallest quantum (packet) which is equal to the charge found on an electron.

$\therefore$ The charge (q) on any body would follow,

$$q = \pm ne, \text{ where } n = 1, 2, 3 \text{ ------ integer}$$

and $$e = \text{charge on an electron} = -1.6 \times 10^{-19}\,\text{C}.$$

(*ii*) Electric charge is conserved ***i.e.*** the total electric charge in an isolated system remains constant. This also means that no **net** charge can be created or destroyed. When an atom is ionised, equal amounts of positive and negative charges are produced. Hence the algebraic sum of charges before and after ionisation remains the same.

(*iii*) Electric charge is a **scalar** quantity.

(*iv*) Electric charge is always associated with mass. (The massless particles like photon do not carry a charge).

(*v*) Electric charge is **additive i.e.** its sum can be found by an algebraic sum.

(*vi*) Electric charge remains unaffected by the motion.

(*vii*) Electric charge at rest causes an electric field, while moving at a constant speed, it causes a magnetic field and when accelerated, it emits electromagnetic waves.

(*viii*) There are **two** kinds of electric charge namely positive and negative.

(*ix*) Electric charge can be **induced** *i.e.* when a neutral body is brought near a charged body, an equal and opposite charge is induced on the neutral body.

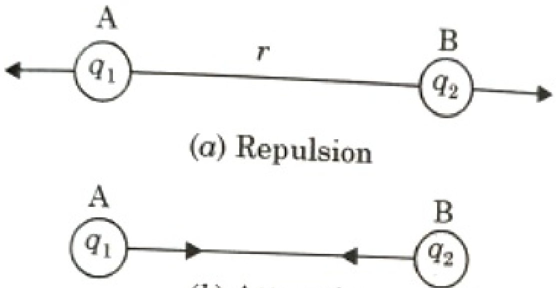
The S.I. unit of charge is coulomb denoted by C. In electrical engineering the unit of electric charge is ampere-hour (Ah). In chemistry we use the unit of charge as **faraday**. One faraday is magnitude of charge of one mole of electrons *i.e.* 6.022×10^{23} electrons.

One coulomb in equivalent to $6.242 \times 10^{18} e$, where e is charge of a proton. Hence charge of electron is -1.602×10^{-19}C. **One coulomb** is defined as the quantity of charge that has passed through a conductor carrying one ampere current in one second.

Coulomb's law states that '**The Magnitude of the electric force between two charges is directly proportional to the product of the two charges and inversely proportional to the square of the distance between them**'.

Consider two charges q_1 and q_2 present in vacuum at points A and B at a distance as shown in Fig 4.1. Then, force between two charges is given by

$$F \propto \frac{q_1 q_2}{d^2}$$



(*a*) Repulsion

(*b*) Attraction

Fig. 4.1

Coulomb's Law for the force between two charges can be written as

$$F = \frac{q_1 q_2}{4\pi\varepsilon d^2} = \frac{q_1 q_2}{4\pi\varepsilon_0\varepsilon_r\, d^2}$$

while for vacuum or air

$$F = \frac{q_1 q_2}{4\pi\varepsilon_0 d^2} \qquad .....(4.1)$$

(because $\varepsilon_r = 1$)

UNIT OF CHARGE :

From equation (4.1),

If

$$q_1 = q_2 = 1 \text{ C}, r = 1 \text{ m, then}$$
$$F = k \text{ newtons} = 9 \times 10^9 \text{ N}$$

Thus **one coulomb is defined as the quantity of charge that exerts a force of 9×10^9 N on an equal charge placed in vacuum at a distance of 1 metre from it.**

Example 4.1. Calculate the coulomb force between two protons separated by a distance of 4×10^{-15} m.

eld is represented by $\vec{B}$ and $\vec{H}$. Both are ... field
roduced by magnetic poles. It is called magnetic field intensity or strength of magnetizing field.

On the other hand the $\vec{B}$ is field produced around a conductor, carrying current. The magnitude of $\vec{B}$ field is equal to the force experienced by a unit charge moving with unit velocity perpendicular to the direction of magnetic field at that point. It is also called magnetic induction or magnetic flux density.

The H field is applied to Poisson's model while, B field is applied to ampere's model.

The S I unit of B is Tesla and CGS unit is gauss. The SI unit of H is ampere/meter (A/m) and CGS unit is Oersteds (Oe). H field is produced due to magnetic charges while B field is produced due to moving electric charges.

2.2 Properties of Magnetic Field $\vec{B}$ and its Units

1. It is a vector field
2. The effective magnetic field at a point due to several sources is vector sum of magnetic field of each individual source at that point. *i.e.* $\vec{B} = \vec{B}_1 + \vec{B}_2 + \vec{B}_3 + \ldots\ldots\ldots$
3. The magnetic field B is directly proportional to the force F experienced by a moving charge which is already directly proportional to charge q and component of velocity along perpendicular direction $i\ e\ v \sin\theta$

Thus $\quad f \propto q\, v\, B \sin\theta$

or
$$f = k\, q\, v\, B \sin\theta$$

or
$$f = q\ (\bar{V} \times \bar{B})$$

or
$$B = \frac{F}{q\, v \sin\theta}$$

if
$$q = 1\ C, = v = 1\,m/s, \theta = 90° \text{ and } F = 1\ N \text{ then } B = 1\ T$$

Thus magnetic field induction B at a point, is said to be one Tesla if a charge of one coulomb moving at right angle to magnetic field with a velocity 1m/s experiences a force of 1 Newton at point.

$$1\ T = 1N/A/m$$

Dimensions of B are $MA^{-1}\ T^{-2}$

Magnetic intensity at a point is the force experienced by a unit north pole placed at that point in a direction in which unit north pole will move when free to do so. The magnetic intensity can also be defined as the number of magnetic lines of force crossing per unit area around that point, the area being held perpendicular to the direction of magnetic lines of force. It is denoted by H. Its SI unit is Ampere/meters (Am^{-1}) or Joule/Tesla/meter^3.

Magnetic intensity is also called magnetic field strength. It is a quantity used in describing magnetic phenomena in terms of their magnetic field and magnetisation.

gnetic Lines of Force

etic lines of force are imaginary lines representing the direction of magnetic field. The awn at any point on these imaginary lines gives direction of the field vector at that density of magnetic lines of force at any point gives the magnitude of the field. They duced by Michael Faraday. Their properties are as follows:

Magnetic lines of force are closed curves. They travel from north pole to south pole outside the magnet and and from south pole to north pole inside the magnet as shown in ig. 4.2.

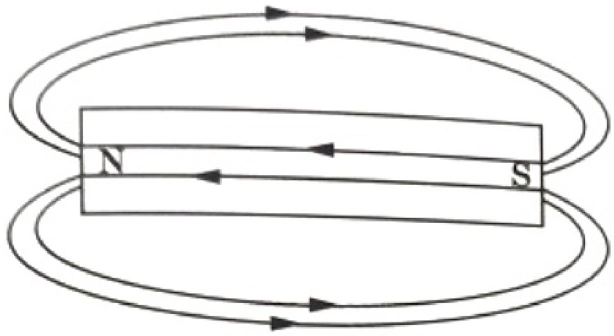


Fig. 4.2

They do not have any origin or end. They are closed and continuous curve.

They do not interact with each other.

They are crowded near poles and distended from magnet as they move away from poles.

They can emerge out of north pole at any angle and can merge into the south pole at any angle.

They never cross each other because an intersection shows two directions of magnetic field at same point, which is not possible.

agnetic Flux

amount or **number of magnetic lines of forces set up in a magnetic circuit is called flux. Its SI unit is Weber (Wb) and CGS unit is Maxwel.** It is a measure of number ic lines of force passing through some surface held in magnetic field. It is denoted by athematically it is the dot product of magnetic field B and surface vector S. Magnetic lar quantity

$$\phi_B = \bar{B}.\bar{S}$$

$$= BS \cos \theta$$

re θ is the angle between the magnetic lines of force and perpendicular distance normal face area.

Magnitude of magne... oil and is inversely proportional to the radius ...

$$B \propto I, \; B \propto \frac{1}{r}$$

1 Magnetic Field due to a Solenoid

A solenoid is a coil of wire. It works like an electromagnet when current flows throu... noid is a long cylindrical helix. A large number of turns of an insulated copper wi... nd over a circular tube. Fig. 4.5 shows a solenoid and the magnetic lines of flux produc... of current through it.

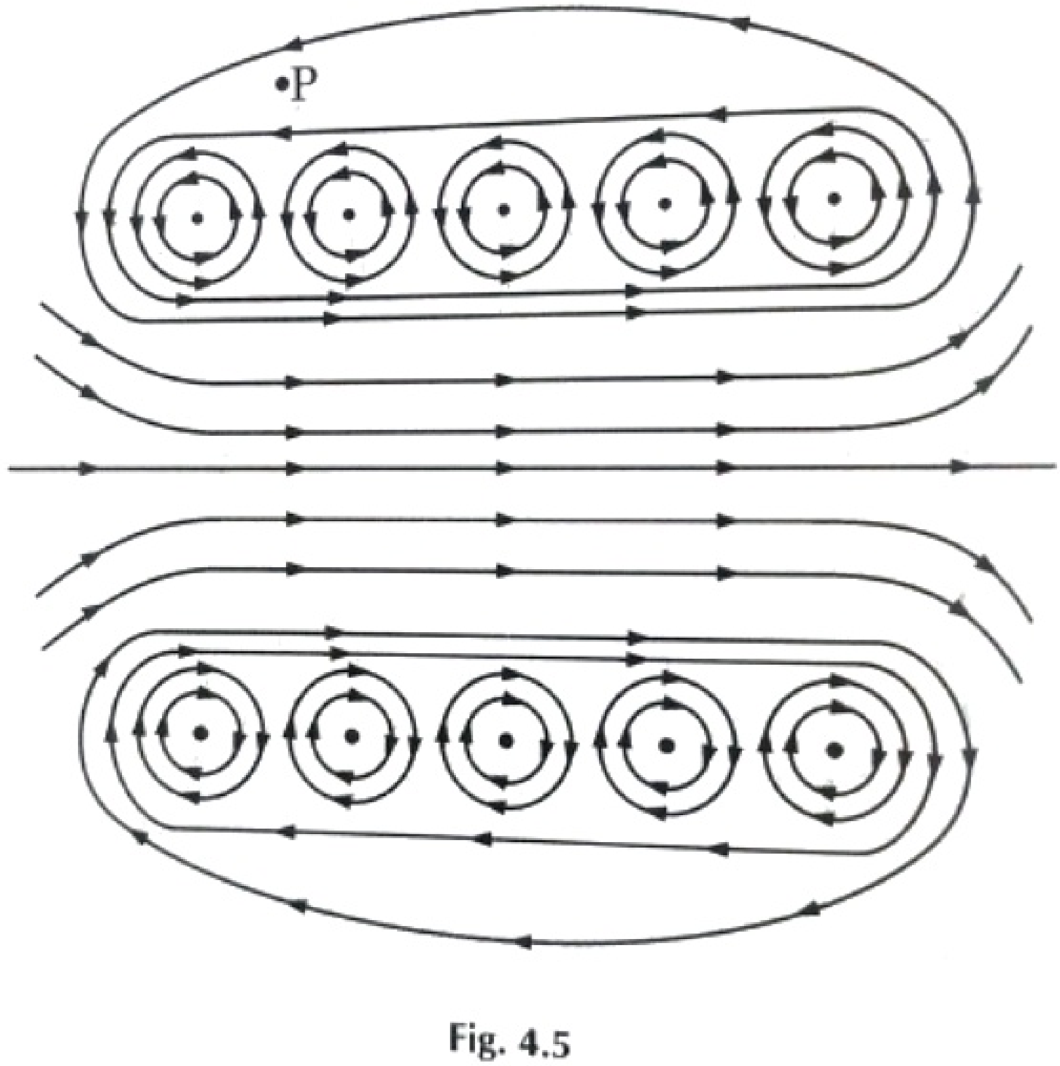


Fig. 4.5

Lines of magnetic field are uniform and parallel to the axis of solenoid within the so... netic field at any point P in the solenoid is given by formulae.

$$B = \frac{1}{2}\mu_0 NT(\cos\theta_1 - \cos\theta_2)$$

where N is the number of turns of solenoid. B varies at different points of solenoid. F... 's variation of B with distance from one end of solenoid.

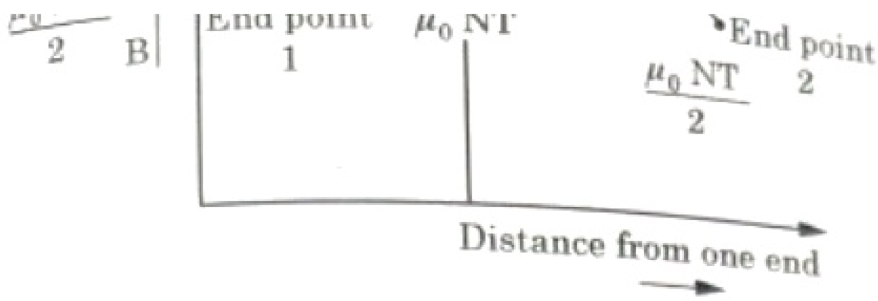


Fig. 4.6

served that value of B at ends of the solenoid is half the value of B at the centre. If ong enough. The value of B in the solenoid is uniform (except at both ends) Direction lines is found by using right hand rule.

netic Circuit and it's Analysis

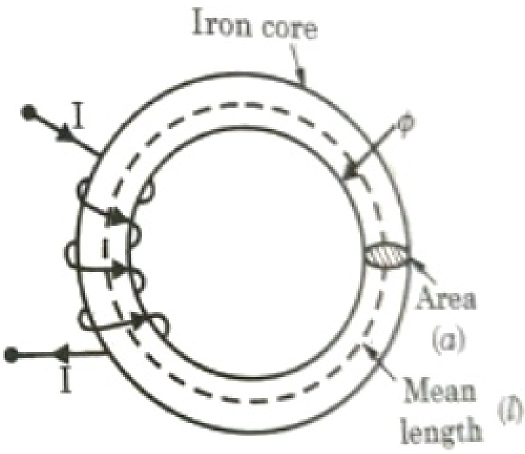


Fig. 4.7

sed path followed by magnetic flux is called **circuit.**

netic circuit usually consists of magnetic ving high permeability (e.g., iron, soft steel circuit, magnetic flux starts form a point and he same point after completing its path.

7 shows a solenoid having N turns wound on e (ring). When current I ampere is passed solenoid, magnetic flux ϕ Wb is set up in the

= mean length of magnetic circuit in m;

= area of cross-section of core in m^2;

$_r$ = relative permeability of core material.

lux density in the core material, $B = \frac{\phi}{a}$ Wb/m^2

etising force in the core material $H = \frac{B}{\mu_0 \mu_r} = \frac{\phi}{a\mu_0 \mu_r}$ AT/m

rding to work law, the work done in moving a unit pole once round the magnetic circuit equal to the ampere-turns enclosed by the magnetic circuit.

$$Hl = NI \text{ or } \frac{\phi}{a\,\mu_0 \mu_r} \times l = NI$$

(i) **Self induced e.m.f.:** It is the e.m.f. ...
linking with it changes.

$$e = -L\frac{di}{dt}$$

Where L is co-efficient of self inductance, $\frac{di}{dt}$ is rate of change of current through the coil itself.

(ii) **Mututally induced e.m.f. :** It is the e.m.f. induced in a coil when the flux produced by another coil linking with it changes.

$$e = -M\frac{di}{dt}$$

Where M is co-efficient of mutual induction, $\frac{di}{dt}$ is rate of change of current flowing through the other coil.

4.7.1 Principle of Self Induction

The property of a circuit, by which an e.m.f. is induced in the circuit whenever the current flowing through it changes, is termed as *self inductance.*

Consider a coil of N turns (air core) carrying a current of I amp. Let the flux linking with the coil be ϕ webers.

Then flux linkages = N I

The lines of flux linking the coil will change with change in current. This will induce an e.m.f. according to Faraday's Law. The e.m.f. so induced is called *Self-induced e.m.f.*

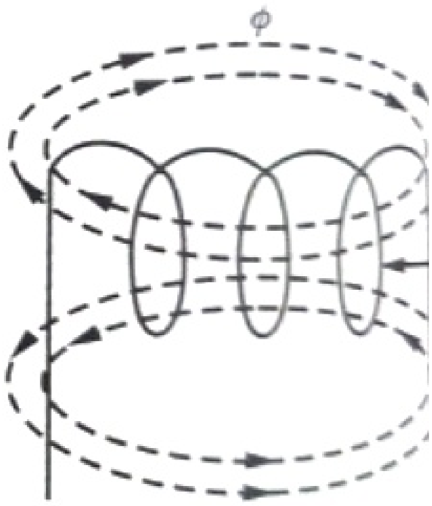


Fig. 4.9

4.7.2 Coefficient of Self-Inductance

$\frac{N\phi}{I}$ *i.e.,* flux linkage per ampere is called the *co-efficient of self-induction or in*... denoted by L.

If the current through a coil changes at the rate of one amp/second and the e.m.f. in it is one volt, then self-inductance is one Henry. Mathematically,

E.M.F. of self-induction, e or $e_L = -L\frac{di}{dt}$

$= -L \times$ Rate of change of current in ampere/Second

4.7.7 Mutually Induced emf

Consider two coils A and B placed close to each other so that the flux produced by one coil completely links with the other coil. Let coil A have a battery and switch S, variable resistor Rh. Let coil B be connected to the galvanometer G as shown in Fig. 4.12.

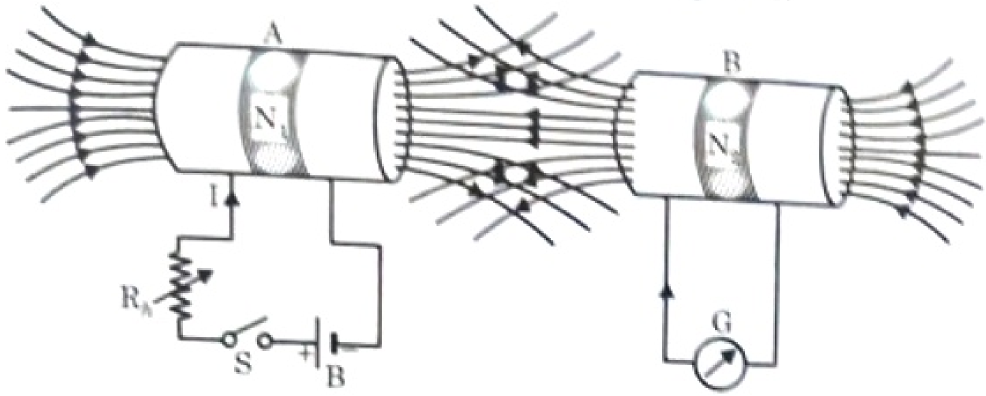


Fig. 4.12

When switch S is open, no current flows through coil A, so no flux is produced by coil A, *i.e.*,no flux links with coil B, therefore, no emf is induced in coil B. Galvanometer shows zero deflection as no current flows through it. When the switch S is closed, current in coil A starts rising from zero value to a finite value, the flux is produced during this period and increases with the increase in current of coil A, flux linking with the coil B also increases and an emf, known as *mutually induced emf,* is induced in coil B, current flows and the galvanometer shows deflection. As soon as the current in coil A reaches its finite value, the flux produced or flux linking with coil B becomes constant, so no emf is induced in coil B, and galvanometer pointer returns back to zero position. If the switch S is now opened, current will start decreasing, resulting in decrease in flux linking with coil B, an emf will again be induced in coil B, but in a direction opposite to previous one. This fact will be seen by the galvanometer deflection in opposite direction.

Hence whenever the current in coil A changes, the flux linking with coil B changes and an emf, known as mutually induced emf, is induced in coil B.

Consider coil A of turns N_1 wound on a core of length l metres, area of cross-section a square metres and relative permeability μ_r. When the current of i_1 amperes flows through it, a flux of $\dfrac{N_1 i_1}{l / \mu_0 \mu_r a}$ is set up around the coil. Presuming that whole of the flux produced due to change of current in coil A links with the coil B having N_2 turns and placed near by coil A.

$$\text{Mutually induced emf, } e_m = -N_2 \times \text{Rate of change of flux linkage of coil B}$$

$$= -N_2 \times \text{rate of change of flux in coil A}$$

$$= -N_2 \frac{d}{dt}\left[\frac{N_1 i_1}{l / \mu_0 \mu_r a}\right] = \frac{-N_1 N_2 a \mu_0 \mu_r}{l} \cdot \frac{di_1}{dt}$$

Similarities

Magnetic circuit	Electric circuit
1. The closed path for magnetic flux is called magnetic circuit.	1. The closed path for electric current is called electric circuit.
2. Flux = m.m.f./reluctance	2. Current = e.m.f/ resistance
3. Flux, ϕ in wb.	3. Current, I in amperes.
4. m.m.f in AT.	4. e.m.f. in V.
5. Reluctance, $S = \frac{l}{a\mu} = \frac{l}{a\mu_0\mu_r}$ AT/Wb	5. Resistance, $R = \rho\frac{l}{a}$
6. Permeance = 1/reluctance = $\frac{1}{S}$	6. Conductance = 1/resistance = $\frac{1}{R}$
7. Permeability, μ	7. Conductivity, $\sigma = 1/\rho$
8. Flux density, $B = \frac{\phi}{a}$ wb/m^2	8. Current density, $J = \frac{1}{a}$ A/m^2
9. Magnetic intensity, $H = NI/l$	9. Electric intensity, $E = V/d$

Dissimilarities

Magnetic Circuit	Electric Circuit
1. The magnetic flux does not flow but it is set-up in the magnetic circuit.	1. The electric current (electrons) actually flow in an electric circuit.
2. For magnetic flux, there is no perfect insulator. It can be set-up even in the non-magnetic material like air, rubber, glass etc. with reasonable m.m.f.	2. For electric current, there are large number of perfect insulators like glass, air, rubber etc. which do not allow it to flow through them under normal conditions.
3. The reluctance (S) of a magnetic circuit is not constant rather it varies with the value of B.	3. The resistance (R) of a material is almost constant as its value depends upon the value of ρ which is almost constant.
4. Once the magnetic flux is set-up in a magnetic circuit, no energy is expanded. However, a small amount of energy is required at the start to create flux in the circuit.	4. Energy is expanded continuously, as long as the current flows through an electric circuit. This energy is dissipated in the form of heat.

co... ...ce (m.m.f.) ... and the number of ingle turn coil produces m.m.f. of 1 AT when a current of 1 Amp. is passed through it.

ies Magnetic Circuits

sider the magnetic circuit It consists of three different sections of magnetic material. Let lengths of various sections be l_1, l_2 and l_3 meters and their area of cross section be A_1, A_2 ... respectively.

l reluctance offered by the magnetic circuit.

$$S = S_1 + S_2 + S_3 \text{ (They are in series)}$$

gnetic circuit may have an air gap.

iron ring with an air gap.

magnetic flux completes its path by flowing through the air gap. It can be that all the magnetic flux leaves the ring, passes through the air and re-enters the iron nplete its path, but practically it is not so. A part of the magnetic flux leaks through the is is known as leakage flux.

t of flux passing through the air gap does not re-enter into the magnetic circuit and is cage. This is called leakage flux and is not useful.

Total flux = Useful flux in air gap + Leakage flux

lay's **First Law:** This law states that when the flux linking with the coil or circuit an emf is induced in it or whenever the magnetic flux is cut by the conductor an emf is the conductor.

lains the production of e.m.f. but does not explain the magnitude of e.m.f. induced.

ay's **Second Law:** This law states that the magnitude of emf induced is directly l to the rate of change of flux linkage and to the number of turns of the coil.

s law' states that the direction of the induced emf and hence direction of the current opposes the cause producing it.

of Induced e.m.f:

n.f. may be induced as

ynamically induced e.m.f. : If the magnetic flux is stationary, while the conductor is igh though the flux such that flux linking with it changes, the e.m.f. induced is called induced e.m.f. EMF induced in generators and alternators uses this principle.

atically induced e.m.f.: If the conductor is stationary while flux is moved, the e.m.f. alled statically induced e.m.f. EMF induced in Transformers is self induced e.m.f. It

lf induced e.m.f.: It is the e.m.f. induced in a coil when the flux produced by it, iking with it changes.

5 BATTERIES

5.1 CELL

A cell is a source of electrical energy. Energy stored in the form of chemical energy, which is converted into electrical energy and is supplied in the form of direct current. The *e.m.f.* and current obtained from a single cell is generally small. For example, an ordinary dry cell has an *e.m.f* of 1.5 volt and can deliver about 0.125 ampere of current. Thus a cell can supply electrical energy to a circuit which requires only 1.5 volt. In most of the situations we require higher voltages or higher currents or both. Higher voltages or higher currents can be obtained by connecting the cells in series or parallel or series parallel combination. The combination of cells is known as battery. Batteries are necessarily used in telephones, motor cars, buses and other automobiles as well as portable radio receivers etc.

5.1.1 Definition

A cell is a source of *e.m.f.* (d.c.) in which chemical energy is converted into electrical energy.

A cell essentially consists of two conducting plates of different materials immersed in an electrolyte. These conducting plates are known as electrodes. The +ve plate is known as anode. The –ve plate is known as cathode. Due to chemical action between the electrodes and the electrolyte, an electric potential difference is established between the two electrodes. When any external load is connected between the +ve and –ve terminals of the cell, current. I flow through the load as shown in figure 5.1. The flow of current produces a gradual change in the chemical composition of electrodes and electrolyte. The process of delivering current continues till one of the electrodes is completely consumed. After this the potential difference between electrodes falls to very small value and the current ceases to flow. At this stage the cell is said to be discharged.

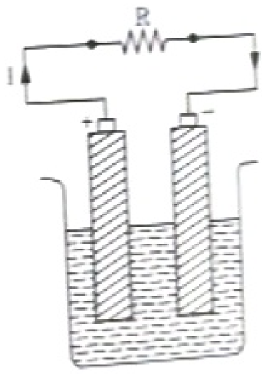


Fig. 5.1

5.1.2 Internal Resistance, e.m.f. and Terminal Voltage of Cell

Internal resistance of a cell is the opposition offered by the cell to flow of current through it. It is represented by r and is shown in series with the cell. It is measured in ohm. It produces heat in the cell when the cell supplies current.

E.M.F. of a cell is the voltage between it's terminals on open circuit *i.e.* when no current being supplied by it. It's value is normally 1.5 volts. It is represented by E.

Terminal voltage is voltage between it's terminals when the cell is connected in a circuit. Terminal voltage of cell depends upon it's internal resistance r and current being supplied by it. It is represented by V.

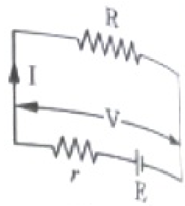


Fig. 5.2

Let a cell of e.m.f E volts, having internal resistance r be connected to a resistance R. Let I be the current supplied by it. The circuit is drawn in fig. 5.2

Then
$$E = V + r = I.R.$$
$$V = E - Ir$$

Example 5.1. A cell has a potential difference of 3 volt when no current flows through. When it supplies a current of 0.4 ampere. The terminal voltage falls to 2.9 volts. Calcul[ate] internal resistance of cell.

Solution.
$$E = V + Ir$$
$$3 = 2.9 + 0.4\,r$$
$$r = \frac{3-2.9}{0.4} = \frac{0.1}{0.4} = 0.25 \text{ ohms.}$$

5.1.3 Types of Cells

There are two types of cells, which are as the following:

1. Primary cells,
2. Secondary cells.

1. **Primary Cells:** The cells in which chemical action is not reversible *i.e.* the cells [which] once discharged cannot be recharged are called primary cells. One of the plates (generally [the -ve] plate) is completely consumed which cannot be recovered. For example in case of a voltaic [cell] there are two plates, one is of copper and the other is of zinc. The electrolyte is dilute solution of sulphuric acid (H_2SO_4), when it delivers current to the load as shown in fig. 5.3. Zinc dissolves in H_2SO_4 forming $ZnSO_4$. As a result of the chemical reaction, zinc plate goes on being consumed. When zinc plate is completely dissolved, the current ceases to flow through the load. In order to revive the process, the –ve plate *i.e.* zinc plate and electrolyte are replaced with fresh materials.

The other major drawback of this cell is that the *e.m.f.* developed and the current su[pplied] are very-very small.

Uses: These are used for torches and other electronic toys etc.

2. **Secondary Cells:** The cells in which chemical action is reversible are called secondary cells i.e. once discharged, these can be re-charged.

When current is delivered to the external load, the chemical process changes the composition of the plates. When the cell is exhausted, the chemical action can be reversed by passing current in the reverse direction through the cell.

In this case, the current is supplied to the cell from some external d.c. source and the process is known as re-charging of the cell.

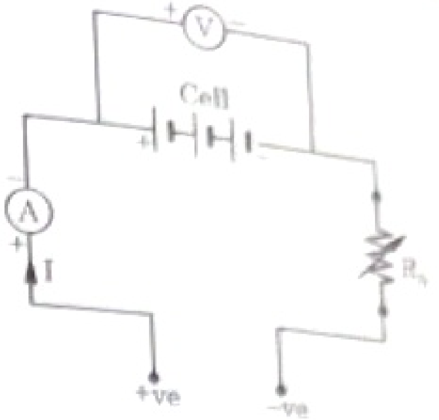


Fig. 5.3

When a cell delivers current to the external load, chemical energy is converted into electrical energy, whereas during re-charging the cell receives electrical energy from the d.c. source which is converted into chemical energy and is stored in the cell. Secondary cells are also known as storage batteries or accumulators.

Uses: These are used for car-battery, emergency light, telephone exchange etc.

5.2 CONCEPT OF BATTERIES

When a number of cells are connected in series, parallel or series-parallel combination it forms a battery. Symbol of battery is given in fig. 5.4.


Fig. 5.4

5.2.1 Types of Batteries

Construction of Lead Acid Battery: A battery consists of a number of cells and each cell of a battery consists of following parts.

1. **Plates:** Plates of a lead acid cell are made of antimonial lead alloy grid. Grids for the positive and negative plates are of same design. Plates support the active materials which take part in the chemical reactions within the cell.

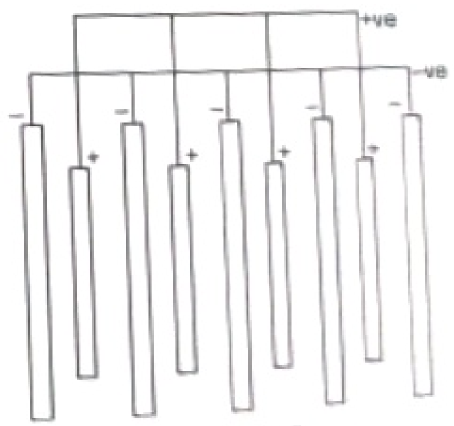


Fig. 5.5

2. **Separators:** The separators are thin sheets of a porous material which are placed between +ve and -ve plates to prevent internal short circuits of the +ve and -ve plates. The plates are made of porous material so that electrolyte can diffuse freely between the plates. The

(iv) As a low voltage supply for operating purpose in many different ways such as high tension switch gear, automatic telephone exchange, wire-less receiver sets etc.

(v) For local lighting of generating and substations during odd times and break downs.

(vi) For starting rotary converters in substations.

(vii) For traffic control system.

5.2.4 Nickel Cadmium Cell

Nickel Cadmium cell was developed by Waldermar Junger in 1889.

The positive plate is built up from a number of steel tubes made of perforated steel. The negative plate is of cadmium. The use of cadmium reduces the internal resistance of the cell.

When the nickle cadmium cell is in charged condition, the active material of the +ve plate (Anode) is $Ni(OH)_4$ and the Negative plate (cathode) is cadmium (Cd). The Electrolyte is a solution of Potassium hydroxide (KOH) with a small addition of lithium hydrate. The specific gravity of electrolyte is 1.2. When the cell is discharged the positive plate is converted to $Ni(OH)_2$ and Negative plate to $Ca(OH)_2$. When the cell is re-charged, the chemical process is reversed *i.e.* positive plate is converted into $Ni(OH)_4$ and Negative plate to Cd.

Discharging: When the cell discharges, the potassium hydroxide (KOH) is dissociated into Potaasium (K^+) and hydroxide (OH^-) ions. The hydroxal ions move to cathode and potassium ions move to anode. The following chemical reactions takes place during discharging.

At cathode : $Cd^+ + 2OH^- \longrightarrow Cd(OH)_2$

At anode : $Ni\,(OH)_4 + 2K \longrightarrow 2KOH + Ni\,(OH)_2$

Thus anode is converted from $Ni(OH)_4$ to $Ni(OH)_2$, and cathode is converted from cadmium (*Cd*) to cadmium hydroxide $Cd(OH)_2$, the strength of the electrolyte remains same.

Charging : When the cell is placed on charging the hydroxal (OH^-) ions move towards anode, whereas the potassium K^+ ions move towards cathode. During charging the following chemical reactions take place.

At anode : $Ni(OH)_2 + 2OH \longrightarrow Ni(OH)_4$

At cathode : $Cd(OH)_2 + 2K \longrightarrow Cd + 2KOH$

Thus anode and cathode regain their previous compositions without changing the strength of electrolyte.

The *e.m.f.* of Nickel Cadmium cell is 1.2 volt when charged and reduces to 1.0 volt when discharged. The specific gravity of electrolyte remains same in charged as well as in discharged conditions. The internal resistance of the cell is very low, even less than lead acid cell.

A Nickel Cadmium cell can be charged in a very short time *i.e.* say 1 hour. A Nickel Cadmium cell can be used upto 20 years of service.

5.6 DISPOSAL OF BATTERIES

Batteries contain many heavy metals and toxic chemicals. Disposal of these batteries a regular waste causes soil contamination and water pollution. This is harmful to human bein Therefore a proper disposal of used batteries is a must. It should not be disposal as munic waste.

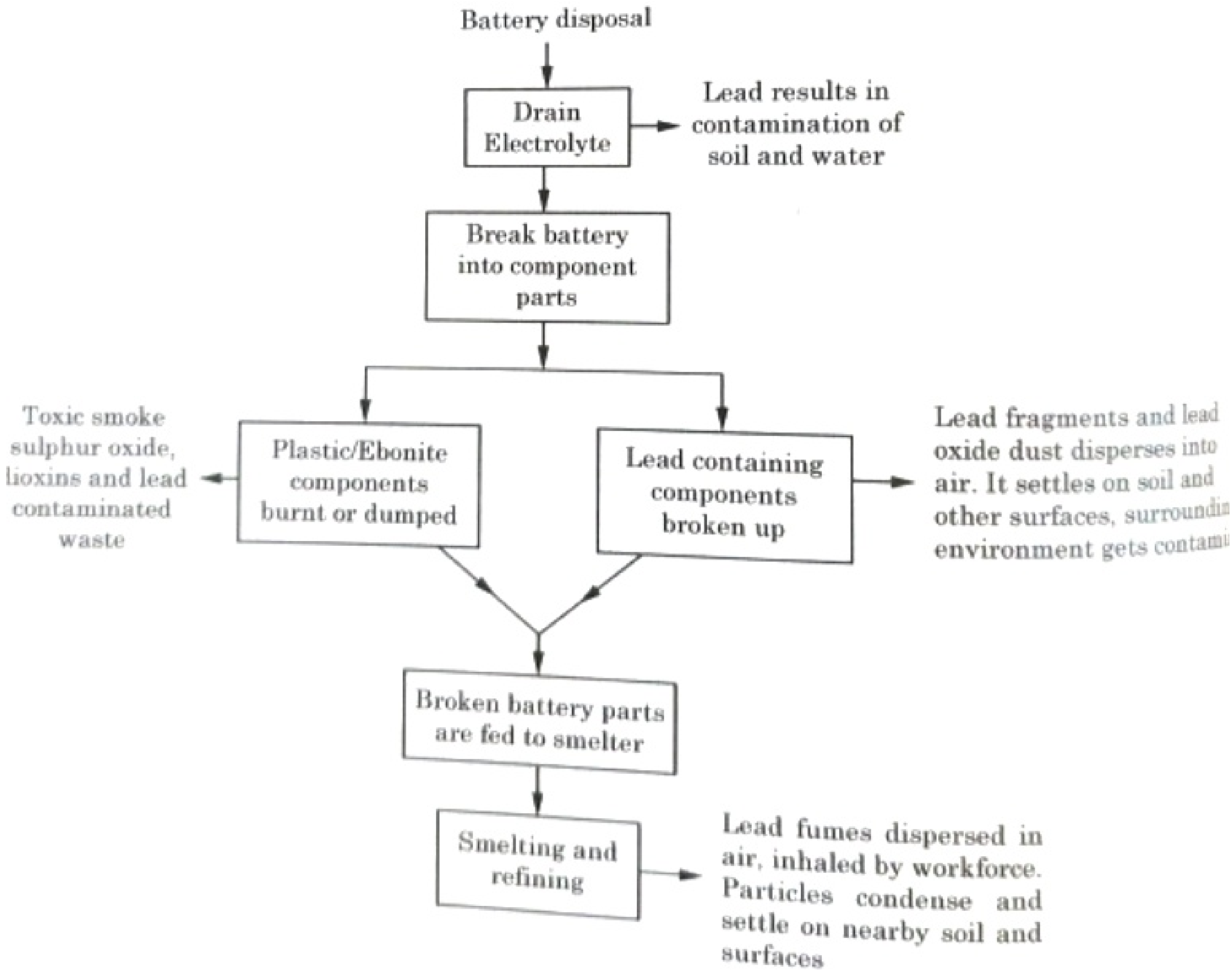
Many of batteries can be recycled. This reduces the number of batteries being disposed a period of time. Different type of batteries should be disposed off in different ways.

5.6.1 Disposal of Lead Acid Batteries

Lead acid batteries can be recycled. Lead is a toxic element and should not be mixed other waste. Casing of a lead acid battery is made of polypropylene which is a type of plasti can be recycled.

Processing of lead which is toxic material results in pollution / disability. It causes long health problem.

A schematic diagram showing disposal of lead acid battery is drawn below:



(i) **Disposal of alkaline batteries:** These batteries contain a small amount of metals such as nickel, cobalt, zinc, maganese or silver. Although these batteries can be recycled but the process is not cost effective. These batteries can be safely disposed off as municipal waste, because of small quantity of metals contained in them.

(ii) **Disposal of lithium-ion batteries:** Wrong handling of Li-ion batteries can result into risk of fire and pollution. Care must be taken to dispose off these batteries in a proper way. Various Do's and Donot's are tabled below for disposal of such batteries.

Do	Donot
Remove battery device and keep them segregated.	Donot dispose off with regular waste.
Insulate battery terminals or wires to prevent any short circuit.	Donot crush, puncture or throw the batteries that might result in short circuiting of electrodes.
Pack batteries in box with dry sand.	Donot keep large number of batteries together. Keep them segregated to avoid fire hazard.
Keep damaged batteries away from useable batteries.	Donot mix damaged and usable batteries.

LAR CELLS

r cell is a device which converts the energy of light falling on it into electricity by aic effect. It is a physical and chemical phenomenon. Electrical characteristics of the h as voltage, current and resistance are light dependent. Thus these characteristics vary t falling on it varies. Voltage generated in solar cells is very small. A number of cells d together to form a solar panel to get higher voltage.

ource of light may be natural light or artificial light. These work as a photo detector to t or other electromagnetic radiations. A solar cell does the same job as is done by cell ry. However it converts light energy into electrical energy while cell of a battery emical energy into electrical energy.

ructionally, solar cell is a sandwich of a type silicon material and a n-type silicon ith sun light falling on n-type surface of the cell, light particles (Photons) bombard the ace of cell to transfer their energy to p-type surface. Flow of electrons makes the flow

11 shows basic structure of a solar cell.

6 PRACTICALS

EXPERIMENT NO. 1

Experiment: **Familiarization of basic components/equipment like ammeter, voltmeter, wattmeter, resistance, capacitor, inductor, energy meter, power factor meter, CRO, multimeter etc. and their operation, uses.**

Objective:

(i) Knowledge of various components, instruments and equipments for measurement of voltage, current, power, resistance, capacitance, energy, power factor etc.

(ii) To know working and use of C.R.O.

(iii) To use a multimeter for various measurements.

(iv) To connect various instruments in a circuit.

Apparatus:

1.	Voltmeter	0–250 V	AC/DC	1 No.
2.	Ammeter	0–5A	AC/DC	1 No.
3.	Watt meter	0–1250 W	AC	1 No.
4.	Energy meter	16A / 250A	AC	1 No.
5.	Power Factor meter			1 No.
6.	Multimeter	Analog/Digital		1 No.
7.	C.R.O.			1 No.
8.	Components	Resistors, capacitors, inductors etc.		

Theory:

(a) **Use of ammeter, voltmeter and wattmeter**

Ammeter: Ammeters are used to measure currents. These can be classified on the basis of type of current (a.c. or d.c.) or the maximum current to be measured during the experiment. The ammeters have very low resistance.

The meters used for measurement of direct current are called permanent magnet moving coil (PMMC) instruments. These have uniform scale, but in our laboratories, the ammeters used for a.c. are moving iron type. These can be attraction type or repulsion type. These instruments have non-uniform scale which is cramped in its lower portion.

When a high current is to be measured, then the coil need not be made of thick wire to ... the full load high current, but a low resistance shunt is connected across the meter coil as sh... in fig. P-1.1.

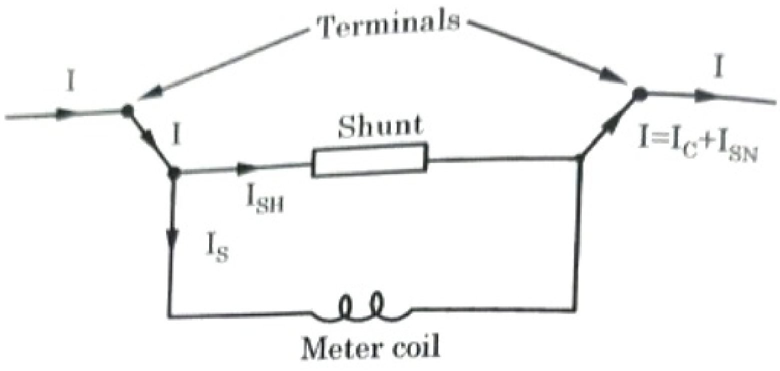


Fig. P-1.1

CKT. Diagram

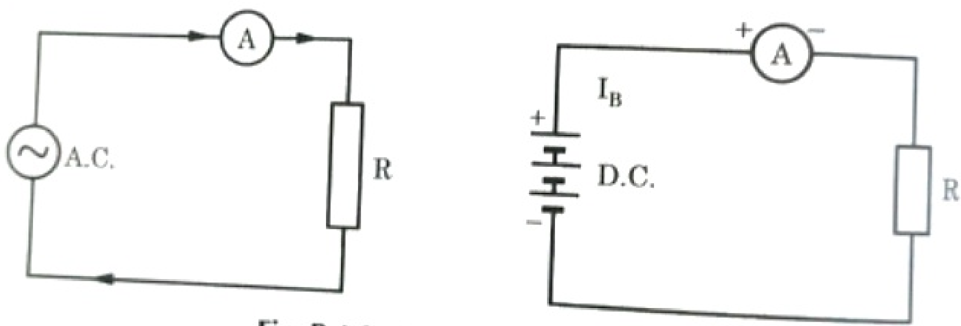


Fig. P-1.2: A.C./D./C. ammeters

Connections of Ammeters: An ammeter is always connected in series with the circuit so that t... circuit current to be measured passes through it.

Observations: Value of d.c. current = ...A

Value of a.c. current = ...A

(b) To study the operation of voltmeters.

Apparatus:

S. No.	Name of apparatus	No.
1.	Voltmeter a.c. (0–5V)	1
2.	Voltmeter d.c. (250 V)	1
3.	Connecting wires	–

Theory: Voltmeters are used to measure voltage or potential difference between two points. These can be of a.c. or d.c. type. These can be used to measure wide range of voltages from few mV to 500V.

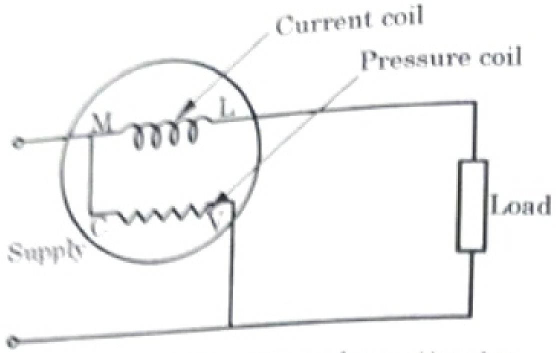


Fig. P-1.5 : Connection of a wattmeter

It consists of two coils. A current coil ML is connected in series with the load. All the load current flows through the coil. CV is potential coil or voltage coil. It is connected parallel to the supply. Terminal M and C are short circuited. Deflection of the wattmeter is proportional to current flowing through the current coil and current flowing through the pressure coil which is proportional to the supply voltage and the phase difference between voltage and current.

$$\therefore \quad P \propto VI \cos \phi$$

Connections:

1. Connect the current coil terminal M to supply, L to load.
2. Connect M and C.
3. Connect V to other terminal of supply.
4. Connect the load. Switch on the supply and measure the power.
5. Vary the load and take new readings.

Observation:

Wattmeter reading = ... Watts

(d) Use of energy meter

Principle : Induction type energy meters are used for measurement of energy consumed by a load connected to a.c. supply in a given period. It is an integrating type of instrument and measures the total quantity of electrical energy consumed by a load in a given period. *It works on the principle of electromagnetic induction as in case of induction motors. When a rotating magnetic field links with a metallic disc, an e.m.f. is induced in it causing flow of eddy currents through it. These eddy currents develop a torque, causing movement of the disc. Rotating magnetic field is produced by passing alternating current through current coil and potential coil of the energy meter.* The disc is suitably suspended in the field of rotating magnetic field.

Construction: Constructional details of an induction type energy meter is shown in fig. P-1.

The operating system can be divided as:

1. Driving System
2. Moving System
3. Braking System
4. Recording System

...ntal line on the screen.
...the middle of screen of
...lates of C.R.O.
...on the screen.
...e is now available on
...k values of wave say
...ive the peak to peak
...cycle.
...(a.c./d.c.) and

Apparatus :

	Name of instrument	Quantity
1.	Analog Multimeter	1
2.	Digital Multimeter	1
3.	Resistor (Any standard value)	5
4.	Connecting leads	Two sets

Theory :

A multimeter is an instrument that can measure a.c. and d.c. voltages, current and resistance. It consists essentially of separate voltage, current and resistance measuring circuits. The meter movement is common for all the three circuits. A selector switch is provided to set up the required circuit for a desired measurement. Fig. P-1.10 shows an analog multimeter while Fig. P-1.11 shows a digital multimeter.

DC (Direct Current) voltage and current do not vary with time. Voltage is potential difference between two points. When a voltage source is included in a closed path with resistors, a circuit is completed, and current flows. Current is electron flow or moving of charges. When current flows across a resistor it offers resistance and voltage drop occurs it. This relationship between voltage (V), current (I), and resistance (R) is known as Ohm's Law:

$$V = IR$$

Thus, if two of the above quantities are known, the third can be calculated.

In the experiment we will use a multimeter to measure resistance, voltage and current (a.c./d.c.).

Fig. P-1.10

Fig. P-1.11

Mica, paper or ceramic capacitor do not have any polarity on it's terminals while electrolytic capacitor have +ve and –ve marked on it's terminals.

It's symbol is C. Capacitance is measured in Micro Farads (μF). Size of electrolytic capacitors is large and these are rated for high voltages.

Inductors: Inductors oppose the change of current flow through it. It causes the current to lag behind the applied voltage by 90°. It's symbol is L and unit is Henery (H). It may be a fixed value inductor or a variable inductor.

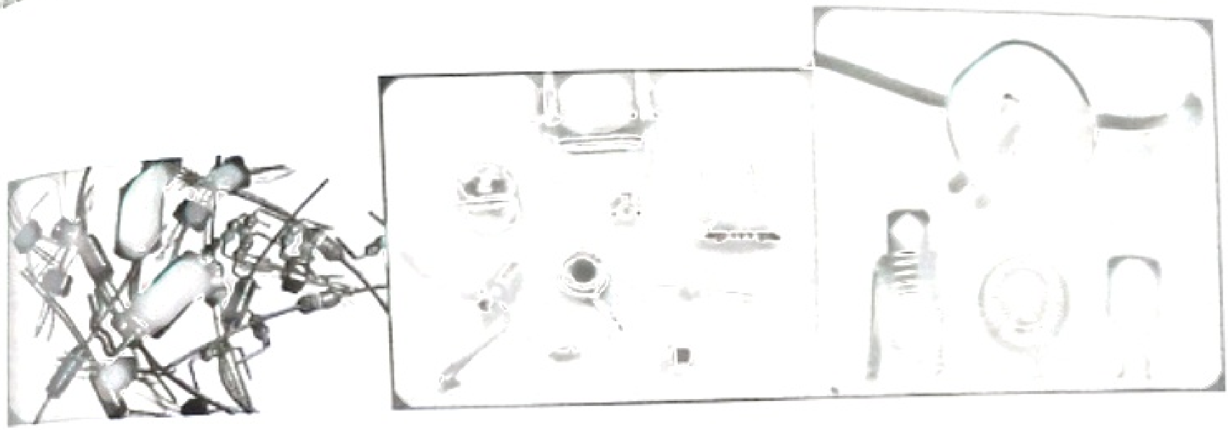


Fig. P-1.16 Types of inductors

Testing: All electronic components must be tested before being soldered in the circuit to ensure it's proper working.

(*i*) **Testing of resistors:** A resistor can either be open or short circuit. It can be tested by using a multimeter.

Set the multimeter for measurement of resistance. *i.e.* set the pointer to zero ohms by touching ends of both leads of multimeter and adjusting the zero adjust knob. Connect the two leads of multimeter to two ends of the resistor.

If meter shows 'Zero' on the scale, the resistor is short circuited. If meter shows 'infinity' on the scale. The resistor is open circuited. In both cases the resistor is not fit for use.

If the resistor is healthy, the multimeter will show it's value on the scale of multimeter.

(*ii*) **Testing of variable resistor (potentiometer):** Remove the potentiometer from the circuit. Use a multimeter to measure the value of resistance between two extreme terminals of potentiometer. It should remain unchanged with movement of knob of potentiometer. It's value must match the given value of potentiometer.

Check the resistance of potentiometer between one end terminal and the central terminal. It must vary linearly or logarithmically with movement of knob of potentiometer.