Learning Objectives

• To learn concepts of electric current
• To learn different voltage sources
• To understand concepts of electric current, electric potential
• To know the concepts of Conductor, Semi conductor and Insulator
• To study the relation between voltage, current and resistance (Ohms Law) through experiment, discussion and simple problems.
• To study the laws of resistance, specific resistance, effect of temperature on resistance.
• To understand series, parallel and series parallel combinations of resistors through discussion, problem solving, simple experiment and demonstration.
• To study basic network elements.
• To solve complicated networks using kirchoffs law, star-delta transformation by discussion.
**1.1 Electric Current**

All electricity comes from the charges carried by the electrons and protons of the atom. Electricity is actually the effect of either the imbalance of these charges on a body or the movement of charges.

The flow of electric charges constitutes an electric current or simply current. The flow of charge is due to transfer of negatively charged particles called electrons. The current in the metal wire, is due to the flow of electrons.
Study of electricity may be classified into two parts 1) The static electricity, which deals with the physical phenomena produced by charges at rest, and 2) The current electricity, which describes the physical affects due to charges in motion or it is electricity in action or electric currents, that carry out the tasks of electrical science in a broad sense.

The flow of electric current along a conductor resembles to the flow of water. Whether we are considering the flow of water or electricity we always have to deal with three things.

(a) Current (flow of electricity usually along a conductor)

(b) Pressure (that which causes the current to flow)

(c) Resistance (that which opposes or regulates the flow of current). Like wise, an inter connected system of water pipes corresponds to an inter connected system of electrical conductors and equipment, known as the electric circuit.

1.1.1 Conductors, Semiconductors, Insulators

(a) Conductors

Materials that conduct electricity are called good conductors or simply conductors. Good conductors offer very low resistance to electric current or conductors are those material which readily allows the flow of electrons through it with least resistance.

Conductors are widely used for wiring circuits in domestic and commercial applications, for winding of motorised appliances, for Generation, transmission and distribution equipments. Metals are good conductors of electricity. But not all metals conduct electricity equally well. Silver conducts electricity better than any other metal. But being expensive copper and aluminium are widely used as conductors. Some non - metals like graphite are also conductors of electricity.

(b) Semi Conductor

Semi conductor is that material which behave both as conductor and also insulators at different temperature, which are generally used in the field of electronics like T.V.s, Taperecorders, mobile phones, in various applications. Eg. Silicon, Germanium.

(c) Insulator

Materials which conduct almost no electricity are called bad conductors or insulators. Insulators have high resistance or Insulator is that material which do not allow the flow of electrons through them. These are also called dielectric
material Eg. Mica, Paper, Wood, Dry air, Dry cloth, porcelain etc.

Insulators play an important role in electric circuits and equipments. The insulation on wires ensure that a low-resistance circuit is not created in case the wires touch i.e. it prevents a short circuit. The insulation on wires also protects us from electric shocks. That is why the tools used by electricians. Such as line tester, screw drivers, and pliers have insulated handle.

1.2 Conventional Electric Current Flow

Conventional current is that which flows from +ve to -ve through the external resistance when connected to a source of supply. Electron current flow is that which flows from -ve to +ve through external resistance. The unit of electric current is ‘Ampere’.

1.2.1 Idea of Electric Potential

If we wish to cause a current of electricity to flow from one point to another, we must rise the potential of the first point above that of the second. Then the pressure is setup proportional to the difference in potential. This difference of potential tends to send a current from the higher potential to the lower as in the case of water.

A battery or generator may be thought of as a pump which pumps the electricity up from the lower level to the higher, and keeps one side of the line at a higher potential than the other, thus setting up pressure between these two points. Accordingly, the electric power company runs two wires to a consumer house and simply agrees to keep the difference in the potential between them. Even the battery acts as a pump to keep left hand side continually at a higher potential than the right hand side.
The difference of potential (Referring to the fig) between A and B is spoken as the fall of potential from A to B, or as the drop in potential from A to B. The same applies to B and C or any other two points.

The difference of potential between two points in an electric circuit is called the drop in potential for that part of the circuit contained between those two points and is the cause of any current flowing between these two points.

With reference to the above fig the terminal A is attached to the high-potential side of the generator, since it is marked (+), and B is attached to the low potential side of the generator, since it is marked (-). The current therefore flows from A through R, then through lamp to B, and back to low potential side of the generator. The generator must continually raise electricity up to the high potential side to make up for what flows away from that side to the low potential side. If no electricity is allowed to flow away from A to B, the generator has to raise no more electricity up to the potential of A. It merely has to keep up the pressure. The term potential is sometimes used instead of voltage to designate electrical pressure. When two points in an electric circuit have a different voltage (pressure), the difference between these points is called the **difference in potential** or the **voltage drop**. In the same way, the pressure between two points in a pipe carrying water is spoken of as the drop in pressure or the difference in head.
1.2.2 Electrical Resistance

It is defined as the property of a substance due to which it opposes the flow of electrons through it. Its unit is ohm (Ω).

Let us try to understand Resistance. In the case of both water and electricity there may be a great pressure and yet no current. If the path of the water is blocked by a valve turned off, there will be no flow (current). Yet there may be a high pressure. If the path of electricity is blocked by an open switch, there will be no current (amperes), though the pressure (volts) may be high. There is therefore, something in addition to the pressure, that determines the amount of the current, both of water and electricity. This is the resistance of the pipes and valves in the case of water and the resistance of the wires and various devices in the case of electricity. The greater the resistance, the less the current under the same pressure.

Resistors are common components of many electrical and electronic devices. Some frequent uses of resistors are to establish the proper value of circuit voltage, to limit current, and to provide a load.

A fixed resistor is one that has a single value of resistance which remains constant under normal conditions.

Fig. 1.4

(b) Rheostats

<table>
<thead>
<tr>
<th>Cast Iron</th>
<th>Grip</th>
<th>Insulated Ring</th>
<th>Resistance</th>
<th>Wire</th>
<th>Slide (Arm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire wound Registers</td>
<td>Composition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Resistance between B and A decreases.
Resistance between B and C increases.
Variable resistors are used to vary the amount of current or voltage for a circuit. Variable resistors are called as rheostats and potentiometers. A rheostat is a variable resistance with two terminals connected in series with a load. The purpose is to vary the amount of current.

![Diagram of a current circuit with a rheostat](image)

Fig. 1.5 Unit of Resistance

We say a wire has one ohm resistance when a pressure of one volt forces a current of one ampere through it.

### 1.2.3 Laws of Resistance

The Resistance ‘R’ offered by a conductor depends upon the following factors:

1. It varies directly as its length (L).
2. It varies inversely as the cross section (a) of the conductor.
3. It depends upon the nature of the material.
4. It also depends upon the temperature of the material.

Let us assume \( R = \frac{\rho L}{a} \) where ‘\( \rho \)' (Rho) is a constant that represents the nature of the material and is known as specific resistance or resistivity of a material.

### 1.2.4 Specific Resistance

Specific resistance of a material is the resistance between the opposite faces of a 1-cm cube of the material. Good conductors will have low values of ‘\( \delta \)' and vice versa. The reciprocal of resistivity is conductivity. The higher the conductivity, the better is the conductor.

Specific resistance is measured in ohm-cm or ohm-inch or micro-ohm-cm.
1.2.5 Specific Resistance of Some Metals

Although copper, on account of its low resistivity, is the metal most widely used for electrical conductors, aluminium, and even galvanized iron are sometimes used. The resistivity of aluminium is $170 \, \Omega \cdot \text{mil} \cdot \text{foot}$ at $20^\circ \text{C}$, about 1.6 times that of copper. But its low specific gravity more than counterbalances this, so that for equal lengths and weights aluminium wire has less resistance than copper and for this reason is coming into more general use.

The resistivity of iron and steel is about 7 times that of copper. These materials, therefore, can be used only where a conductor of large cross section can be installed, as in the case of a third rail or where a very little current is to be transmitted as in the case of a telegraph.

1.3 Problems on Laws of Resistance

1. A manganin wire of resistance 1000 ohms, length of 200 m has a cross sectional area of 0.1 mm$^2$. Calculate its resistivity.

Given $R = 1000 \, \Omega$; $L = 200 \, \text{m}$; $A = 0.1 \, \text{mm}^2 = (0.1/10^6) \, \text{m}^2$

Required: $\rho = ?$

Solution:

$\rho = \frac{R \cdot L}{A}$

$\rho = 1000 \times 0.1 / 10^6 \times 200$

$\rho = 50 \times 10^{-8} \, \Omega \cdot \text{m}$

2. Determine the resistance of 91.4 mts annealed copper wire, having a cross section of 1.071 cm$^2$, resistance of copper having 1.724 micro - ohm - cm at $20^\circ \text{C}$?

Given: $L = 91.4 \, \text{mts}$; $a = 1.071 \, \text{cm}^2$

$\alpha = 0.00001724 \, \Omega \cdot \text{cm} \cdot \text{Cm} = 91400 \, \text{cm}$

Required: $R = ?$

Solution:

$R = \rho \frac{L}{a} = 0.00001724 \times 91400 / 1.071$

$R = 0.147 \, \Omega$

3. Find the resistance at $20^\circ \text{C}$ of annealed copper wire of 1 mm$^2$ cross section and 100 m long with a resistivity of $1.73 \times 10^6 \, \text{cm}^2$.

Given: $l = 100 \, \text{m} = 10^4 \, \text{cm}$; $a = 1 \, \text{mm}^2 = 0.01 \, \text{cm}^2$

Required: $R$ at $20^\circ \text{C}$

Solution:

$R = \rho \frac{L}{a} = 1.73 \times 10^4 / 10^4 \times 0.01$
Therefore $R = 1.73 \, \Omega$

4. Find the resistance of a coil of copper wire of 150 m length of 3 sq mm cross section. The resistivity of copper is $1.724 \times 10^{-8} \, \Omega \cdot m$

Give: $L = 150 \, m$, $a = 3 \, sq \, mm = 3 \times 10^{-6} \, sqm. \, mm$

$L = 1.724 \times 10^{-8} \, \Omega \cdot m$

Required: Resistance = ?

Solution: $R = \frac{\delta L}{a} = 1.724 \times 10^{-8} \times \frac{150}{3 \times 10^{-6}}$

$R = 50 \times 1.724 \times 10^{-2}$

5. Calculate the length of copper wire of 1.25 mm dia has a resistance of $4 \, \Omega$, if the specific resistance of the material is $1.73 \times 10^{-8} \, \Omega \cdot m$

Given: $L = ?$

Solution $R = \frac{\delta L}{a}$ or $L = \frac{Ra}{L}$

$L = 4 \times 3.14 \times 1.25^2 \times 10^{-6} / 4 \times 1.73 \times 10^{-8} = 283.54 \, mts$

### 1.4 Effect of Temperature on Resistance

Connect a tungsten filament lamp across the battery as shown in Fig. 1.6. The voltmeter across the lamp gives the potential across it. By varying the number of cells in the circuit, the current taken by the lamp varies as listed below.

![Fig. 1.6](image-url)
1.4.1 Temperature Coefficient

Temperature coefficient of a material may be defined as the increase in resistance per ohm of original resistance per degree centigrade rise in the temperature. Metals increase in resistance when their temperature is raised and decrease in resistance when cooled as the temperature is decreased resistance also decreases

\[
\text{Increase in resistance for } 1^\circ \text{C rise in temp} = \alpha \times R_0 \times t
\]

Original resistance at (0°C)

\[
R_t = R_0 (1 + \alpha_0 t) \quad \text{and} \quad \alpha = \frac{R_t - R_0}{R_0 t}
\]

Where \( R_0 \) = Conductor resistance at O°C.

\( R_t \) = Conductor resistance at \( t^\circ \text{C} \).

\( t \) = Rise in temperature

\( \alpha_0 \) = Temperature co-efficient and resistance at O°C

for all pure metals this co-efficient is nearly the same lying between the values 0.003 and 0.006 and depends upon the intial temperature.

Coefficient of Resistance

‘\( \alpha \)’ is called positive, if the resistance increases with the temperature, and it is negative if the resistance decreases with the temperature. For metals and

<table>
<thead>
<tr>
<th>V (Volt)</th>
<th>I (Amp)</th>
<th>R(Ohm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>0.29</td>
<td>6.9</td>
</tr>
<tr>
<td>4.0</td>
<td>0.45</td>
<td>8.9</td>
</tr>
<tr>
<td>6.0</td>
<td>0.56</td>
<td>10.7</td>
</tr>
<tr>
<td>8.0</td>
<td>0.66</td>
<td>12.1</td>
</tr>
</tbody>
</table>

Table 1.1

It will be observed from the last column of the table that the resistance of the bulb is increasing as the potential across it is increasing. Similarly it can be proved that the resistance of most of the metals increase with temperature.
alloys $\alpha$ is positive and for carbon, electrolytes and Insulators it is negative.

For example: The resistance of copper wire and eureka wire is directly proportional to the temperature i.e. as temperature increases resistance increases and vice versa, this is called positive temperature coefficient of resistance.

The internal resistance of a battery and carbon is inversely proportional to the temperature i.e. as temperature increases the resistance decreases. This may be known as negative temperature coefficient.

1.4.2 Effects of Temperature - Simple Problems

1. The resistance - temperature coefficient of phosphor bronze is $39.4 \times 10^{-4}$ at 0°C. Find the temperature coefficient at 100°C.

Given : $\alpha_o = 39.4 \times 10^{-4}$; $t= 100^\circ$C

Required : $\alpha_{100}$ = ?

Solution : $\alpha_{100} = \frac{\alpha_o}{1+\alpha_o \cdot t} = 39.4 \times 10^{-4}/1+39.4 \times 10^{-4} \times 100$

$\alpha_o = 28.26 \times 10^{-4}$

2. The field winding of a motor has a resistance of 45 ohms at 0°C. What is resistance at 50°C? The temperature coefficient for copper is 0.00428 per °C at 0°C?

Given : $R=45 \Omega$ at 0°C, $\alpha_{copper} = 0.00428$

Required : $R$ at 50 °C = ?

Solution : We know $R_t=R_o (1+\alpha_o \cdot t)$

Resistance at 50 °C = $R = 45 (1+0.00428 \times 50)$

$R=45 \times 1.244$

$= 55.98 \text{ or } R=56 \ \Omega$

3. A coil of wire has a resistance of 40Ω at 25°C. What will be its resistance at 55°C. The temperature coefficient of the material is 0.0043 per °C at 0°C.

We know $R_t=R_o (1+\alpha_o \cdot t)$

Let $R_{25}$ is the resistance at $25^\circ$C = 40Ω

$R_{55}$ is the resistance at $55^\circ$C - ?

$\alpha_o$ is the temperature coefficient at $0^\circ$C.
\[
R_{55}/R_{25} = R_0 \times (1+0.0043\times55)/R_0 \times (1+0.0043\times25) = 1.2365/1.1075
\]
\[
R_{55} = R_{25} \times 1.2365/1.1075 = 40 \times (1.2365/1.1075)
\]
Therefore \(R_{55} = 44.68 \ \Omega\)

4. If the temperature co-efficient of copper at 20°C is 0.00393, find its resistance at 80°C. If the resistance of electromagnet at 20°C is 30 \(\Omega\).

Given \(R_{20} = 0.00393\) and \(R_{20} = 30 \ \Omega\)

Solution The relation between \(R_{20}\), \(R_{80}\) and \(R_{20}\)

\[
R_{80} = R_{20} (1 + R_{20} (80 - 20))
\]
\[
R_{80} = 30 (1 + 0.00393 \times 60)
\]
\[
R_{80} = 37.08 \ \text{ohms}
\]

### 1.5 Ohm’s Law

This law is named after the German Mathematician George Simon ohm who first enunciated it in 1827. Ohm’s law states that the ratio of the potential difference \((v)\) between any two points of a circuit to the current \((I)\) flowing through it is constant provided the temperature remains constant. The constant is usually denoted by resistance \((R)\) of the circuit.

Hence \(R = V/I\)

\(\text{ohms} = \text{volts} / \text{Ampers}\) Where \(V\) = voltage between two points.

\(I = \text{Current flowing}\)

\(R = \text{Resistance of the conductor}\)

\(I = V/R\) \quad or \quad \(V = IR\)

\(\text{Amper} = \text{volts} / \text{ohms}\) \quad or \quad \(\text{Volts} = \text{Amperes x ohms}\)
ohm’s law can be applied to an electric circuit as a whole or it can be applied to any part of it. This is an important law in electrical engineering. This law is applicable for d.c. circuits only.

The ohm’s law equation can be memorized and practiced effectively by using an ohm’s law circles as shown in Fig. 1.7

(a) Basic Circuit Components

Resistor, inductor and capacitor are the three basic components of a network. A resistor is an element that dissipates energy as heat when current passes through it. An inductor stores energy by virtue of a current through it. A capacitor stores energy by virtue of a voltage existing across it. The behaviour of an electric device may be approximated to any desired degree of accuracy of a circuit formed by inter connection of these basic circuit elements.

(b) Resistor

A Resistor is a device that provides resistance in an electric circuit. Resistance is the property of circuit element which offers opposing or hindrance to the flow of current and in the process electrical energy is converted in to heat energy. A Physical device whose principle electrical characterstic is resistance is called resistor.

(c) Inductors

The electrical element that stores energy in association with flow of current is called inductor. The basic circuit model for the inductor is called inductance. Practical inductors are made of many turns of thin wire wound on a magnetic core or an air core. A unique feature of the inductance is that its presence in a circuit is felt only when there is a change in current.

(d) Capacitors

A capacitor is a device that can store energy in the form of a charge separation when it is suitably polarized by an electric field by applying voltage across it. In a simplest form a capacitor consists of two parallel conducting plates separated by air or any insulating material such as mica. It has the characteristic of storing electrical energy (charge) which can be fully retrieved in an electric field. A significant feature of the capacitor is that its presence is felt in an electric circuit when a changing potential difference exists across the capacitor. The presence of an insulating material between the conducting plates does not allow the flow of d.c. current, thus a capacitor acts as an open circuit in the presence of d.c. current.
The ability of the capacitor to store charge is measured in terms of capacitance.

### 1.5.1 Ohms Law Problems

1. The current passing through a lamp is 0.5 amp and the supply voltage is 250 volts. Calculate the resistance of filament lamp.
   
   Given: \( I = 0.5 \) amp; \( V = 250 \) volts
   
   Required: \( R = ? \)
   
   Solution: \( R = \frac{V}{I} \) as per ohms law
   
   \[ R = \frac{250}{0.5} = 500 \, \Omega \]

2. A 230 volts tester has a resistance of 23 \( \Omega \). What would be the minimum rating of the fuse in the electric circuit for using the tester?
   
   Given: \( V = 230 \) volts
   
   Required: \( I = ? \)
   
   \( R = 23 \, \Omega \)
   
   Solution: As per ohms law \( I = \frac{V}{R} = \frac{230}{23} = 10 \) amps
   
   Note: the rating of the fuse means the maximum current the fuse allows to pass through it, beyond which the fuse melts, thus disconnecting the circuit.

3. An electric iron takes a current of 2.2 amp from 220 volts supply. What is its resistance.
   
   Given: \( I = 2.2 \) amp
   
   Required: \( R = ? \)
   
   \( V = 220 \) Volts
   
   Solution: \( R = \frac{V}{I} = \frac{220}{2.2} = 100 \, \Omega \)

4. A battery of negligible resistance is connected to a coil of 20 \( \Omega \) resistance. What must be the battery emf in order that a current of 1.5 amp may flow the circuit.
   
   Given: \( R = 20 \, \Omega \) \( I = 1.5 \) amp
   
   Required: \( V = ? \)
   
   Solution: \( V = IR = 20 \times 1.5 = 30 \) volts
5. The potential difference between the terminals of an incandescent lamp is 220 volts and the current is 0.22 amp. What is the resistance of the lamp.

Given: P.d=220 volts ; I=0.22 amp

Required: R=?

Solution: \( R = \frac{V}{I} = \frac{220}{0.22} = 1000 \ \Omega \)

### 1.6 Resistance in Series

When the resistors are connected in such a fashion that they are in random or connected end to end then they are said to be in series as shown in 1.8.

Consider water analogy system. Let there be three pipes of different cross sectional area which are connected to each other as shown in Fig. 1.8. Whatever be the rate of water entering the pipe at P, the same rate of water will be at outlet Q, as it cannot be that the water coming out in pipe of bigger diameter will be more. While in lesser diameter it will be less. But the pressure in different cross-sectional area will be different.

As discussed above (i.e water analogy) the different resistors (or electrical appliances) having different resistances can be connected in series as shown in Fig. 1.10, the potential difference across all of them be V volt which causes same current I to flow in each of them but the potential across each of them will be different. So the sum of all these potentials \( V_1, V_2, V_3 \) will be equal to the applied voltage V.
Fig. 1.11 represents the progressive fall in potential across each of resistors.

Applying ohm’s law to each of the resistors we get

\[ V_1 = IR_1 \]
\[ V_2 = IR_2 \]
\[ V_3 = IR_3 \]

\[ \therefore V = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3 \]
\[ \therefore V/I = R_1 + R_2 + R_3 \]

Let \( R_1, R_2, R_3 \) = resistance of three resistors connected in series.

\( I \) = current flowing in the circuit (or in all the resistors)
\( V \) = applied voltage
\( V_1, V_2, V_3 \) = voltages across each resistor

\( R_1, R_2, R_3 \) respectively.

If \( R \) is the total combined resistance of all the resistors, then
In general if 'n' number of resistors having resistances of \( R_1, R_2, \ldots \ldots \), \( R_n \) are connected in series, then the total resistance of the combination is

\[ R = R_1 + R_2 + \ldots \ldots + R_n \]

**In Series Circuit**

i) Current remains same in each branch of resistance and line.

\[ I = I_1 = I_2 = I_3 \]

ii) Applied voltage is the sum of the branch voltages.

\[ V = V_1 + V_2 + V_3 \]

iii) Hence total resistance is the combined resistance of all

\[ R = R_1 + R_2 + R_3 \]

**Applications of Series Circuits**

Series circuits are commonly seen in applications such as street lamps, and airport runway lamps. Another example of an everyday occurrence is lighting at temples and houses during festivals and decoration of Christmas trees. When one of the lamp in the string burns out, all the bulbs do not glow because the circuit is no longer complete for current flow. The fused bulb causes an open circuit for current flow. If a string contains 10 bulbs and if it is connected to a 200-volts source, 20 volts will appear across each bulb. If one bulb burns out, then 200 volts will appear across the remaining 9 bulbs, and 22.2 volts will appear across each bulb. This increased voltage can burn out another bulb and so on. In the case of airport runway lamp and street lamps, normally constant current variable voltage sources are used to avoid burning of bulbs and to maintain continuous illumination. When one of the bulb burns out, a device at the lamp automatically short circuits the defective lamp, thus allowing other bulbs to glow continuously. The variable voltage source will automatically reduce the voltage across the circuit reducing the current flow through the lamps (normal rated current is maintained) thus preventing further burning out of lamps.
1.6.1 Resistance in Parallel

Resistance are said to be connected in parallel if one end of all the resistors is connected to a common point, similarly the other end of all the resistors is connected to another common point, then these two common points are connected across the source.

Consider water analogy, in which A and B are two pipes at different levels. Let them be joined by three pipes, P, Q and R of different diameters in parallel as shown in 1.12. If the pressure at three values at same levels is measured, it will be observed that it is same. The same water pressure will force the water current in the three pipes; since the pipes are of different diameters, the water current in the three pipes will be different.

Similarly, now consider that the three resistors which are so connected that all their one ends are joined together and their other ends are also connected together. The two end A and B are connected to a supply source V, so that the same potential forces the current in all the three resistances.

![Diagram](image1)

Fig. 1.12 The pressure in pipes P, Q, R is same but the water current in 3 pipes is different

![Diagram](image2)

Fig. 1.13 Resistances connected in parallel

![Diagram](image3)

Fig. 1.14 Three bulbs glowing very bright
Let $R_1, R_2, R_3$ are the resistances connected in parallel.

‘$V$’ be the voltage applied across all resistances.

‘$I$’ be the current among all branches.

**In Parallel Circuit**

(i) Voltage remains same in each branch

\[ i.e. \quad V = V_1 = V_2 = V_3 \]

(ii) Current is divided into separate branches

\[ i.e. \quad I = I_1 + I_2 + I_3 \]

(iii) Total Resistance in all branches

\[ \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \]

as per ohms law \( I=V/R \) i.e.

\[ I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad \text{or} \quad I = V \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) \]

or \( I/V = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \) or \( 1/R = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \)

All bulbs, fans etc will be connected in parallel to the supply voltage.

**Applications of Parallel Circuits**

Parallel circuits are widely used in the light distribution circuits in homes and factories. These circuits are supplied from constant voltage - variable current sources. Parallel circuits are also used on ships for their service distribution systems, where many branch circuits are connected in parallel across the busbars. In home and factory distribution circuits, all parallel circuits are connected to the main circuit and each parallel circuit will have a fuse in it. In actual practice, almost all distribution electrical circuits are parallel circuits.

**1.6.2 Resistance in Series Parallel Combination**

![Fig. 1.15 Resistance of Series Parallel Combination](image)
In this type of connection both series and parallel connections are used. Hence both the rules are applicable to this circuit. In this figure Resistance \( R_2 \) and \( R_3 \) are in parallel and \( R_1 \) is in series to this parallel combination. First the parallel combination of resistances \( R_1 \) and \( R_2 \) should be solved, then the equivalent resistance from a series circuit should be solved.

Practical Applications of Series Parallel Circuits

Series parallel circuits are common features of many electronic circuits. They are used in a variety of situations where different voltages and currents are required.

<table>
<thead>
<tr>
<th></th>
<th>Series Circuit</th>
<th>Parallel Circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diagram</strong></td>
<td><img src="image1.png" alt="Series Circuit Diagram" /></td>
<td><img src="image2.png" alt="Parallel Circuit Diagram" /></td>
</tr>
<tr>
<td><strong>Current</strong></td>
<td>The current is same in all resistors of the circuit. ( I = I_1 = I_2 = I_3 = ... )</td>
<td>The total current supplied to circuit is equal to the sum of the currents through the several branches ( I = I_1 + I_2 + I_3 + ... )</td>
</tr>
<tr>
<td><strong>Voltage</strong></td>
<td>The total voltage equals the sum of the voltages across the different resistors of the circuit. ( V = V_1 + V_2 + V_3 + ... )</td>
<td>The voltage across a parallel combination is the same as the voltage across each branch of resistor. ( V = V_1 = V_2 = V_3 = ... )</td>
</tr>
<tr>
<td><strong>Resistance</strong></td>
<td>The total resistance equals the sum of the resistances of the separate resistors ( R = R_1 + R_2 + R_3 + ... )</td>
<td>The reciprocal of the total or combined or equivalent resistance equals the sum of the reciprocals of the resistances of the individual branch resistors.</td>
</tr>
</tbody>
</table>
Voltage dividers: In many electronic devices, like radio receivers and transmitters, television sets, the circuit requires different voltages at different points. These different voltages have to be obtained from a single voltage source. The most common method of meeting these requirements is given by the use of voltage dividers.

1.6.3 Series Parallel Simple Problems

1. Three resistances of 2, 10 and 20 Ω are connected in series. Find the equivalent value of resistance.

\[ R_1 = 2 \, \Omega \]  
\[ R_2 = 10 \, \Omega \]  
\[ R_3 = 20 \, \Omega \]  

\[ R_{eq} = R_1 + R_2 + R_3 = 2 + 10 + 20 = 32 \, \Omega \]

\[
\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots
\]

or \[ G = G_1 + G_2 + G_3 + \ldots \]

2. Three resistance of 2, 10 and 20 Ω are connected in parallel. Find the equivalent resistance.

\[ R_1 = 2 \, \Omega \]  
\[ R_2 = 10 \, \Omega \]  
\[ R_3 = 20 \, \Omega \]  

\[
\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots
\]

or \[ G = G_1 + G_2 + G_3 + \ldots \]
(10+2+1)/20 = 13/20 or R=20/13  R=1.61 Ω

3. Two lamps of rating 220 V, 50 W and 220 V, 100 W are connected in series across 220 V supply. Calculate the voltage across each lamp and power consumption.

What will be the power consumption if the two lamps are connected in parallel?

Solution:

Given data:

| V = 220 V | V₁, V₂ = ? |
| P₁ = 60 W | P = ? |
| P₂ = 100 W |

Resistance of 60 W lamp, \( R₁ = \frac{V²}{P₁} \)

\( = \frac{(220)²}{60} = 806.7 \) Ω

Resistance of 100 W lamp, \( R₂ = \frac{(220)²}{100} = 484 \) Ω

Total resistance when connected in series

\( R = R₁ + R₂ = 806.7 + 484 = 1290.7 \) Ω

Current \( I = \frac{V}{R} = \frac{220}{1290.7} = 0.1704 \) A

So voltage across 60 W lamp, \( V₁ = IR₁ \)

\( = 0.1704 \times 806.7 \)

\( = 137.5 \) V Ans.

So voltage across 100 W lamps, \( V₂ = IR₂ \)

\( = 0.1704 \times 484 \)

\( = 82.5 \) V Ans.

Power consumption \( P = VI \)

\( = 220 \times 0.1704 \)

\( = 37.5 \) W Ans.
When the lamps are connected in parallel the power consumption = 60 + 100 = **160 W** Ans.

4. Find the total resistance of the following circuit.

![Series Parallel Combination Circuit Diagram]

Resistance between $R_2$ and $R_3$

i.e. $B^1$ and $C_1 = \frac{2 \times 4}{2+4} = \frac{8}{6} = 4/3 \Omega$

\[
\text{Resistance between } B^1 = \left( \frac{4}{3} + 6 \right) \times 6 = \frac{4}{3} + 6
\]

\[
\frac{4}{3} + 6 + 6 = 15/7 \Omega
\]

Resistance between $AD$ i.e. $R_1 + (R \text{ betn } B^1C_1) + R \text{ betn } D$

\[
= 3 + \left( \frac{15}{7} \right) + 6 = \frac{78}{7} = 11.5 \Omega
\]

### 1.7 Explanation of Elements of D.C. Network

**Circuit**: A circuit is that which allows a current to pass through it. It consists of a number of branches.

**Junction**: Junction is that point where different paths of current meet, $O, A, B, C$ are junctions.

**Branch**: Branch is a part of a circuit or network. $AB$ is one branch. $BC$ is another branch or network.
Loop: Any closed circuit is called loop. OABC is a loop.

Network: The connection of parameter (R-L-C) in different ways is called an Electrical network.

Current Direction: In comming currents will be towards the Junction point and outgoing currents will be away the junction point.

Active Network: The circuit which consists of parameters (i.e. R,L,C) with source of e.m.f is called an Active network.

Passive Network: Any circuit which consists only parameters (R,L,C) and no source of emf is called passsive network.

Parameters: The Resistance, Inductance, capacitence are called the parameters of the circuit.

Linear Circuit: A linear circuit is that in which the values of its parameters are constant.

Non Linear Circuit: Non-linear circuit is that in which the values of its parameters change with the voltage or current.

1.8 Kirchoff’s Law

The current in various branches of large network can not be found out by ordinary methods. By application of kirchoff’s laws, complicated networks can be solved.

Gustav Robert Kirchoff (1824 - 1887) a German physicist, published the first systematic description of the laws of circuit analysis. These laws are known as Kirchoff’s current law (KCL) and Kirchoff’s voltage law (KVL). His contribution forms the basis of all circuit analysis problems.
1) **Current law** or **point law** It States that in any net work of wires carrying currents the algebraic sum of the currents meeting at Junction (or point) is zero. It is also called as point law.

![Fig. 1.15 Five conductors carrying current and meeting at a point](image)

\[ I_1 + I_4 = I_2 + I_3 + I_5 \]

or

\[ I_1 + I_4 - I_2 - I_3 - I_5 = 0 \]

This can also be defined as the total currents flowing towards a Junction is equal to that total currents flowing away from the junction.

(2) **Mesh law or voltage law**

: In any closed electric circuit, the sum of potential drops (I.R) is equal to the sum of the impressed e.m.f.s.

![Fig. 1.17 Three resistors connected in delta](image)

From the circuit ABCDE

\[ i_2 R_4 + i_1 R_3 = E \]
1.8.1 Application of Kirchoff’s Law to the Wheat Stone Bridge

Wheat stone bridge is used to measure the unknown resistance in a given network. It consists of four arms. If the current in the galvanometer is zero it is called a balanced Circuit, then the products of the resistance of opposite arms are equal. Suppose the value of current through the galvanometer is not zero then the kirchoffs laws are applied to find the currents and values of unknown resistance then it is called an ‘unbalanced’ bridge circuit.

Fig. 1.19 Wheat stone bridge

1.9 Solutions of Network Using Kirchoff’s Law

1. AB = 3Ω , BC =6Ω , CD =12 Ω and DA =10Ω , 2 volt cell is connected between B and D and a galvanometer of resistance 20Ω between A and C. Find the current through the galvanometer ?

Let I be the current passing
through the cell, and various currents are shown in the sketch.

Consider the closed circuit DACB. We get

\[-10 I_1 - 20 I_2 + 12 (1 - I_1) = 0\]

or

\[12 I - 22I_1 - 20 I_2 = 0 \quad \text{--------- (1)}\]

Consider the closed circuit ABCA

\[-3 (I - I_2) + 6 (1 - I_1 + I_2) + 20 I_2 = 0\]

\[6I - 9I_1 + 29 I_2 = 0 \quad \text{----------(2)}\]

Again consider closed circuit DABED

\[-10 I_1 - 3 (I_1 - I_2) = 2\]

\[-13I_1 + 3 I_2 = 2 \quad \text{----------(3)}\]

Solving the equation (1) and (2) we get

\[I_1 = -39/2 I_2\]

And substituting in (3) gives

\[I_2 = 1 / 13 = 0.78 \text{ mA}\]

The current passing through the galvnometer is 0.78 m.amp.

1.10 Star Delta Transformation

Concept of transformation:

By the application of Kirchoff’s laws some problems cannot be solved and finds great difficulty due to number of equations. Such problems can be simplified by using star - delta or delta - star transformations.

1.10.1 Transformation from Star to Delta

Fig. 1.20(a) Three resistor connected in star (b) Three resistor connected in delta
The figure shows two systems of connections of resistances. In star or ‘Y’ connection there is a common point for all the three resistors, and in delta or mesh connection the three are connected in series to form the loop and the junctions are taken out to form three supply points. The common point in star connection is called ‘Neutral’. The delta connection will have no neutral point. Assuming that the star connection is to be converted into delta connection. If the two networks are to be identical the resistance between any pair of lines will be the same when the third loop is opened.

\[
R_{AB} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_B} = R_A + R_B + \frac{R_A R_B}{R_C}
\]

\[
R_{BC} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_A} = R_B + R_C + \frac{R_A R_B}{R_A}
\]

\[
R_{CA} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_C} = R_A + R_C + \frac{R_A R_C}{R_C}
\]

### 1.10.2 Transformation from Delta To star

#### How to remember:

The equivalent delta resistance between any two points is given by the sum of star resistances between those terminals plus the product of these two star resistances divided by the third resistor.

\[
R_A = \frac{R_{AB} R_{CA}}{R_{AB} + R_{BC} + R_{CA}}
\]

\[
R_B = \frac{R_{BC} R_{AB}}{R_{AB} + R_{BC} + R_{CA}}
\]

\[
R_C = \frac{R_{CA} R_{BC}}{R_{AB} + R_{BC} + R_{CA}}
\]

As seen from the above expression it should be remembered that resistance of each line of the star is given by the product of resistances of the two delta sides that meet at its end divided by the sum of three delta resistance.

### 1.10.3 Simple Problems

(a) Transformation from (Δ to Y)

**Problem:**

1Ω, 2Ω, 3Ω are connected in Delta. Transform this values into star.
Solution:

\[ R_a = \frac{1 \times 2}{2 + 3 + 1} = \frac{1}{3} \Omega \]
\[ R_b = \frac{1 \times 3}{2 + 3 + 1} = \frac{1}{2} \Omega \]
\[ R_c = \frac{2 \times 3}{2 + 3 + 1} = 1 \Omega \]

(b) Transformation from (Y to Δ)

**Problem:** 1Ω, 2Ω, 3Ω are connected in star.

Transform this values into Delta

**Solution:**

\[ R_{ab} = \frac{(1 \times 2) + (2 \times 3) + (3 \times 1)}{3} = \frac{11}{3} \Omega \]
\[ R_{bc} = \frac{(1 \times 2) + (2 \times 3) + (3 \times 1)}{1} = 11\Omega \]
\[ R_{ac} = \frac{(1 \times 2) + (2 \times 3) + (3 \times 1)}{2} = \frac{11}{2} \Omega \]

**Key Concepts**

- Concept of electric current, different voltage sources
- Ohms law
- Laws of resistance
- Network elements and Kirchhoff’s law
- Simple electric circuit.
- Problem solving with various combinations of resistors.
Activity

- Collect various sources of electricity like torch cell, cycle dynamo and mobile phone battery
- Collect technical broachers of portable generators
- Calculate current in various appliances used at home by simple method.

Short Answer Type Questions

1. What is current?
2. Define conductor, semiconductor and insulators with examples.
3. What do you understand by electric potential?
4. What is specific resistance?
5. Explain temperature coefficient of resistance.
6. Define Ohm's law
7. Define Kirchhoff's laws.
8. What is a circuit?
9. What is a capacitor? Write its applications.
10. Explain an Inductor and its uses.
11. Name different types of Resistors and its uses.
12. What is a Junction?
13. What is a loop?
14. Write the applications of series circuit.
15. Write the applications of parallel circuit.
16. Distinguish between insulator and conductor.
17. Define electric potential and state its units.

Long Answer Type Questions

1. Mention the equation for the transformation of Delta circuit to star circuit?
2. Mention the equation for the transformation of star circuit to delta circuit.


4. How are the resistances connected? Explain series and parallel combination of resistances w.r.t. \( V, I \) and \( R \).

5. List as many differences as you can in comparing series circuit with parallel circuit.

**Numerical Problems**

1. The resistance of a conductor 1 mm\(^2\) in cross-section and 10 mm in length is 0.173 \( \Omega \). Determine the specific resistance of the material.

2. The temperature coefficient \( \alpha \) of phospher bronze is \( 39.4 \times 10^{-4} \) \( ^\circ \text{C} \). Find the coefficient \( \alpha \) for a temperature of (a) 20\(^\circ\)C, and (b) 100\(^\circ\)C.

3. What will be the current drawn by a lamp of 250 volts, 25 watts when connected to 230 volts supply?

4. Find the current in each branch of the network shown in fig using Kirchhoff's laws.

![Diagram of a network with resistances](image.png)
5. Three resistors 10 Ω, 20 Ω and 30 Ω are connected in star. Determine the value of equivalent resistance in delta connection.

**Project Oriented / OJT Related Questions**

1. Prepare the circuit with using different loads (Resistance, Inductance, Capacitance)

2. Observe Ohm’s law in calculating V, I and R in finding values of different loads.
Learning Objectives

• To understand the concept of work, power and energy through discussion
• To develop concept on units of work, power and energy through demonstration
• To provide the skill of energy calculation of monthly electricity bills through assignment

2.1 Systems of Units - SI System

Engineering is a Applied Science with a very large number of physical quantities like distance, time, speed, temperature, force, voltage, resistance etc. In order to cover the entire subject of Engineering six Fundamental quantities i.e. mass, length, time, current, temperature and luminous intensity have been selected, which need to be assigned proper and standard units. In this chapter, we shall focus our attentions the mechanical, electrical and thermal units of work, power and energy.

2.2 Work

Electrical work is said to be done in an electric circuit when, Q ampere-second of electricity passes through a circuit against a potential difference of V volt.
Then, work or work done = \( V\times Q \)
\[ \begin{align*}
&= V\times I t \text{ watt.sec and (WS)}
\end{align*} \]

The practical unit of work is kilo-watt-hour (kWh)

\( 1 \text{ kWh} = 36 \times 10^5 \text{ watt-second or joules.} \)

The mechanical work is said to be done on or by a body when a force acting upon it causes to change its state.

i.e. work or work done = Force x distance
\[ w.d = F\times d \]

The unit of mechanical work is joule (J) in SI systems

- newton-metre (N-m) in MKSA systems
- kilogram-metre (kg-m) in MKS system.

1 joule (J) = 1 watt-second
1 joule (J) = 1 newton-metre (N-m)

one kg-m = 9.81 N-m

Heat unit of work is calorie or kilo-calorie.

### 2.2.1 Power

In stating the rating of electrical apparatus it is customary to give not only the voltage at which it operates, but also the rate at which it produces or consumes electrical energy. The rate of producing electrical energy is called the power, and is measured in watts and kilowatts. Thus a lamp may be rated 100 watts at 230 volts. Rate of doing work is called power or power is the rate at which energy is expanded or the rate at which work is performed.

Electrical power is the rate at which work is done in an electric circuit.

i.e. Electric Power, \( P = \frac{\text{work done in electric circuits}}{\text{Time taken}} \)

\[ \begin{align*}
&= \frac{VI t}{t} = VI \text{ watt (W)}
\end{align*} \]

\[ \begin{align*}
&= V \times \frac{V}{R} = \frac{V^2}{R} = I^2 R \text{ watt (W)}
\end{align*} \]

Bigger units of power are:

\( 1 \text{ kW} = 1000 \text{ W} = 10^3 \text{ W} \)
1 MW = 1000000 W = 10^6 W

Electric power expended in a circuit is manifested in the form of heat or motion. In the case of electric lamps, electric irons, electric cooking ranges etc., power is expended in the form of heat. In an electric motor or electromagnet, the power is expended in the form of motion, and work is done. An electric current flowing through a wire will always produce heat, although in many cases the rise in temperature is not noticeable.

Mechanical power is the rate of doing work.

i.e. power, \( P = \frac{w.d.}{time} \)
\[ = F \times d \times \frac{1}{t} = F \times (d/t) \]
\[ = F \times \text{velocity} \]

1 HP (Metric) = 735.5 watt
1 HP (British) = 745.5 watt.

The power required to keep a continuous current of electricity flowing is the product of the current in amperes by the pressure in volts. this gives the power in watts.

Watts = amperes x volts.

The Bigger unit is kilowatt

1 kw = 1000 watts

To determine the power in an electric circuit

If we wish to know the power that is being consumed in a certain part of an electric circuit, we have to insert an ammeter to measure the current in that part of the circuit and multiply the ammeter reading by the voltmeter reading. This gives power directly in watts.

Watts = volts x amperes

Use of the watt meter

Instead of using two separate instruments, an ammeter and a voltmeter, to measure the power consumed in a certain part of a circuit, we may use a single instrument called a wattmeter. This instrument is a combination of an ammeter and a voltmeter. Ammeter has a low resistance to carry current and a voltmeter has a high resistance to carry the voltage.
2.2.2 Energy

Energy is capacity for doing work. Energy may exist in several forms and may be changed from one form to another. For example, a lead acid battery changes chemical energy into electrical energy on discharge and vice versa on charge. A generator changes mechanical energy into electrical energy etc.

Energy of a person or an engine or an electric motor is known to us only when it does some work.

Electric Energy

The total amount of work done in an electric circuit is called electrical energy.

If an electric lamp of 100-watts gives light continuously for, say 16 hours, the electrical energy consumed is $100 \times 16 = 1600$ watts hours.

The Joule or watt second is a very small unit of electrical energy, so for commercial purpose energy is measured in watt hours (wh) and kilowatt hours (kwh). The kilowatt hour is called board of trade unit (B.O.T.)

1. B.O.T. unit = 1kwh = 1000 wh = 36,00,000 joules.

2.3 Conversion of Electrical Units to Thermal Units

Heat is a particularly important form of energy in the study of electricity, not only because it affects the electrical properties of the materials but also because it is liberated whenever electric current flows. This liberation of heat is the conversion of electrical energy to heat energy.

The thermal energy was originally assigned the unit ‘calorie’. One calorie is the amount of heat required to raise the temperature of one gram of water through $1^\circ C$. If ‘$S$’ is the specific heat of a body, then amount of heat required to raise the temperature of m gm of body through $O^\circ C$ is given by

$$\text{Heat gained} = (ms\theta) \text{ calories}$$

It has been found experimentally that 1 calories = 4.186 joules so that heat energy in calories can be expressed in joules. Infact, the thermal unit calorie is obsolete and unit joule is preferred these days. For heating equipments, the term thermal efficiency is used. It is the ratio of useful heat to the total heat produced.

$$\eta = \frac{\text{Useful heat}}{\text{Total Heat - losses}} = \frac{\text{Total heat}}{\text{Total heat}}$$
Total heat produced electrically = \( Vlt / 4200 \) K.Cal

1 Joule = 4.2 calories

Calories = \( 1/4.2 \times \) Joules = 0.42 x Joules

Calorie is the bigger unit, compared to joule. Heat produced in calories

\[ H = mst \]

\( m = \) mass of the substance in grams.

\( S = \) Specific heat of the substance, \( S=1 \) for water and

\( t = \) change in temperature i.e., \( (t_2-t_1) \) in °C.

\[ H = 0.24 Vlt \text{ Calories} \]

\[ = 0.24 I^2 R t \text{ Calories} \]

\[ = 0.24 (V^2 / R) t \text{ calories} \]

### 2.4 Problems on Work - Power - Energy

1) A force of 10 Newtons is pulling a weight, through a distance of 4 meters. Calculate the work done.

Work done = force \( \times \) distance

\[ = 10 \text{ Nw} \times 4 \text{ mts} \]

\[ = 40 \text{ Nw-m or Joule} \]

2) If a table on the floor is pulled with a force of 4 Nw through a distance of 3 mts in 6 seconds, calculate the rate at which work done or calculate the power of the person who pulled the table.

Power = Work done / Time Taken = \( (4 \times 3) / 6 = 2 \text{ Nw-m /Sec} \)

Note: (1) Newton - meter = joule

(2) \( (\text{Newton} \times \text{Metres}) / \text{Seconds} = \text{Nw-m/sec} \)

\[ = \text{Joules / Seconds = Watts} \]

3) If an engine does a work of 150kg-m in 4 seconds. Calculate the H.P. of the engine.

H.P. of the engine = \( (\text{work done in kg - m/sec}) / 75 \)

\[ = (150 / 4) / 75 = 1/2 \text{ Hp} = 0.5 \text{ H.P} = \frac{\text{Work done in kg-m}}{\text{Time in minute x 4500}} \]
Newton's = kgs x 9.8

(4) A 220 volts lamp takes a current of 0.3 amps and gives light for 100 hours. Calculate its power in watts and in H.P.

\[ \text{Watts} = \text{volts} \times \text{amperes} \]
\[ = 220 \times 0.3 = 66 \text{ watts} \]
\[ \text{H.P.} = \frac{\text{Watts}}{735.5} = \frac{66}{735.5} = 0.0897 \text{ H.P.} \]

(5) A 220 volts electric lamp takes a current of 0.3 amps and gives light continuously for 16 hours. Calculate the energy consumed in (a) Joules  (b) watt hours  (c) Kilo-watt hours or B.O.T. units or Simply units

(a) Energy = Volt x Amp x Seconds
\[ \text{Joules} = \text{volts} \times \text{amperes} \times \text{seconds} \]
\[ = 220 \times 0.3 \times (16 \times 60 \times 60) = 3801600 \text{ Joules} \]

(b) Watt-hour = watts x hours
\[ = (220 \times 0.3) \times 16 \times 60 = 1056 \text{ wh} \]

(c) kilo-watt-hours =
\[ \text{Kwh} = \frac{\text{wh}}{1000} = \frac{3801600}{1000} \times \frac{1}{100} = 38.016 \text{ Kwh} \]

The fundamental unit of electrical energy is joule, but, as it is very small, the kwh or Board of trade unit (B.O.T.unit) or unit and has become the practical unit.

(6) A man lifts a head of 100kg through a height of 2 mts in 3 seconds. Calculate the energy spent or work done. Also find out his power.

\[ \text{Work done or energy spent} = \text{Force} \times \text{distance moved} \]
\[ = 100 \times 2 = 200 \text{ kg mtr} \]
\[ \text{Newton-meter} = 9.8 \times 9.8 \times 200 = 1960 \text{ Nw-m} \]
\[ \text{Horse power} = \frac{(\text{Kg} \times \text{mts} / \text{sec})}{75} = \frac{200}{3} \times 75 = 8/9 \text{ H.P.} \]
\[ \text{Energy spent in joule} = \text{energy spent in Nw – mtr} \]
\[ = 1960 \text{ joule} \]
Electric power = watts = Joules / Seconds = 1960 / 3 = 653.33 watts

(7) Calculate the power of a pump which can lift 100 kg of water to store it in a water tank at a height of 19m in 25 S? (Take the value of g = 10 m/s²)

In lifting water, the pump works against gravity.

\[
\text{Work done} = mgh = 100 \text{ kg} \times 10 \text{ m/s}^2 \times 19 \text{ m} = 19000 \text{ J}
\]

\[
\text{Power} = \frac{w}{t} = \frac{19000 \text{ J}}{25 \text{ S}} = 760 \text{ Watts.}
\]

### 2.5 Billing for the Electrical Energy Consumption or the Calculations for the Electrical Energy Consumed

**General procedure**

(1) An electric heater takes a current of 1.5 amps at 240 volts and works for 3 hours per day. Calculate the monthly electric bill at the rate of 75 paise per unit. Add Rs 2/- as monthly rent for the energy meter.

\[
\text{Kilo-watt-hours (kwh) = units} = 240 \times 1.5 \times 3 / 1000 \text{ perday}
\]

\[
= 1.08 \text{ units/day}
\]

\[
\text{units/month} = 1.08 \times 30 \text{ days} = 32.4 \text{ units/month}
\]

\[
\text{cost of the electrical energy consumed in a month} = Rs. \ 32.4 \times 75 / 100 = Rs. \ 24.30/- \text{ paise}
\]

\[
\text{meter rent} = Rs \ 2/- \text{ p.m}
\]

\[
\text{Total monthly electrical bill} = Rs \ 24.30 + Rs \ 2/- = Rs \ 26.30/-\text{Ps}
\]

(2) In a house there are 4 lamps of 60 watts each working for 6 hour/day and 2 tube lights working for 8 hours/day and 4 Fans of capacity 60 watts each working for 14 hours/day, and two electric irons of ½ kw capacity each used 1½ hours/day. The house is closed every Sunday, calculate the monthly electrical bill based on a tariff of 75 paise per B.O.T. unit. You may take 4 Sundays/month and add Rs 2/- Per monthly rent for the energy meter.

\[
\text{Energy consumed by lamps} = 4 \times 60 \times 6 = 1440 \text{ Wh/day}
\]

\[
\text{Energy consumed by Tube Lights} = 2 \times 60 \times 8 = 640 \text{ wh/day}
\]
Energy consumed by Fans  \( 4 \times 60 \times 14 = 3360 \text{ wh/day} \)

Energy consumed by Elect. Irons \( 2 \times 500 \times 3/2 = 1500 \text{ wh/day} \)

Working days in a month = 30 – 4 Sundays

\[ = 26 \text{ days} \]

Kwh/month = \( 6940 \times 26 / 1000 = 180.44 \text{ units/month} \)

Cost of electrical energy consumed = 180.44 x 75/100

Rs. 135.33 Ps.

Meter rent = Rs. 2/- per month

Monthly Elect. Bill = Rs 135.33 + Rs 2/- = 137.33/-

(3) An Electrical installation consists of 10 light points of 60 watts each, 12 lamps of 40 watts each, 6 fans of 60 watts capacity each, and a pump motor of ½ H.P. Assuming that 50% of lights and fans are used for 6 hours per day and the water pump works for 4 hours daily, calculate the kwh consumed/month and the monthly electrical bill based on a tariff of 70 paise/unit. Add Rs 2/- as monthly rent for the energy meter.

Total power of light points \( 10 \times 60 = 600 \text{ watts} \)

Total power of lamps \( 12 \times 40 = 480 \text{ watts} \)

Total power of fans \( 6 \times 60 = 360 \text{ watts} \)

Total = 1440 Watts

Therefore 50% of 1440 watts = 720 watts

watt-hours/day = \( 720 \times 6 = 4320 \text{ wh} \) taken by lights and fans

power taken by pump motor = \( ½ \times 735.5 \times 4 = 1471 \text{ wh/day} \)

Total Wh consumed/day = 4320 + 1471 = 5791 Wh

therefore Kwh/month = \( 5791 \times 30 / 1000 = 173.73 \text{ units} \)

Cost of energy consumed/month

\[ = 173.73 \times 70/100 = Rs \ 121.611/- \]

Meter rent = Rs 2/- per month

Therefore Total monthly Elect.Bill = Rs 121.611/- + Rs 2/-

\[ = Rs \ 123.611/- \]
(4) Calculate the bill of electricity charges for the following load fitted in an electrical installation.

(a) 20 lamps 100 watts each working 6 hours/day.
(b) 10 ceiling fans 120 watts each working 12 hours/day.
(c) 2 kw heater working 3 hours/day

Rate of charges for light and fans is 20 paise per unit and heater and motor 15 paise/unit.

Light load = 1000 x 20 x 6 / 1000 = 12 kwh
10 ceiling fans 120 watts each 12 hrs/day = 120 x 10 x 12 / 1000
Total light load = 12 + 14.4 = 26.4 kwh

**Power load**

2 kw heater 3 hrs/day = 2 x 3 = 6 kwh / day
2 B.H.P. motors having 85% efficiency
Motor input = 2 x 746 x 100 / 85 wats
Load for 4 hrs/day = (2 x 746 x 100 / 13 x 1000) x 4/1 = 7.021 kwh
Total power load = 7.021 + 6 = 13.021 kwh

Cost light = 26.4 x 20 / 100 = Rs. 5.28 /-
Power = 13.021 x 15 / 100 = Rs. 39.063 / 20 = Rs. 1.95 /-
Total cost = 5.28 + 1.95 = Rs. 7.23 /Ps.

**Key Concepts**

- Power and power rating
- Calculation of Energy consumption and energy tariff

**Activity**

- List power rating of different loads in Watts, Kilowatts and HP
- Students are directed to note down the rated power of each appliance of his house. Note the working hours of each appliance for one day. Calculate the energy consumption and compare it with energy meter reading.
Short Answer Type Questions

1. Define work and write its units.
2. Define power and write its units.
3. Define Energy and write its units.
4. What is the meaning of B.O.T?
5. What is J?
6. How to convert H.P. into watts?
7. What is the relation between the mechanical units and electrical units of power?
8. Give the name of 10 domestic appliances.

Long Answer Type and Numerical Questions

1. A force of 10 Newtons is required to push a cycle through a distance of 4 meters. Calculate the work done in 1) Newton Metres and 2) kg-mts.
   Ans. 1) 40 Nw - m 2) 4.077 kg-mts

2. A domestic installation consists of the following
   a. Six 60 watts lamps working for 8 hours/day
   b. Four tubelight working for 10 hours/day.
   c. Three fans of 60 watts each working for 12 hours/day
   d. Two electric irons of ½ kw each working for 2 hours/day.

   Calculate the monthly electric bill at the rate of 75 paise/kwh. Meter rent is Rs. 2/- p.m. 
   Ans : 196.40 /

3. An office of electrical installation comprises the following loads. Calculate the energy charges paid to the supply authority for the month of November.
   Energy consumption 10 paise/unit for power load and 20 paise unit for lighting load, Air conditioner, Pump, heater. Calculators are connected to the power circuit. The office worked for 25 days of that month except security section which worked on all days.
   60 No.’s 4 ft. 40 watt tube light works 8 hours / day
   4 No.s 60 watt lamps, 12 hours/day for security purpose
   16 No.’s , 60 watts ceiling fans 6 hours/day,
1 No. 1000 watt Air conditioner for 5 hours/day
1 No 750 watt lamp 2 hours/day
2 No.’s Electric calculator 500 watt 1 hrs/day
One electric heater 1500 watts for 2 hrs/day.
Metre rent at Rs. 2/- and 10/- surcharge on charges also made by Authorities.

Ans. Rs. 189.16

Ans. For lighting 710.4 kwh Rs. 142.08 /

For power 262.5 kwh Rs. 26.25 /-
Learning Objectives

- To understand different effects of electric current through discussion and demonstration
- To learn applications of heating effect of electric current by demonstration and discussion
- To know Joules law of heat.

3.1 Effects of Electrical Energy

Resistance in electric circuits produces heat just as mechanical friction produces heat. This is called the heat of resistance.

3.2 Heating Effect of Electric Current

When electric current (i.e. flow of free electrons) passes through a conductor, there is a considerable ‘friction’ between the moving electrons and the molecules of the conductor. The electrical energy supplied to the conductor to overcome this ‘electrical friction’ (which we refer it as resistance) is converted into heat. This is known as heating effect of electric current.

The heating effect of electric current is utilised in manufacturing of many heating appliances such as electric heater, electric kettle, electric toster, soldering iron etc. The basic principle of these appliances is the same. Electric current is
passed through a high resistance (called heating element), thus producing the required heat. The heating element may be either nichrome wire or ribbon wound on some insulating material that is able to withstand heat.

### 3.3 Joule’s Law

According to Joules law, the heat produced in a current carrying conductor is directly proportional to the square of the current and to the resistance of the conductor and to the time of flow of current.

\[ H = \frac{I^2 R t}{J} \text{ calories} \]

- \( H = \) Heat produced in calories
- \( I = \) Current in Amperes
- \( R = \) Resistance of the conductor in ohms.
- \( T = \) Time for flow of current in seconds and
- \( J = \) Joules mechanical equivalent of heat which is a constant.

\[ J = 4.2 \text{ Joules} / \text{calories} \]

i.e. 1 calories of heat = 4.2 Joules.

1 Joule = 0.24 calories

\[ \text{Joules} = 4.2 \times \text{calories} \]
\[ \text{Calories} = 0.24 \times \text{Joules} \]

Calories is the amount of heat required to rise the temperature of 1 gm of water through 1°C.

#### 3.3.1 Heat Produced by flow of current

When electricity is passed through a wire, heat is produced due to the collision of electrons in the wire. The amount of heat (friction) produced depends on square of current, resistance of the wire material and time for which Current has passed through the wire as explained in Joules law.

**(a) Filament or Incandescent Lamp**

Fig: 3.1 represent a metal filament lamp. It consist a fine wire or filament made of tungsten and is placed in a glass-bulb containing inert gas. The lamp emits when current passes through the filament.
(b) Fluorescent Lamp

It mainly consists of fluorescent tube, choke (ballast) and a starter as shown in Fig. 3.2. The fluorescent tube coated with fluoresence powder and consists of mercury vapour plus small amount of argons gas. The choke steps up the supply voltage to start the fluorescent tube and regulates the current afterwards. Starter provides voltages kick for ignition.

(c) Electric Kettle

Electric kettles are used to boil water, milk, tea etc. Electric kettles may be of saucepan type or immersion type as shown in Fig. 3.3. In some type of kettle an ejector type safety device is incorporated to prevent low quality of liquid in it.
(d) Electric Cooker

It is a simple form of heat producing appliance for cooking. It mainly consists of a heating elements and heater plate as shown in Fig 3.4. The heating element is made of nichrome wire and it may be either exposed type or enclosed type. The heater plates are usually made of porcelain material with grooves on one side to accommodate the supply, heat will be produced in it.
The basic principle of electric iron is to convert electrical energy into heat energy, with which the clothes will be pressed. Fig. 3.5 shown the various parts of an electric iron.

(i). **Sole Plate or Base Plate**: It is a chromium coated flat bottom surface. It receives heat from the heating element and is used to press or iron the electric clothes.

![Diagram of Electric Iron Parts](image)

Fig. 3.5 Electric Iron
(ii) **Heating element:** It is made of nichrome strip or wire placed in between two mica sheets. It is placed over the base-plate to transfer the heat developed to it.

(iii) **Asbestos Plate:** It is placed over the heating elements to prevent the heat to the sole-plate.

(iv) **Pressure Plate:** It is made of cast iron and it clamps the heating elements to the sole-plate.

An electric iron also consists a heal plate to fix the terminals and a top cover to hide all parts and at the same time serves the decoration. The handle is usually made of ebonite (or wood).

An automatic electric iron consists a thermostat which controls the temperature is required.

**(e) Space Heater**

It is basically consists of a heating element and a heat reflector as shown in Fig. 3.6. The heating element is made of nichrome and is wound on a ceramic or china clay tubes. The reflector is in the form of semi-circle or concave and the inner surface is chromium plated or epoxy powder painted galvanised steel to reflect the heat. Space heaters also known as room heaters. These heaters are suitable for continuous or intermittent use. These heaters are ideal for use in locations where direct heat is required for personnel without affecting the ambient room temperature and provide solar type zone hating with the efficiency if radiant heaters. Instant visible heat, absolute silent operation, long range heat projection, light weight and easy to install are some of the features of these heaters. The heaters are available with or without fan assistance for additional heating.
(f) Geysers

Geysers provide hot water in a house at different points such as bathrooms, kitchens, wash-basins etc. It mainly consists of immersion element operates in direct contact with water. Geysers are more efficient water heaters.

![Fig 3.7 Geyser](image)

(g) Infrared Lamp

It is nothing but incandescent lamps covered with a red coloured infrared filter made of silicon. The filter emits the heat radiation developed by the incandescent lamp at the frequency of infrared radiation. The infrared radiation can be focussed at a point by some means. It is used in medical fields for the treatment of muscular pains or nervous disorder of human beings.

3.4 Practical Applications of Heating Effects of Electric Current

The heat produced in a high resistance wire is utilized in the following appliances:

3.5 Simple Problems

(1) A wire of resistance 10 \( \Omega \) is kept in water in a tin and a current of 2 amperes is passed through this wire for half an hour. Calculate the heat received by water.

Heat produced H = \( 0.24 \ I^2 \ R \ t \) calories.

\[
= 0.24 \times 2^2 \times 10 \times 30 \times 60 \text{ Calories.}
\]

\[
= 1728 \text{ Calories.}
\]

\[
= 1.728 \text{ Kilo-Calories.}
\]

(2) The mass of water in a calorimeter was 250 gms. A coil of resistance 15 ohms was immersed in water and a current of 2 amperes is passed through this wire for 15 minutes. Calculate the final temperature of water, if its initial temperature was 25°C. neglect all losses.

Heat produced in Calories = \( H = 0.24 \ I^2 \ R \ t \)

\[
= 0.24 \times (2)^2 \times 15 \times 15 \times 60
\]

\[
= 12,960 \text{ Calories.}
\]

But in physics heat

= Mass x Specific heat x change of temp in °C.

= \( M \times \text{st} \) Calories and Where \( t = (t_2 - t_1)\)°C

\[
12,960 = 250 \times 1 \times (t_2 - t_1)
\]

\[
t = 12,960 / 250 \times 1 = 51.84°C
\]

\[
(t_2 - t_1) = 51.84°C
\]

(3) An immersion water heater of resistance 25 ohms is kept in a water bucket and connected to 230 volts supply mains. Mass of water is 10 kg. Initial temperature is 25°C. Find the time taken for the water to reach boiling point. neglect all the losses.

Heat produced H = \( 0.24 \ V^2 \ / \ R \ x \ t \) = \( M \times s \ x \ (t_2 - t_1) \)

\[
t = m \times s \times (t_2 - t_1) \times R / 0.24 V^2
\]

\[
t = 10,000 \times 1 \times (100-25) \times 25 / 0.24 \times (230)^2 \approx 1476.84 \text{ sec.}
\]

or \( t = 14666.84 / 60 \times 60 = 0.41 \text{ hours.}
\]

\[
= 0.41 \times 60 = 24.6 \text{ minutes.}
\]
4) On the name plate of electric kettle, it is written as 750 watts and 220 volts. Determine the thermal efficiency of the kettle. If it takes 20 minutes to raise the temperature of one kg. of water from 20°C to boiling point.

Thermal efficiency of kettle

\[
\text{Thermal efficiency of kettle} = \frac{\text{Output in calories} \times 100}{\text{input calories}}
\]

\[
= \text{Calories actually utilized by water} \times 100 / \text{Intake calories by the kettle.}
\]

\[
= m \times s \times (t_2 - t_1) \times 100 / 0.24 \times I^2 R \times t
\]

\[
= 1000 \times 1 \times (100 - 20) / 0.24 \times 750 \times 20 \times 60
\]

\[
= 1000 / 27 = 37.037\%
\]

**Key Concept**

- Heating effect of electric current
- Application of joules law of heat
- Simple problems to strengthen the theoretical understanding

**Activity**

- Collect technical broachers of appliances available in market using heating effect.
- Find out heat produced by Electric Iron/Room Heater/Hot plate/Geyser by using different instruments like voltmeter, ammeter, watt meter and calorie meter.
- Observe how the temperature is proportional to Power rating heating appliance.

**Short Answer Type Questions**

1) State Joules law

2) Give the names of 5 electrical Appliances where heating effect is utilised.

**Project Oriented / OJT related Questions**

1) List out the appliances working on heating effect of electric current.

2) Find out how Water Heater / Geyser, Microwave Oven are working.
Learning Objectives

- To recognise different types of magnets and their properties through discussion and demonstration or assignment.
- To develop clear idea about magnetic and non magnetic materials and to classify them through collection of materials by demonstration and discussion.
- To familiarize different terms related to magnetism by discussion.
- To learn magnetic effects of electric current and different laws associated with it by discussion.
- To study magnetic circuits and its elements through discussion.

4.1 Introduction to Magnets

Magnet is the substance which attracts magnetic material such as iron, nickel, cobalt steel, manganese etc. The magnetic properties of materials were known from ancient times. A mineral discovered around 800 B.C. in the town of Magnesia was found to have a wondrous property. It could attract pieces of iron towards it. This mineral is called Magnetite after the place where it was discovered. Further, it was found that thin strips of magnetite always align themselves in particular direction when suspended freely in air. For this property, it was given the name ‘Leading Stone’ or ‘Lead stone’. Later, it was found that magnetite is mainly composed of oxides of iron (Fe₃O₄). These are now known
Electrician Technician

as magnets and the study of their property is called MAGNETISM.

William Gilbert did the first detailed study of magnets and their properties in 1600. Magnets are now widely used for variety of purposes. Magnets form an essential component of all generators used for the production of electricity, transmission and utilization of electric power. They are also used in electric motors that are an essential component of many machines and gadgets that operate on electricity. Modern electronic gadgets, like television, radio, tape recorder, electric door bells also make use of magnets. Working of may of these devices also depends on the magnetic effect of electric current.

Here we are going to learn some fundamental definitions and principles about magnets.

4.2 Magnetic Pole - Magnetic Axis - Pole Strength

4.2.1 Magnetic Pole

When a bar magnet is dipped into iron fillings or iron dust, there are two regions where fillings mainly get attracted. These two regions are called pole of a magnet or the strongest part of the magnet near the ends are called Pole.

The poles will not be at the ends. but they are nearer to the ends. When suspended freely in air, the end pointing North is called North Pole and the end pointing South is called South Pole.

Magnetic poles do not exist Separately. It means we can never separate or isolate a north pole of a magnet from its South Pole. Magnetic poles always exist in opposite pairs.

4.2.2 Magnetic Axis

An imaginary line passing through magnetic north and South pole of a bar magnet is called Magnetic axis.
Between the two poles there is a region showing no attraction. This region is called Magnetic equator. This is also called Neutral Line. Magnetic axis and the neutral line will be mutually at 90 and the neutral line bisects the magnetic axis.

### 4.2.3 Pole Strength

The power of the magnet to attract or repel is called pole strength of the magnet. The greater the pole strength, the higher the power of the magnet. The pole strength doesn’t depend on size of magnet. The magnet may be biggest in size but may be less powerful, and vice versa. The pole strength is expressed in terms of unit poles or webers. One unit pole emanates one weber of flux.

### 4.3 Properties of Magnets

1. The magnet always attracts magnetic substances. (iron, steel, cobalt, nickel etc)
2. The magnet has two poles and when it is freely suspended, it comes to rest pointing North and South directions. This is called directive property of a magnet.
3. Like poles repel and unlike poles attract each other.
4. If a magnet is broken into pieces, each piece becomes an independent magnet.
5. A magnet loses its properties when it is heated, hammered or dropped from height.
6. A magnet can impart its properties to any magnetic material. This means when a bar magnet is rubbed over an unmagnetised piece of iron or steel, it changes into a temporary magnet.
7. Repulsion is the surest test of magnetism.
8. Magnetic force can easily pass through non-magnetic substances.
4.3.1 Uses of Magent

The magnets are widely used in many ways for example 1) To find out N-S direction at any place on earth 2) To find out the direction at any point on sea (navigation) 3) To detect magnetic materials. 4) For electrical machines 5) In measuring Instruments etc.

4.4 Typical Shapes of Magnet

Magnets are made in different shapes according to use and application. The common shapes are given below.

![Fig. 4.4 Magnet Shapes](image)

4.5 Classification of Magnets

```
Classification of Magnets

Natural Magnets
  Lead Stones

Artificial Magnets
  Permanent Magnets
  Temporary Magnet
    Electro Magnet

Bar Magnet
  U-Shaped Magnet
  Horse Shoe Magnet
  Compass Magnet
```
Natural Magnets: The magnets found in nature such as lead stone which can be used in navigation is known as Natural Magnets. The natural magnet has a chemical composition of $\text{Fe}_3\text{O}_4$.

Artificial Magnets: The magnet prepared by Artificial methods or by man made methods is known as Artificial magnet. It is further classified as i) Permanent Magnet and ii) Temporary or Electromagnet.

Permanent Magnet: The magnet which retains the magnetic properties for a long period (indefinitely) is known as Permanent Magnet in many applications we need permanent magnets. Most permanent magnets are made of ALNICO, an alloy of Aluminium, Nickel and Cobalt. Permanent magnets of different shapes and sizes are being made from ferrite. These being light, strong and permanent. Most of the electrical measuring instruments, such as ammeters, voltmeters, galvnometers etc contain a permanent magnet.

Electro Magnet

Magnetism and electricity were considered to be two separate phenomena for a long time. However in 1820, the Danish physicist Hans Christian Oersted (1777 - 1851) made an important discovery that established a relation between electricity and magnetism.

Manual method is used to prepare magnets of small strength only like compass needle. To prepare strong magnets, electrical method is to be used. If a coil of insulated copper wire be wrapped round on a cylinder of cardboard (forms a solenoid) the bar to be magnetised inserted in the cylinder and a strong electric current passes through the coil, the bar will be found to be magnetised. or Electro magnets are made by winding the coils of insulated copper wire over a soft iron or steel pieces. The core becomes a powerful magnet as long as current is passing.

If the piece is of steel, when the current is stopped and the bar be removed, it becomes a permanent magnet. If the piece is of soft iron, it will be a strong magnet.

Applications of Electromagnets

Electro magnets are widely used in Industries and also in many situations in daily life. They are used in cranes to lift heavy loads of scrap iron and iron sheets.

(1) One of the most important uses of electromagnets is in generators and motors, where they are used to create the intense magnetic fields which are necessary for the conversion of mechanical energy into electrical energy and
vice versa. The coils wound on the field poles are to create the magnetic field.

(2) The fact that certain materials get struck, to magnets is used to make i) magnetic door closers ex. in refrigerators in which a weak magnetic strip all round the door ensures that the door remains firmly shut  2) Magnetic latches or catches, used in windows, cupboard doors  3) magnetic strickers  4) magnetic clasps in handbags  5) magnetic pin, paper, clip holders and so on.

(3) Electromagnets are used to separate magnetic substances, like iron nickel and cobalt, from non-magnetic substance, like copper. Zinc, brass, Plastic and paper. They are also used to remove ‘foreign bodies’ like iron fillings from the eyes of a patient. They are used in all electrical machines, transformers, electric bells, telegraphs, telephones, speakers, audio and video tape recorders and players, relays etc.

(4) Data (in computer hard disks, floppies and tapes) and audio visual signals (video tapes) can be stored by coating special surfaces with magnetic material. In all these, the particles of the magnetic coating get aligned in a particular way by a magnetic field produced by a recording head, much the same way as domains get aligned in the presence of magnetic field. The differently aligned particles then represent data, sound or audio visual signals. The same principle is used to store information in the magnetic stripes found on credit cards, ATM cards, some air line and train tickets, telephone cards etc.

4.5.1 Comparison of Magnetic Properties of Soft Iron & Steel

<table>
<thead>
<tr>
<th>Soft Iron</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) It can be highly magnetised.</td>
<td>(1) It cannot be magnetised very high.</td>
</tr>
<tr>
<td>(2) It loses its magnetism as inducing magnet is remove i.e. its magnetism is temporary.</td>
<td>(2) It does not lose its magnetism as the inducing magnet is removed. The magnetism is permanent in nature.</td>
</tr>
<tr>
<td>(3) It is used for making temporary magnets (electromagnets)</td>
<td>(3) It is used for making permanent bar magnet, horse shoe magnet etc.</td>
</tr>
</tbody>
</table>
4.5.2 Comparison Between Electromagnet and Permanent Magnet

<table>
<thead>
<tr>
<th>Electromagnet</th>
<th>Permanentmagnet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Polarity can be changed easily.</td>
<td>1) Polarity cannot be changed easily.</td>
</tr>
<tr>
<td>2) Strength can be varied.</td>
<td>2) Strength cannot be varied.</td>
</tr>
<tr>
<td>3) Cost is more</td>
<td>3) Cost is less</td>
</tr>
<tr>
<td>4) Suitable in case of motors and generators of large size.</td>
<td>4) Not suitable for larger size motor and generators</td>
</tr>
<tr>
<td>5) Electric bells, signals, Indicators</td>
<td>5) Not possible.</td>
</tr>
<tr>
<td>6) Can be used in lifting work, holding the job</td>
<td>6) Not possible.</td>
</tr>
<tr>
<td>7) Cannot be used in Navigation.</td>
<td>7) Mostly used in Navigations as a magnetic needle.</td>
</tr>
<tr>
<td>8) Cannot be used in cycle dynamo and motor cycle magnetos..</td>
<td>8) Can be used in cycle dynamo and small toys</td>
</tr>
</tbody>
</table>

4.6 Rules to Find Out Polarity

End Rule

1. Looking at the end of the bar, if the current in the coil is counter-clockwise in direction that end will be a north pole. If it is clock wise it will be South pole. This rule is used to find out the polarity of the electromagnet.

![Fig. 4.5 Coil Carrying Currents](image)

Hand Rule: (or) Helix Rule

Hold the thumb of the right hand at right angles to the fingers. Place the
hand on the wires with the palm facing the bar and the fingers pointing in the direction of the current. The thumb will point the N-pole of the bar. This rule is used to find the polarity of the poles of an electromagnet. Right hand thumb rule, or right hand palm rule is used for determining the direction of magnetic lines of force around straight conductor.

![Hand Rule](Fig. 4.6)

**Ampere Rule**

Imagine a man swimming in the circuit in the direction of the current with his face to the bar, his left hand points towards north pole of the bar. It is used for finding the direction of lines of force around a wire carrying current. Ampere rule can also be used for finding direction of magnetic needle.

![Ampere's Swimming Rule](Fig. 4.7)

### 4.7 Magnetic Fields

The region around a magnet, in which the force of attraction and repulsion can be detected is called a magnetic field. The magnetic field is filled with the magnetic lines of force.

Magnetic lines of force is nothing but the path along which iron fillings will re-adjust in a magnetic field.
4.7.1 Magnetic Lines of Force

It is a closed continuous curve in a magnetic filed along which an isolated North pole could travel is called lines of force. or the paths along which iron fillings will re-adjust in a magnetic field will be the magnetic lines of force or flux or It is a closed curve starts from North pole and ends at south pole of a magnet.

A line of force has no real existence, it is only imaginary. The lines of force are also called magnetic lines of force or magnetic flux. The magnetic flux is expresses in webers. One weber is equal to $10^8$ lines of force.

To carry the electric current we generally use copper or aluminium cables, because the resistance of these metals is low compared with the resistance of other materials.

Similarly, to carry a magnetic flux we generally use iron or soft steel material because the reluctance of these materials is low compared with the reluctance of other materials.

4.7.2 Flux Density

The number of lines of magnetic flux per unit area, represented by letter B.

$$\text{Flux density } B = \frac{\text{Flux (} \phi \text{)}}{\text{Area (} A \text{)}} \text{ webers} / \text{metre}^2$$

4.7.3 Properties of Magnetic Lines of Force

1. They are closed continuous curves.
2. They travel from north to south outside the magnet and from south to north inside the magnet.
3. They contract laterally, that is they bend along the length of a magnet.
4. They mutually repel each other.
5. They never intersect with each other.
6. They are imaginary and have no real existence.

Typical field pattern of different Magnets

4.8 Inverse Square Law

(Law of Magnetic force - Attraction or Repulsion)

The force between two magnetic poles are:
(1) Directly proportional to the product of the pole strengths.

(2) Inversely proportional to the square of the distance between the two poles (inverse square law).

(3) Inversely proportional to the absolute permeability of the surrounding medium.

Let $A$ and $B$ are the two poles placed at a distance of $d$ meters. Let $m_1$ and $m_2$ be the pole strengths of $A$ and $B$ poles in webers.

\[
\text{Force between two poles according to coulomb's law of magnetism can be expressed by}
\]

\[
F \propto \frac{m_1 m_2}{d^2}
\]
or

\[
F = k \frac{m_1 m_2}{d^2} \text{ newtons}
\]

Where $K$ is a constant and depends on the medium. If medium is air vacuum the value of $K$ is equal to $1 / 4\pi \mu_0$ and in any other medium with $\mu_r$ relative permeability its value equal to $1 / 4\pi \mu_0 \mu_r$. Therefore

\[
F = \frac{1}{4\pi \mu_0} \frac{m_1 m_2}{d^2} \text{ newtons in air medium}
\]

\[
F = \frac{1}{4\pi \mu_0 \mu_r} \frac{m_1 m_2}{d^2} \text{ newtons in other medium}
\]

The phenomenon of magnetism depends upon a certain property of the medium called its permeability.

### 4.8.1 Unit Magnetic Pole or Pole Strength

Let $m_1 = 1, m_2 = 1$ and $d = 1$ m the force

\[
F = \frac{1}{4\pi \mu_0}
\]

Newtons. Hence a unit magnetic pole may be defined as the pole which when placed in air at a distance of one meter from a similar and equal pole.
strength repel with a force of \( \frac{1}{4 \pi \mu_0} \) newtons - 63340 Nw.

or One unit magnetic pole may be defined as the strength of the magnet that it exerts a force of a dyne when placed at a distance of one cm from another unit pole in a medium of unit permeability.

### 4.9 Simple Problems

1. Two unlike magnetic poles are placed in air at a distance of 20 cm from each other and their pole strengths are 5 m wb and 3 mwb. Determine the force of attraction between them.

   ![Diagram of two magnetic poles](Image)

   \( m_1 = 5 \text{ mwb} \quad m_2 = 3 \text{ mwb} \)

   \( d = 0.2 \text{ m} \)

   \[ F = \frac{m_1 m_2}{4 \pi \mu_0 d^2} = \frac{0.005 \times 0.003 \times 10^7}{4\pi \times 4\pi \times 0.2^2} = 23.77 \]

   \( (\mu_o = 4\pi \times 10^{-7}) \)

2. Two poles of which one is 6 times stronger than the other exerts on each other a force of 8N when placed 100 cm apart in air. Find the pole strength?

   Let the strength of one pole be \( m \) wb. and the strength of other pole = 6m . wb

   Distance = 100 cm = 1 mtr.

   \[ F = \frac{m_1 m_2}{4 \pi \mu_0 \mu_r d^2} \]

   \[ 6m^2 \times 10^7 = 8 \times 4\pi \times 4\pi \times 1 \]

   \[ m^2 = \frac{8 \times 16\pi^2}{6 \times 10^7} = \frac{1263.30}{6 \times 10^7} = 0.2105 \]

   \[ m = 4.586 \text{ wb or 0.00458 wb} \]
3. If two similar poles are separated by a distance of 1 cm repel each other by a force of 10 Newtons. Find the pole strength of each of them.

\[ f = 10^5 \text{ NW}; \ m_1=m_2=m^2; \ d=1\text{cm}=10^{-2}\text{m} \]

\[ f = \frac{m_1m_2}{4 \pi \mu_0 d^2}; \ 10^5 = \frac{m^2 \times 10^7}{4 \pi x (10^{-2})^2} \]

\[ \therefore m = \frac{4 \pi x (10^{-2})^2 x 10^{-5}}{10^7} = 3.5 \times 10^{-8} \text{ wb} \]

4. A magnet in the shape of square cross sectional area has a pole strength of 0.5 \times 10^{-3} and cross sectional area of 2 cm \times 3 cm. Calculate the strength at a distance of 10 cm from pole in air.

Pole strength = \( m = 0.5 \times 10^{-3} \text{ wb} \)

distance = \( d = 10 \text{ cm} = 0.1 \text{ m} \)

Field Strength

\[ H = \frac{m}{4 \pi \mu_0 \mu_r d^2} \text{ N / wb} \]

\[ H = \frac{m}{4 \pi \times 4\pi x (0.1)^2} \text{ Nw/ wb} \]

Therefore \( H = 3166.28 \text{ Nw / wb} \)

5. Two identical poles having pole strengths \( 1 \times 10^{-3} \text{ wb} \) repel each other with a force of 6.33 Nw when placed in air. Determine the distance between them.

\( m_1 = m_2 = 1 \times 10^{-5} \text{wb} \) \quad F=6.33 \text{ Nw} \)

\( \mu_r = 1 \text{ (Air); } d = ? \)

\[ F = \frac{m_1 m_2}{4\pi \mu_0 \mu_r d^2} = \frac{1 \times 10^{-3} \times 1 \times 10^{-3} \times 10^7}{4\pi \times 4\pi x 1 \times d^2} \]

\[ \therefore d^2 = \frac{1 \times 10^{-3} \times 1 \times 10^{-3} \times 10^7}{16 \pi^2 x 6.33 \times 1} = 10 \text{ cm} \]

\( d = 3.162 \text{ cm} \)

6. A pole of strength 0.005 \text{ wb} placed in a magnetic field experiences a force of 2.37 Nw. Find the intensity of magnetic field
\[ m = 0.005 \text{ wb} ; \quad F = 2.37 \text{ NW} ; \quad H = ? \]

Field strength \( H = \frac{F}{M} \) \ Farads / meters

\[ H = \frac{2.37}{0.005} = 474 \text{ Nw / Wb} \]

### 4.10 Magnetic Effects of Electric Current

H.C. Oersted demonstrated that whenever current passes through a conductor, a magnetic field is created around the conductor throughout its length. or A current carrying conductor has a magnetic field associated with it. This accidental discovery was the first evidence of a long suspected link between electricity and magnetism. The production of magnetism from electricity (which we call electromagnetism) has opened a new era. The operation of all electrical machinery is due to the applications of the magnetic effects of electric current in one form or the other.

To detect the presence of such a field you can carry out the following activity

Make a simple electric circuit consisting of a long straight wire, a battery and a plug key. Arrange the circuit so that the straight wire is placed parallel to and over the compass needle. Now switch on the circuit.

As the current passes through the wire, the needle gets deflected. If the current flows from North to South, the north pole of the needle moves towards east. If the current is reversed then the needle moves from South to North.

A compass needle placed under a long straight line pointing towards north in which current flows from north to South. the compass needle is shown deflecting - its north pole moving towards east.

The current in this wire flows from South to north. The north pole of the needle is seen deflecting towards west.

![Fig. 4.8 Deflection of compass needle magnet](image-url)
Conclusions from oersted’s experiment:

(1) Whenever current is passed through a straight conductor, it behaves like a magnet.

(2) The magnitude of magnetic effect increases with the strength of current.

(3) The magnetic field setup by a conductor is at right angles to the direction of flow of current. The reason for this statement is that magnetic needle sets itself at right angle to the conductor carrying current.

(4) The direction in which the north pole of magnetic needle will move depends upon

(i) The direction of current in conductor

(ii) The relating position of conductor with respect to magnetic needle. It means it will depend upon whether the conductor is above needle or below needle.

**Ampere Rule**: (For finding the direction of movement of magnetic needle)

![Ampere's Swimming rule](image)

Imagine a swimmer swimming in the direction of current and always looking at the magnetic needle such that current enters from his feet and leaves from his head. Then the direction in which the left hand of swimmer points gives the direction of movement of north pole of freely suspended magnetic needle.

From Figure, the swimmer is swimming in the direction of current and looking at needle. His left hand is pointing towards west. Hence, the north pole of magnetic needle will deflect towards west. If a current carrying conductor is placed at right angles to the lines of force of a magnetic field, a mechanical force will be exerted on the conductor. The magnitude of the mechanical force can be calculated by using Ampere’s law.
4.10.1 Magnetic Field around a Straight Conductor

Take a flat cardboard and over it fix a white sheet of tape. In the middle of the card board make a hole and through it pass a thick wire as shown in fig. Connect the ends of a wire to a battery through a connecting wire.

Plot the magnetic lines of force around the conductor with the help of plotting compass. It is observed that the lines of force are in the form of concentric circles. The direction of lines of force will be clock wise.

If the experiment is repeated but the current is passed in opposite direction, the lines of force will be in anti clock wise direction.

Further more, it is found that on increasing the strength of current, the number of magnetic lines of force around conductor increases. This inturn, increases the magnetic strength of conductor.

4.10.2 Rule for Determining the Direction of Magnetic Lines of Force around Straight Conductor

Right hand thumb rule

Imagine you are holding the conductor with the palm of your right hand, such that thumb points in the direction of flow of current. Then the direction in which fingers curl around conductor gives the direction of magnetic lines of force.

In. fig. 4.11 The fingers are curling in anti - clock wise direction when thumb is pointing in the direction of current. Therefore the direction of magnetic lines of force is anti - clock wise.
4.11 Force on a current carrying conductor in a magnetic field

Immediately after Oersted’s discovery of electric currents producing magnetic fields and existing forces on magnets, Ampere suggested that magnet must also exert equal and opposite force on a current-carrying conductor. The force due to a magnetic field acting on a conductor can be demonstrated by the following activity.

Fig. 4.12 A current carrying rod, AB, experiences a force perpendicular to the length and the magnetic field

A current carrying rod, AB, experiences a force perpendicular to the length and the magnetic field. Take a small aluminium rod AB. Suspend it horizontally by means of two connecting wires from a stand, as shown in fig 4.12. Now, place a strong horse shoe magnet in such a way that the rod is between the two poles with the field directed upwards. If a current is now passed in the rod from B to A, you will observe that the rod gets displaced. This displacement is caused by the force acting on the current-carrying rod. The magnet exerts a force on the rod directed towards the left, with the result that the rod will get...
deflected to the left. If you reverse the current or interchange the poles of the magnet, the deflection of the rod will reverse, indicating thereby that the direction of the force acting on it gets reversed. This shows that there is a relationship among the directions of the current, the field and the motion of the conductor.

In the above activity you considered the direction of the current and that of the field perpendicular to each other and found that the force is perpendicular to both of them. The three directions can be illustrated through Fleming's left hand rule.

4.11.1 Fleming's Left Hand Rule

Stretch the fore finger, the central finger, and the thumb of your left hand mutually perpendicular to each other. If the fore finger shows the direction of the field and the central finger that of the current, then the thumb will point towards the direction of motion of the conductor.

We have studied that current is simply a flow of charges. This means that moving charges in a magnetic field would also experience a force. The direction of the force on a moving positive charge is exactly the same as that on a current and is given by Fleming's left hand rule.

![Fig. 4.13 Fleming's left hand rule](image)

**Note:** The Fleming's left hand rule can be used to find out the direction of current in an electric motor.

4.12 (a) Field Pattern of an Isolated N-Pole

The flux emanates from N-pole and reaches an isolated south pole at a far of place. This is only imaginary.
4.12(b) Field Pattern of Bar Magnet

The flux emanates from ‘N’ - pole and reaches ‘S’ - pole outside the magnet and inside from south to north of the magnet and they do not cross each other. Each line forms a complete loop. The magnetic field is always thought of a flux or current of magnetism which goes around its circuit.

The magnetic flux going through a magnetic circuit is not as real as an electric current flowing through an electric circuit, but can be treated in a similar way. The magnetic lines can be thought of like a bundle of stretched rubber bands.

4.12(c) Field Pattern of ‘U’ Shaped Magnet

From the fig. 4.16 we observe that the magnetic lines of force travels from north pole towards south pole.
4.12.1 Magnetic Field Strength

Field intensity or magnetising force (H) at any point is the force exerted over a unit N - Pole of 1 weber placed at that point. Suppose ‘N’ is the pole and it is required to find the field strength at point ‘p’ at a distance of d meters from N. Let the pole strength of the pole be ‘m’ webers. Imagine a unit N pole placed at point ‘P’. By applying inverse square law, the force (repulsion here) between the two poles is given by:

\[ F = \frac{m \times 1}{4 \pi \mu_0 d^2} \text{N/ wb} \]

\[ F = H \text{ or} \]

\[ H = \frac{m}{4 \pi \mu_0 d^2} \text{N/ wb (or AT/m)} \]

The field strength is a vector quantity.

4.12.2 Properties of Magnetic Lines of Force around Straight Conductor

(1) The magnetic lines of force are in the form of concentric circles.

(2) The plane of magnetic lines of force and hence, magnetic field is at right angle to the plane of conductor carrying current.
(3) The direction of magnetic lines of force reverses with the changes in the direction of flow of current.

(4) On increasing the magnitude of current in conductor, the number of magnetic lines of force increases.

(5) Magnetising force at ‘p’ due to a long straight current carrying conductor at a distance of ‘R’ meters is

\[ H = \frac{I}{2\pi R} \] A T / m

Fig. 4.17 Magnetic lines around a straight conductor

4.12.3 Magnetic Field due to a Current in a Circular Coil

Take a drawing board and fix over it a white sheet of paper. Make two holes A and B in drawing board and pass through it a thick copper coil. Connect the ends of copper coil to a dry cell through a Switch and variable resistance close the circuit and plot magnetic lines of force with the help of plotting needle.

It is seen that magnetic lines of force around A are in anti-clock wise direction, Whereas that around B are in clock wise direction. However the magnetic lines of force near the centre of coil become almost parallel. As these lines of force seem to enter the coil from the side of the experiment, we can say that face of coil towards the experiment acts as south pole. Conversely, the face opposite to experiment acts as north pole.

If we relate the above observation to the flow of current in the coil, then we can say that if the current flows in the coil in clock wise direction facing the experimenter, then that face of the coil will act as south pole. In the same way, if the current in coil facing experimenter is in anti-clock wise direction, then that face of the coil will behave like north pole.
4.12.4 Magnetic Field in a Solenoid

An insulated copper coil wound around some cylindrical cardboard or plastic tube, such that its length is greater than its diameter and behaves like a magnet when electric current flows through it, is called a solenoid.

When an electric current is made to flow through it, then each turn of the coil behaves like a magnetic. In the figure, the current is flowing into the coil in a clockwise direction, therefore the left-hand side of each turn of the coil acts as the south pole, whereas the right-hand side of each turn of the coil acts as the north pole. Thus, the situation becomes similar to small bar magnets placed end to end with their opposite poles facing each other, such that they collectively act as a bar magnet. Thus, the solenoid behaves like a bar magnet. From this, it is clear that if the
number of turns in solenoid increases, then the magnetic effect also increases.

![Fig. 4.20 Magnetic Field in a solenoid](image)

The strength of magnetic field of the solenoid depends upon the following factors:

1. It is directly proportional to the number of turns in solenoid. It means the more the number of turns, the more is the magnetic strength of the solenoid.

2. It is directly proportional to the magnitude of current flowing through solenoid. It means the more the magnitude of current, the more is the magnetic strength of the solenoid.

3. It is directly proportional to the diameter of coil. It means the wider the coil, the more is the magnetic strength.

4. It depends upon the nature of material on which the coil is wound.

It has been found that if solenoid is wound on soft iron, then due to magnetic induction, it gets highly magnetised. Thus strength of magnetic field strongly increases. In such a situation solenoid is called electromagnet.

It behaves like a magnet as long as the current flow through it.

Magnetising force at the centre of a long solenoid

\[ H = \frac{NI}{2L} \text{ AT/m} \]

If it is a short solenoid \( H = \frac{NI}{2L} \text{ AT/m} \)
4.13 Field due to Two Parallel Conductors

When the currents are in the same direction the magnetic lines between the currents are neutralised and the conductors try to come closer due to attraction.

In the second case when the currents are in opposite direction the magnetic lines outside the conductors neutralize and the conductors try to go further due to repulsion.

Ampere

If two long straight parallel conductors carry some unknown but equal currents and if their common length is one metre and the distance between them (centre to centre) is also one metre and if that mutual force acting between them is $2 \times 10^{-7}$ newtons, then the value of that unknown current is one ampere.

4.14 Magnetic Circuits

Magnetic circuit is the path followed by magnetic flux. Magnetic flux follows a complete loop or circuit coming back to its starting point.

It is possible to establish magnetic flux in a definite limited path by using magnetic material of high permeability. In this manner, the magnetic flux forms a closed circuit exactly as an electric current does in an electric circuit.

The amount of flux produced in a magnetic circuit depends upon the property of magnetic material opposing the production of flux and this property is called reluctance of the material.

Magnetic circuits are found in all electrical machines in transformers, in motors and in many other devices.

4.14.1 Flux

Group of magnetic lines of force is called flux. $1 \text{ wb} = 10^8$ lines.
4.14.2 Magneto Motive Force (M.M.F)

This is similar to emf. in electric circuit. It is the force which drives the flux in magnetic path. Its unit is Ampere - turn (AT)

\[ \text{MMF} = \text{Amperes} \times \text{No. of turn} \]
\[ = \text{Magnetising force} \times \text{length of circuit} \]
\[ = \text{HL - AT} \]

4.14.3 Reluctance (OR Magnetic Resistance)

Whenever we wish to setup an electric current in a circuit, we always have to overcome the resistance of the electric circuit, which opposes the flow of current. Similarly we have seen that there is always magnetic resistance, which we call reluctance, and which always opposes the setting up of the magnetic flux in the circuit just as the resistance of an electric circuit depends upon the material and dimensions of the circuit. So the reluctance of a magnetic circuit depends upon the material and dimensions of the magnetic circuit.

4.14.4 Relation between MMF, Flux and Reluctance OR Ohm’s Law for Magnetic Circuit

In the magnetic circuit we have magnetic pressure setting up a magnetic flux against the resistance offered by the magnetic reluctance.

\[ \text{Magnetic Flux} = \frac{\text{magnetomotive force}}{\text{magnetic reluctance}} \]
\[ \text{Reluctance} = \frac{\text{MMF}}{\text{Flux}} \]
\[ \text{Magnetic lines} = \frac{\text{ampere - turns}}{\text{reluctance}} \]
\[ \text{Ampereturns} = \text{magnetic lines} \times \text{reluctance} \]

4.14.5 Flux Density and Magnetising Force

It is the flux lines per cross sectional area normal to the flux lines. It is mentioned in webbers per square metre. It is denoted by letter ‘B’.

\[ \text{Flux density} = \frac{\text{Flux}}{\text{Area}} = \frac{\text{Webers}}{\text{meter}^2} \]

Magnetising Force

The magnetising force (H) is really the magnetic pressure required to send a given number of lines through 1 inch of the magnetic circuit.

It is similar to the voltage required to send a given electric current through a mile of wire of given dimension. H is the no. of ampere-turns required to send a given number of lines through one inch of a given circuit.
\[ H = \frac{NI}{L} \text{ Ampere turns per meter length} \]

### 4.15 Comparison between Electric Circuit and Magnetic Circuit

<table>
<thead>
<tr>
<th>Electric Circuit</th>
<th>Magnetic Circuit</th>
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</thead>
<tbody>
<tr>
<td><img src="image1" alt="Electric Circuit Diagram" /></td>
<td><img src="image2" alt="Magnetic Circuit Diagram" /></td>
</tr>
</tbody>
</table>

2. E.M.F is the source to pass current

3. Current in amperes; current density in A/m²

4. Current EMF / Resistance

5. Resistance = \( R = \rho L/a \) and is constant

6. Conductance = \( 1/R \)

7. Energy is wasted as long as the current lasts.

8. No leakage of current

9. Current can be insulated i.e. it cannot pass through all the mediums.

10. Current flow is true flow.

11. Equivalent circuit.

2. MMF is the source to pass flux (MMF is caused by flow of current)

3. \( \phi \) is in webers; Flux density to \( \text{wb/m}^2 \)

4. Flux = MMF / Reluctance

5. Reluctance = \( \frac{L}{\mu_r} \) A
   
   It varies as \( \mu_r \) variable.

6. Permeance = \( 1/ \text{Reluctance} \)

7. Energy is required to establish the flux only and not for maintaining it.

8. There is leakage of flux.

9. There is no magnetic insulator. The flux passes through all the mediums.

10. There is no actual flow of flux. It is only the effect. Hence the word “Flow of Flux” is misleading.

11. Equivalent circuit.
Key Concept

• Concept of magnetism and electro magnetism
• Associated properties and rules of magnetism-electromagnetism.
• Concepts on magnetic effect of electric current

Activity

• Collect two bar magnets apply the rules and note down the observations.
• Collect magnets used for different applications and note the working mechanism
• Collect a cycle dynamo - Prepare a model generator
• Collect a box type relay used in refrigerator and observe its working mechanism.
• Collect a door bell and note down its working mechanism.

Project Oriented / OJT related Questions

• Prepare your observations of D.O.C starter working mechanism.
• Prepare your observations on relays used in Refrigerator / Grinder / Washing Machine / Microwave Oven / Water heater etc.

Short Answer Type Questions

1. What is a Magnet?
2. Define pole, Magnetic axis and pole strength
3. Explain the properties of magnet.
4. Define end rule, where do you apply this rule.
5. Define hand rule and explain its application.
6. Define Ampere rule
7. Describe magnetic field.
8. What is magnetic current (or flux)?
10. Draw the magnetic field pattern of a bar magnet.
11. Draw the magnetic field pattern of a horse show magnet.
12. Mention various applications of permanent and electromagnet.

13. What are the laws of magnetism.

14. What is ‘Field intensity’?

15. State four properties of magnetic lines of force.


17. Write the names of the appliances using magnetic effect of electric current.

18. What is a magnetic circuit?

**Long Answer Type Questions**

1. How does magnets classified?

2. How do you prepare a magnet by electrical methods and explain its applications.

3. Compare permanent magnet with electromagnet.

4. State the Inverse square law of magnetism.

5. Explain Flemings left hand rule.

6. Explain the following (a) Flux (b) MMF (c) Reluctance.

7. Compare between electric and magnetic circuit.
Learning Objectives

- To develop concepts on Electromagnetic Induction using Faraday Laws of Electromagnetic Induction
- To familiarize on various instruments and machines using electromagnetic induction principle.
- To learn different types of induced emf.
- To study the lifting power of electro magnet.

5.1 Concept of Electro Magnetic Induction

The transfer of electric energy from one circuit to another without the aid of the electric connections is called induction. When electric energy is transferred by means of a magnetic field, it is called electro-magnetic induction. This type of induction is universally employed in the generation of electric power. Electro-magnetic induction is also the principle which makes possible the operation of electric transformers.

Electromagnetic induction occurs whenever there is a relative movement between a conductor and a magnetic field, provided that the conductor is cutting across (linking with) magnetic lines of force and is not moving parallel to them. The relative movement may be caused by a stationary conductor and a moving field or by a moving conductor with a stationary field. A moving field may be provided by a moving magnet or by changing the value of the current in an
electromagnet.

The phenomenon of electromagnetic induction was discovered by Michael Faraday (1791 - 1867) an English physicist in 1831. He formulated the basic laws underlying the phenomenon of electromagnetic induction and known after his name.

5.1.1 Lenz’s Law

It states that ‘An induced current is always flows in such direction that its field opposes any change in the existing field.

or

‘An induced current is always flows in such a direction, that it opposes the very cause of its production”

5.1.2 Flemings Right Hand Rule

Flemings Right hand rule can be used to find out the direction of induced emf in a conductor cutting magnetic flux.

Hold the thumb and the first two fingers of the right hand mutually at right angles. Place the fore finger in the direction of the flux and turn the hand so that the thumb points in the direction of motion. The second finger will point in the direction of the induced emf.

![Flemings Right hand rule](image)

**Fig. 5.1 Flemings Right hand rule**

The direction of the induced emf is such that it tends to oppose the change in flux which induces it

Magnitude of induced emf: \( e = Blv \) Volts
B = Uniform magnetic field in webers
L = Length of conductor in mts.
V = Velocity of the conductor in mts / sec

Direction of induced emf:

Direction of induced emf depends upon Fleming Right hand rule:

Force on a current carrying conductor is

\[ F = BIL \text{ Newtons.} \]

\( B = \text{Field Intensity in wb/m} \)
\( I = \text{Current in Amps} \)
\( L = \text{Length of conductor in mts.} \)

Field intensity inside a solenoid.
\[ H = \frac{NI}{L} \text{ amper turns / mts} \]

5.2 Faraday’s Laws of Electro Magnetic Induction

1st Law:

It states that “whenever the magnetic flux links with a coil or circuit changes, an e.m.f is induced in it” or “Whenever a conductor cuts the magnetic flux, an e.m.f is induced in the conductor”.

Explanation

Fig. 5.2 shows an arrangement used by Faraday to study the production of electricity from magnetism. A bar magnet is placed close to a coil whose terminals are connected to a sensitive galvanometer \( G \) as shown in Fig. 5.2 (a). As it is, some flux is linking the coil but there is no deflection of the galvanometer. Now, suppose the magnet is suddenly brought closer to the coil (or the coil is moved closer to the magnet) as shown in Fig. 5.2(b), there is a momentary deflection in the galvanometer. If the magnet is suddenly moved away from the coil (or the coil is moved away from the magnet), as shown in Fig. 5.2(c) there is a momentary deflection in the galvanometer (but the deflection is in the opposite direction to the earlier).
The deflection of the galvanometer indicates the production of e.m.f in the coil. The only cause of the production can be the sudden movement of the magnet form the coil or vice-versa. It is important to note that the actual cause for the production of e.m.f is the change of the flux linking with the coil. Stationary flux, however strong it may be, will never induce any e.m.f in a stationary conductor / coil.

2nd Law:

It states that “The magnitude of the induced e.m.f is equal to the rate of change of flux linkages”.

Let \( e \) = induced e.m.f (V)

\( N \) = number of turns in a coil

\( \phi_1 \) = initial flux linkages (wb)

\( \phi_2 \) = final flux linkages (wb)

\( t \) = time taken to change the flux from \( \phi_1 \) to \( \phi_2 \)

Initial flux linkages = \( N \phi_1 \)

Final flux linkages = \( N \phi_2 \)

Change of flux linkages = \( N\phi_2 - N\phi_1 = N(\phi_2 - \phi_1) \) vb -turns

According to Faraday’s second law

Induced e.m.f, \( e = \frac{\text{Change of flux linkages}}{\text{time}} \)

\( = \frac{N(\phi_2 - \phi_1)}{t} \) volt

Putting the above equation in differential form, we get

\( e = \frac{d}{dt} (N\phi) \)

\( = N \frac{d\phi}{dt} \) volt

\[ e = -N \frac{d\phi}{dt} \] volt
Usually, a minus sign is given to signify that the direction of the induced e.m.f opposes the very cause producing it.

5.2.1 Types of E.M.F’s Dynamically and Statically Induced E.M.F’s

The emf produced by electromagnetic induction can be divided into two types.

(1) Dynamically induced emf (motionally)
(2) Statically induced emf (No motion)

The magnetic flux through a circuit or coil or conductor may be changed by various means, and by that change of flux linkages causing the production of induced emf.

### Statically Induced EMF

If an emf is induced without moving either the conductor or the flux, such as in transformers and reactors static emf is induced. This is classified into two types.

(1) Self induced emf (Current changes in the coil itself)
(2) Mutually induced emf (Action of neighbouring coil)

**Self Induced EMF**

It is defined as the emf induced in the coil due to increase or decrease of the current in the same coil. If the current is constant, no. emf is induced. When a current is passed to a circuit due to self induced emf the flow of current in the circuit is opposed.
Mutually Induced EMF

Coil ‘B’ is connected to a galvanometer. coil ‘A’ is connected to a cell. The two coils are placed close together. The coil connected to a supply is called primary coil A. The other coil ‘B’ is called secondary coil. The coil in which emf is induced by mutual induction is called secondary coil.

When current through coil ‘A’ is established by closing switch ‘S’ then its magnetic field is setup which partly links with or threads through the coil ‘B’. As current through ‘A’ is changed the flux linked with ‘B’ is also changed. Hence mutually induced emf is produced in ‘B’ whose magnitude is given by Faraday’s law and direction by Lenz’s law.

The property of inducing emf in one coil due to change of current in other coil placed near the former is called mutual induction and this property is used in Transformers and Induction coils.
5.3 Inductance

Inductance is defined as the property of the coil due to which it opposes the change of current in the coil. This is due to Lenz’s law.

**Lenz Law**

It states that “An induced current is always flows in such a direction that it field opposes any change in the existing field”.

or

An induced current is always flows in such a direction that it opposes the very cause of its production.

5.3.1 Self Inductance

Self inductance is defined as the webers turns / ampere of the coil and is denoted by the letter ‘L’ and its units as Henry (H).

The expression of self Induction by definition is

\[ L = \frac{N \phi}{I} \]  

\( N = \) No. of turns of a coil.  
\( I = \) Current in Amps  
\( L = \) Self Inductance  
\( \phi = \) Flux in webers

5.3.2 Mutual Inductance

When current in coil ‘A’ changes, The changing flux linking coil ‘B’. Induces emf in coil ‘B’ and is known as mutually induced emf. Mutual inductance between two coils ‘A’ and ‘B’ is the flux linkages of one coil B due to one ampere of outset in the other coil ‘A’

Let \( N_1 = \) No. of turns of coil ‘A’  
\( N_2 = \) No. of turns of coil ‘B’  
\( I_1 = \) Current in coil A  
\( I_2 = \) Current in coil B.  
\( A = \) Area of cross section of coil.  
\( \phi, \phi_I = \) Flux linking with coil A and B.
Hence by definition of expression of mutual inductance (m) 
= \( N_2 \phi_2 \) henry

and \( M = \frac{N_1 N_2 A \mu_o \mu_r}{L} \) Henry

5.3.3 Self Induction

Self Induction is the phenomenon by which an alternating emf is induced in a coil when an alternating current flows, through that coil.

5.3.4 Mutual Induction

The process of production of an e.m. f in one circuit when the current changes in another circuit (kept close to first circuit) is called “Mutual Induction”.

5.3.5 Coefficient of Coupling

The co-efficient of magnetic coupling indicates that there is mutual induction (m) between the two or more coils. so also each coil will have its own self induction (L).

Thus coefficient of magnetic coupling between two coils are more coils is given by the equation.

\[ K = \frac{m}{\sqrt{L_1 L_2}} \]

\( K \) = co-efficient of magnetic
\( L_1 \) = Self Inductance of coil (1)
\( L_2 \) = Self Inductance of coil (2)
\( M \) = Mutual Inductance between two coils

5.4 Energy Stored in a Magnetic Field

Energy stored = \( 1/2 LI^2 \) Joules
\( L \) = Inductance of coil
\( I \) = Current passing through the circuit
\( T \) = Time taken

5.4.1 Lifting Power of a Magnet

The Principle of lifting power of a magnet is employed in iron ore industry and steel plants for transportation purposes.
The expression for the lifting power of a magnet is given

\[
F = \frac{B^2 A}{9.81 \times 2\mu}
\]

\(F\) = Force of attraction between two poles  
\(A\) = Area of pole in \(m^2\)  
\(B\) = Flux density in \(wb / sq. \, m\)

Fig. 5.5 Lifting power of magnet

5.4.2 Simple Problems

(1) Find the average value of induced emf in a coil of 800 turns when the magnetic flux changes uniformly from 0.0020 wb to 0.0025 wb in 0.1 sec.

**Solution:**

\[
N \phi = \text{Change of Flux} = 0.0025 - 0.0020 = 0.0005 \, \text{wb and } dt = 0.1 \, \text{sec.}
\]

\[
e = 800 \times 0.0005 / 0.1, \quad e = 4 \, \text{volts}
\]

(2) If the direction of the flux of 0.0003 wb linked with a coil of 100 turns is reversed in 0.01 sec. Find the emf induced in the coil?

**Solution:** Induced emf \(e = N \, d \phi / dt\) volts

As the flux changes from 0.003 wb up in one direction, 0.0003 wb in 0.01 sec. then \(d \phi = (0.0003) - (-0.0003) = 0.0006 \, \text{wb}\)
\[ dt = 0.01 \text{ sec} \]
\[ e = N \frac{d\phi}{dt} = 100 \times 0.0006 / 0.01 = 6 \text{ volts} \]
\[ e = 6 \text{ volts} \]

(3) A straight conductor 8 mts long is moved at right angles to a uniform field of 1 wb / m² at a speed of 0.5 m / sec. Calculate the emf induced in volts.

**Solution**:

Given \( B = \text{Flux density} = 1 \text{ wb} / \text{m}^2 \)

\( L = 8 \text{ mts} , \ V = 0.5 \text{ m} / \text{sec} \)

\( e = B L V \text{ volts} \)

\( e = 1 \times 8 \times 0.5 = 4 \text{ volts} \)

(4) In a coil with 700 turns and a current of 6 amp produced a flux of 6 \times 10^{-5} \text{ wb}. Find the Inductance of the coil.

**Solution**:

\( N = 700, \ \phi = 6 \times 10^{-5} \text{ wb} , \ I = 6 \text{ amps} \)

\( \text{Self Inductance } L = \frac{N \phi}{I} \text{ Henry} \)

\( L = 700 \times 6 \times 10^{-5} / 1 \text{ Henry} = 0.0007 \text{ Henrys} \)

(5) An air cored toroidal coil has 450 turns and a mean length of 0.942 m and a cross-sectional area of 5 \times 10^{-4} \text{ m}^2. Calculate the self inductance of the coil.

**Solution**:

\( N = 450, \ \mu_r = 1 \text{ (air as medium)} \)

\( L = 0.942 \text{ m} , \ A = 5 \times 10^{-4} \text{ m}^2 \)

\[ L = \frac{\mu_0 \mu_r A N^2}{L} \]

\[ = 4 \times 3 \times 10^{-7} \times 1 \times 5 \times 10^{-4} \times 450^2 / 0.942 \]

\[ L = 0.000135 \text{ Henry} \]

(6) The shunt field winding of a D.C. motor has 900 turns and its resistance when voltage is 240 volts. The flux created is equal to 1 m wb. Calculate the self inductance of the shunt field winding.
Solution:

N = 900, φ = 1 m wb, V = 240 volts, R = 80 ohms

\[ L = \frac{N\phi}{I} \quad \text{and} \quad I = \frac{V}{R} \quad I = \frac{240}{80} = 3 \text{ ohms} \]

Hence \( L = \frac{900 \times 0.0001}{3} = 0.3 \text{ henry} \)

(7) A coil of 600 turns produced the Flux of 0.05 wb and self Inductance of coil is 0.001 Henry at normal current. Find out the current in the coil.

Solution

\[ L = 0.001\text{H}, \quad N = 600 \text{ turns}, \quad \phi = 0.05\text{wb} \]

\[ L = \frac{N\phi}{I} = 0.001 = 600 \times 0.05 / I. \]

Therefore \( I = 300 \text{ Amp.} \)

(8) Two identical coils of 400 turns each lies in parallel plane and produced the the flux of 0.004 wb. If the current of 8 amp is flowing in one coil, Find the mutual Inductance between coil?

Solution :

\[ N_2 = 400 \text{ turns}, \quad \phi = 0.04 \text{wb} \quad I = 8 \text{ amps.} \]

\[ M = \frac{N_2\phi}{I} = 400 \times 0.4 / 8 = 2 \text{ Henry} \]

(9) The winding of a transformer have an Inductance \( L_1 = 8 \text{H}, \quad L_2 = 0.8 \text{H}, \quad \text{and mutual Inductance is } 0.56. \) Find the co-efficient of coupling i.e. \( k = ? \)

Solution :

\[ L_1 = 8 \text{ H}, \quad L_2 = 0.008 \text{ H}, \quad m = 0.56 \]

\[ K = \frac{m}{\sqrt{L_1L_2}} = \frac{0.56}{\sqrt{0.8 \times 0.08}} = 0.7 \]

co-efficient of magnetic coupling 0.7

10) The field winding of a D.C. shunt generator possesing an Inductance of 1.0435 H. The exciting voltage is 230 volts and current passing through the coil is 4.6 amp. Calculate the energy stored in the magnetic field?

Solution :

\[ L = 1.0435 \text{H}, \quad I = 4.6 \text{ amp} \]
Energy stored in a coil is \( \frac{1}{2} LI^2 \)

\[ = \frac{1}{2} \times 1.0435 \times 1 \times 4.6^2 \]

\[ = 11.84 \text{ Joules} \]

(11) A solenoid 1.5 m in length and 15 cm in diameter has 400 turns. Calculate the energy stored in the magnetic field when a current of 2 amp flows in the solenoid?

**Solution:**

1 = 1.5 m, dia = 15 cm, \( N = 400 \mu \)

\( l = 2 \text{ amp} ; \mu_o = 1 \text{ (Air)} \)

\[ L = \frac{\mu_o \mu_r AN^2}{L} = \frac{4\pi \times 10^{-7} \times 1 \times \pi \times 0.15^2 \times 400^2}{1} \]

\[ L = \frac{4\pi \times 0.15^2 \times 16 \times 10^{-7} \times 10^4}{6} \]

\[ L = 0.0023 \text{ Henry} \]

Energy stored = \( \frac{1}{2} LI^2 \)

\[ = \frac{1}{2} \times 0.0023 / 1 \times 1/22 = 0.0002875 \]

**Key Concepts**

a. Electro magnetism

b. Magnetic circuit and electric circuit.

c. Electromagnetic induction and its applications

**Short Answer Type Questions**

(1) What do you understand by Dynamically induced emf?

(2) Self induced emf - Define?

(3) What is Inductance?

(4) What is Self Induction?

(5) Give the equation for energy stored in magnetic field?

(6) Write the formula for lifting power of a Magnet?
(7) Write the expression for induced emf in a coil?

(8) What is Lenz’a law?

(9) What is Induction?

(10) Classify the induced emf’s.

**Long Answer Type Questions**

(1) Define Faraday’s law of Electromagnetic Induction.

(2) Define Fleming’s Right hand rule.

(3) Define Self Inductance and Mutual Inductance?

(4) Define Magnetic coefficient of coupling?

**Activity / On Job Training**

a. Collect electric bell observe how electromagnet works

b. Collect a relay of refrigerator/voltage stabilizer and observe how electromagnet is effectively useful

c. Observe the implementation of electromagnetic induction in electric motors like ceiling fans, mixer grinder, pump sets,
Learning Objectives

- To develop concept on chemical effect of electric current
- To understand primary and secondary cells
- To learn Ah and Wh efficiencies of cell
- To learn charging methods of cells
- To familiarize with maintenance of secondary cell
- To study developments or latest cells available in the market. Such as maintenance free battery, emergency light battery, inverter battery etc.,

6.1 Chemical Effects of Electric Current

Whenever an electric current flows through some liquid or solution or water, the current reacts with that solution and the solution or water is decomposed into its constituents. This effect of electric current is called the chemical effects of electric current. The vice versa is also true. That is if two or more chemical substances react with each other as in the case of cells electric current is produced.

The decomposition of water into oxygen and hydrogen is the example of the chemical effects of electric current. Chemical effects of electric current passing through electrolytes is electrolysis, Faraday did many experiments on electrolysis and stated his two laws.
6.1.1 Electrolysis

Electrolysis is the name given to the chemical decomposition which occurs in electrolysis when electric current passes through them.

Consider a solution of copper sulphate (CuSO₄). When CuSO₄ is dissolved in water, its molecules split up into Cu⁺⁺ ions and SO₄⁻⁻ ions.

\[ \text{CuSO}_4 \rightarrow \text{Cu}^{++} + \text{SO}^{-4} \]

Let copper plates connected to battery be placed into this solution. These plates are called electrodes. These electrodes connected to the positive pole of the battery is known as anode, while the other connected to the negative pole of the battery is called cathode. The Cu⁺⁺ (Positive copper ions) go to the cathode and the negative sulphate ions SO₄⁻⁻ go towards the positive electrodes i.e. anode. The movement of the ions constitutes a flow of electric current through the external circuit the current due to the motion of the electrons.

When SO₄⁻⁻ ions reaches the anode, it gives up its charge and ceases to be an ion. The two electrons given by SO₄⁻⁻ ion enter the anode and become part of the electron stream in the external circuit. Similarly Cu⁺⁺ ion reaches the cathode, it gives up its charge and make up its deficiency of two electrons from the cathode.

This whole process is called electrolysis.

6.1.2 Electrolyte

The current can pass through some liquids and also it cannot pass through some other.

For example: Pure distilled water, Kerosene oil, alcohol are insulator of electric current and dilute acid, alkali, salt solutions are conductors. These conductors are called electrolytes.

6.1.3 Faraday’s Laws of Electrolysis

Faraday determined two laws which govern the phenomenon of electrolysis.

First Law

Whenever current (D.C.) passes through an electrolytic solution, the solution is decomposed and the amount of mass liberated from it at an electrode is directly proportional to the quantity of electricity passed through that solution.

\[ \text{Quantity of electricity} = Q = \text{Current in Amps} \times \text{time in seconds} \]
Q in coulombs = Current in Amps X time in seconds

Q = It

From the first law \( m \propto It \) i.e. \( m \propto Z \cdot It \text{ gms} \)

Where ‘Z’ is a constant, and it is called the electro-chemical-equivalent (E.C.E.) of that substance which is liberated at the electrode.

\[ Z = \frac{m}{It} = \text{mass liberated in gms / coulomb}. \]

E.C.E. of silver = 0.001118 g = gms/coulomb.

E.C.E. of copper = 0.0003265 gms/coulomb.

6.1.4 Example Problems

1) Given that the E.C.E. of silver is 0.001118 gms/coulomb, find the time taken for a current of 2 Amps. to pass through a silver nitrate solution to liberate silver of mass 10 gms.

**Solution:**

\[ Z = \frac{m}{It} \text{ gms} \]

\[ t = \frac{m}{ZI} = \frac{10}{0.00118 \times 2} = \frac{10^7}{1118} \times 2 \text{ seconds} \]

\[ = 4472.27 \text{ sec} = 1.242 \text{ hours}. \]

2) Determine the quantity of electricity to be passed through a silver nitrate solution to liberate silver of mass of 15 gms from it and deposit on the cathode.

**Solution**

\[ m = Z \cdot It = ZQ \]

Quantity of Electricity \( Q = \frac{m}{z} \)

\[ \frac{15}{0.00118} = \frac{15 \times 10^6}{1118} \text{ Columbs} \]

\[ Z = 0.001118 \]

\[ = 13416.816 \text{ Columbs} \]

**Second Law**

If a number of different electrolytes are connected in series and if the same amount of current is passed through all of them simultaneously for the same time then the amount of masses in gms. Liberated through all these electrolytes are directly proportional to their chemical equivalent weights.
6.2: Cells - It’s Components

Definition of Battery

Cell

In electrical engineering, a cell means a container, which contains some chemical substances which react with each other and a potential difference is created between the two terminals Anode and Cathode and if these two terminals are joined externally by a wire, an electric current is passed through this wire, this is called a cell.

Components of a cell

1) Glass container
2) Copper plate (+ Ve) Anode:
3) Zinc plate (- Ve) Cathode
4) Dilute Sulphuric Acid.

6.2.1 Battery

The combination of cells is called Battery. One cell can not be called as a battery. If some cells are connected in Series or in parallel or both in series and parallel connection then only be called as Battery.

6.2.2 Primary Cells - Defects and Remedies

Dry cell

Primary Cell

The Voltaic cell is called as primary cell.
Cathode
Glass vessel
Dilute H₂SO₄
Zinc electrode
Copper electrode
Hydrogen Bubbles
Anode
Cathode
Glass vessel
Dilute H₂SO₄
Copper Electrode
Zinc electrode
Positive terminal
Negative terminal
Expansion Chamber
electrolyte paste
Zinc container (cathode)
Carbon electrode
Steel cover
Paper gasket
Insulating washer
Paste coated blotting paper separator
Cardboard or plastic jacket

Fig. 6.2 Dry Cell

Fig. 6.3 Chemical Changes in a cell
6.2.3 Working of Simple Voltaic Cell

The actual chemical reaction starts at the Zinc plate. Positive Zinc ions come out from the zinc plate and go to the electrolyte. i.e. dilute $H_2So_4$ thus making the Zinc plate -Ve with respect to the electrolyte then a potential difference is established between the Zinc plate and the + Ve plate (copper). The potential difference thus established between the anode (copper plate) and the cathode(Zinc plate) is called Electro motive force(E.M.F) of the cell.

Now, when the emf is established between the two plates i.e. anode copper and cathode Zinc and if we connect these two plates outside with wire through some resistance, then the current passes from + Ve to - Ve outside the plates and - ve to + ve inside the cell through the electrolyte. In this way the simple voltage cell supplies the load current.

When the cell supplies load current, The zinc of the cathode is eaten away and Zinc Sulphate is formed,

Which is represented by the equation

$$Zn + H_2So_4 = Zn So_4 + H_2$$

The Hydrogen gas is liberated and goes towards the + ve plate i.e. anode, and accumulates on the +ve plate. This hydrogen gas accumulation on + ve plate slowly increases and the hydrogen bubbles completely encircles the copper plate throughout and thereby the complete anode is cut off from the solution.

When the +ve plate is cut off from the solution, the flow of current stops. This defect is called “polarisation”. Polarisation creates two defects.

1) The internal resistance of the cell increases.

2) Back EMF is setup and the main E.M.F is reduced, hence the current decreases.

There is a remedy for this defect. The remedy is that a depolarizing agent is kept in the electrolyte which reacts with the hydrogen gas and there by a new substance is formed and hydrogen dis appears. There is one more defect, which is called “Local action” due to the presence of impurities in Zinc which produce local cells and create (eddy) currents. The remedy for this local action is that the complete surface of the Zinc plate is amalgamated.

6.2.4 Dry Cell

The touch light cell or a transformer cell or a quartz watch cell etc can be called as a dry cell. This is a primary cell. If this primary cell is discharged once cannot be charged again.
Truely it can not be dry. It has to be wet. If it is completely dry it can not work. We have to pour some drops of water in it so that it can work. But still it is called dry cell. Dry cell is nothing but the modification of the **Leclanche** cell.

In the figure 6.4 what you see is a Zinc cyclinder in which a paste is there, ‘W’ which consists of a plaster of paris, flour, zinc chloride salt ammoniac and water. The next to this paste is “B” which is another paste composed of carbon and oxide of manganese, Zinc Chloride, saltammoniac and water. In the centre is a rod. ‘C’ which is made of carbon, which acts as positive terminal and the bottom of the zinc cylinder as negative terminal. There is a hole at the top called ‘Vent’. Through this hole the hydrogen gas escapes outside, so that it cannot reach and encircle the postive electrode i.e. the carbon rod “C”. This entire thing is covered with mill board. This is known as what is a dry cell.

The internal resistance is less. The EMF cannot be more than 1.5 V.

![Fig. 6.4 Dry Cell](image)

**6.2.5 Secondary Cell, Difference between Primary and Secondary cells**

**Secondary Cell**

The primary cells make use of a chemical process which is not reversible. The cells have to be replaced after giving active service, e.g dry cells have to be discarded when discharged. The secondary cells on the other hand work on a reversible electro-chemical process, i.e. the cells have to be electrically charged
before putting into service. These are discharged during active service i.e. while supplying current for a circuit. When completely discharged, the cells can be recharged by feeding electrical energy into the device. The other major advantage is the capacity of supplying electrical energy which is higher in the case of secondary cells. In other words a secondary cell can supply more current for a long period as compared to a primary cell and can be recharged again and again.

<table>
<thead>
<tr>
<th><strong>Primary Cell</strong></th>
<th><strong>Secondary Cell</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. If recharged once, cannot be recharged.</td>
<td>1. If discharged, can be recharged.</td>
</tr>
<tr>
<td>2. For recharging, whole material d.c. is to be replaced.</td>
<td>2. It can be easily charged by giving supply.</td>
</tr>
<tr>
<td>3. These are light in weight.</td>
<td>3. Heavy in weight.</td>
</tr>
<tr>
<td>4. Mostly used for intermittent work with low current rate.</td>
<td>4. Can be used for conditions rating with heavy load currents.</td>
</tr>
<tr>
<td>5. Low life</td>
<td>5. High life</td>
</tr>
<tr>
<td>6. For example, Daniel cell, Leclanche cell, Dry cell etc.</td>
<td>6. Lead acid cell: Nickel iron</td>
</tr>
</tbody>
</table>

### 6.3 Lead Acid Cell - Principle of Working

P and Q are two lead plates called Electrodes p is positive Anode and “Q” is negative cathode.

![Fig. 6.5 Charging of Cell](image)

Now Suppose, we connect a battery across the electrodes. Plate “P” to positive terminal of the battery and plate “Q” to the negative terminal of the
battery then the current starts from the positive terminal of the battery and enters into the positive plate ‘P’ i.e. anode of the cell. And inside the cell the current flows from anode to the cathode and from cathode, it comes out and goes to the negative terminal of the battery. This process is called charging.

During this charging process, the hydrogen gas appears at the cathode Q and the oxygen at the positive plate ‘P’.

This oxygen at “P” reacts with this lead plate and forms the dark brown lead Peroxide (pbo) and at the positive plate, the hydrogen gas bubbles rise to the surface and escape, to the atmosphere without reacting with the negative plate ‘Q’. So that the negative plate remains the same.

This charging of the secondary cell has to continue non stop for some hours so that the cell is fully charged.

How can we say the cell is fully charged? If the emf of the cell becomes 2.2 volts and the specific gravity of the electrolyte becomes 1.21 or as we say 12.10; then we can say that the cell is fully charged and ready to work.

Now the battery has been removed in Fig. and a resistance and Ammeter is connected in series are connected across the terminal ‘P’ and Q. Current (D.C) starts from “p” and passes through the external load resistance and ammeter, and enters into the negative plate ‘Q’ and inside the cell it travels from negative to positive.

Note the direction of current is completely reversed to that of charging.

This process of supplying load current is called discharging. What happens during discharging? When the cell is discharging i.e. supplying current to the load, the lead peroxide which was formed on the positive plate during charging, will slowly disappear from “p” and because of chemical reaction taking place on both the plates; Pb So₄ is formed on both the plates ‘P’ and ‘Q’. And some
traces of lead monoxide (Pbo) are also formed on both the electrodes ‘P’ and ‘Q’.

If the EMF falls to 1.8 volts and if the specific gravity of the electrolyte comes down to 1180, we can say that the cell has been completely discharged. If we still further discharge the cell, it will be completely spoiled. An insoluble substance known as lead sulphate is formed which will completely ruin the cell.

Also we should never short circuit the cell; i.e. we should never join the two electrodes ‘P’ and ‘Q’ by simply wire of low resistance. This short circuit causes heavy current to flow which firms sulphates, disintegration of active material and buckling of the plates.

6.3.1 Chemical Changes for Plante Type Plates

Plante type plates means positive plate pale “P” is coated with Pbo₂ and negative plate is coated with spongy lead.

Discharging process

At the time of discharging hydrogen gas appears at the + ve plate and oxygen appears at - ve plate. This is just reverse to charging. The Hydrogen at the + ve plate combines with the peroxide there as indicated by the following equation.

\[ \text{Pbo}_2 + \text{H}_2 = \text{Pbo} + \text{H}_2\text{O} \]  ———— I

\[ \text{Pbo} + \text{H}_2\text{SO}_4 = \text{Pb SO}_4 + \text{H}_2\text{O} \]  ———— II

The oxygen reacts at the negative plate as follows.

\[ \text{Pb} + 0 = \text{Pbo} \]  ———— III

\[ \text{Pbo} + \text{H}_2\text{SO}_4 = \text{Pb SO}_4 + \text{H}_2\text{O} \]  ———— IV

Charging process

In charging oxygen is liberated at the positive plate and hydrogen at the negative plate (Just reverse to discharging) the oxygen at the + ve plate combines with Pbo——I Producing Pbo₂, Therefore

\[ \text{Pbo} + 0 = \text{Pbo}_2 \]  ———— V

And Pb SO₄ is converted to Pbo as follows.

\[ \text{Pb SO}_4 + \text{O} + \text{H}_2\text{O} = \text{Pbo}_2 + \text{H}_2 + + \text{SO}_4 \]  ———— VI

The Hydrogen at the negative plate combines with the products there in 3 and 4 equations above as follows:
\[
PbO + H_2 = Pb + H_2O \quad \text{(VII)}
\]
\[
PbSO_4 + H_2 = Pb + H_2SO_4 \quad \text{(VIII)}
\]

By equation 6 and 8 density of the electrolyte is increased and by the equations 2 and 4 density is decreased. By knowing the specific gravity of the electrolyte, we can easily determine the condition of the cell. This is the best test to know the condition of the cell.

6.3.2 The two Efficiencies of a Cell

The efficiency of a cell can be expressed in two ways:

One is called “Energy efficiency” and the second one is called “Quantity efficiency”. Energy efficiency is expressed in Ampere hours.

1) Quantity efficiency or Ampere-hour efficiency
\[
\text{Efficiency} = \frac{\text{Amperes} \times \text{hours given out}}{\text{Ampere hours taken in}} \times 100
\]

2) Energy efficiency or watt-hour efficiency
\[
\text{Efficiency} = \frac{\text{Watts} \times \text{hours given out}}{\text{Watts} \times \text{hours taken in}} \times 100
\]

or
\[
\text{Efficiency} = \frac{\text{Volts} \times \text{Ampers} \times \text{hours given out}}{\text{Volts} \times \text{hours} \times \text{Ampere taken in}} \times 100
\]

or
\[
\text{Efficiency} = \frac{\text{Watts} \times \text{hours discharged}}{\text{Watts} \times \text{hours charged}} \times 100
\]

6.4 Methods of Charging and Maintenance of Lead Acid Cells

Methods of Charging

In general, there are two methods of charging batteries or Accumulators (the name accumulator, as it accumulates, means adds or stores the electrical energy) from d.c. supply there are two methods of charging a lead acid battery.

1) Constant current method.

2) Constant voltage method.
Constant Current Method

Constant current method of charging is usually adopted for initially charging the new batteries. According to this method charging current is kept constant throughout by adjusting the external resistance R. This method of charging is defective to the extent that it does not take into consideration the state of charge of the battery. Usually high, charging rate is required for fully discharged battery in the beginning and this rate of charging should go down as battery approaches its fully charged rate. This drawback is removed when we charge the battery according to constant voltage method.

Constant Voltage Method

In this method, charging voltage is held constant throughout the charging. Charging current in the beginning is high which however reduces as the back emf of the battery increases. This is the most common method of charging. The battery is charged till the cells are gassing freely and the specific gravity of the electrolyte and the terminal voltage of cells remain constant. The fully charged battery has following indications.

Specific gravity of electrolyte 1260 to 1280
Voltage of cell 2.1 volts

Where specific gravity can be determined by hydrometer and voltage by cell tester accurately.

![Diagram of charging circuit](image)

Fig. 6.7
6.5 Maintenance of Lead Acid Cells

Care and maintenance of lead acid cell is most important. Otherwise the batteries will get spoiled.

The following points should be observed:

1) If the voltage of the lead acid cell comes down up to 1.8 volts per cell, the battery should not be used. It should be kept aside. As we studied earlier an insoluble substance called, lead sulphate is formed which will damage/spoil the cell.

2) See that, always the plates are submerged inside the electrolyte. The level of the electrolyte should be always 15 mm above the top level of the plates. The plates should never be exposed to air. Now and then we should pour distilled water in the cells to keep the level of the electrolyte constant. Because the electrolyte gets evaporated after some time.

3) Never leave the discharged battery in that discharged condition for a long time. Otherwise, it completely gets spoiled.

4) Keep the cell in dry and clean position.

5) The charge and discharge should be at normal rates.

6) While charging, vent plug should be kept loose for passing out of the evolved gases if any.

7) The naked flame, near the battery, while charging, should be avoided.

8) While preparing electrolyte, water should not be poured into the acid, but acid should be poured in water drop by drop.

6.6 Fuel Cell

A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidizing agent. Hydrogen is the most common fuel, but hydrocarbons such as natural gas and alcohols like methanol are sometimes used. Fuel cells are different from batteries in that they require a constant source of fuel and oxygen to run, but they can produce electricity continually for as long as these inputs are supplied.

Welsh Physicist William Grove developed the first crude fuel cells in 1839. The first commercial use of fuel cells was in NASA space programs to generate power for probes, satellites and space capsules. Since then, fuel cells have been used in many other applications. Fuel cells are used for primary and backup power for commercial, industrial and residential buildings and in remote or
inaccessible areas. They are used to power fuel cell vehicles, including automobiles, buses, forklifts, airplanes, boats, motorcycles and submarines.

There are many types of fuel cells, but they all consist of an anode (negative side), a cathode (positive side) and an electrolyte that allows charges to move between the two sides of the fuel cell. Electrons are drawn from the anode to the cathode through an external circuit, producing direct current electricity. As the main difference among fuel cell types is the electrolyte, fuel cells are classified by the type of electrolyte they use. Fuel cells come in a variety of sizes. Individual fuel cells produce very small amounts of electricity, about 0.7 volts, so cells are “stacked”, or placed in series or parallel circuits, to increase the voltage and current output to meet an application’s power generation requirements. In addition to electricity, fuel cells produce water, heat and, depending on the fuel source, very small amounts of nitrogen dioxide and other emissions. The energy efficiency of a fuel cell is generally between 40-60%, or up to 85% efficient if waste heat is captured for use.

Fig. 6.8 Fuel Cells

Types of Fuel Cells; Design

Fuel cells come in many varieties; however, they all work in the same general manner. They are made up of three adjacent segments: the anode, the electrolyte, and the cathode. Two chemical reactions occur at the interfaces of the three different segments. The net result of the two reactions is that fuel is consumed,
water or carbon dioxide is created, and an electric current is created, which can be used to power electrical devices, normally referred to as the load.

At the anode a catalyst oxidizes the fuel, usually hydrogen, turning the fuel into a positively charged ion and a negatively charged electron. The electrolyte is a substance specifically designed so ions can pass through it, but the electrons cannot. The freed electrons travel through a wire creating the electric current. The ions travel through the electrolyte to the cathode. Once reaching the cathode, the ions are reunited with the electrons and the two react with a third chemical, usually oxygen, to create water or carbon dioxide.

The most important design features in a fuel cell are:

- The electrolyte substance. The electrolyte substance usually defines the type of fuel cell.
- The fuel that is used. The most common fuel is hydrogen.
- The anode catalyst, which breaks down the fuel into electrons and ions. The anode catalyst is usually made up of very fine platinum powder.
- The cathode catalyst, which turns the ions into the waste chemicals like water or carbon dioxide. The cathode catalyst is often made up of nickel.
- A typical fuel cell produces a voltage from 0.6 V to 0.7 V at full rated load. Voltage decreases as current increases, due to several factors:
  - Activation loss
  - Ohmic loss (voltage drop due to resistance of the cell components and interconnects)
  - Mass transport loss (depletion of reactants at catalyst sites under high loads, causing rapid loss of voltage)

To deliver the desired amount of energy, the fuel cells can be combined in series and parallel circuits, where series yields higher voltage, and parallel allows a higher current to be supplied. Such a design is called a fuel cell stack. The cell surface area can be increased, to allow stronger current from each cell.

6.6.1 Silver - Oxide Battery

A silver oxide battery (IEC code: S) is a primary cell with relatively very high energy/weight ratio.

They are costly due to the high price of silver.
They are available in either very small sizes as button cells where the amount of silver used is small and not a significant contributor to the overall product costs, or in large custom design batteries where the superior performance characteristics of the silver oxide chemistry outweigh cost considerations.

The large cells found some applications with the military, for example in Mark 37 torpedoes or on Alfa class submarines.

Spent batteries may be processed for their silver content.

![Fig. 6.9 Silver Oxide Battery](image)

**Chemistry**

A silver oxide battery uses silver oxide as the positive electrode (cathode), zinc as the negative electrode (anode) plus an alkaline electrolyte, usually sodium hydroxide (NaOH) or potassium hydroxide (KOH). The silver is reduced at the cathode from Ag(I) to Ag and the zinc is oxidized from Zn to Zn(II).

The chemical reaction that takes place inside the battery is the following:

\[
Zn + Ag_2O \xrightarrow{KOH / NaOH} ZnO + 2Ag
\]

Zinc is the activator in the negative electrode and corrodes in alkaline solution. When this happens, it becomes difficult to maintain the capacity of the unused battery.

The zinc corrosion causes electrolysis in the electrolyte, resulting in the production of hydrogen gas, a rise of inner pressure and expansion of the cell.

Mercury has been used in the past to suppress the corrosion, despite its harmful effects on the environment.

**History**

This technology had the highest energy density prior to lithium technologies. Primarily developed for aircraft, they have long been used in space launchers and crewed spacecraft where their short cycle life is not a drawback.
Non-rechargeable silver–zinc batteries powered the Saturn launch vehicles, the Apollo Lunar Module, lunar rover and life support backpack. The primary power sources for the command module were the hydrogen/oxygen fuel cells in the service module.

They provided greater energy densities than any conventional battery, but peak power limitations required supplementation by silver–zinc batteries in the CM that also became its sole power supply during re-entry after separation of the service module.

Only these batteries were recharged in flight. After the Apollo 13 near-disaster, an auxiliary silver–zinc battery was added to the service module as a backup to the fuel cells.

The Apollo service modules used as crew ferries to the Skylab space station were powered by three silver–zinc batteries between undocking and SM jettison as the hydrogen and oxygen tanks could not store fuel cell reactants through the long stays at the station.

6.6.2 Solar Cell

A solar cell (also called photovoltaic cell or photoelectric cell) is a solid state electrical device that converts the energy of light directly into electricity by the photovoltaic effect.

Assemblies of solar cells are used to make solar modules which are used to capture energy from sunlight. When multiple modules are assembled together (such as prior to installation on a pole-mounted tracker system), the resulting integrated group of modules all oriented in one plane is referred to in the solar industry as a solar panel. The electrical energy generated from solar modules, referred to as solar power, is an example of solar energy.

Fig. 6.10 Solar Cell
Photovoltaic is the field of technology and research related to the practical application of photovoltaic cells in producing electricity from light, though it is often used specifically to refer to the generation of electricity from sunlight.

Cells are described as photovoltaic cells when the light source is not necessarily sunlight (lamplight, artificial light, etc.). These are used for detecting light or other electromagnetic radiation near the visible range, for example infrared detectors, or measurement of light intensity.

**Applications**

Solar cells are often electrically connected and encapsulated as a module. Photovoltaic modules often have a sheet of glass on the front (sun up) side, allowing light to pass while protecting the semiconductor wafers from abrasion and impact due to wind-driven debris, rain, hail, etc. Solar cells are also usually connected in series in modules, creating an additive voltage. Connecting cells in parallel will yield a higher current; however, very significant problems exist with parallel connections. For example, shadow effects can shut down the weaker (less illuminated) parallel string (a number of series connected cells) causing substantial power loss and even damaging excessive reverse bias applied to the shadowed cells by their illuminated partners. As far as possible, strings of series cells should be handled independently and not connected in parallel, save using special paralleling circuits. Although modules can be interconnected to create an array with the desired peak DC voltage and loading current capacity, using independent MPPTs (maximum power point trackers) provides a better solution. In the absence of paralleling circuits, shunt diodes can be used to reduce the power loss due to shadowing in arrays with series/parallel connected cells.
To make practical use of the solar-generated energy, the electricity is most often fed into the electricity grid using inverters (grid-connected photovoltaic systems); in stand-alone systems, batteries are used to store the energy that is not needed immediately. Solar panels can be used to power or recharge portable devices.

**Materials**

Different materials display different efficiencies and have different costs. Materials for efficient solar cells must have characteristics matched to the spectrum of available light. Some cells are designed to efficiently convert wavelengths of solar light that reach the Earth surface. However, some solar cells are optimized for light absorption beyond Earth’s atmosphere as well. Light absorbing materials can often be used in multiple physical configurations to take advantage of different light absorption and charge separation mechanisms.

Materials presently used for photovoltaic solar cells include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium selenide/sulfide.

Many currently available solar cells are made from bulk materials that are cut into wafers between 180 to 240 micrometers thick that are then processed like other semiconductors.

Other materials are made as thin-films layers, organic dyes, and organic polymers that are deposited on supporting substrates. A third group are made from nanocrystals and used as quantum dots (electron-confined nanoparticles). Silicon remains the only material that is well-researched in both bulk and thin-film forms.

**Lifespan**

Most commercially available solar panels are capable of producing electricity for at least twenty years. The typical warranty given by panel manufacturers is over 90% of rated output for the first 10 years, and over 80% for the second 10 years. [citation needed] Panels are expected to function for a period of 30 to 35 years.

**Key Concepts**

- Concept on conversion of chemical energy to electrical energy
- Primary and secondary cells
- Maintenance of cells
- Latest developments in cells and their technology
Activity

- Collect model battery study the construction parts working
- Visit a battery charging shop/auto-electrical works and learn charging and testing procedure.
- Collect technical broachers of Exide and other leading battery manufacturing companies.
- Visit a battery assembling unit.

Short Answer Type Questions

1) What is B - H curve
2) Define cell
3) What are the two efficiencies of a cell.
4) What is a battery?
5) What are the components of a cell?
6) What is chemical effect of electric current.
7) Define flux density and magnetising force.
8) What is reluctance?
9) What do you understand by magnetic effect of electric current?

Long Answer Type Questions

1. Compare the electrical circuit with magnetic circuit.
2. Define faradays laws of electrolysis.
3. What are the two defects in a simple voltaic cell and describe remedies.
4. Write the differences between primary and secondary cells.
5. What is constant current system of charging a battery.
6. What is constant voltage system of charging a battery?

Project Oriented / OJT Related Questions

1. List out the material working on chemical effect.
2. Visit Battery selling / charging cum repairing centre and learn battery testing and charging method (spend one week to learn total testing and repairing method).
Learning Objectives

- To understand concepts of electrostatics
- To understand charge, potential, coulomb's law, and associated terms
- To learn functions of a capacitor
- To learn the methods of connecting capacitors in a circuit
- To practice simple problems on charge, capacitor.

7.1 Definition of Electric Charge and its Units

So far we have dealt entirely with current electricity, that is electricity in motion. Whereas electrostatics means the static electricity or electric charges at rest, and it is defined as that branch of science which deals with electricity at rest. The study of the behavior of static electricity is called electrostatics.

When two objects are rubbed together, electrons are removed from surface atoms, relatively more from one material than from the other. The object whose atoms acquire excess of electrons is said to have a negative static charge, the other object gaining a positive charge. The term static means fixed, or at rest.

If a rubber rod is scoured (rubbed) with a piece of wool, electrons tend to collect on the surface of the rubber rod, impairing a negative static charge, while
positively charged atoms at the surface of the wool give it a positive static charge. When a glass rod is rubbed with a piece of silk, the rod becomes positively charged, the silk negative. This phenomenon can be experienced by many people while wearing polyester shirt, the shirt and the hair on the hands will be rubbed slightly causing the hair on the hand will be attracted by the shirt. When two clouds rub each other acquire heavy charges and at times will be discharged to earth producing what is called lightning. Results in these and similar cases depend upon the particular physical and electrical nature of the materials involved.

These simple facts were discovered by Dr. Gilbert in Queen Elizabeth’s reign. Ebonite was, of course not known at that time; Gilbert used a naturally occurring ‘plastic’ material namely amber. Gilbert recognized that are seemed to be two kinds of “amber effect”, or electricity, and he called these two kinds “resinous” (like resin) and viereous (like glass). Later “resinous electricity” was called negative, and “vitereous electricity” was called positive. This choice of positive and negative is unfortunate, as we shall see later.

**Positive and Negative charge**

Since the aggregate of the positive electricity on the protons of any atom is exactly equal to the aggregate of negative electricity on the electrons, therefore an atom is electrically neutral. If some of the outer electrons are removed then the atom remains an atom, but its chemical nature may be altered, and what is immediately obvious, the balance of positive to negative electricity will be upset. There will, in fact be a surplus of positive electricity, and if this removal of some of the electrons has been common to all the atoms in a body, this body will be charged positively, or will have acquired a positive charge.

If, on the other hand, an electron is added instead of removed there will be preponderance of negative electricity, and if this addition has been made to all the atoms of the body this body will be charged negatively, or will have acquired a negative charge.

The process by which an originally neutral atom becomes positively charged through the removal of electrons (or addition of electrons) is called ionization and the atom itself is called an ion.

Summarizing, we can say that positive electrification is the result of a deficiency of electrons, while negative electrification is the result of a excess of electrons. The total deficiency, or excess, of electrons is called the charge.
7.2 Definition of Unit Charge

One Coulomb of charge referred as unit charge may be defined as that charge which when placed in air at a distance of one metre from an equal and similar charge is repelled with a force of $9 \times 10^9$ newtons.

7.3 Coulombs Laws of Electrostatics

1st Law

It states that “Like charges of electricity repel each other, where as unlike charges of electricity attract each other”.

Explanation of 1st Law

Fig 7.1 represents a small ball of very light material such as plant pulp (known as pith), suspended by a string. If the ball is given a positive charge, and a charged rubber rod is brought near as shown in Fig 7.1 (a), the positively charged body will be attracted, swinging towards the negatively charged rod, and thus showing that unlike charges attract. If the positively charged glass rod is brought near the ball, as shown in Fig 7.1 (b), the ball will be repelled swinging away from the glass rod, showing that two positively charged or two negatively charged bodies repel each other. The rule for interaction between positive and negative electrical charges may be stated as follows : Unlike charges attract; like charges repel.
2nd Law

It states that the force exerted between two point charges is

(i) directly proportional to the product of their strength.

(ii) inversely proportional to the square of the distance between them and

(iii) inversely proportional to the absolute permittivity of the surrounding medium.

This law is also known as inverse square law

Mathematically the second law can be expressed as

\[ F \propto \frac{Q_1 Q_2}{\varepsilon d^2} \]

Where \( F \) = force between two charges (newton)
\( Q_1, Q_2 \) = strength of the two point charges (coulomb)
\( d \) = distance between two point charges (metre)
\( \varepsilon \) = absolute permittivity of the surrounding medium and \( \varepsilon = \varepsilon_0 \varepsilon_r \) F/m
(farad / metre)

\( \varepsilon_0 \) = absolute permittivity of the free space or vacuum and is equal to 8.854 x 10^{-12} farad / metre.

\( \varepsilon_r \) = relative permittivity of the medium (dimensionless) or specific inductive capacity.

\( K \) = Proportionality constant and its value depends on the system of units employed. In SI units,

\[ K = \frac{1}{4 \pi} \]

Hence \( F = \frac{Q_1 Q_2}{4 \pi \varepsilon_0 \varepsilon_r d^2} \) newton.

\[ F = \frac{(Q_1 Q_2 / 4\pi \times 8.854 \times 10^{-2} \times \varepsilon_r d^2 )}{N} \]

\[ = (9 \times 10^9 Q_1 Q_2 / \varepsilon_r d^2) \text{ N} \ldots.. \text{ in a medium} \]

\[ = (9 \times 10^9 Q_1 Q_2 / d^2) \text{ N} \ldots.. \text{ in air / vacuum.} \]
If \( Q_1, Q_2 = 1 \) coulomb
\( d = 1 \) metre

Then force \( F = 9 \times 10^9 \) newton.

Note: The force will be attractive if the charges are of opposite nature and
the force will be repulsive if the charges are of same nature.

Hence one coulomb\(^*\) of charge may be defined as:

That charge which when placed in free space (or vacuum on air) from an
equal and opposite (similar) charge at a distance of one metre attracts (repel) it
with a force of \( 9 \times 10^9 \) newton.

7.4 Permittivity \( (\varepsilon = \varepsilon_o \varepsilon_r) \)

It is the property of the medium and it plays an important role in electrostatic
phenomenon. Every medium supposed to possess two primitivities.

- absolute permittivity of free space or vacuum (on air) \( \varepsilon_o (<1) \)
- relatively permittivity of dielectric strength or specific inductive capacity
  or capacitivity of the medium \( \varepsilon_r \).

The permittivity or absolute permittivity of the medium
\[ \varepsilon = \varepsilon_o \varepsilon_r \text{ farad / metre} \]
\[ \varepsilon_o = 8.854 \times 10^{-12} \text{ F/m} \]
\[ \varepsilon_r = 1 \text{ for free space or vacuum or air (dimensionless)} \]

The ratio of the electric flux density or displacement, \( D \) to field intensity, \( E \)
at any point is called as the permittivity or absolute permittivity, \( \varepsilon \).
\[ \varepsilon = \frac{D}{E} = \frac{\text{Coloumb / m}^2}{\text{Volt / m}} \quad \text{or} \quad \varepsilon = \varepsilon_o \varepsilon_r \]

7.4.1 Example Problems (Laws of Electro Statics)

Example 1. Two small balls having charges one double the other are placed
at a distance of 0.5 m apart in air. If the repulsive force between the balss is 2.75
newton, determine the charge on each ball.

Solution:

Given Data
Example 1

Determine the force between two charged objects when they are placed at a distance of 0.5 m apart in air.

Solution:

Given data:

\[ Q_1 = Q \]
\[ Q_2 = 2Q \]
\[ d = 0.5 \text{ m} \]
\[ \varepsilon_1 = 1 \]
\[ F = 2.75 \text{ N} \]

The force between two objects can be calculated using the formula:

\[ F = \frac{Q_1 Q_2}{4 \pi \varepsilon_0 \varepsilon_r d^2} \text{ N} \]

Substituting the given values:

\[ 2.75 = \frac{Q_1 \times 2Q}{4\pi \times 8.854 \times 10^{-12} \times (0.5)^2} \]

Solving for \( Q_2 \):

\[ Q_2 = \frac{2.75 \times 4\pi \times 8.854 \times 10^{-12} \times (0.5)^2}{2} \]

\[ = 3.825 \times 10^{-11} \]

\[ Q = 6.184 \mu \text{coulomb} \]
\[ Q_1 = Q = 6.184 \mu \text{C} \]
\[ Q_2 = 2Q = 12.368 \mu \text{C} \]

Example 2

Determine the force between two electrons, when they are placed at a distance of 1 cm apart in air.

Solution:

Given data:

Note: The charge of an electron is \( 1.602 \times 10^{-19} \text{ C} \)

\[ Q_1 = -1.602 \times 10^{-19} \text{ C} \]
\[ Q_2 = -1.602 \times 10^{-19} \text{ C} \]
\[ d = 0.01 \text{ m} \]
\[ \varepsilon_0 = 1 \]

\[ F = ? \]
\[ F = \frac{1.602 \times 10^{-19} \times 1.602 \times 10^{-19}}{4\pi \times 8.854 \times 10^{-12} \times (0.01)^2} = 2.3 \times 10^{-24} \text{ Newtons.} \]

### 7.5 Field Pattern of +ve, -ve, Like and Unlike Charges

The pattern of the lines of force can be obtained by sprinking gypsum crystals on a glass plate placed over the highly charged body.

The direction of lines of force as given by Faraday is that these start from positive charge and end over over the negative charge as shown in Fig.7.3. Further the lines having same direction repel each other while lines of opposite direction attract each other.

![Fig. 7.3 Representation of the lines of force emerging from an isolated positive charge](image1)

(b) Representation of the force of an isolated negative charge

![Fig. 7.3](image2)

Also, the lines of force do not touch each other or cross each other and they are normal to the surface. When the two charges of opposite nature are placed near each other the lines of force attract along their lengths but expand laterally as shown in fig 7.4.

![Fig. 7.4 Representation of the lines of force when two charges of opposite nature are placed near each other](image3)
7.6 Field strength or field intensity or electric intensity (E)

Field strength or electric field intensity at any point within an electrostatic field may be defined in any one of the following three ways.

(i) “The force experienced by a unit charge placed at a point is said to be the electric field strength”. It is represented by the letter \( E \), and is measured in newton/coulomb (N/C)

\[ Q_1 = Q \text{ Coulomb} \]
\[ Q_2 = 1 \text{ Coulomb} \]

The force experienced by the unit charge at a distance of ‘d’ meter is
Electric field strength is a vector quantity, since it is a force having both magnitude as well as direction.

(ii) “It is equal to the lines of the force passing normally through a unit area at that point”.

\[ Q = \text{Charge of a body in coulomb} \]
\[ Q/\varepsilon = \text{lines of force produced by charged body in coulomb.} \]
\[ A = \text{area through which lines of force passing in m}^2. \]

then \[ E = \frac{Q}{A} \text{ newton / coulomb or volt / metre} \]

\[ E = \frac{Q}{\varepsilon \varepsilon_0 A} = \frac{Q/A}{\varepsilon_0 \varepsilon} \quad \text{Since } D = \frac{Q}{A} \]

(iii) “Electric field intensity at any point in an electric field is equal to the potential gradient at that point.

if \[ V \text{ (or } dv \text{)} = \text{potential difference (or fall in potential) between two points in volt.} \]
\[ d \text{ (or } dx \text{)} = \text{distance between two points in metre} \]

then \[ E = \frac{V}{d} \text{ or } \frac{dv}{dx} \text{ voltmeter} \]

\[ E = \frac{dv}{dx} \text{ V/m} \]
7.6.1 Applications of Dielectrics

The most common application of dielectric is as a capacitor to store energy. Capacitors are classified according to the dielectric used in their manufacture. They can be broadly classified under the following categories.

1. Capacitors using vacuum, air or gases as dielectrics.
2. Capacitors using mineral oil as dielectric.
3. Capacitors using a combination solid-liquid dielectric.
4. Capacitors with only solid dielectric like glass, mica etc.

The first type is used in applications where energy loss in the capacitor should be small and the value of the capacitance is also limited. It is essentially used in high frequency circuits like radios and for frequency measuring devices when precision is important.

Oil filled capacitors are used in applications where the capacitance required is large and a fair degree of power loss is tolerated. It is mainly used as static condenser for power factor (PF) improvement of small installations.

Oil impregnated paper capacitors are used to make capacitors of large value and small size. Precision is not important in these applications. They too find application in PF improvement devices and radio circuits on account of their cheapness and versatility.

Mica, a solid dielectric, is used to make standard capacitors for laboratories. Its dielectric constant does not change much with temperature and time. It has high dielectric constant and insulation resistance and low dielectric loss. It is the ideal dielectric known today.

7.7 Capacitance

A capacitor essentially consists of two conducting surfaces separated by an insulating medium called dielectric. The conducting surfaces may be in the form of either circular or rectangular or spherical cylindrical in shape.

Let a battery be connected across two plates of a capacitor through a sensitive galvanometer (or a lamp) and a switch S as shown in Fig 7.7.

Since, the switch is open there will not be any current flow through the circuit. When the switch is closed, then there will be momentary current flow from P to Q through Galvanometer and a battery as shown in Fig 7.7.
The current strength can be seen with the help of Galvanometer. This current is due to the fact that the positive terminal of the battery will attract some of the negatively charged electrons form plate P and move towards the plate Q. So, plate P acquire positive charge and the plate Q acquire negative charge. Hence, potential difference is established between plates P and Q. This transient flow of electrons causes a charging current and develops electric field across plates P and Q and this field grows as the electrons continue to move form plate P and Q. This movement of the electrons ceases when the p.d between plates become equal and opposite to the battery e.m.f.

A clear understanding of the operation of a capacitor may be had by studying the hydraulic analogy shown in Fig 7.8 The capacitor is represented by a chamber separated in to equal sections by an elastic diaphragm representing dielectric. These chambers are connected to a centrifugal pump by means of pipes. The pump represents the battery in an electric circuit, and the valve in one of the pipes represents a switch.
Electrician Technician

When pump rotates, it forces water into one of the chambers and causes the diaphragm to stretch. Water from the other chamber then flows out towards the pump. One of the chambers contain more water than the other, and the diaphragm being stretched, maintains a pressure differential between the chambers. When the diaphragm pressure is equal to the pump pressure, the water will stop flowing, and the chamber may be said to be charged. If the valve is then closed, the diaphragm will maintain the differential of pressure between the sections of the chamber. When the pump is stopped and removed, and the valve is opened, the water will immediately flow from the section which has the higher pressure to the section which has the lower pressure. As soon as the pressures are equal, the flow will cease.

In like manner, if switch S is opened and the battery is removed the potential across the plates remains and the dielectric medium between capacitor plates is under a state of strain and energy will remain in the electric field as shown in fig 7.7(c). If a resistance is shunted across the capacitor plates as shown in Fig., the electrons rush from plate Q to P and the electric field collapses and the energy stored in the electric field will be dissipated as heat in the resistor.
Silent points to be observed are:

(1) The function of the battery is merely to cause the transfer of electrons from plate P to Q and hence create a p.d across the plates. Its function is analogous to that of a hydraulic pump.

(2) There is no continuous flow of current in the circuit which stops when the p.d. across the plates becomes equal as that of battery. In other words the capacitor blocks D.C. but it permits A.C. for details refer A.C. circuits.

Let Q coulomb be the charge which has developed at one of the capacitor plates from the instant of closure of switch S to the instant after the current has ceased to flow and V be the p.d. established across the plates.

The \( V \propto Q \quad \text{or} \quad Q = CV \)

or \( C = Q/V = \text{coulomb} / \text{volt} \).

where \( C \) is a constant called the capacitance of the parallel plates. The capacitance depends on the dimensions of the plates, the distance between the plates and on the type of dielectric.

Hence capacitance may be defined as the property of a capacitor to store electricity.

or

The capacitance of a capacitor may be defined as, the amount of charge required to create a unit potential difference across its plates.

The unit of capacitance is coulomb / volt which is also called a farad (in memory of Michael Faraday).

1 farad = 1 coulomb / 1 volt.

Farad is too big unit for practical purpose, so generally micro farad (\( \mu \text{F} \)) or pico farad (PF or \( \mu \mu \text{F} \)) are generally used, which are equivalent to

1 \( \mu \text{F} = 10^{-6} \) farad

1 PF = 1 \( \mu \mu \text{F} = 10^{-12} \) farad.

### 7.8 Types of Capacitor

The capacitors are manufactured in a wide variety of sizes and styles. Some very low capacity capacitors are merely tiny wefers of metal separated by an insulator, large capacitors may weight several kilograms. The capacitors are usually identified by the dielectric used.
Electrolytic Capacitors: These are either wet or dry type. The wet type capacitors consists of an aluminium anode which is centrally mounted in an aluminium or ceramic or plastic cylinder filled with an electrolytic solution usually ammonium borate which acts as a cathode. When d.c. supply is given to anode and cathode, a very thin film of aluminium oxide $\text{Al}_2\text{O}_3$ is formed on the surface of the anode. The extremely small aluminium oxide acts as the dielectric and the combination becomes a capacitor of very large capacitance for small physical dimensions. For successful operation, such capacitors must always be used with proper polarity, otherwise gas formation within the electrolyte may burst the capacitor.
The dry type capacitor consists of two sheets of aluminium foil as anode and cathode separated by a fine guaze or paper soaked in an electrolyte (ammonia solution or boric acid solution) are rolled up and encased in a waxed card board or plastic tube. Due to their high capacitance such capacitors are used in smoothing circuits in radio work and filter circuits etc.

Mica is one of the best natural insulating materials. Consequently capacitors with mica as dielectric have very low losses and can be made for high voltage ratings 10 kV d.c or so. Their capacitance range is from 1 PF to 0.01 F. Mica capacitors consists of a series of metal foils separated by mica layers. The assembly is rigidly clamped in metal or plastic case. Mica capacitor are used for audio frequency coupling and tuning.

Ceramic capacitors consists of thin ceramic discs coated with metal and copper, terminals are connected to the metal. Ceramic capacitors have the smallest dimensions are compared to other capacitors due to high relative permittivity of the ceramic. They are available in the range of 1 PF to 0.1 µF and upto 1000 V d.c. They have very low power factor and which decreases with increase in frequency. They are used in transistor circuits for short wave work.

Fixed capacitors of both the dry and electrolytic type are manufactured in a wide variety of shapes as shown in Fig. 7.8 the electrolytic capacitors are marked to indicate the correct method of connection in to circuit.

7.8.1 Uses of Capacitors

Variable capacitors are used in electronic circuits whenever it is necessary or desirable to change the capacitance in order to turn the circuit or to change the circuit values. As in the case with any other type of capacitor, the capacitance of a variable capacitor is determined by the number and area of its plates. As shown in fig 7.9, the variable capacitor consists of a set of rotor plates and a set of stator plates.

The stator plates are mounted on a shaft in such a way that they may be rotated and caused to mesh with the stator plates, a thin layer of air exists between the two sets of plates, and there is no electrical connection between them. The capacitance is greatest when the plates are completely meshed.

7.9 Capacitors in Series and Parallel

Fig.7.10 shows three capacitors connected in series. The same charging current must flow through all the three capacitors. If a charging current of 1 ampere flows from time t, the charge on each capacitor is same. i.e.
Q = Q₁ = Q₂ = Q₃ = I₁

let C₁, C₂, C₃ = capacitances of three capacitors.

V₁, V₂, V₃ = p.d’s across three capacitors

V = applied voltage

C = equivalent or total or combined capacitance.

In series combination, charge on all capacitors is same but the p.d’s across each will vary according to their capacitances.

V₁ = \( \frac{Q}{C₁} \)  \( \frac{Q}{C₂} \)  \( \frac{Q}{C₃} \)

V = \( \frac{Q}{C} \)

or V = V₁ + V₂ + V₃

\( \frac{Q}{C} = \frac{Q}{C₁} + \frac{Q}{C₂} + \frac{Q}{C₃} \)

\( \frac{1}{C} = \frac{1}{C₁} + \frac{1}{C₂} + \frac{1}{C₃} \)

In general \( \frac{1}{C} = \frac{1}{C₁} + \frac{1}{C₂} + \ldots + \frac{1}{C₃} \)
Capacitors in Parallel

Fig. shows three capacitors are connected in parallel across a source voltage $V$. The total charge supplied by the source will be shared by each capacitor and it will depend on their capacitances.

\[ Q_1 = C_1 V \]
\[ Q_2 = C_2 V \]
\[ Q_3 = C_3 V \] and
\[ Q = CV \]
\[ Q = Q_1 + Q_2 + Q_3 \]
\[ CV = C_1 V + C_2 V = C_3 V \]
\[ C = C_1 + C_2 + C_3 \]

In general $C = C_1 + C_2 + \ldots + C_n$

It is noteworthy that the formulae for the total capacitance of the capacitors connected in series and parallel are reverse of the formulae for similar resistance circuits.

Capacitors in series parallel combination

Let us consider a series-parallel combined circuit as shown in Fig. 7.12 (a) and its equivalent circuit in Fig. 7.12 (b)

$C_2$ and $C_3$ are in parallel and their equivalent capacitance is $C_7$ as shown in Fig. 7.12 (b).

Therefore $C_7 = C_2 + C_3$
Similarly \( C_8 = C_4 + C_5 + C_6 \)

Equivalent capacitance of the total circuit ‘C’ is

\[
\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_7} + \frac{1}{C_8}
\]

Total charge supplied from the source \( (Q_1 = Q_7 = Q_8 = Q) \)

\[
Q = CV
\]

Therefore \( V_1 = \frac{Q}{C_1} \), \( V_2 = \frac{Q}{C_7} \), \( V_3 = \frac{Q}{C_8} \)

Now the charge on each capacitor

\( Q_1 = Q = C_1 V_1 \)

\( Q_7 = Q = Q_2 + Q_3 \)

\( Q_2 = C_2 V_2 \)

\( Q_3 = C_3 V_3 \)

\( Q_8 = Q = Q_4 + Q_5 + Q_6 \)

\( Q_4 = C_4 V_3 \)

\( Q_5 = C_5 V_3 \) and \( Q_6 = C_6 V_3 \)

7.10 Energy Stored in Capacitor

When a capacitor is being charged, it always involves some expenditure of energy by the charging agency. This energy is stored in the electrostatic field set up in the dielectric medium of the capacitor. On discharging the capacitor, the electrostatic field collapses and the stored energy is released.

When the capacitor is completely uncharged, little work is done in transferring first charge from one plate to another. But further instalments have to be carried against the p.d. already established across the plates by first charge.

If at any instant during charging period the voltage on the capacitor is \( v \) and charge on plate is \( q \), by definition, \( v \) is equal to the work done in shifting one coulomb of charge form one plate to another. If ‘dq’ is the charge next transferred, then the work done is

\[
dW = v \, dq
\]

But \( q = Cv \)

or \( dq = C \, dv \)
Therefore \( dW = Cv \, dv \).

Total work done on a capacitance of \( C \) (farad) to a voltage of \( V \) volt is

\[
W = \int_{0}^{V} dW = \int_{0}^{V} Cv \, dv = C \left[ \frac{v^2}{2} \right]_{0}^{V} = \frac{1}{2} CV^2 \text{ Joule}
\]

Hence the energy stored equals the work \( W \)

\[
E = \frac{1}{2} CV^2 = \frac{Q^2}{2C} \text{ joule}
\]

### Example Problems

**Example 1:** Two capacitors, having capacitances of 10 microfarad and 15 microfarad respectively are connected in series across a 200 V d.c supply. Calculate

(i) The charge on each capacitor

(ii) The p.d. across each capacitor

(iii) The energy stored in each capacitor

**Solution:**

\( C_1 = 10 \times 10^{-6} \text{ F} \)

\( C_2 = 15 \times 10^{-6} \text{ F} \)

\( V = 200 \text{ V} \)

Then \( q = ? \), \( V_1, V_2 = ? \)

\( E_1, E_2 = ? \)

\[
\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{10 \times 10^{-6}} + \frac{1}{15 \times 10^{-6}} = 1.667 \times 10^5
\]

Therefore \( C = 6 \times 10^{-6} \text{ F} \)

(i) Charge on each capacitor

\( Q = CV = 6 \times 10^{-6} \times 200 = 1.2 \text{ millo coulomb ans.} \)
Electrician Technician

(ii) \[ V_1 = \frac{Q}{C_1} = \frac{1.2 \times 10^{-3}}{10 \times 10^{-6}} = 120 \text{ V Ans.} \]

\[ V_2 = \frac{Q}{C_2} = \frac{1.2 \times 10^{-3}}{15 \times 10^{-6}} = 80 \text{ V Ans.} \]

(iii) \[ E_1 = \frac{1}{2} C_1 V_1^2 \]
\[ = \frac{1}{2} \times 10 \times 10^{-6} \times (120)^2 \]

\[ E_2 = \frac{1}{2} C_2 V_2^2 \]
\[ = \frac{1}{2} \times 15 \times 10^{-6} \times (80)^2 \]

**Example 2:** Three capacitors 2 \( \mu \text{F}, 1 \ \mu \text{F} \) and 4 \( \mu \text{F} \) are connected in parallel across a 220 V.d.c supply. Find the equivalent capacitance and the charge on each capacitor.

**Solution:**

Given Data
\[ C_1 = 2 \times 10^{-6} \text{ F} \]
\[ C_2 = 1 \times 10^{-6} \text{ F} \]
\[ C_3 = 4 \times 10^{-6} \text{ F} \]
\[ V = 220 \text{ V} \]

Find \( C = ? \)
\[ Q_1, Q_2, Q_3 = ? \]

Equivalent capacitance
\[ C = C_1 + C_2 + C_3 = 2 \times 10^{-6} + 1 \times 10^{-6} + 4 \times 10^{-6} \]
\[ = 7 \ \mu \text{F Ans.} \]
\[ Q_1 = C_1 V = 2 \times 10^{-6} \times 200 = 400 \ \mu \text{C, Ans.} \]
\[ Q_3 = C_2 V = 1 \times 10^{-6} \times 200 = 200 \ \mu \text{C, Ans.} \]
\[ Q_3 = C_3 \cdot V = 4 \times 10^{-6} \times 200 = 400 \mu C, \text{ Ans.} \]
\[ = 800 \mu C \text{ Ans.} \]

**Key Concepts**
- Concept on charge, positive and negative charges
- Coulombs law
- Connecting capacitors and its application.

**Activities**
- Collect different capacitors and find their values and uses
- Collect the capacitors of different appliances used at your home and learn testing procedure.

**Short Answer Type Questions**
1. What is positive and negative charge?
2. What is permittivity?
3. Define dielectric strength.
4. List various capacitors.
5. What is capacitence?
6. What are the uses of capacitors?
7. What is electric Intensity?

**Long Answer Type Questions**
1. State Coulomb’s law of electrostatics.
2. Explain series combination of capacitors.
3. State the relations of parallel capacitors.

**Project Oriented / On Job Training Questions**
- During OJT / Prepare a list of Equipment, machinery you have come across and note down the types of capacitor and values used in them.