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CHAPTER 11

HEAT

Caloric Theory:

Up to the beginning of the nineteenth century.Heat considered a weightless and invisible fluid called caloric which existed in every material body. Hot bodies were said to contain more caloric than the cold bodies. The caloric theory could explain satisfactorily much process such as heat conduction and mixing of substance in a calorimeter. This concept of heat fluid was refused by count Rumford.

Definition of Heat:

Heat is the form of energy that is transferred from a hot body to a cold body because of difference in temperature between them. It is not the property of the body.

Internal energy:

The internal energy is the sum of all microscopic kinetic and potential energies of the molecules in the body.

Units of heat and relation between them:

I) Joule (J); it is the S.I units of heat.

II) Calorie (cal.); it is the old unit of heat.

III) British thermal unit (B.T.U); it is the unit of heat in British engineering system or F.P.S system

1 cal = 4.18J =4.2J

1 B.T.U = 1055 J

1 B.T.U = 252 cal

Temperature:

The quantitative determination of degree of hotness or coldness is called temperature.

(OR)

Temperature depends upon the average translational kinetic energy of the molecules of a body. It is property that determines the direction of heat flow, because heat flows from higher temperature to lower temperature. It is denoted by "T" and its S.I unit is "Kelvin"

Thermal Equilibrium:

When two bodies at different temperatures are brought in thermal contact with each other, the heat starts flowing from the hot body to the cold body till the temperature of both the bodies becomes same, then they are said to be in Thermal Equilibrium.

Scales of Temperature:

Temperature is measured on three different scales;

1. Celsius(or Centigrade) Scale:

On centigrade scale the lower fixed point (melting point of ice) is taken as 'O ^{0}C', where as the upper fixed point (boiling point of water) is taken as '100 ^{0}C', and the space between the two points is divided into hundred equal parts, each part measures a temperature of '1 ^{0}C',.

2. **Fahrenheit Scale:**

On Fahrenheit scale the lower fixed point (melting point of ice) is taken as '32 ^{0}F' whereas the upper fixed point (boiling point of water) is taken as '212 ^{o}F. The space between the two points is divided into 180 equal parts; each part measures a temperature of '1^{o}F. Each division on centigrade scale is equal to "9/5" divisions on Fahrenheit scale.

3. **Kelvin or Absolute Scale:**

On Kelvin scale the lower fixed point (melting point of ice) is taken as '273K', whereas the upper fixed point (boiling point of water) is taken as '373 K'. The Space between the two points is divided into 100 equal parts, each parts measures a temperature of '1 K'.

Hence each division on centigrade scale in numerically equal to each division on the Kelvin scales.

Conversion Of Scales Of Temperature:

1. $T_F = 1.8T_C + 32$
2. $T_C = \frac{T_F - 32}{1.8}$
3. $T_K = T_C + 273$

Relation among Three Scales Of Temperature:

$$\frac{^0C - 0}{100} = \frac{^0F - 32}{180} = \frac{K - 273}{100}$$

Thermometric Properties:

Property of a substance which changes uniformly with the change of temperature in named thermometric property. For example the volume of a liquid in a vessel the volume of a fixed mass of gas kept at constant pressure, the pressure of a fixed mass of gas maintained at constant volume, electrical resistance of a metal are some of the many measureable physical properties which changes with the change of temperature.

Thermometer:

It is a device used to measure the temperature of any substance its working is based on the thermometric properties.

Thermal Expansion:

Most of the bodies expand on heating. This expansion in size of a body on heating is called thermal expansion. Solids show increase in length, area or in volume, whereas liquids and gases expand in volume.

Reason for Thermal Expansion:

When a body is heated the energy gained by the molecules increases their kinetic energy due to which they vibrate more energetically and with greater amplitude, as a result of which their overall size increases or in other words thermal expansion take place.

Linear Expansion:

Expansion in length of solids on heating is called linear expansion.

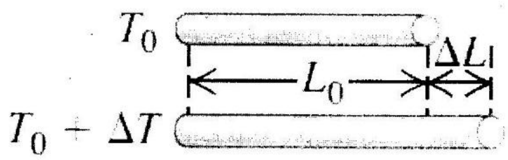
Mathematical Expression for Linear Expansion:

Consider a rod of length "L_o" of uniform area of cross-section. It is heated through a certain temperature ΔT so that its new length becomes L'. It has been observed experimentally that the increase in length ΔL of the rod is directly proportional to the initial length L_o and to the rise in temperature ΔT.

$$i.e. \quad \Delta L \propto L_o \text{ - - - - - - - - } (i)$$

$$\Delta L \propto T \text{ - - - - - - - - } (ii)$$

By combining (i) and (ii)



$$\Delta L \propto L_o \ \Delta T$$

$$\Delta L = \alpha L_o \Delta T$$

Where "α" is the constant of proportionality, it is known as "Coefficient of linear expansion". The above equation may also be written as:

$$\alpha = \frac{\Delta L}{L \ \Delta T}$$

Coefficient of linear expansion may be defined as:

"The increase in the length per unit original length per degree rise in temperature".

Or

"The fractional change in length per degree change in temperature".

Value of "α" depends upon material of the rod. Materials that expand more have high value of "α". The unit of "α" is per degree Celsius ($^oC^{-1}$) or per degree Kelvin (K^{-1}).

Since $\Delta L = L' - L_o$

Where L' is the final length of the rod

But

$$\Delta L = aL_o \ \Delta T$$

$$L' - L_o = aL_o \times \Delta T$$

$$L' = L_o + aL_o \ \Delta T$$

$$L' = L_o(1 + \alpha \Delta T)$$

The above formula gives us final length L' of the rod in the terms of its initial length L_o, Coefficient of linear expansion "α" and the rise in temperature ΔT.

- **Cubical Expansion or Volume Expansion:**

Expansion in volume of solid, liquid or gas on heating is called Cubical Expansion or Volume Expansion.

Mathematical Expression of Cubical Expansion or Volume Expansion:

Consider a body of volume "V_o" whose temperature is change through "ΔT". Experimentally it has been observed that the change in volume "ΔV" is directly proportional to its initial volume "V_o" and to the rise in temperature "ΔT"

$$i.e.\ \Delta V \propto V_o \text{ -------(i)}$$

$$\Delta V \propto \Delta T \text{ ------(ii)}$$

By combining (i) and (ii)

$$\Delta V \propto V_o \times \Delta T$$

$$\Delta V = \beta V_o \times \Delta T$$

Where "β" is the constant of proportionality, known as "Coefficient of volume expansion".

Hence, $$\beta = \frac{\Delta V}{V_o \Delta T}$$

Hence coefficient of volume expansion may be defined as:

"The increase in the volume per unit original volume per degree rise in temperature".

Or

"The Fractional change in volume per degree change in temperature".

Value of "β" depends upon material of the body. The unit of "β" is per degree Celsius ($^oC^{-1}$) or per degree Kelvin (K^{-1}).

Since $$\Delta V = V' - V_o$$

Where V' is the final volume of the body.

$$\Delta V = \beta V_o \Delta T$$

But $$V' - V_o = \beta V_o \Delta T$$

$$V' = V_o + \beta V_o \Delta T$$

$$\boxed{V' = V_0(1 + \beta \Delta T)}$$

The above formula gives us final volume V' of the body in the terms of its initial volume V_o, its coefficient of volume expansion "β" and the rise in temperature "ΔT".

Relation between coefficient of linear and volumetric expansion

$$\beta = 3\alpha$$

Consider a rectangular box of initial length 'l_o', height 'h_o' and width 'w_o' at temperature "T_1". The volume 'V_o' of the box will be.

FIG, Seeinclassleecture

$$V_o = l_o w_o h_o ---------- (i)$$

After heating the box it expends and its dimensions becomes l',h' and w'at temperature (T_2). The final volume of the box will be.

$$V' = l'w'h' ------- (ii)$$

According to the definition of linear expansion, Final length will be:

$$l' = l_o(1 + \alpha\Delta T)$$

Similarly,

$$w' = w_o(1 + \alpha\Delta T)$$

And $h' = h_o(1 + \alpha\Delta T)$

Where "α"the coefficient of linear expansion is put the values in equation (ii)

$$(ii) => V' = l'w'h'$$

Or $$V' = l_o(1 + \alpha\Delta T)w_o(1 + \alpha\Delta T)h_o(1 + \alpha\Delta T)$$

$$V' = l_o w_o h_o(1 + \alpha\Delta T)3$$

Using formula; $(a+b)^3 = a^3+3a^2b+3ab^2+b^3$

Because α is very small so its square and higher powers are neglected.

So, $$V' = V_o[1 + 3(\alpha\Delta T) + 0 + 0]$$

$$V' = V_o[1 + 3\alpha\Delta T]$$

Using equation:

$$V' = V_o(1 + \beta\Delta T);$$

$\beta = coefficient\ of\ volume\ expansion.$

Comparing above two equations:

$$V_o(1 + \beta\Delta T) = V_o[1 + 3\alpha\Delta T]$$

$$1 + \beta\Delta T = 1 + 3\alpha\Delta T$$

$$\boxed{\beta = 3\alpha}$$

Bimetallic Strip or Thermostat:

Definition:

A bimetallic strip is a device used to maintain a steady temperature. Bimetallic strips are used in many devices, for example, thermostats, thermometers and fire alarms etc.

Principle:

Bimetallic strip is a piece of two different metals (or alloys) Length-wise firmly attached together. Since thermal expansion of different materials is different, some expand more than the others, therefore when a bimetallic strip is heated, it bends. The metal which has higher co-efficient of expansion expands more and is on the outer side of the curve whereas the metal which expands less is on the inner side of the curved strip.

Working:

In an electrical heating circuit, the bimetallic strip works as an electric contact breaker. When temperature rises; the bimetallic strip bends and the contact is broken. The current stops to flow. When the temperature falls, the strip contracts and the contact is restored. Hence heating starts again. In this way, a desired temperature is maintained.

Gas Laws:

Boyle's law"

Statement:

For a given mass of a gas and at constant temperature volume is inversely proportional to the pressure.

Mathematical Expression:

If "V" denotes the volume and "P" pressure

Then $$V \propto \frac{1}{P}$$

$$V = (constant)\frac{1}{P}$$

$$PV = Constant$$

Value of the constant depends upon mass and temperature of the gas. For a certain mass and temperature;

$$P_1 V_1 = P_2 V_2$$

- Real gasses obey Boyle's law at low pressure and high temperature.
- Real gasses deviate from Boyle's law at high pressure and low temperature.

Graphical Repetition: *FIG See in class lecture*

Graph between pressure and volume of a Gas at constant temperature is a hyperbolic curve.Graph between "P" and 1/V of gas atConstant temperature is a straight lineRelation between pressure, volume and mass of a gas constant temperature is;

$$\frac{P_1V_1}{m_1} = \frac{P_2V_2}{m_2}$$

Where; m_1= initial mass of the gas

m_2= final mass of the gas

Charle's law:

Statement:

For a given mass and at constant pressure, the volume of a gas is directly proportional to the absolute temperature.

Mathematically:

If "V" and "T" denote the volume and absolute temperature of a gas respectively then;

$$V \propto T$$

$$V = (\text{Constant})\, T$$

$$\frac{V}{T} = Constant$$

Graphical Repetition Of Charle's Law:

Graph between temperature and volume of a gas at Constant pressure is a straight line. At very low temperature, all gases get liquefied, hence Charles' law not obeyed anymore and the graph deviates from straight line.

However, if the straight line is extrapolated below the boiling point of a gas the straight line meets the axis oftemperature at -273^{0}C and the volume of the gas become zero. This would be possible if the Gas was cooled to -273^{0}C without changing into liquid and of course this is not possible. This temperature is called absolute zero. It is the temperature at which volume of any gas Poetically becomes zero.(-273^{0}C = 0K). Absolute zero is also defined as. It is a temperature at which the motions of the molecules of any substance cease to move.

General Gas Equation: (Combination of gas laws)

Suppose for a given mass of a gas the initial parameters are;

Pressure =P_1 Temperature = T_1 and volume = V_1

Now suppose temperature is kept constant and pressure is change such that the final Parameters are:

Pressure =P_2, temperature =T_1 and volume = V_X

FIG See in class lecture

Applying Boyle's law we get;

$$P_1 V_1 = P_2 V_X$$

$$V_X = \frac{P_1 V_1}{P_2} - - - - - (i)$$

Now keep the pressure constant and change the temperature such that the final parameters become;

Pressure=P_2, temperature =T_2 and volume =V_2

Applying charle's law we get;

$$\frac{V_X}{T_1} = \frac{V_2}{T_2}$$

$$V_X = \frac{V_2 T_1}{T_2} ------(ii)$$

Comparing eq (i) and (ii) we get;

$$\frac{P V_1}{P_2} = \frac{V_2 T_1}{T_2}$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} --------(iii)$$

$$\frac{PV}{T} = CONSTANT$$

$$\frac{PV}{T} = R_m$$

For different gases, value of the constant R_m depends upon the number of molecules of the gas.

For 1 mole of the gas, the constant has the same value for all gases and then it is denoted by "R".

Thus for one mole of a gas we have;

$$\frac{PV}{T} = R$$

For "n" moles;

$$\frac{PV}{T} = nR$$

$$PV = nRT$$

This is general gas equation "R" is moral gas constant

R=8.314 J/mol.K

Kinetic Molecular Theory of Gases:

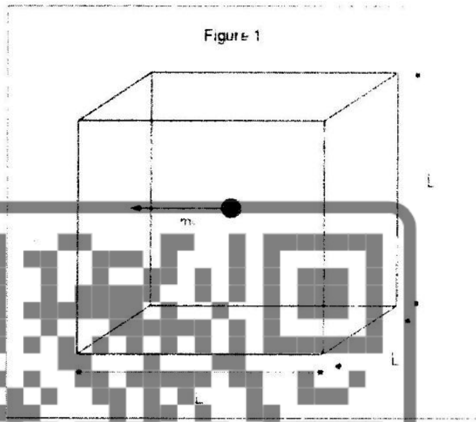
The properties of gas are described by a set of fundamental assumptions which are given as:

1. A gas consists of particles called molecules. Depending on the gas each molecule will consist of an atom or group of atom. All the molecules of a gas in a stable state are considered identical.
2. Any finite volume of a gas consists of very large number of these molecules. This assumption is justified by experiments. At standard conditions there are 3×10^{25} molecules in a cubic meter.
3. The molecules are separated by large distance as compare to their own dimensions. The diameter of a molecule considered as a sphere, is about 3×10^{-10}m.

4. Molecules move in all directions and with various speeds and making elastic collisions with one another and with the walls of a container can be considered perfectly smooth.
5. Molecules exert no forces on one another except during collisions. There for in between collisions with other molecules or with the walls of the container and in the absence of the external forces, they move freely in straight lines.
6. Newtonian mechanics is applicable to the motion of molecules.

Interpretation of the Pressure of Gas on the Basis of Kinetic Molecular Theory of Gases:

Pressure of the gases is due to those collisions which the molecules have with the walls of the container.



Let us consider a container of cubical shape and calculate pressure of the gas on one of its walls which on the left side of the container.

Suppose,

Mass of each molecule of the gas =m

Length of each side of container = l

Total number of molecules = N

Velocity of one of the molecules striking the wall = $\vec{v}$

Component of velocity along x-axis =v_x

For One Molecule

Initial momentum along x-axis = $m(-v_x) = -mv_x$

Momentum after collision with the wall =mv_x

Change in momentum = ΔP $mv_x-(-mv_x)$ =$2mv_x$

Suppose a molecule takes "t" second for each collision. Then distance covered in that time along x-axis is 2l hence;

$$S = vt$$

$$2l = v_x t$$

$$t = \frac{2l}{v_x}$$

Now, the rate of change of momentum is,

$$\frac{\Delta P}{\Delta t} = \frac{2mv_x}{\frac{2l}{v_x}}$$

Or the force exerted by one molecule = $\frac{mv_x^2}{l}$

FIG, See in class lecture

Total force exerted by all the molecules is;

$$F=\frac{mv_{1x}^2}{l}+\frac{mv_{2x}^2}{l}+........+\frac{mv_{nx}^2}{l}$$

$$F=\frac{m}{l}\left(v_{1x}^2+v_{2x}^2+.......+v_{nx}^2\right)$$

Multiplying and dividing by "N"

$$F=\frac{mN}{l}\left(\frac{v_{1x}^2+v_{2x}^2+.......+v_{nx}^2}{N}\right)$$

or

$$F=\frac{mN}{l}\left(\overline{v_x^2}\right)$$

Hence, pressure on the wall is

$$P=F/A$$

$$P=\frac{\frac{mN}{l}\left(\overline{v_x^2}\right)}{l^2}$$

$$P=\frac{mN}{l^3}\left(\overline{v_x^2}\right)$$

$$\frac{mN}{l^3}=\frac{Mass\,of\,the\,gas}{Volume\,of\,the\,gas}$$

$$\frac{mN}{l^3}=Density\,of\,the\,gas$$

$$\frac{mN}{l^3}=\rho$$

Therefore above equation becomes;

$$P=\rho\,\overline{v_x^2}----(i)$$

$\overline{v_x^2}$ = Mean square of x-components of velocity

Now we may write the magnitude of average velocity of particle as;

$$\overline{v^2}=\overline{v_x^2}+\overline{v_y^2}+\overline{v_z^2}----------(ii)$$

And according to KMT gas particles move at random therefore,

$$\overline{v_x^2}=\overline{v_y^2}=\overline{v_z^2}$$

Thereforeeq (ii) becomes:

$$\overline{v^2}=\overline{v_x^2}+\overline{v_x^2}+\overline{v_x^2}$$

$$\overline{v^2}=3\,\overline{v_x^2}$$

$$\overline{v_x^2}=\frac{1}{3}\overline{v^2}$$

Putting value of $\overline{v_x^2}$ in eq (i):

$$\boxed{P = \frac{1}{3}\rho\overline{v^2}}$$

This equation gives the pressure of an ideal gas on the basis of KMT.

<u>Average translational K.E of the molecules of an ideal gas is directly proportional to the absolute temperature of the gas .</u>

Proof:

Pressure of an ideal gas given by;

$$P = \frac{1}{3}\rho\overline{v^2}$$

Where;

$\overline{v^2}$ = Average square speed of molecules

P= density of the molecule

$$\rho = \frac{Mass\ of\ the\ gass}{volume\ of\ the\ gas}$$

$$\rho = \frac{mN}{V}$$

Put the value in above equation we get;

$$P = \frac{1}{3}\frac{mN}{V}\overline{v^2}$$

$$PV = \frac{1}{3}m N\overline{v^2}$$

Where; m=mass of one molecule

N=total No. of molecules

Re-arranging the equation we get;

$$PV = \frac{1}{3}N\left(m\overline{v^2}\right)$$

$$PV = \frac{2}{3}N\left(\frac{1}{2}m\overline{v^2}\right)$$

But, $PV=nRT$; (General gas eq)

Therefore;

$$nRT = \frac{2}{3}N\left(K.E_{av}\right)$$

Where;

F

N=no. of moles of the gas

R= molar gas constant

T= absolute temperature

K.E= Average Translational K.E

But;

$$n = \frac{Mass\,of\,the\,gas}{molecular\,mass}$$

$$n = \frac{mN}{mN_A} = \frac{N}{N_A}$$

Note that molecular mass is the mass of one mole of the gas or the mass of Avogadro number of molecules

Put the value of "n" in eq (i)

$$\frac{N}{N_A} RT = \frac{2}{3} N (K.E_{av})$$

$$\frac{R}{N_A} T = \frac{2}{3} (K.E_{av})$$

Where N_A= Avogadro's number = 6.02 x10^{23} molecules/mole

But

$$\frac{R}{N_A} = k = Boltzmann's\ constant$$

$$kT = \frac{2}{3}(K.E_{av})$$

$$K.E_{av} = \frac{3}{2} kT \text{ --------- } (ii)$$

Therefore;

$$K.E_{av} = (Constant)T \Rightarrow K.E_{av} \propto T$$

<u>Certification of Boyle's Law And Charles's Law:</u>

The pressure of an ideal gas is given by;

$$P = \frac{1}{3}\rho \overline{v^2}$$

Where;

$\overline{v^2}$ = average square speed of molecules

P= density of the gas

P=Pressure of the gas

$$p = \frac{Mass\,of\,the\,gas}{Volume\,of\,the\,gas}$$

$$p = \frac{mN}{V} = \frac{Mass\,of\,the\,gas}{Volume\,of\,the\,gas}$$

Therefore;

$$P = \frac{1}{3}\frac{mN}{V}\overline{v^2}$$

$$PV = \frac{1}{3}mN\overline{v^2}$$

Multiplying and dividing by 2 on R.H.S

$$PV = \frac{1}{3}N\left(m\overline{v^2}\right)$$

$$PV = \frac{2}{3}N\left(\frac{1}{2}m\overline{v^2}\right)$$

But, $K.E_{av} = \frac{3}{2}kT$

Therefore;

$$PV = \frac{2}{3}N\left(\frac{3}{2}kT\right)$$

Therefore;

PV=NkT-------------------(*i*)

Where N = Total no. of molecules

K = Boltzmann's constant

T = Absolute Temperature

For Boyle's Law:

It is clear that for a given mass of a gas at constant temperature;

PV=Constant

This is Boyle's law

For Charle's Law:

As proved in eq (i)

PV=NkT

$$\frac{V}{T} = \frac{Nk}{P}$$

It is clear that for given mass of a gas at constant pressure;

$$\frac{V}{T} = Constant$$

This is Charles's Law

Root Mean Square Velocity:

It is square root of the average square speed of molecules of a gas.

i.e $v_{rms} = \sqrt{\overline{v^2}}$

Relation between Root Mean Square Speed and Absolute Temperature Of a Gas:

$$K.E_{av} = \frac{3}{2}kT$$

$$\frac{1}{2}m\,\overline{v^2} = \frac{3}{2}kT$$

$$\overline{v^2} = \frac{3kT}{m}$$

$$\sqrt{\overline{v^2}} = \sqrt{\frac{3kT}{m}}$$

$$v_{rms} = \sqrt{\frac{3kT}{m}}$$

Relation Between V_{rms} and Pressure Of Gas:

$$P = \frac{1}{3}\rho\overline{v^2}$$

As; $\frac{3P}{\rho} = \overline{v^2}$

$$\sqrt{\overline{v^2}} = \sqrt{\frac{3P}{\rho}}$$

Boltzmann's Constant (K):

It is the value of gas constant per molecule i.e

$$k = \frac{R}{N_A} = \frac{8.314\frac{j}{mol.K}}{6.02\times10^{23}\,molecules/mol}$$

$$k = 1.380\times10^{-23}\,j/molecules.K$$

Heat Capacity(C):

Amount of heat required to raise the temperature of a body to unit degree is called "Heat Capacity".

Formula:

ΔQ=Amount of heat absorbed by the body.

ΔT=Change (increase) in temperature

Then

$$\Delta Q \propto \Delta T$$

$$\Delta Q = C\Delta T$$

Where, C is the constant of proportionality. It is known as"Heat Capacity".

$$C = \frac{\Delta Q}{\Delta T}$$

Unit: it unit is JK^{-1} or j^0C^{-1}

Specific Heat Capacity:

Amount of heat required to raise the temperature of a unit mass of a substance through unit degree of temperature (1^0C or1K), is called "Specific Heat".

Formula:

ΔQ= Amount of heat absorbed by the body.
ΔT= Change (increase) in temperature.
M= Mass of substance
Then

$$\Delta Q \propto \Delta T ---------(i)$$
$$\Delta Q \propto m ---------(ii)$$

Combining eq (i) and (ii)

$$\Delta Q \propto m\,\Delta T$$
$$\Delta Q = cm\Delta T$$

Where, "C" is the constant of proportionality.It is known as "Specific" heat Capacity" of a body.

$$c = \frac{\Delta Q}{m\Delta T}$$

Unit: its unit is $JKg^{-1}K^{=1}$ Or $JKg^{-1}\,{}^{0}C^{-1}$

Molar Specific Heat:

Amount of heat required to raise the temperature of one mole of a substance through one Kelvin (or $1\,^{o}C$) of temperature, is called molar specific heat.

Formula:

ΔQ=Amount of heat absorbed by the body.
ΔT= Change (increase) in temperature.
n= number of moles of a substance

$$\Delta Q \propto \Delta T -------(i)$$

Then

$$\Delta Q \propto n --------(ii)$$
$$\Delta Q \propto n\Delta T$$
$$\Delta Q = C\,n\Delta T$$

Where, "C" is the constant of Proportionality. It is known as "Molar Specific heat capacity" of a substance.

$$C = \frac{\Delta Q}{n\Delta T}$$

Unit: its unit is J $mole^{-1}K^{-1}$ Or $Jmol^{-1}\,{}^{O}C^{-1}$

Types of Molar Specific Heat Of Gases:

The molar specific heat of a gas depends whether or not the gas allowed to expand.
They are:

i. Molar specific heat at constant pressure; (Cp)
ii. Molar specific heat at constant pressure; (Cv)

Relation Between Specific Heat (c) and Molar Specific Heat (C).

Using definition

$$c = \frac{\Delta Q}{m\Delta T} \text{ --------- } (i)$$

$$c = \frac{\Delta Q}{n\Delta T} \text{ --------- } (ii)$$

And

Where, n=no of moles

$$n = \frac{m}{M} = \frac{mass\,in\,gass}{Molecular mass}$$

So, eq (ii)

$$C = \frac{\Delta Q}{\left(\frac{m}{M}\right)\Delta T}$$

$$C = \frac{M\Delta Q}{m\Delta T}$$

$$C = M\left(\frac{\Delta Q}{m\Delta T}\right)$$

Using eq (i)

$$c = \frac{\Delta Q}{m\Delta T}$$

$$C = Mc$$

$$Or \quad C = cM$$

Molar specific heat = (Molecular mass) x (Specific Heat Capacity)

From above equation; Molar Specific heat is defined as, "Product of the molecular mass and specific heat capacity of a substance is called molar specific heat."

Cp-Cv=R

Proof:

Consider two isotherms (A graph between P and V at constant temperature is called an isotherm) at temperatures "T_1" and "T_2" ($T_2 > T_1$) since internal energy depends upon temperature, it changes when there isa change in temperature. Hence each isotherm represents constant internal energy. If the gas is heated from T1 to T2 along path "a c" it'svolume will remain constant, similarly if the same gas is heated along path "a b" from temperature Ti to T2, it's pressure remains constant. Since change in internal energy is independent of path. Therefore, change in internal energy of gas will be equal whatever path is followed between these two isotherms. We know that at constant volume (Isochoric process) no work is done therefore,

$$\Delta W = 0$$

FIG See in class lecture

Applying first law of thermodynamics we get

$$\Delta Q_v = \Delta W + \Delta U$$

$$\Delta Q_v = \Delta U \quad (since\,\Delta W = 0)$$

Hence, heat is supplied at constant volume it is totally used to change the internal energy ΔU of the system. If "n" is the number of moles of the gas and Cv represents it's molar specific heat at constant volume then the amount of heat supplied to the system at constant volume is given by:

$$\Delta Q_v = nC_v\Delta T$$

$$but\,\Delta Q_v = \Delta U$$

$$\Delta U = nC_V\Delta T ------------(i)$$

When a gas is heated under constant pressure (isobaric process) along path "a b", there will be some work done by the system. Work done by the system at constant pressure is given by:

$$\Delta W = P\Delta V ------------(ii)$$

Where, V is the change in volume of the gas. In case heat supplied is partially used to raise the temperature (or internal energy and partially to do work. Heat is supplied at constant pressure is given by as.

$$\Delta Q_p = nC_p\Delta T ---------(iii)$$

According to first law of thermodynamics

$$\Delta Q_p = \Delta W + \Delta U$$

The change in internal energy in both cases will be' equal because the gas is heated in both cases from the temperature Ti to T2herefore, from equations (i), (ii) and (iii) we get;

$$nC_p\Delta T = P\Delta V + nC_V\Delta T --------(iv)$$

For initial state of gas:

$$PV_1 = nRT_1$$

Similarly for final state (after heating the gas at constant pressure) we have:

$$PV_2 = nRT_2$$

The change in state of the gas is given by

$$PV_2 - PV_1 = nRT_2 - nRT_1$$

$$P(V_2 - V_1) = nR(T_2 - T_1)$$

$$or\,P\Delta V = nR\Delta T$$

Substituting this expression in equation (iv) we get.

$$nC_p\Delta T = nR\Delta T + nC_v\Delta T$$

$$nC_p\Delta T - nC_v\Delta T = nR\Delta T$$

$$(C_p - C_v) =$$

$$C_p - C_v = R$$

The above relation shows that Cp>C and the difference between the two molar specific heatsof a gas is equal to universal gas constant R.

Molar Heat Capacities For a Mono-Atomic Gas:

C_v= 3/2 R, C_p = 5/2R and C_p 5/3Cv

Proof:

For this, consider "n" moles of a mono-atomic gas at constant volume. The amount of heat supplied to the system is completely used to increase the internal energy of the gas i.e. to increase the translational K.E of "nNA" number of molecules.

Mathematically;

$$\Delta Q_V = \Delta U$$
$$\Delta Q_V = N(\Delta K.E_{(T)})$$
$$\Delta Q_V = nN_A(\Delta K.E_{(T)})$$
$$nC_V\Delta T = nN_A(3/2K\Delta T)$$
$$C_V = 3/2(N_AK)$$
$$C_V = 3/2R -------(i)$$

Substituting=8.313J/mol.k

Cv = 3/2 (8.313)

Cv = 12.46 j/mol.k

Similarly,

According to the relation between "Cp" and Cv" of ideal gas,

Cp-Cv = R

Putting Cv= 3/2 R

Cp -3/2 R = R

C_p = R + 3/2R

Cp = (2R+3R)/2

C_p=5/2R------------- (ii)

Substituting R= 8.3 13 J/mol.k

C_p = 5(8.313)/2

C_p = 20.78 J/mole.k

$Eq1 =>$ C=3/2R

2/3C=R ------------- (iii)

$Eq2 =>$ C_p=5/2R

2/5C_p = R------------- (iv)

Comparing eq (iii) and (iv)

2/3Cv = 2/5C_p

C_p =5/3C_v-------------------- Proved

Thermodynamics:

"The branch of physics deals with the temperature dependent properties of matter and change of states is called thermodynamics". The study of thermodynamics also gives an idea about the transformation of heat energy and mechanical energy.

Law of Thermodynamics:

The basic principles and techniques concern with the transformation of heat energy into mechanical energy or vice versa, are known as "Laws of thermodynamics".

Thermodynamic Equilibrium:

If the thermodynamic co-ordinates (pressure, volume, temperature, internal energy and entropy etc) of a system doesnot change even for an infinite interval of time, the system is said to be in thermodynamic equilibrium.

First Law of Thermodynamics:

This law is based on the experimental research done by the "ROWLAND" and "MAYER" in 1842 and "JOULE" and "HELMHOLTZ" in 1847. This law basically explains the conservation of energy in respect of transformation of heat energy and mechanical energy.

This is Law States,

"When heat is transferred into mechanical energy or vice versa, the total amount of energy remains constant".

Explanation:

Suppose that the amount of heat "ΔQ" is added to a system which increases the internal energy of the system by an amount, "ΔU" and also helps the system to do some useful work, "ΔW" according to first law of thermodynamics, the conservation of energy during thermodynamic change can be written as,

$$\Delta Q = \Delta U + \Delta W$$

This equation is commonly called equation of first law of thermodynamics. It states, "The sum of internal energy and work done by the system is equal to the supplied energy".

Note: "ΔQ" is positive when heat enters the system and negative when it leaves the system.

"ΔW" is positive when work is done by the system and negative when it is done on the system.

Application of First Law of Thermodynamics:

Isobaric Process:

"A thermodynamic system, in which pressure is kept constant during the processing, is called an Isobaric Process".

Technique of the Process:

To achieve an isobaric process, a gas enclosed in a vessel having a movable piston at upper end.

Explanation of the Process:

Consider a gas as working substance and enclosed within a vessel at volume "V_1" and temperature "T_1".

Let the Pressure on the piston of vessel is kept constant. When "ΔQ" amount of heat is supplied to the system, some part of it used in increasing the K.E of molecules and rest of heat is utilized in doing work. Thus with supply of heat, the gas will expand and its final parameters becomes "V_2" and "T_2" respectively.

During an isobaric process the gas will perform some useful work against the constant Pressure

The magnitude of such a work is given by. *FIG See in Class Lecture*

$$\Delta W = F \times d$$
$$\Delta W = PA \times d$$
$$\Delta W = P(Ad)$$
$$\Delta W = P\Delta V$$
$$\Delta W = P(V_2 - V_1)$$

Application of first law of thermodynamics:

By the equation of first law of thermodynamics,

$$\Delta Q = \Delta U + \Delta W$$

Putting

$$\Delta W = P(V_2 - V_1)$$
$$\Delta Q = \Delta U + P(V_2 - V_1)$$

This expression shows the modified from of first law of thermodynamics in case of an "Isobaric process".

P-V-Diagram of an isobaric Process:

The P-V-Diagram of an isobaric process will describe a horizontal straight line.

Isochoric Process;

"A thermodynamic process in which maximum internal energy during process is called an isochoric process"

Technique of the process:

To achieve an isochoric process, the piston of vessel is kept fixed at the initial position. For this we increase the external pressure on the piston with the supply of heat energy.

Explanation of the process:

Consider a gas as working substance and enclosed in a vessel in a pressure "P_1" and temperature "T_1'

Let the volume of the gas is kept constant. When "ΔQ" heat is supplied to the system, it is directly used in increasing the molecular kinetic energy of the gas and thus the molecular impact with the surface of piston increases. To balance the increasing intermolecular forces we increase the external pressure up to the limit so that volume of the gas remains constant. After this process, the final parameters of the gas will become, "P_2"and "T_2".

FIG See in class lecture

During an isochoric process, the displacement of the piston against the external pressure remains zero and thus no work is supposed to be done by gas against the external pressure i.e.

$$\Delta W = 0$$

Application of first law of thermodynamics:

From the equation of first law f thermodynamics,

$$\Delta Q = \Delta U + \Delta W$$

Putting

$$\Delta W = 0$$

$$\Delta Q = \Delta U$$

i.e. in an isochoric process, whole supplied heat is utilized in increasing the internal energy of the working substance.

P-V-Diagram of an isochoric Process:

The P-V-Diagram of an isochoric process will describe a vertical straight line.

Isothermal Process:

"A thermodynamic process, in which temperature of working substance is kept constant throughout the process, is called an isothermal process".

Technique of the Process:

To perform an isothermal process, the working substance is filled into a vessel of insulated walls and a conducting base. For processing, this vessel is placed on a heat reservoir of same initial temperature as that of gas.

Explanation:-

Consider a gas as working substance in a vessel having insulated walls and a conducting base.

Let the initial parameter of the gas are "P_1","V_1"and "T_1". The vessel is placed on a heat reservoir at "T_1"when the pressure on the piston is decreased to "P_2" the gas will expand and its volume is increased by"V_2". Due to expansion the gas will cool down and thus some heat will be conducted into the gas through conduction base until unless the temperature of gas is maintained to "T_1".

FIG , See in class lecture

Condition of Process;

During an isothermal process, the initial and final internal energy of the gas equals the other and thus, the change of internal energy of the system will remain zero.

i.e. $\Delta U = 0$

Application of first law of thermodynamics:

From the equation of first law of thermodynamics,

$$\Delta Q = \Delta U + \Delta W$$

Putting

$$\Delta U = 0$$

$$\Delta Q = \Delta W$$

The amount of heat entered into the system will be equal during isothermal expansion.

P-V-Diagram:

The P-V-Diagram of an isothermal process will describe a curve, called isotherm curve. This curve follows the statements of Boyle's law. Hence, the equation of Boyle's law, PV=constant Holds true in case of an isothermal process.

Adiabatic Process:

"A thermodynamic process, in which no heat will enter or reject out of the system, is called an adiabatic process'.

Technique of the process;

To perform an adiabatic process, the working substance is filled into a vessel of insulated walls and conducting base. For processing this vessel is placed on a heat insulator.

Explanation:

Consider a gas as a working substance in a vessel of insulated walls and a conducting base. For Achieved an adiabatic process the vessel is placed on a heat insulator. Let the initial parameters of the gas are P_1 V_1 and T_1.

When the pressure is decreased to "P_2" the gas will expand and its volume increase by 'V_2" while this adiabatic expansion, the gas will cool down and its temperature is decreased to "T_2".

Condition of the Process:

As no heat will enter or eject out of the system, therefore, the change of heat for the system will remain zero i.e. $\Delta Q = 0$

Application of the Process:

From the equation of first law of thermodynamics,

$$\Delta Q = \Delta U + \Delta U$$

$$\Delta Q = 0$$

Putting

$$0 = \Delta U + \Delta W$$

$$\Delta W = \Delta U$$

$$OR$$

$$-\Delta W = \Delta U$$

This expresses the first law of thermodynamics in case of an adiabatic process. This shows that the work done by the gas is equal to its own loss of internal energy. And work done on the gas is equal to gain internal energy,

P-V Diagram:

The P-V diagram for an adiabatic process will describe a steep curve, called adiabatic curve. The equation PV= constant holds true for such a curve. Where, "y" is called adiabatic constant and equal to the ratio of "C_p" and C_v".

i.e. $\gamma = C_p / C_v$

Second law of thermodynamics:

The second law of thermodynamics is based on two fundamental principles formulated by CLASUSIUS and LORD KELVIN to explain the processing of a COLD ENGINE and HEAT ENGINE.

i. KELVIN'S STATEMENT:

In 1851, Lord Kelvin suggested a basic principle about the working of a heat engine.

According to the Lord Kelvin's ideology, "It is impossible to operate a heat engine in a cyclical process to cconvert heat entirely into work, with no other change taking place".

This ideology leads towards the operation of a perfect heat engine which states,

"It is impossible to construct a perfect heat engine which may convert all the supplied heat into useful work".

The Kelvin's statement can be expressed can be expressed by the following schematic diagram.

FIG, See in class lecture

ii. CLAUSIUS STATEMENT:

In 1850, clausius expressed a basic principle about the working of a COLD ENGINE. He concluded that, "It is impossible to cause heat to flow from a cold body to hot body without the expenditure of energy."

The clausius statement can be expressed by the following schematic diagram.

FIG, See in class lecture

Kelvin's and Clausius Statements are equivalent to each other:

Proof:

We can prove that both statements are equivalent by showing that either of these statements is supposed to be false. Suppose that Kelvin's statement is false, that we could have engine with one hundred percent efficiency, that takes heat from a source and convert it completely into work. If we connect this perfect heat engine to a refrigerator, we can take heat from hot body and convert completely to work this work can be used to operator refrigerator, which convey heat from cold body to hot body without expenditure of work, which is contrary to clausius statement.

FIG, See in class lecture

CARNOT ENGINE:

In 1824, a French scientist, SADI CARNOT has proposed an ideology of heat engine which is very close to an IDEAL HEAT ENGINE, as it has maximum theoretical efficiency than rest of all the HEAT ENGINE, but never be 100% infect the heat engine designed by the Carnot was free from heat losses mainly appear due to FRICTION and CONDUCTION. *FIG, See in class lecture*

Construction:

A Carnot engine consists of a CYLINDER and a PISTON. The walls of the cylinder and piston are made of insulated material, but base of cylinder is kept conductor. An ideal gas is filled into the cylinder as working substance.

F

Working: (Cycle of Carnot Engine)

The operating cycle of Carnot's engine consists of four steps, called carnot cycle.

FIG, See in class lecture

Process #1 (Isothermal Expansion):

It expresses an isothermal expansion. During this process, the pressure is decreased from "P_1" to "P_2" and thus ideal gas will expand from "V_1" to the new volume "V_2". During process the gas will cool down and hence some heat, say "Q_1" will be entered into the system of gas to maintain its temperature up to initial temperature,"T_1". Hence, $P_2<P_1$, $V_2>V_1$, T_1 (final) $=T_1$ (initial)

Process #2 (Adiabatic Expansion):

It expresses an adiabatic expansion. During this process, applied pressure is further decreased from "P_1"to "P_2" to "P_3". So that ideal gas with further expand to "V_3" from "V_2". During adiabatic expansion, ideal gas cools down to a lower temperature of "T_2". Hence $P_3<P_2$, $V_3>V_2$ and T_2 (final) $<T_1$ (initial)

Process #3 (Isothermal Compression):

It expresses an isothermal compression. During this process, the applied pressure is increased by "P_4" from "P_3" and thus the volume of gas will heat up to a higher temperature and hence some heat, say"Q2" will be rejected out from the system to maintain its temperature up to "T_2". Hence $P_4>P_3$, $V_4<V_3$, T_2(final) = T_2(initial)

Process #4 (Adiabatic Compression):

It expresses an adiabatic compression. During this process, the applied pressure is further increased from "P_4" to initial pressure"P_1". The ideal gas is thus compressed to initial volume of"V_1". During adiabatic compression, ideal gas will heat up at a temperature of "T_1". Hence , $P_1>P_4$, $V_1<V_4$, T_1(final)$>T_2$(initial)

After completing process #4, ideal gas will return back to its initial parameters and hence, a cycle of Carnot engine is said to be done by the ideal gas.

Derivation for the Theoretical Efficiency of Carnot Engine:

We know that the ratio of output of an engine will describe its EFFICIENCY. It is symbolized by "E". Its magnitude is measured by 'percentage (%)'.

$$Efficiency = \frac{Output}{Input}$$

$$or \qquad Efficiency = \frac{Work\ done}{Heat\ supplied\ from\ hot\ body}$$

$$Efficiency = \frac{\Delta W}{Q_1} \qquad \therefore \Delta W = Q_1 - Q_2$$

$$E = \frac{Q_1 - Q_2}{Q_1}$$

$$E = \frac{Q_1}{Q_1} - \frac{Q_1}{Q_1}$$

$$E = 1 - \frac{Q_2}{Q_1} \qquad where, Q_1 > Q_2$$

This expression represents theoretical efficiency of Carnot engine interm of heat of hot reservoir and cold reservoir.

If "T_1" and "T_2"be the temperature related to "Q_1" and "Q_2" heat respectively, then the above expression interm of temperature can be written as.

$$E = 1 - \frac{T_2}{T_1}$$

Where, $T_1 > T_2$

According to the equation of theoretical efficiency of Carnot engine, if less be the ratio of heats or ratio of temperatures, more efficiency heat engine can be made.

P-V Diagram of Cannot Cycle:

FIG, See in class lecture

Noted That:

i. If T1=T2 or Q1=Q2, then E=0
ii. If T_2/T_1 .1 or $Q_2/Q_1>1$, then theoretical efficiency of Carnot engine be discussed.
iii. If $T_2/T_1 = 1$ or $Q_2/Q_1=1$ then theoretical efficiency of Carnot engine becomes zero.
iv. If $T_2/T_1=0$ or $Q_2/Q_1=0$ then theoretical efficiency of Carnot engine becomes 100%. Infect, to attain such a result the value of "Q_2" or "T_2" should be equal to zero and when we do such an operation, we may not able to completer the cycle of Carnot engine.

It means, T2/T1=0 or Q2/Q1=0 and Hence, E=100%

So, one can say that theoretical efficiency of Carnot engine never becomes 100% even is it an ideal engine.

Entropy:

"Entropy is a measure of molecular disorder."

Or

"Entropy is a measure of unavailability of energy."

- In any thermodynamic process, entropy either increases or remains constant.

If ΔQ is the amount of heat supplied to a system or removed from a thermodynamic system at constant absoluteTemperature "T" then the change in entropy ΔS is given by;

$$\Delta S = \Delta Q / T$$

Change in entropy is positive when heat enters the system but if heat is removed from the system then it is negative.The unit of entropy is J/K.

Second Law of Thermodynamics In Terms Of Entropy;

Entropy in terms of second law of thermodynamics can be stated as;

"When an isolated system undergoes a thermodynamic change, the entropy of the system either remains constant or increases."

Entropy in a Reversible Process:

By using theorem we may write as,

$$1-\frac{Q_2}{Q_1}=1-\frac{T_2}{T_1}$$

$$\frac{Q_2}{Q_1}=\frac{T_2}{T_1}$$

$$\frac{Q_2}{T_2}=\frac{Q_1}{T_1}$$

It means that the ratio between heat and their respective temperature always remains constant during the whole process. So in general if "Q" be the amount of heat absorbed at a temperature of

"T" in going from the adiabatic "A" to adiabatic "B" then from the above results we may write as;

$$Q/T = Constant$$

As, we know that the constant term in an adiabatic process called entropy an denoted by "S" thus;

$$\Delta S = \Delta Q/T$$

This equation shows the second law of thermodynamics in term of entropy. It should be noted here that "ΔQ" is positive when heat is added and negative when heat is removed from the system.

The Change Of Entropy In Irreversible Process:

Consider a simple irreversible cycle in which "Q_1" heat is absorbed at a temperature "T_1" and "Q_2" heat is rejected at temperature "T_2" then net change in entropy $=\frac{Q_1}{T_1}-\frac{Q_2}{T_2}$ since,

$\frac{Q_1}{T_1}>\frac{Q_2}{T_2}$, therefore, $\Delta S>0$

Net change in entropy > 0 i.e. positive one. So we observe that in an irreversible cycle there is always a net gain of entropy.

- As we know that the net change in entropy is called "Entropy change of universe". So from the above we conclude that in an irreversible process there is always increase in entropy of universe. Thus the second law of thermodynamic expressed in term of "principle of increase of entropy as".

"The entropy of the universe increase during an irreversible process".

Also, "The Entropy of the universe remains constant during reversible process".

CHAPTER 11

IMPORTANT SCIENTIFIC REASONS

Q.1 Why is the earth not in thermal equilibrium with the sun?

Ans: The earth is not in thermal equilibrium with the sun, because the earth is being warmed by the absorbed radiant energy, it is also loosing heat in various ways. Moreover they are not in perfect thermal contact with each other.

Q.2 It is observed that when a mercury-in-glass thermometer is put in a flame, the column of mercury first descends and then rises. Explain?

Ans: When a mercury-in-glass thermometer is put in a flame, the glass bulb expands first, so the column of mercury descends. But no sooner the heat reaches the mercury in the bulb, it expands, this expansion is greater than that of the glass bulb. So, now the mercury rises in the column.

Q.3 Is it possible to cool a room by keeping the refrigerator door open?
(OR) What happens to the temperature of a room in which an air conditioner is left running on a table in the middle of the room?

Ans. If the door of a refrigerator is left open (*Or If an air conditioner is left running in the middle of a room*), the temperature of room cannot be decreased or it cannot cool. Whatever heat is removed from the air directly in front of the open refrigerator (*Air conditioner*) is deposited directly back into the room at the rare of the unit. In this way the temperature will increased a bit due to the heat exhausted by the running compressor of the refrigerator.

Q.4 When a sealed thermos bottle full of hot coffee is shaken, what are the changes, if any in:
a) the temperature of the coffee b) the internal energy of the coffee

Ans. a) The temperature of the coffee increases due to shaking.
b) The internal energy of the coffee increases. In fact, the work done in shaking the coffee appears as increase in internal energy. Hence the temperature of the coffee increases. (Due to friction of the walls of the flask.)

Q.5 When a block with a hole in it is heated, why does not the material around the hole expand into the hole and make it small?

Ans. Thermal expansion of homogeneous substances causes increase in all directions with the same linear thermal expansion coefficient. This increase in all directions causes an effective magnification of an object. So heating the block, it expands in all direction and causes a little change in shape of the hole, as see in the experiments.

Q.6 Why the efficiency of Carnot engine less than 100%?

Ans. Formula for efficiency of Carnot engine is given by: Efficiency $\eta = \left(1 - \frac{T_2}{T_1}\right) \times 100$

it is clear from the formula that if the cold reservoir is at absolute zero temperature (T_2=0K) only then the efficiency can be 100%. Since such reservoir is not available. So maximum efficiency is always less than 100%. In most practical cases the cold Reservoir is near room temperature.

The greater is the difference between the temperatures of a hot body and cold body the engine will be more efficient. However the ratio (T_2 / T_1) cannot be zero so the engine become 100% efficient .Further

I

(T_2 / T_1) is always something less than one but more than "0" so in practice there can be not be any engine 100% efficient.

Q.8 Why specific heat at constant pressure is greater than specific heat at constant volume ($C_P > C_V$)?

Ans. When heat is supplied to a gas at constant volume it is used in increasing its translational Kinetic energy and hence temperature, no internal work is done to expand the gas (i.e . $\Delta W=0$). But when heat is supplied to a gas at constant pressure some Part of heat is used in doing internal work to raise the piston up. Some of the heat energy Used to increase internal energy and hence temperature. Therefore for equal rise in temperature More heat is required at constant pressure than at constant volume .So molar specific at constant Pressure is greater than molar specific heat at constant volume ($C_P > C_V$).

MULTIPLE CHOICE QUESTIONS
From Past Papers

2001

Q1(a)(i)The pressure exerted by the gas molecules on the walls of a vessel increases if the:
* Temperature of the gas decreases
* Velocity of the molecules of the gas decreases
* Collision of the molecules of the gas with its walls increases
* None of the above happens

Q1(a)(ii)The net change in entropy of a system in a natural process is:
* Positive
* Negative
* Zero
* Infinite

Q1(a)(iii)Which of the following statements is true:
* Heat can be converted completely into work
* Work can be converted completely into heat
* Both work and heat are inter-convertible
* Neither heat nor work is inter-convertible

Q2(a)(i) The K.E of the molecules of an ideal gas at absolute zero temperature will be:
* Infinite
* Zero
* Very high
* Below Zero

Q2(a)(ii)In an isothermal process, the internal energy of the system:
* Remains the same
* Increases
* Decreases
* None of them happens

Q2(a)(iii)Which of the following statements is true:
* High pressure and low temperature
* Low pressure and high temperature
* High pressure and high temperature
* none of these

2002 (Pre Engineering)

Q1(a)(i) Choose the correct Statement:
* The product of P and T is constant if the volume is constant
* The ratio of P and V is constant if the temperature is constant
* The product of P and V is constant if the temperature is constant
* The product of V and T is constant if the pressure kept constant

Q1(a)(ii) The S.I unit of heat:
* Joule
* Calorie
* Centigrade
* Fahrenheit

Q1(a)(iii) Zero on the Celsius is equal to:
* 273 K
* 32 K
* 100 K
* 212 K

Q2(a)(i) The internal energy of a system depends on:

* Pressure * Volume * Temperature * Entropy

Q2(a)(ii) The entropy of the universe:

* Always remains constant * Always decreases
* Either remains constant or increases * Always increases

Q2(a)(iii)The process during which no external work is performed as:

* Isothermal * Isochoric * Isobaric * Adiabatic

2002 (Pre Medical)

Q1(a)(i) The temperature on Fahrenheit scale corresponding the Absolute Zero is:

*32°F * –180°F * –460°F * 212°F

Q1(a)(ii) The pressure exerted by a column of mercury 76cm high at 0°C is called:

* 1 liter * $1cm^3$ *1 atmosphere *$1N/m^2$

Q1(a)(iii) The universal gas constant per molecule in 1 mol is called:

* Planck's constant* Stefan's Constant*Avogadro's constant*Boltzmann's constant

Q2(a)(i) The quantity of heat required for per degree rise in temperature of a body is called:

* Heat of vaporization * Heat of fusion* Specific heat capacity* Heat capacity

Q2(a)(ii) The P-V diagram shown in the figure is for:

* An Isothermal change * An Adiabatic change
* An Isochoric change * None of these

Q2(a)(iii) In Isobaric process the work done is equal to:

* $C_V/n\Delta T$ * $C_P/n\Delta T$ * $R\Delta T/n$ * $nR\Delta T$

2003 (Pre Engineering)

Q1(a)(i) According to Charles' Law:

* PV = constant * V/T = constant * VT = constant * P/V = constant

Q1(a)(iii) The temperature at which centigrade scale is equal to Fahrenheit scale:

* 0° * –32° * –40° * –273°

Q1(a)(i) The quantity of heat required to raise the temperature of 1 gram of a substance through 1°C is known as:

* Specific heat * Latent heat * Calories * Joule

Q2(a)(i) The internal energy is an Isothermal process:

* Increase * decrease * becomes zero * remains the same

Q2(a)(ii) The maximum efficiency of a heat engine is obtained by:

* increasing the temperature of hot and cold body simultaneously, keeping other factors constant
* decreasing the temperature of the sink and increasing the temperature of the source, keeping other factors constant

* decreasing the temperature simultaneously
* None of these

Q2(a)(iii) The change of Entropy is given by:
* $\Delta S = \Delta Q/T$ * $T/\Delta Q$ * $\Delta Q = \Delta Q/\Delta T$ * $\Delta S = \Delta U/T$

2003 (Pre Medical)

Q1(a)(i) 273 Kelvin corresponds to:
* 273°C * –32°F * 0°C * –273°C

Q1(a)(ii) One cubic meter is equal:
* $10^6 cm^3$ * $10^2 cm^3$ * $10^3 cm^3$ * $10^{-3} cm^3$

Q1(a)(iii) If the pressure of a gas is doubled, keeping the temperature constant, the volume of the gas is:
* reduced to one-fourth * doubled
* reduced to one-half of the original volume * increased four times

Q2(a)(i) According to Charles Law:
* VT=constant when the pressure is constant
* V/T=constant when the pressure is constant
* PV=constant when the temperature is constant
* None of these

Q2(a)(ii) If the volume of the system remains constant during a process, it is called:
* Isochoric * Isothermal * Isobaric * Adiabatic

Q2(a)(iii) Boltzmann Constant is equal to:
* RN_A * R/N_A * N_A/R * $\sqrt{R}/N_A$

2004

Q#1 (a) (i) During the Adiabatic change, the pressure and the volume formula of a gas is given by:
* PV = Constant * $P^{\gamma}V$ = Constant * $(PV)^{\gamma}$ = Constant * PV^{γ} = Constant

Q#1 (a) (ii) Centigrade and Fahrenheit scales can never be equal at any temperature.
(False)

Q#1 (a) (iii) The coefficient of linear expansion is ________ times the coefficient of volume expansion. *(1/3)*

Q#2 (a) (i) The unit of specific heat is:
* $J\,Kg^{-1}{}^{o}C^{-1}$ * $J\,Kg^{-1}\,K^{-1}$ * J Kg °C * $J\,Kg^{-1}\,{}^{o}C$

Q#2 (a) (ii) If heat energy is removed from the system, the change in Entropy is positive.
(False)

Q#2 (a) (iii) In an Isobaric process the work done is _________. *(PΔV)*

2005

Q#1 (a) (i) RMS velocity of a gas molecule at absolute zero temperature is:
* 9×10^6 m/sec * 3×10^3 m/sec * 273 m/sec * zero

Q#1 (a) (ii) The value of Boltzmann constant is:
* $3.85\times10^{-23}\ JK^{-1}$ * $2.185\times10^{-12}\ JK^{-1}$ * $1.62\times10^{-22}\ JK^{-1}$ * $1.38\times10^{-23} JK^{-1}$

Q#1 (a) (iii) The heat required to produce a unit change in the temperature of a unit mass of substance is called;
* Heat capacity * Molar heat * Specific heat * Latent heat

Q#2 (a) (i) The difference of molar specific heats at constant pressure and at constant volume per mole is called:
*Molar Heat * Heat constant * Boltzmann constant * Gas constant

Q#2 (a) (ii) A domestic pressure cooker is based on:
* Adiabatic process * Isothermal process * Isobaric process *Isochoric process

Q#2 (a) (iii) The absolute temperature corresponding to 212°F is:
* 485 K * 373 K * 161 K * 100 K

2006

Q#1 (a) (i) In Celsius scale 1°C in magnitude is equal to:
* 32°F * 16°F * 0°F * 1.8°F

Q#1 (a) (ii) The maximum work done can be measured in the process called.
* Isobaric * Isochoric * Isothermal * Adiabatic

Q#1 (a) (iii) The change in disorder of the system is equal to:
* $\Delta S=\frac{\Delta T}{Q}$ * $\Delta S=\frac{\Delta Q}{T}$ * $\Delta S=\frac{\Delta Q}{\Delta T}$ * $\Delta S=\Delta Q.T$

Q#2 (a) (i) One cubic metre volume is equal to:
* $10^2 cm^3$ * $10^3 cm^3$ * $10^6 cm^3$ * $10^{-3} cm^3$

Q#2 (a) (ii) In C.G.S. system one calorie of heat is equal to:
* 11.184J * 2.184J * 3.184J * 4.184J

Q#2 (a) (iii) The efficiency of a Carnot engine is given by:
* $1-\frac{T_1}{T_2}-1$ * $\frac{T_1}{T_2}-1$ * $\frac{T_2}{T_1}-1$ * None of them

2007

Q#1 (a) (i) Fahrenheit and Celsius scales of temperature coincide at
* 0° * 273° * −273° * −40°

Q#1 (a) (ii) The volume of a given gas at constant pressure become zero at:
* 273 K * 273 °C * −273 K * −273 °C

Q#1 (a) (iii) According to the Kinetic Theory of gases the absolute temperature of a perfect gas is:
* Inversely proportional to the K.E. of the molecules
* Independent of the kinetic energy of the molecules
* Equal to the kinetic energy of the molecules
* Directly proportional to the average translational kinetic energy of the molecules.

Q#2 (a) (i) The area of a Carnot cycle represents:
* Useful work * Energy loss due to leakage * Heat rejected * Heat absorbed

Q#2 (a) (ii) Two ends 'A' & 'B' of a rod are at temperatures −10°C and −30 °C. The heat will flow from:

* –30°C to –10°C * will not flow at all * –10°C to –30°C *None of the above

Q#2 (a) (iii) 273 K is equal to:

* 0°F * –32 °F * –273 °F * 32 °F

2008

Q#1 (a) (i) The kinetic energy per mole of a gas is:

* 3/2 kT * 2/3 kT * 3/2 RT * nRT

Q#1 (a) (ii) If the volume of a given mass of a gas is double without changing its temperature, the pressure of the gas is:

* reduced to ½ of the initial value * the same as the initial value

* reduced to ¼ of the initial value * double of the initial value

Q#1 (a) (iii) A bimetallic thermostat works on the principle of:

* linear expansion * bulk expansion

* differential linear expansion * all the these

Q#2 (a) (i) The area bounded by an isothermal and an adiabatic curve in a PV diagram for a heat engine represents:

* heat intake * heat rejected * work done * total kinetic energy

Q#2 (a) (ii) Entropy has been called the degree of disorder because:

* the entropy of the universe remains constant

* the entropy of the universe always increases.

* the entropy of the universe always decreases.

* none of these

Q#2 (a) (iii) A thermodynamic process in which the change in volume of the system is zero tells that:

* the work done by the system is maximum.

* the work done on and by the system is zero.

* the work done on the system is maximum.

* none of the above

2009

Q#1 (a) (i) Heat energy cannot be measured in:

* J * B.T.U. * Kelvin * Calorie

Q#1 (a) (ii) Boyle's Law holds good for an ideal gas in a process called:

* Isobaric * Isochoric * Isothermal * Adiabatic

Q#1 (a) (iii) According to the Second Law of Thermodynamics 100 percent conversion of heat energy into work is:

* Possible * Not possible

* Possible when conditions are ideal

* Possible when conditions are not ideal

Q#2 (a) (i) If no heat flows into or out of a system, the process is called:

* Isobaric * Isothermal * Isochoric * Adiabatic

Q#2 (a) (ii) The molar heat capacities of polyatomic gases as compared to the mono–atomic gases are:

* Greater * Smaller * Equal * Infinite

P

Q#2 (a) (iii) Thermostat is a device used to keep the:

* Temperature constant * Entropy constant * Heat constant * Pressure constant

2010

(vi) Two steam engines A and B have their sources at 600°C and their sinks at 300°C and 200°C respectively:

* They are equally efficient * A is more efficient than B
* B is more efficient than A
* If their sinks are interchanged, their efficiencies will not change

(vii) On Fahrenheit scale the temperature of 50°C will be:

* 40°F * 10°F * 122°F *105°F

2011

(v) Kinetic energy per mole of an ideal gas is:

* 3/2 kT * 2/3 kT * 3/2 RT * 2/3 RT

(viii) In an Adiabatic expansion the internal energy of the gas:

* remains the same * decreases * increases * becomes zero

2012

(i) The maximum work done is possible in this process

*isobaric *isothermal *isochoric *adiabatic

(ii) Absolute zero correspond to this temperature on Fahrenheit scale:

* 32 F * –180 F * –460 F * 212 F

(iii) One kilowatt hour energy is equal to:

* 3.6 x 10^5 J * 36 x 10^5 J *746 watt *6.3 x 10^5 J

2013

(i) The sum of all the energies of the molecules in a substance is called,

* heat energy * temperature * kinetic energy * potential energy

(ii) The kinetic energy per mole of a gas is

*.3/2 kT * nRT * 2/3 kT *3/2 RT

2014

(iv) In this process no heat enters or leaves the system:

*Isochoric *Isobaric *Adiabatic *Isothermal

(xii) Heat energy cannot be measured in:

*Joule *BTU *Kelvin *Calorie

(xvi) The average internal energy of an ideal gas is called:

*Pressure *Volume *Temperature *Heat

2015

(ii) Kinetic energy per mole of an ideal gas is:

* 3/2KT *2/3KT *3/2RT *2/3RT

v) If the temperature of a cold body is decreased the efficiency of Carnot engine will:
* increase * decrease * remain constant * none of these

CHAPTER-11 **NUMERICALS**

From Past Papers

1986

Q.2. (c) 10kg of water falls through a height of 854m and all the energy is effective in heating the water. To what temperature will the water be raised if it was initially at 20°C?
(21.99°C)

1987

Q.1. (c) The efficiency of the heat engine is 50%. If the temperature of the cold reservoir is 300K, find the temperature of the hot reservoir.
(600K)

1990

Q.1. (c) A heat engine performs work 0.4166 watts for one hour and rejects 4500J of heat energy to the sink. What is the efficiency of the engine?
(25%)

Q.2. (c) At a certain temperature the average kinetic energy of hydrogen molecule is 6.2×10^{-21} J, the mass of the hydrogen molecule is 3.1×10^{-27}Kg. Find
① The temperature and
② RMS speed **(299.5K, 2×10^3m/s)**

1991

Q.1. (c) A cylinder contains an ideal gas below frictionless piston in it. If the gas in the cylinder is supplied 3000J of heat and the piston rise by 0.35m, while the internal energy of the system increases by 400J. Calculate the work done by the piston.
(2600J)

Q.2. (c) One-gram mole of a gas occupies a volume of $24.93m^3$ at a pressure of $500N/m^2$. Find the temperature of the gas in centigrade. **(1226.27°C)**

1993

Q.1. (c) A tank contains 20.0 liters of air at 30°C and 5.01×10^5 N/m^2 pressure. What is the mass of air and what volume will it occupy at one atmospheric pressure at 0°C? The average molecular mass of air is 28.8g $mole^{-1}$. **(0.1145kg, 89.38 liters)**

Q.2. (c) The molar specific heat of a monatomic gas at constant volume is 3/2 R. Find Its molar specific heat at constant pressure. Also show that γ = 1.66 for monatomic gases.

P

1994

Q.2. (c) 1200 joules of heat energy are supplied to the system at constant pressure. The internal energy of the system is increased by 750 joules and the volume by 4.5 cubic meters; find the work done against piston and the pressure on the piston. **(450J, 100N/m^2)**

1995

Q.1. (c) A meter bar of steel is correct at 0°C and another at –2.5°C what will be the difference between their lengths at 30°C? (For steel $\alpha = 1.1 \times 10^{-5}\,°C^{-1}$). **($2.75 \times 10^{-5}$m)**

Q.2. (d) A heat engine performs work at the rate of 500 K.W. The efficiency of the engine is 30%. Calculate the loss of heat per hour. **(4.2×10^9J)**

1996

Q.1. (d) In an isobaric process when 2000J of heat energy is supplied to a gas in a cylinder, the piston moves through 0.1m under a constant pressure of 1.01×10^5 N/m^2. If the area and the piston is 5×10^{-2} m^2, calculate the work done and the increase in the internal energy of the system. **(505 J, 1495 J)**

Q.2. (d) Find the rms speed of the nitrogen molecules at 27°C. Given the mass of nitrogen molecule to be 4.67×10^{-26} Kg, k = 1.38×10^{-23}J/K **(515.71m/s)**

1997

Q.1. (d) A glass flask is filled to the 'mark' with 60 cm^3 of mercury at 20°C. If the flask and its contents are heated to 40°C, how much mercury will be above the mark? α for glass = 9×10^{-6}/°C and β for mercury = 182×10^{-6}/°C. **(0.186 cm^3)**

Q.2. (d) A Carnot engine whose low temperature reservoir is 200°K has an efficiency of 50%. It is desired to increase this to 75%. By how many degrees must the temperature be decreased, if higher temperature of the reservoir remains constant? **(100K)**

1998

Q.1. (d) Find the root-mean square of a hydrogen molecule at 7°C. Take the mass of a hydrogen molecule to be 3.32×10^{-27} kg and Boltzmann's Constant = 1.38×10^{-23} J/K **(1868.57 m/s)**

Q.2. (d) 540 calories of heat is required to vaporize 1gm of water at 100°C. Determine the entropy change involved in vaporizing 5 gm of water. (1 calories = 4.2 joules) **(30.40 J/K)**

1999

Q.1. (d) Show that for a monoatomic gas $C_p = 5/2\,R$, where the symbols C_p and R have their usual meanings.

Q.2. (d) Find the Efficiency of a Carnot Engine working between 100°C and 50°C. **(13.4%)**

2000

Q.1. (d) Calculate the volume occupied by a gram mole of a gas at 10°C and pressure of one atmospheric. **(0.023m^3)**

Q.2. (d) When 2000J of heat energy is supplied to a gas in a cylinder at constant pressure of 1.01×10^5 N/m^2, piston of area of cross section 2×10^{-2} m^2, moves through 0.5 m, calculate work done and increase in internal energy. **(1010 J, 990 J)**

2001

Q.1. (d) If one mole of mono-atomic gas is heated at constant pressure from –30°C to 20°C, find the change in its internal energy and the work done during the process.

C_P = 20.8 J/mole K, C_V = 12.5J/mole K **(625 J, 415 J)**

Q.2. (d) An ideal heat engine operate in Carnot's cycle between temperatures 227°C and 127°C and it absorbs 600 joules of heat energy, find the:

i) Work done per cycle ii) Efficient of the engine **(120 J, 20%)**

2002 (Pre Med. group)

Q.1. (d) Find V_{rms} of Hydrogen molecule at 100°C. Take mass of molecule 3.32×10^{-27} kg. **(2156.66 m/s)**

Q.2. (d) When 2000J of heat energy is supplied to a gas in a cylinder at constant pressure of 1.01×10^5 N/m^2, piston of area of cross section 2×10^{-2} m^2, moves through 0.5 m, calculate work done and increase in internal energy. **(1010 J, 990 J)**

2002 (Pre Engg. group)

Q.1. (d) A heat engine performs 1000 J of work and at the same time rejects 4000J of heat energy to cold reservoir. What is the efficiency of the engine if the difference in the temperature between sink and source of this engine is 75°C, find the temperature of its source. **(20%, 375 K)**

Q.2. (d) A cylinder of diameter 1cm at 30°C is to be slid in to a hole in a steel plate. The hole has a diameter of 0.99970 cm at 30°C. To what temperature must the plate be heated. **(57.28 °C)**

2003 (Pre Med. group)

Q.1. (d) The low temperature reservoir of Carnot engine is at 5°C and has an efficiency of 40%. It is desired to increase the efficiency to 50%. By how much degree should the temperature of hot reservoir be increased? **(92.67 K)**

Q.2. (d) An air storage tank whose volume is 110liters contains 2kg of air at a pressure of 15atm. How much air would have to force into the tank to increased the pressure to 18atm, assuming no change in temperature. **(0.4kg)**

2003 (Pre Engg. group)

Q.1. (d) 1200 J of heat energy are supplied to a system at constant pressure. The internal energy of the system is increased by 750 joules and the volume by 4.5 cubic meters; find the work done on piston and pressure on piston. **(450 J, 100 N/m^2)**

Q.2. (d) The low temperature reservoir of Carnot engine is at 5°C and has an efficiency of 40%. It is desired to increase the efficiency to 50%. By how much degree should the temperature of hot reservoir be increased? **(92.67 K)**

2004

Q.1. (d) Calculate the density of the hydrogen gas, considering it to be an ideal gas, when the V_{rms} of its molecule is 1850 m/s at 0°C and 1atm. **(0.08853 kg/m^3)**

Q.2. (d) The low temperature reservoir of Carnot engine is at –3°C and has an efficiency of 40%. It is desired to increase the efficiency to 50%. By how much degree should the temperature of hot reservoir be increased? **(90 K)**

2005

Q.1. (d) A brass ring of 20cm diameter is to be mounted on a metal rod of 20.02cm diameter at 20°C. To what temperature should the ring be heated? ($\alpha_{Brass} = 19 \times 10^{-6}$ °C^{-1}.) **(72.63 °C)**

Q 2 (d) A 100gm copper block is heated in boiling water for 10min and then it is dropped into 150gm of water at 30°C in a 200gm Calorimeter. If the temperature of water is raised to 33.6°C. Determine the Specific heat of the material of the calorimeter. (S_c = 386 J/kg K). **(409.77 J/kg °C)**

P

2006

Q.1. (d) Find the change in volume of a brass sphere of 0.6m diameter when it is heated from 30°C to 100°C? ($\alpha = 19 \times 10^{-6}$°$C^{-1}$.) **($4.5 \times 10^{-4}$ m^3)**

Q.2. (d) A Celsius thermometer in a laboratory reads surrounding temperature as 30°C, what is the temperature on Fahrenheit and Absolute scale? **(86 °F, 303 K)**

2007

Q.1. (d) Calculate the density of the hydrogen gas, considering it to be an ideal gas, when the V_{rms} of its molecule is 1850 m/s at 0°C and 1atm. **(0.08853 kg/m^3)**

Q.2. (d) A heat engine performs work at the rate of 500KWatt the efficiency of the engine is 30%. Calculate the loss of heat per hour? **(4.2×10^9J)**

2008

Q.1. (d) A steel bar is 10cm in length at –2.5°C. What will be the change in its length when it is at 25°C? ($\beta$for steel = 3.3×10^{-8} K^{-1}) **(3.025×10^{-6} m)**

Q.2. (d) A Carnot Engine performs 2000J of work and rejects 4000J of heat to the sink. If the difference of temperature between the source and the sink is 85°C, find the temperatures of the source and the sink? **(252K, 170.25K)**

2009

Q.1. (d) A scientist stores 22 gm of a gas in a tank at 1200 atmospheres. Overnight the tank develops slight leakage and the pressure drops to 950 atmospheres. Calculate the mass of the gas escaped. **(4.58gm)**

Q.2. (d) In an isobaric process 2000 J of heat energy is supplied to a gas in a cylinder, the piston of area 2.0×10^{-2} m^2 moves through 40 cm under a pressure of 1.01×10^5 N/m^2. Calculate the increase in internal energy of the system. **(1192J)**

2010

2.(iii) A heat engine performing 400J of work in each cycle has an efficiency of 25%. How much heat is absorbed and rejected in each cycle? **(1600J, 1200J)**

2011

2.(vi) A 200gm piece of metal is heated to 150˚C and then dropped into an aluminum calorimeter of mass 500gm, containing 500gm of water initially at 25˚C. Find the final equilibrium temperature of the system if the specific heat of metal is 128.100 J/kg-K, specific heat of aluminum is 903 J/kg-K, while the specific heat of water 4200 J/kg-K. **(26.243°C)**

2012

Q2(x) A Carnot engine whose low temperature reservoir is 200K has an efficiency of 50%. It is desired to increase this to 75%. By how many degrees must the temperature of low temperature reservoir be decreased if the temperature of high temperature reservoir remains same?

2013

Q2(x) The difference of temperature between a hot and a cold body is 120 °C.If the heat engine is 30% efficient, find the temperature of the hot and cold body.

2014

Q2(vii) Calculate root mean square speed of Oxygen molecule at 800 K. Its molar mass is 32 g and universal gas constant R = 8.31 J/mol.K

2015

Q2(vi) A heat engine performing 200J of work in each cycle has an efficiency of 30%. For each cycle of operation. (a) How much heat is absorbed? (b) how much heat is expelled?

P

CHAPTER 12

ELECTROSTATICS

Electrostatics:

It is the branch of physics deals with the behaviors and characteristics showed by electric charges at rest.

Electric Charge:

"The positive or Negative electrical behavior showed by an atom or a substance due to deficit or excess of conduction electrons, is often referred as Electric Charge".

Quantization of Electric Charge:

The minimum magnitude of electric charge appear; either on an atom or a substance due to transfer of a valence electron (Conduction Electron). The value of which will be equal to $\pm(1.6\times10^{-19})$ coulomb. It is symbolized by "e".

Thus, if "n" number of conduction electrons is transferred from a substance to the other, then magnitude of charge on them is given by:

$$q = \pm ne$$

where, n=1,2,3,4,5,6 and $e = 1.6\times10^{-19}C$

The phenomenon of producing charge shows Quantization of Electric Charge in which charge on electron is said to be "Quantized".

Test Charge:

"A charge, whose distribution of charges shows no affect on any other charge, is called a Test Charge". It is considered as a Positive Charge and mathematically expressed as;

$$Test\ charge = \lim_{q\to 0} q$$

Where, "q_o" represents a test charge.

Unit of Electric Charge:

In S.I systems, the magnitude of charge is measured by "Coulomb". It is symbolized by "C". It is defined as, "Charge on two bodies is said to be one coulomb each if they are one meter apart and experience a force of $9\times10^9 N$."

P

Electrostatic Force:

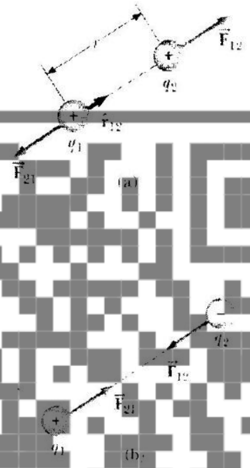
In 1785, Sir Charles Augustine de Coulomb, generalized a force of attraction and repulsion between two charged bodies by using torsion balance. "The force of attraction or repulsion exists between two charged bodies is referred as Electrostatic Force".

Coulomb's Law:

Statement:

The force of attraction or repulsion between two static point charges is directly proportional to the product of the magnitude of the charges and inversely proportional to the square of the distance between them.

Mathematically:



Consider two point charges q1 and q2 placed at a distance "r" from each other. The electrostatic force (F) between them will be:

$$F \propto q_1 q_2 \text{ ------- } (i)$$

$$F \propto \frac{1}{r^2} \text{ ------- } (ii)$$

Combining equation *(i)* and *(ii)*

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

$$F = k\,\frac{q_1 q_2}{r^2}$$

where "k" is the constant of proportionality. Its value depends upon the nature of medium between two charges.

1. For Space (Vacuum):

If the medium is free space (vacuum) between two charges then value of "k" Is given as:

$$k = \frac{1}{4\pi\varepsilon_o}$$

And its value is approximately is 9×10^9 Nm^2/C^2

Where "ε_o" is called "permittivity of free space". Its value is 8.85×10^{-12} C^2/Nm^2 so equation (iii) will be

$$F = \frac{1}{4\pi\varepsilon_o}\,\frac{q_1 q_2}{r^2}$$

And vector form is:

$$\overline{F} = \frac{1}{4\pi\varepsilon_o} \cdot \frac{q_1 q_2}{r^2} \hat{r}$$

"$\hat{r}$" is the unit vector specifies the direction of force.

2. <u>For Dielectric Medium:</u>

If the medium between charges is not a free space (vacuum) then the value of "k" is given as:

$$k = \frac{1}{4\pi\varepsilon_m} \text{ --------- } (i)$$

Where "ε_m" is the permittivity of the dielectric medium. Let "ε_r" the relative permittivity of the medium it is given as:

$$\varepsilon_r = \frac{\varepsilon_m}{\varepsilon_o}$$

$$\varepsilon_m = \varepsilon_r \, \varepsilon_o$$

so, equation (i) will

$$k' = \frac{1}{4\pi \, \varepsilon_r \, \varepsilon_o}$$

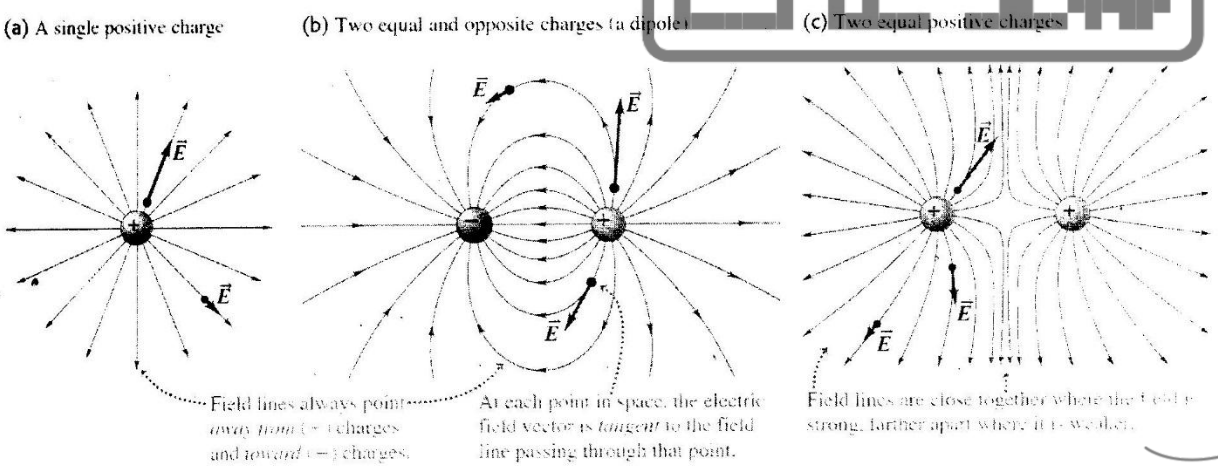
so, the equation (iii) will have the form

$$F' = k' \frac{q_1 q_2}{r^2}$$

$$F' = \frac{1}{4\pi \, \varepsilon_r \, \varepsilon_o} \frac{q_1 q_2}{r^2}$$

<u>Electric Field:</u>

An electric field is a region around a charged body in which any other charge experiences electrostatic force.



Electric Lines of Force:

The existence of electric field around a source charge can be examined by drawing imaginary lines with the help of a test charge called, "Electric Lines of Force".

Characteristics of Electric Lines Of Force:

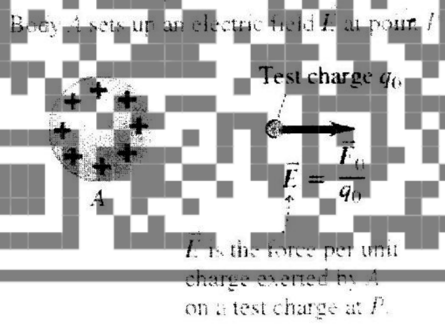
Some essential characteristics of electric lines of force are given below:

1. The electric lines of force always direct away from the centre of a Positive Source Charge.
2. The electric lines of force always direct towards the centre of a Negative Source Charge.The electric lines of force never intersect each other.
3. In case of variable electric field, the region of electric field will be stronger enough where separation between electric lines of force is found less.
4. In case of variable electric field, the region of electric field will be weaker enough where separation between electric lines of force is found large.
5. The electric lines of force between two oppositely charged plates remains perpendicular onto the plane of charged sheet, but remains parallel to each other.
6. The electric lines of force with such an electrical behavior produce Uniform Electric Field.

Electric Intensity:

Force experienced by a unit positive charge at a point in an electric field is called electric field intensity.

Suppose that a test charge is set inside an electric field of a source charge at point "p". "The electrostatic force experienced by unit charge, is referred as Electric Intensity of the Field at that point".



Mathematically,

$$E=F/q_o$$

Unit

As; $E = F/q_0$

$E = F/q_0$

E = Newton/Coulomb

E = N/C

Hence the unit of electric intensity is Newton per Coulomb.

Electric Intensity in Terms of Electric Lines of Force:

Intensity of electric field at a point may also be defined as the number of electric lines of force per unit area of a very small surface placed perpendicular to the electric lines at that point.

General Expression For Electric Intensity at a Point:

For this, consider an electric field around a source charge of magnitude, "q". let, a test charge of magnitude "q_0" is set at point ***"p"*** lies at a distance of "r" from the centre of source charge. If "F" be the magnitude of electrostatic force on test charge "q0", then electric intensity of the field at point "p" is given by,

$$\vec{E} = \frac{\vec{F}}{q_o}; \qquad E = \frac{F}{q_o}$$

$$\vec{E} = \frac{\left(\frac{1}{4\pi\varepsilon_o}\frac{q\ q_0}{r^2}(\hat{r})\right)}{q_0}$$

$$\vec{E} = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}(\hat{r})$$

This expression represents Electric Intensity of the field at point "p" lies at a distance "r" from the centre of a source charge of magnitude "q".

According to this equation,

$$\left|\vec{E}\right| \propto q$$

$$\left|\vec{E}\right| \propto \frac{1}{r^2}$$

Electric Flux:

Suppose that an element area is set inside a uniform electric field in a manner that some electric lines of force are said to be passed through the surface of element area. At this condition, one can say that Electric Flux is appeared through the element area. It is a Scalar Quantity and depends on total number of electric lines of force that are appeared across the surface of element area. It is symbolized by ϕ_e

Mathematical Explanation:

Suppose that an element surface of area $\overrightarrow{\Delta A}$ is set inside a uniform electric field of strength, in a manner that its surface (area) vector makes an angle "0" with the direction of electric field. The magnitude of electric flux through the surface directly depends on following two factors:

1. The magnitude of electric intensity of the field.

$$\Delta\Phi_e \propto (E)----------(i)$$

2. The component of element area acts parallel to the direction of electric field

$$\Delta\Phi_e \propto (\Delta A\cos\theta)----------(ii)$$

By combining the two relations under a single expression we have,

$$\Delta\Phi_e \propto (E)(\Delta A\cos\theta)$$
$$\Delta\Phi_e = E\Delta A\cos\theta$$
$$\Delta\Phi_e = \vec{E}.\Delta\vec{A}$$

Mathematical Definition:

$$\Delta\Phi_e = \vec{E} \, . \, \Delta\vec{A}$$

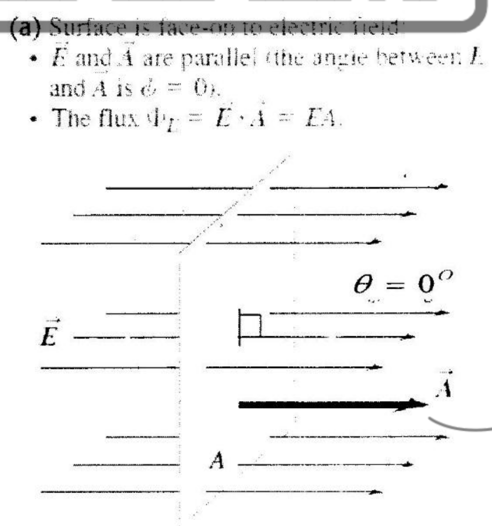
It means, "The Dot-Product of electric intensity of the field and element area of a surface will describe electric flux though surface of element area".

This ideology shows that electric flux is in fact, a Scalar Quantity.

Special Cases of electric Flux:

Case#1: Maximum Electric Flux Through Surface of Element Area:

When surface of an element area is oriented parallel to the direction of electric field the maximum number of electric lines of force is appeared through the surface of element area and thus Maximum Electric Flux is said to appear through the surface.



Mathematical Justification:

According to the expression of electric flux,

P

$$\Delta\Phi_e = \vec{E} \cdot \Delta\vec{A}$$

$$\Delta\Phi_e = E\Delta A\cos\theta. \text{--------} (i)$$

$$in\,this\;case\,\vec{E}\;|\;|\;\Delta\vec{A}, therefore, \theta = 0^0$$

$$\Delta\Phi_e = E\Delta A\cos O^0$$

$$\Delta\Phi_e = E\Delta A(1)$$

$$\Delta\Phi_e = E\Delta A$$

Hence the magnitude of maximum flux will be equal to "$E\Delta A$"

Case#2: Minimum Electric Flux Through Surface of Element Area:

When surface of an element area is oriented normal to the direction of electric field then no electric lines of force are seemed to appear across the surface of element area and thus Minimum Electric Flux is said to appear through the surface. The magnitude of which remains zero.

Mathematical Justification:

According to the expression of electric flux,

$$\Delta\Phi_e = \vec{E}.\Delta\vec{A}$$

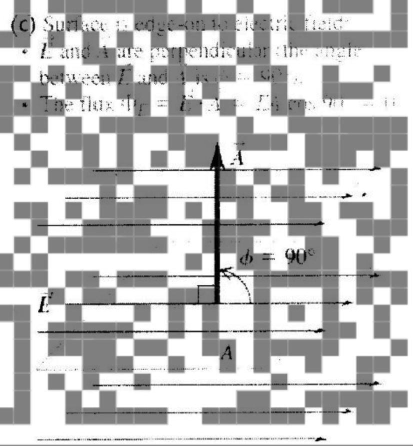
$$\Delta\Phi_e = E\Delta A\cos\theta \text{--------} (i)$$

$$in\,this\,case, \vec{E}|\;|\Delta A\cos 0^o$$

$$\Delta\Phi_e = E\Delta A\cos 90^0$$

$$\Delta\Phi_e = E\Delta A(0)$$

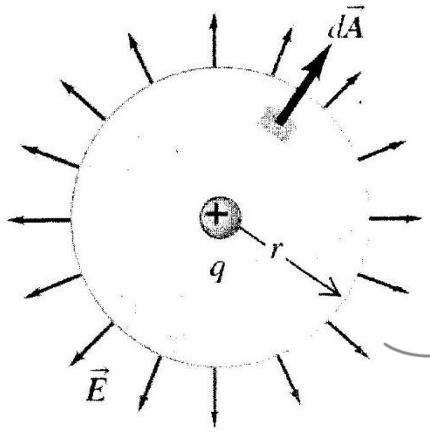
$$\Delta\Phi_e = 0$$



Hence the magnitude of minimum flux will remain "zero".

Electric Flux through a Closed Spherical Surface:

Consider a closed sphere of radius, "r" enclosing a point charge of magnitude, "q" at its centre. To determine electric flux appearing at the surface of sphere, the entire surface of the sphere is Sub-divided into 'N" number of element surfaces each of area, A so that the strength of Electric field within surfaces each of element area remains same, say . Thus, the electric flux through an element area will be *(F. L\A)* and sum of *(i. tA)* from first component to the Nth component of surface area will describe total electric flux through the sphere. Mathematically,



$$\Phi_e = \Delta\Phi_{e1} + \Delta\Phi_{e2} + \Delta\Phi_{e3} + ... + \Delta\Phi_{eN}$$

$$\Phi_e = (\vec{E}.\Delta\vec{A})_1 + (\vec{E}.\Delta\vec{A})_2 + ... + (\vec{E}.\Delta\vec{A})_N$$

$$\Phi_e = \sum_{i=1}^{i=N} (\vec{E}.\Delta\vec{A})_i$$

$$\Phi_e = \sum_{i=1}^{i=N} (E.\Delta A \cos\theta)_i$$

$Since, \vec{E} \,||\, \Delta\vec{A}, therefore\ \theta = 0^0$

$$\Phi_e = \sum_{i=1}^{i=N} (E\Delta A \cos 0^0)_i$$

$$\Phi_e = \sum_{i=1}^{i=N} (E.\Delta A)_i$$

$$\Phi_e = E\sum_{i=1}^{i=N} (\Delta A)_i$$

$$\Phi_e = E(Area\ of\ sphere)$$

$$\Phi_e = E(4\pi r^2) ------(i)$$

$Substituting\ E = \frac{1}{4\pi\varepsilon_0} \times \frac{q}{r^2}$

$$\Phi_e = \left(\frac{1}{4\pi\varepsilon_0} \times \frac{q}{r^2}\right) \times (4\pi r^2)$$

$$\Phi_e = \frac{q}{\varepsilon_0}$$

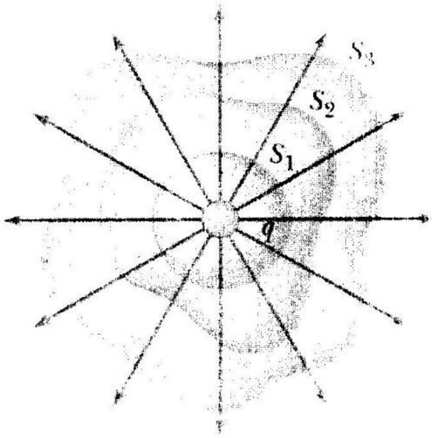
This expression represents total electric flux through the surface of a sphere, encloses a point charge of magnitude "q" at the centre. According to this expression;

1. The magnitude of total electric flux through a sphere directly depends on magnitude of point charge. i.e. $\Phi_e \ \alpha \ q$

2. The magnitude of total electric flux through a sphere is independent of size of sphere.

P

Electric Flux through an Arbitrary Closed Surface:



Suppose that an arbitrary closed surface, "S" is set inside an electric field of a source charge. To determine electric flux through surface, "S" let us sub-divides the closed surface into "N" number of element patches each of surface area, "A" so that the strength of electric field within surface of each element area remains constant, say *E*. Thus, the electric flux through surface of each element area will be equal to $(\vec{E}.\Delta\vec{A})$ and hence, sum of electric flux through all individual patches from first to Nth component will express total electric flux through the closed arbitrary surface. Mathematically,

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$$\Phi_e = \Delta\Phi_{e1} + \Delta\Phi_{e3} + ... + \Delta\Phi_{eN}$$

$$\Delta\Phi_e = (\vec{E}.\Delta\vec{A})_1 + (\vec{E}.\Delta\vec{A})_3 + ... + (\vec{E}.\Delta\vec{A})_N$$

$$\Phi_e = \sum_{i=1}^{i=N} (\vec{E}.\Delta\vec{A})_1$$

This expression represents total electric flux through an Arbitrary closed surface. The magnitude of which depends on the magnitude of $\vec{E}$ *and* $\Delta\vec{A}$.

Gaussian Surface:

"A hypothetical closed surface encloses a system of a point charges, is referred as Gaussian Surface".

Gauss' Law:

This law infect, shows a relation between total electric flux through a Gaussian Surface and total charges enclosed by that surface. According to this law, "the total electric flux through a Gaussian Surface is equal to the product of l/E0 and total amount of charges enclosed by that surface".

Proof:

To verify the statement of Gauss' Law in electrostatics, let us consider a Gaussian Surface, "S" enclosing a system of charges of magnitude, (q_1, q_2, q_3, ..., q_n).

To determine the electric flux through Gaussian Surface due to system of charges, let us assume charge of magnitude "q" by neglecting rest of others. Now, draw an imaginary sphere around the charge, "q_1' by considering it as the centre of sphere. The electric flux through imaginary sphere due to charge, "q_1" will be "q_1/ε_o". As, the total number of electric lines of force appearing through the imaginary sphere and Gaussian Surface "s" remains same, therefore, the electric flux through the Gaussian Surface, "Φ_1" due to charge, "q_1' will be equal to "q_1/ε_o". In the same fashion, the electric flux through the same Gaussian Surface due to charge of magnitude, ($q_2, q_3, \ldots, q_n$) will be equal to $\frac{q_2}{\varepsilon_0}, \frac{q_3}{\varepsilon_0}, \frac{q_4}{\varepsilon_0}, \ldots\ldots \frac{q_n}{\varepsilon_0}$ respectively.

Hence, the total flux through Gaussian Surface due to system of charges is given by;

Total electric flux through Gaussian Surface = $\Phi_1 + \Phi_2 + \Phi_3 + \ldots + \Phi_n$

$$\Phi_e = \frac{q_1}{\varepsilon_0} + \frac{q_2}{\varepsilon_o} + \frac{q_3}{\varepsilon_0} \ldots\ldots + \frac{q_n}{\varepsilon_0}$$

$$\Phi_e = \frac{1}{\varepsilon_0}(q_1 + q_2 + q_3 + \ldots + q_n)$$

$$\Phi_e = \frac{1}{\varepsilon_0}\left(\sum_{i=1}^{i-n} q_i\right)$$

$\left(\sum_{i=1}^{i-n} q_i\right)$ = *total amount of charges enclosed by Gaussian Surface* = Q

$$\Phi_e = \frac{1}{\varepsilon_0}(Q)$$

This statement verifies Gauss' law in electrostatics.

Application of Gauss' Law:

Electric Intensity at A Point Due To A Charged Sheet of Infinite Extent:

Consider a thin non-conducting sheet of infinite Extent having uniform distribution of positive charges on its surface. Lets the surface charge density of the sheet is "σ". To determine electric intensity at point "p" lies at a distance of i from the plane of sheetassume a closed cylinder of cross-sectional area, "A" through the sheet so that it remains perpendicular on to the plane of sheet and contains point "p" at its one end at which electric intensity is to be determined. Now, by considering imaginary cylinder as Gaussian Surface and apply Gauss' Law which states

$$\Phi_e = \frac{1}{\varepsilon_0}(Q) ------(i)$$

To Find TotalElectric Flux through Gaussian Cylinder:

The Gaussian cylinder contains three surfaces, two at the ends of same cross-sectional area, "A" and the third is curved surface.

The electric flux through each end of cylinder will be "EA", *E LXA* at the surface "S1" and "S2", lies at the ends. Similarly, the electric flux through curved surface of cylinder remains *"zero"*, as *E* ± at the surface "S3", lies curved portion of the cylinder. Hence, the total electric flux through the Gaussian cylinder is given by,

$$\Phi_e = \Phi_e(s_1) + \Phi_e(s_2) + \Phi_e(s_3)$$
$$\Phi_e = (EA) + (EA) + (0)$$
$$\Phi_e = 2EA$$

To Find Charges EnclosedBy The Gaussian Cylinder:

According to the definition of surface charge density,

$$\sigma = \frac{\Delta Q}{\Delta A}$$

$$\Delta Q = \sigma \ \Delta A$$
$$\sum_{i=1}^{i=n}(\Delta Q)_i = \sigma \sum_{i=1}^{i=n}(\Delta A)_i$$
$$Q = \sigma \ A$$

Where, "A" is the cross-sectional area of the Gaussian Cylinder.

Application:

For this, substituting the value of "q" and "Q" in eq (i)

$$(2EA) = \frac{1}{\varepsilon_0}(\sigma A)$$

$$(2E) = \frac{\sigma}{\varepsilon_0}$$

Eq(i)=>

$$E = \frac{\sigma}{2\varepsilon_0}$$

$$\overline{E} = \frac{\sigma}{2\varepsilon_0}(\hat{r})$$

Where, $\hat{r}$ is a unit vector along the direction of Electric Field Intensity and as well as along the direction of position vector drawn from the plane of sheet to the point "p" at which electric intensity is determined.

2: ELECTRIC INTENSITY AT A POINT DUE TO A CHARGED SPHERICAL SHELL:

Consider a non-conducting spherical shell of radius," a" having uniform distribution of positive charges on its surface. Let, surface charge density of charge shell is *"σ"*. To determine electric intensity at point "P" lies at a distance of r from the centre of charged spherical shell, assume a concentric sphere around the charged shell of radius "r". Now, by considering imaginary sphere "S" as Gaussian Surface and apply Gauss' Law which States,

$$\Phi_e = \frac{1}{E_0}(Q) ----------- (i)$$

To Find Total ElectricFlux Through Gaussian Sphere "S":

For this the entire surface of Gaussian Sphere ***"S"*** is sub-divided into "n" number of element patches each of surface area, *"ΔA"* so that the strength of electric field within each element area remains same, say *"E"*. Thus, the electric flux through the surface of each an individual element area will be equal to *(E.L\A)* and hence the electric flux through surface of entire Gaussian Sphere "5" is given by; -

$$\Phi_e = \sum_{i=1}^{i=n} \left(\vec{E}.\Delta\vec{A}\right)$$

$$\Phi_e = \sum_{i=1}^{i=n} \left(E\Delta A\cos\theta\right)$$

Since,

$$\vec{E} \,||\, \Delta\vec{A}, therefore\, \theta = 0^0$$

$$\Phi_e = \sum_{i=1}^{i=n} (E\Delta A\cos\theta)$$

$$\Phi_e = \sum_{i=1}^{i=n} (E\Delta A)_i$$

$$\Phi_e = E\sum_{i=1}^{i=N} (\Delta A)_i$$

$$\Phi_e = E(Area\, of\, Gaussian sphere)$$

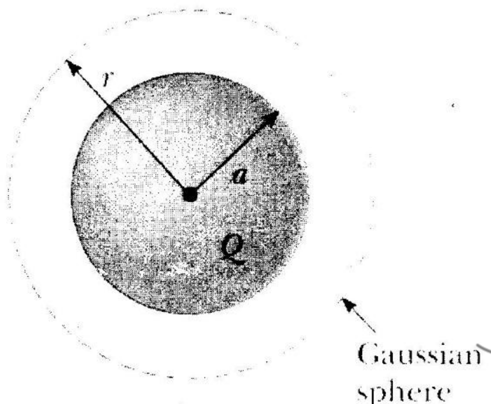
$$\Phi_e = E(4\pi r^2)$$

To Find Total Magnitude Of Charges Enclosed By The Gaussian Sphere "S":

According to the definition of surface charges density,

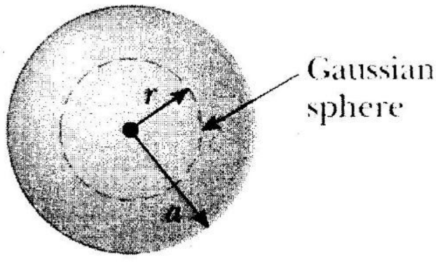
$$\sigma = \frac{\Delta Q}{\Delta A}$$

$$\Delta Q = \sigma\, \Delta A$$



(a)

P



(b)

$$\sum_{i=1}^{i=n}(\Delta Q)_i = \sigma\sum_{i=1}^{i=n}(\Delta A)_i (\Delta Q)_i = \sigma\sum_{i=1}^{i=n}(\Delta A)_i$$

$$Q = \sigma(4\pi a^2)$$

For this, substituting the value of "Φ_e" and "Q" in equation (i)

Eq(i)=>.

$$E(4\pi r^2) = \frac{1}{\varepsilon_0}(\sigma 4\pi a^2)$$

$$E = \frac{\sigma}{\varepsilon_0}\times\frac{a^2}{r^2}$$

(Or)

$$\vec{E} = \frac{\sigma}{\varepsilon_0}\times\frac{a^2}{r^2}(\hat{r})$$

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\times\frac{Q}{r^2}(\hat{r}); \quad \left(\sigma = \frac{Q}{4\pi a^2}\right)$$

Special Cases:

i. If Point "P" lies On The Surface Of Sphere:

Then $r = a$

$$As: \vec{E} = \frac{\sigma}{\varepsilon_0}\times\frac{a^2}{r^2}(\hat{r}) \text{ Putting } r = a$$

$$\vec{E} = \frac{\sigma}{\varepsilon_0}(\hat{r})$$

ii. If Point "P" Lies At The Centre Of Sphere:

Then $\sigma = 0$ as, no electric charge exists at the centre. Thus, the intensity at point ***'lp'*** remains "zero"

i.e. $\boxed{E = 0}$

3,Electric Intensity Between Two oppositely Charged Plates:

Consider two oppositely charged plates separated by a certain small distance "d" and held parallel to each other. When there is air or vacuum between the two plates the field will be r uniform. At any point "p" between the plates, electric intensity **"ri"** due to positive plate will be directed away from the plate and it's magnitude is given by;

$$E_1 = \frac{\sigma}{2\varepsilon_0}$$

Where "*σ*" is the surface charge density. Electric intensity due to the negative plate is directed towards the plate and its magnitude is given by:

$$E_2 = \frac{\sigma}{2\varepsilon_0}$$

Since, *"E1"* and E2 are in the same direction, therefore, the magnitude of net electric intensity "E" will be,

$$E = E_1 + E_2$$

$$Or\ E = \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0}$$

$$E = \frac{\sigma}{\varepsilon_0}$$

$$\vec{E} = \frac{\sigma}{\varepsilon_0} r$$

The above formula shows that the electric field between two oppositely charged parallel plates, separated by a small distance, is uniform and is directed form positive to negative plate. If an insulator (a dielectric medium) is present between the two plates then. Because of "Polarization" of atoms of the medium, Magnitude of "E" decreases by "ε_r" times. Where "ε_r" is the "Relative permittivity" or "Dielectric constant" of the medium.

$$\vec{E} = \frac{\sigma}{\varepsilon_r \varepsilon_0} r$$

Potential Difference:

The amount of work done in shifting a test charge against the direction of electric field Intensity expresses change of Potential Energy of test charge between the same two points. It is symbolized by "ΔU".

Definition:

"The change of potential energy per unit test charge will describe Potential Difference between the two points, when test charge is shifted between same two points against the direction of electric intensity of a source charge."

It is a Scalar quantity and symbolized by "ΔV".its magnitude is measured by "VOLT" after the name of a scientist.

P

Formula:

If "ΔU" be the change of P.E of a test charge "q_o" in displacing between two points against electrostatic force of a source charge, then by definition Potential Difference between two points is given by;

$$P.d\ ,\Delta V = \frac{Change\ in\ potential\ energy}{Test\ charge}$$

$$\Delta V = \frac{\Delta U}{q_0}$$

Unit: (In S.I system of units)

According to the equation of P.D between two points,

$$\Delta V = \frac{\Delta U}{q_0}$$

$$\Delta V = \frac{joule}{Coulomb}$$

$$\boxed{\Delta V = VOLT}$$

Definition Of "VOLT":

"If a Positive test charge of magnitude 1 Coulomb gains 1 Joule of potential energy in moving between the two points, then Potential Difference of 1 Volt is said to be established between same two points"

Mathematical Explanation:

Suppose that a test charge of magnitude "q0" is displaced to $\overrightarrow{\Delta r}$ from a point "P" to point "P", against the direction of electric field formed by a Source Charge of magnitude "q".

The amount of work done by the test charge in displacing between the two points is given by;

$$\Delta W = \vec{F}.\overrightarrow{\Delta r}$$

$$\Delta W = (q_0\vec{E}).(\overrightarrow{\Delta r}) \qquad \because \vec{E} = \vec{F}/q_0$$

$$\Delta W/q_0 = \vec{E}\,.\overrightarrow{\Delta r} \qquad here\ \Delta W = \Delta U$$

$$\Delta U/q_0 = \vec{E}\,.\,\overrightarrow{\Delta r} \qquad \because \Delta V = \Delta U/q_0$$

$$\Delta V = \vec{E}\,.\,\overrightarrow{\Delta r}$$

This expression represents Potential Difference between the two points.

Mathematical Definition:

$$As,\ \Delta V = \vec{E} \cdot \vec{\Delta r}$$

This equation implies, "The Dot Product of electric intensity of the field and element displacement of a test charge between the two points will express Potential Difference between the same two points."

This ideology shows that potential difference between two points is infect a Scalar quantity.

Relation between Electric Intensity and Potential Difference:

According to the equation of potential difference between the two points,

$$\Delta V = \vec{E} \cdot \vec{\Delta r}$$

$$\Delta V = E \Delta r \cos\theta$$

Since, $\vec{\Delta r}\ remains\ opposite\ to\ \vec{E}\ therefore,\ \theta = 180$

$$\Delta V = E\Delta r \cos 180$$

$$\Delta V = E\Delta r(-1)$$

$$\Delta V = -E\Delta r$$

$$\frac{\Delta V}{\Delta r} = -E$$

Here, $\frac{\Delta V}{\Delta r}$ represents change of electric potential with respect to the change of position called "GRADIENT OF ELECTRIC POTENTIAL" and symbolized by "Grad V". It shows a vector quantity i.e. $\vec{E}$ - mathematically,

$$\frac{\Delta V}{\Delta r} = -\vec{E}$$

$$\frac{dV}{dr} = -E$$

$$Grad V = -E$$

$$\vec{\nabla} V = -\vec{E}$$

$$\left(\frac{\partial}{\partial x} i + \frac{\partial}{\partial y} j + \frac{\partial}{\partial z} k\right) V = -\vec{E}$$

By comparing coefficient of i,j and k we have;

1. Along X-Axis:

Eq(i)

$$\frac{\partial V}{\partial x} = -E_x$$

$$E_x = -\frac{\partial V}{\partial x}$$

$$E_x = -\frac{\Delta V}{\Delta x} --------(a)$$

2. Along Y-Axis:
Eq(i)

$$\frac{\partial V}{\partial y} = -E_y$$

$$E_y = -\frac{\partial V}{\partial y}$$

$$E_y = -\frac{\Delta V}{\Delta y} \text{ ---------- } (b)$$

3. Along Z-Axis:
Eq(i)

$$\frac{\partial V}{\partial z} = -E_z$$

$$E_z = -\frac{\partial V}{\partial z}$$

$$E_z = -\frac{\Delta V}{\Delta z} \text{ ---------- } (b)$$

The equations a, b and c show that the negative rate of change of electric potential with respect to change of position in space gives electric intensity along the decreasing function of electric potential.

Relation Between K.E And Potential Difference:

$$\text{Potential Difference} = \frac{\text{Work (or change in potential energy)}}{\text{Charge}}$$

$$\Delta V = \Delta W / q$$

$$\Delta W = q\Delta V$$

Hence, if charge "q" is accelerated through potential difference "ΔV" then it will lose potential energy and at the same time gain an equal amount of ICE, which is given by,

$$\frac{1}{2}mv^2 = q\Delta V$$

Electron Volt:

"Electron Volt" is the unit of energy used in atomic and nuclear physics.
"One electron volt (1e.v) is the amount of energy gained by electron when it is accelerated through a potential difference of 1 volt".

Hence,

$$\Delta V = Volt$$

q = e 1.6021x10^{-19} coulomb

$$\therefore \frac{1}{2}mv^2 = q\Delta V$$

$$\frac{1}{2}mv^2 = 1.6021 \times 10^{-19} \times 1$$

$$\frac{1}{2}mv^2 = 1.6021\times10^{-19}$$

$$\therefore 1e.v = 1.6021\times10^{-19}\ Joules$$

Capacitor:

Capacitor is a device used to store electric charge and energy.

A simplest capacitor consists of two similar metal plates held parallel to each other and separated by a small distance. The space between the two metal plates is filled by an insulator called a "Dielectric medium". Charge "Q" stored on any one plate of the capacitor is directly proportional to the potential difference "V" across the two plates.

$$Q \alpha V$$

$$Q = CV$$

Where "C" is a constant of proportionality, it represents "Capacitance of the capacitor".

Capacitance of a Capacitor:

Capacitance of the capacitor may be defined as;

"The charge stored on a capacitor when unit potential difference is applied across its plates".

Unit of Capacitance: V

Unit of capacitance is "Farad". Capacitance of the capacitor is said to be one farad (iF) if on giving one volt PD between the plates each plate stores one Coulomb (1C) charge.

$$1\ \text{Farad} = \frac{1\ \text{Coulomb}}{1\ \text{Volt}}$$

'Capacitance of AParallel Plates Capacitor:

For this, consider a parallel-plate capacitor with the following geometric constant

1. Area of each plate = A

FIG, See in class lecture

2. Distance between plates = d
3. P.D Applied between plates = V
4. Amount of charge on each plate =Q
5. The strength of electric field between plates = $E = \frac{\sigma}{\varepsilon_0} = \frac{Q/A}{\varepsilon_0} = \frac{Q}{A\varepsilon_0}$
6. Medium between plates is "AIR".

To Find P.D Between Plates:

According to eq of P.D, i.e. $\Delta V = \vec{E}.\vec{\Delta r}$. Thus P.D between two charged plates of capacitor is given by;

This eq represents capacitance of a parallel plate's capacitor, when air is filled between the plates.

According to this eq.

1. Capacitance is directly proportional to the Area of Plates i.e. "C α A"
2. Capacitance is inversely proportional to the distance between Plates i.e. "C α 1/d"

When A Dielectric Medium Is Set Between Plates:

If a dielectric medium of permittivity, "ε_m"is filled in the space between two plates, then capacity of parallel plate capacitor is given by;

P

$$C = \frac{A\varepsilon_0\,\varepsilon_r}{d}$$

$$C = \left(\frac{A\varepsilon_0}{d}\right)\varepsilon_r$$

$$C = C.\varepsilon_r$$

where ε_r is called "Dielectric Constant". Its value depends on the nature of material of insulated medium.

Definition of Dielectric Constant:

"The ratio of capacitance of a parallel plate's capacitor in presence of **a** Dielectric medium to the capacitance of same capacitor in presence of Air is known a Dielectric Constant".

As $C' = C\ \varepsilon_r$

$C' / C = \varepsilon_r$

Combinations of Capacitors:

Any two or more capacitors can be combined with the opposite terminals of a battery in two ways:

1. In Series
2. In Parallel

1.**Combination Of Capacitors In Series:**

If two or more capacitors are connected with the opposite terminals of a battery in such a way that:

a) The magnitude of charges on plates of each capacitor remains same.

b) The P.D across the plates of any one capacitor differs from the P.D of any other capacitor.

Then the capacitors are said to be connected in series. A series combination of three capacitors of capacitance "C_1", "C_2" *and* "C_3" is shown by the following circuit diagram:

Derivation for The Equivalent Capacitance Of Series Combination Of Capacitors:

For this, let us assume that:

i. the magnitude of charges on plates of each one capacitor is "Q"

i. The P.D across the plates of capacitor of capacitance "C_1", "C_2","C_3"and "Ce" is "V_{ab}" "V_{db}', "V_{de}" and "V_{ae}" respectively.

iii. The capacitance of equivalent capacitor= Ce=?

According to the characteristics of series combination of capacitors

$$V_{ae} = V_{ab} + V_{db} + V_{de}$$

$$\frac{Q}{C_e} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

$$\frac{Q}{C_e} = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

$$\frac{1}{C_e} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

If "n" number of capacitors are connected in series then reciprocal value of their equivalent capacitance is given by;

$$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ... + \frac{1}{C_n}$$

$$\frac{1}{C_e} = \sum_{i-1}^{i=n}\left(\frac{1}{Ci}\right)$$

2. Combination Of Capacitors In Parallel:

If two or more capacitors are connected with the opposite terminals of a battery in such a way that:

a) The P.D across the plates of each one capacitor remains same.

b) The magnitude of charges on plates of any one capacitor differs the magnitude of charges on plates of any other capacitor then the capacitors are said to be connected in parallel.A parallel combination of three capacitors of capacitance "C1", "C2" and "C3" is shown by the following circuit diagram: -

Derivation for The Equivalent Capacitance Of Parallel Combination Of Capacitors:

For this, let us assume that:

i. The P.D across the plates of each one capacitor is "V_{ab}".

ii. The magnitude of charges on plates of capacitor of capacitance "C1", "C2", "C3" and "Ce" is "Q_1", "Q_2", "Q_3" and "Q" respectively.

iii. The capacitance of equivalent capacitor = $C_e = ?$

According to the characteristics of parallel combination of capacitors,

$$Q = Q_1 + Q_2 + Q_3$$

$$C_e V_{ab} = C_1 V_{ab} + C_2 V_{ab} + C_3 V_{ab}$$

$$C_e V_{ab} = V_{ab}(C_1 + C_2 + C_3)$$

$$C_e = C_1 + C_2 + C_3$$

If two or more capacitors are combined in parallel, then their equivalent capacitance will equal to the sum of capacitance of individual capacitors that are connected in parallel.

Hence, if "n" numbers of capacitors are connected in parallevl then their equivalent capacitance
is given by:

P

Compound Capacitor:

A compound capacitor is one where the space between the plates is partially filled with a dielectric medium.

Consider a capacitor containing air and slab of dielectric medium between the plates.

Let

- t = thickness of dielectric medium slab.
- d = distance between the plates.
- d_0 = thickness of air
- $d_0 = d - t$

This system serves s two capacitors in series as shown in fig. let "C" is the capacitor with dielectric medium and "C" is the capacitance of capacitor with air and C_d is the capacitance of the compound capacitor. .,

Then

$$\frac{1}{C_a} + \frac{1}{C'} + \frac{1}{C}$$

$$C = \frac{A\varepsilon_0}{d_0}$$

Using relation

$$C' = C = \frac{A\varepsilon}{t}$$

Where, A = area of the plates

ε = permittivity of the dielectric medium = $\varepsilon_0\varepsilon_r$

$$\frac{1}{C_d} = \frac{1}{C'} + \frac{1}{C}$$

$$\frac{1}{C_d} = \frac{C + C'}{C'C}$$

$$C_d = \frac{CC'}{C + C'}$$

$$C_d = \frac{\left(\frac{A\varepsilon_0}{d_0}\right)\left(\frac{A\varepsilon}{t}\right)}{\left(\frac{A\varepsilon_0}{d_0}\right) + \left(\frac{A\varepsilon}{t}\right)}$$

$$C_d = \frac{\dfrac{A^2 \varepsilon_0 \varepsilon}{d_0 t}}{\dfrac{A\varepsilon_0 t + A\varepsilon d_0}{d_0 t}}$$

$$C_d = \frac{A^2 \varepsilon_0 \varepsilon}{A(\varepsilon_0 t + \varepsilon d_0)}$$

$$C_d = \frac{A\varepsilon_0 \varepsilon}{\varepsilon_0 t + \varepsilon d_0}$$

$$C_d = \frac{A\varepsilon_0 (\varepsilon_0 \varepsilon_r)}{\varepsilon_0 t + \varepsilon_0 \varepsilon_r d_0}$$

$$C_d = \frac{A\varepsilon_0^{\,2} \varepsilon_r}{\varepsilon_0 (t + \varepsilon_r d_0)}$$

$$C_d = \frac{A\varepsilon_0 \varepsilon_r}{\varepsilon_0 d_0 + t}$$

$$C_d = \frac{A\varepsilon_0}{\dfrac{\varepsilon_0 d_0 + t}{\varepsilon_r}}$$

$$C_d = \frac{A\varepsilon_0}{(d_0 + \dfrac{t}{\varepsilon_r})}$$

$$C_d = \frac{A\varepsilon_0}{(d - t) + t/\varepsilon_r}$$

P

CHAPTER-12

MULTIPLE CHOICE QUESTIONS
From Past Papers

2001

Q#3 (a) (i) The Electric Flux through a closed surface depends on the:
* Magnitude of the charge enclosed by the surface
* Position of the charge enclosed by the surface
* The shape of the surface
* None of the above

Q#3 (a) (ii) When three capacitors are joined in series, the total capacitance,
* Less than the value of the minimum capacitance
* Equal to the sum of the capacitance
* Greater than the maximum capacitance
* None of the above

Q#3 (a) (iii) The unit of electric intensity is:
* N C /m * V m * N C * V / m

2002 (Pre Engineering)

Q#3 (a) (i) The Electric Intensity between two similar charged plates is:
* σ/ε_o * $\sigma/2\varepsilon_o$ * Zero * $2\sigma/\varepsilon_o$

Q#3 (a) (ii) The Electric flux through a surface will be minimum, when the angle between E and A is:
* 90° * 0 ° * 45° * 60°

Q#4 (a) (i) Which of the following cannot be the unit of electric intensity?
* N/C * V/m * J/C–m * J/C

Q#5 (a) (i) Electron volt is a unit of:
* Energy * Force* Potential Difference * Current

Q#6 (a) (ii) One joule per coulomb is called:
* Ampere * Volt * Farad * Tesla

2002 (Pre Medical)

Q#3 (a) (ii) The force per unit charge is known as:
* Electric Flux * Electric Field Intensity
* Electric Potential * Electric Current

Q#3 (a) (iii) If 4μF and 2μF capacitors are connected in series, the equivalent capacitor is:
* 0.76 μF * 6 μF * 2 μF *1.33 μF

Q#6 (a) (iii) With the introduction of a dielectric between the plates of a capacitor, its capacitance:
* increases * decreases * remains constant * becomes zero

2003 (Pre Medical)

Q#3 (a) (i) If two capacitors of 5μF and 7μF are connected in parallel, their equivalent capacitance will be:

* 0.12 μF * 12 μF * 0.34 μF * 2.9 μF

Q#3 (a) (iii) If a dielectric slab is introduced between the plates of a parallel plate capacitor, kept at a constant potentials, the charge on the capacitor:

* decrease * increase * remains unchanged * becomes zero

Q#6 (a) (i) One electron volt is equal to:

* 1.6×10^{-11}J * 1.6×10^{-19}J * 1.6×10^{-19}V * 3.1×10^{-13} V

2003 (Pre Engineering)

Q#3 (a) (i) The presence of dielectric between the plates of a capacitor results in:

* increase in the capacitance * decrease in the capacitance
* no change in the capacitance * none of these

Q#3 (a) (ii) The change in potential energy per unit charge between two points in an electric field is called:

* electric intensity * Permittivity * Potential difference * Absolute potential

2004

Q#3 (a) (i) The magnitude of Electric Intensity between two oppositely charged plates is:

* $2\sigma/\varepsilon_o$ * $\sigma/2\varepsilon_o$ * $\sigma/3\varepsilon_o$ * σ/ε_o

Q#3 (a) (ii) In case of a parallel combination of capacitors, the net capacity is greater than the greatest individual one. (*True or False*)

Q#3 (a) (iii) The presence of a dielectric between the plates of a capacitor results in _____________. (*Fill in the Blank*)

Q#4 (a) (ii) A parallel plate capacitor is given a charge Q. If the separation between the plates is doubled, its capacity will be doubled. (*True or False*)

Q#5 (a) (i) One joule per coulomb is called:

* farad * gauss * ampere * volt

Q#6 (a) (iii) _______ can be expressed in terms of electron volts. (*Fill in the Blank*)

2005

Q#3 (a) (i) The minimum electrical charge possible in isolated form is:

* 1.6×10^{-19}C * 1×10^{12}C * 1×10^{-6}C * One Coulomb

Q#3 (a) (ii) The change in potential energy of a unit charge between two points in an electrical field is called:

* Intensity * Permittivity * Potential Difference * Flux

P

Q#6 (a) (ii) A dielectric = 2 is inserted between the plates of a 20μF capacitor. Its capacitance will become:

* 10 μF   * 18 μF   * 22 μF   * 40μF

2006

Q#3 (a) (ii) If 4μF and 2μF capacitors are connected in series, the equivalent capacitor is:

* 1.33 μF   * 0.75 μF   * 6 μF   * 2 μF

Q#5 (a) (i) The quantity $\Delta V / \Delta S$ is called:

* Electric potential   * Electric Field Intensity
* Potential Gradient   * Electric Induction

Q#5 (a) (iii) The concept of the electric lines of force was introduced by a famous scientist called:

* Newton   * Einstein   * Coulomb   * Faraday

2007

Q#3 (a) (i) Decreasing the separation of two positive charges by one half will cause the force of repulsion to be changed by:

* ¼ time   * 2times   * ½ time   * 4 times

Q#4 (a) (i) Which of the following cannot be the unit of electric intensity?

* N/C   * V/m   * J/C–m   * J/C

Q#4 (a) (iii) Which of the following is not a scalar quantity?

* Potential   *EMF   * Electric Flux   * Electric Intensity

2008

Q#3 (a) (i) The introduction of dielectric between the oppositely charged plates causes the intensity to:

* increase   * decrease   * remain constant   * increase & decrease

Q#3 (a) (ii) Two positive point charges repel each other with a force of 4×10^{-4} N when placed at a distance of 1 meter. If the distance between them is increased by 2m, the force of repulsion will be:

* 1×10^{-4}N   * 8×10^{-4}N   * 2×10^{-4}N   * 4×10^{-4}N

Q#4 (a) (i) Electric flux through the surface of a sphere which contains a charge at its centre depends on the:

* amount of charge outside the sphere.   * surface area of the sphere.
* amount of charge inside the sphere   * radius of the sphere.

2009

Q#3 (a) (i) When a dielectric is placed in an electric field, it becomes:

* Negatively charged only   * Positively charged only
* Polarized   * Conductive

Q#3 (a) (ii) The capacitance of a parallel plate capacitor does not depend on the:

* area of the plates * nature of the plates
* distance between the plates * medium between the plates

Q#4 (a) (i) The change in potential energy per unit charge between the two points in an electric field is called:

* Intensity * Flux * Potential * Permittivity

2010

(viii) Decreasing the separation of two positive charges by one-half will cause electrostatic force of repulsion to change by:

(a) 4 time (b) 2 times (c) ½ time (d) ¼ time

(ix) Two capacitors of 3 μ F and 6 μ F are connected in series, their equivalent capacitance is: (a) 9 μ F (b) 2 μ F (c) $\frac{1}{2}$ μ F (d) 3 μ F

(x) Which of the following cannot be a scalar quantity?

(a) Electrical Potential (b) EMF (c) Electric Flux (d) Electric Intensity

2011

(iv) If an electrostatic force between two electrons at a distance, is F Newton, the electrostatic force between two protons at the same distance is:

* Zero * F/2 * F * 2F

(xiii) The relation $-\Delta V/\Delta r$ represents:

* Gauss's law * electric flux * electric intensity *potential difference

2012

(ii). If the area of plates of a parallel plate capacitor is doubled the capacitance:

*is doubled *remains unchanged *is half *is increased 4 times

(iii) The electric intensity between two uniformly oppositely charged parallel plates is:

*σ / ε_o *$\sigma / 2\varepsilon_o$ *$2\sigma / \varepsilon_o$ *zero

(ix). Joule per coulomb is called:

*Farad *Ampere *Volt *Henry

2013

(ix). The number of electrons in one coulomb charge is

*6×10^{20} *1.6×10^{18} *6.25×10^{18} *9.1×10^{19}

2014

(vi) Two capacitors of 3 μF and 6 μF are connected in series, their equivalent capacitance is

*9 μF *2 μF *1/2μF *3 μF

P

(xi) This is not a scalar quantity

*Electricflux *Electric intensity *EMF *Electric potential

(xv) Joule per coulomb is called:

*Farad *Henry *Ampere *Volt

2015

(vi) Decreasing the separation between two identical charges by one-half causes the repulsive force to become:

* one-fourth * half * double *fourfold

(xiv) 1 MeV, is equal to:

* 1.6×10^{-19}J *1.6×10^{-13}J *1.6×10^{18}J *1.6×10^{19}J

CHAPTER-12 **NUMERICALS**

PAST PAPER

1990

Q.4. (c) An oil drop having a mass of 0.002kg and charge equal to 6 electron's charge is suspended stationary in a uniform electric field. Find the intensity of electric field. (Charge of electron = 1.6×10^{-19}C) **(2.04×10^{16} V/m)**

1991

Q.4. (c) Calculate the potential difference between two plates when they are separated by a distance of a 0.005m and are able to hold an electron motionless between them. (Mass of electron = 9.1×10^{-31} Kg) **(2.79×10^{-13} volts)**

1993

Q.3 (c) Calculate the equivalent capacitance and charge on 5μF capacitor as show in the figure

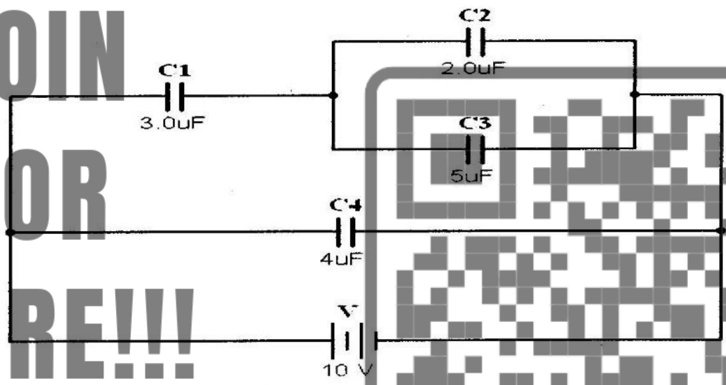
$C_1 = 3\mu$ F

$C_2 = 2\mu$ F

$C_3 = 5\mu$ F

$C_4 = 4\mu$ F

V = 10 volts



(6.1μF)

1994

Q.4. (c) Two horizontal parallel metallic plates, separated by a distance of 0.5cm are connected with a battery of 10 volts. Find:

1. The electric field intensity between the plates.
2. The force on a proton placed between the plates. **(2000V/m, 3.2×10^{-16} N)**

1995

Q.4. (c) Two capacitors of capacitance 400μF and 600μF are charged to the potential difference of 300volts & 400volts respectively. They are then connected in parallel. What will be the resultant potential difference and charge on each capacitor? **(360V, 0.144C, 0.216C)**

1996

Q.3. (c) A thin sheet of positive charge attracts a light charged sphere having a charge -5×10^{-6} C with a force 1.69N. Calculate the surface charge density of the sheet. ($\epsilon_o = 8.85\times 10^{-12}$ C^2/Nm^2) **(5.98×10^{-6}coul/m^2)**

Q.4. (c) A particle of mass 0.5g and charge 4×10^{-6}C is held motionless between two oppositely charged horizontal metal plates. If the distance between them is 5mm, find:

P

(i) The electric intensity (ii) The potential difference between the plates.

(1225V/m, 6.125 V)

1997

Q.3. (c) A capacitor of 200 pF is charged to a P.D. of 100 volts. Its plates are then connected in parallel to another capacitor and are found that the P.D. between the plates falls to 60 volts. What is the capacitance of the second capacitor? **(133.33pF)**

1998

Q.3. (c) Calculate the force of repulsion on $+2 \times 10^{-8}$ coulomb charge. If it is placed before a large vertical charged plate whose charge density is $+ 20 \times 10^{-4}$ coulombs/m^2. **(2.26 N)**

1999

Q.3. (c) Two capacitors of 2.0 μF and 8.0μF capacitance are connected in series and a potential difference of 200 volts is applied. Find the charge and the potential difference for each capacitor. **(3.2 x 10^{-4}Coul, 160V, 40V)**

2000

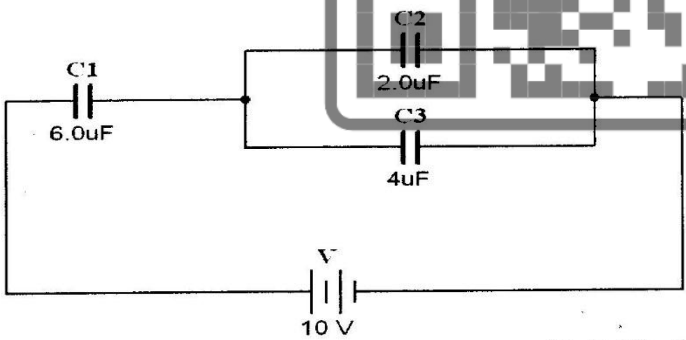
Q.3. (c) A charged particle of −17.7 μC is close to a positively charged thin sheet having surface charge density 2×10^{-8}Coul/m^2. Find the magnitude and direction of force acting on the charged particle. **(0.02N, towards the −ve charge)**

2001

Q.3. (c) A parallel plate capacitor has the plates 10cm x 10cm separated by a distance of 2.5cm. It is initially filled with air, what will be the increase in its capacitance if a dielectric slab of the same area and thickness 2.5cm is placed between the two plates? (Take $\epsilon_R = 2$) **(3.54pF)**

2002 (Pre Med. group)

Q.3. (d) Find the equivalent capacitance in the given circuit and charge on each capacitor:



(3μF, 30 μC, 10 μC, 20 μC)

Q.4. (d) A small sphere of weight 5×10^{-3}N is suspended by a silk thread 50mm long which is attached to a point on a large charge insulating plane. When a charge of 6×10^{-8}C is placed on the ball the thread makes an angle of 30° with the vertical; find the charge density of the plane. **(8.515 x 10^{-7} C/m^2)**

2002 (Pre Engg. group)

Q.5. (d) A proton of mass 1.67×10^{-27} kg and a charge of 1.6×10^{-19}C is to be held motionless between two horizontal parallel plates 10cm apart: find the voltage required to be applied between the plates. **(1.0228×10^{-8} V)**

2003 (Pre Med. group)

Q.5. (d) A particle carrying a charge of 10^{-5}C starts from rest in a uniform electric field of intensity $50 Vm^{-1}$ Find the force on the particle and the kinetic energy it acquires when it is moved 1m. **(5×10^{-4}N, 5×10^{-4}J)**

2004

Q.3. (d) An electron has a speed of 10^6 m/s. Find its energy in electron volts. **(2.8125eV)**

2006

Q.3. (d) How many electrons should be removed from each of the two similar spheres, each of 10 gm, so that electrostatic repulsion is balanced by the gravitational force? **(5.39×10^6 electrons)**

2007

Q.3. (d) How many excess electrons must be placed on each of the two small spheres placed 3.0cm apart if the force of repulsion between the spheres is 10^{-19}N? **(625 electrons)**

2008

Q.3. (d) A capacitor of 12 μF is charged to a potential difference 100V. Its plates are hen disconnected from the source and are connected parallel to another capacitor. The potential difference in this combination comes down to 60V. What is the capacitance of the second capacitance? **(8μF)**

2009

Q.3. (d) A proton of mass 1.67×10^{-27} kg and charge 1.6×10^{-19} C is to be held motionless between two horizontal parallel plates 6cm apart; find the voltage required to be applied between the plates. **(6.13725 nV)**

2010

2. (x) How many electrons should be removed from each of two similar spheres each of 10 gm so that electrostatic repulsion may be balanced by gravitational force ($e = 1.602 \times 10^{-19}$ C)? **(5.4×10^6 electrons)**

2011

2. (vii) A proton of mass 1.67×10^{-27} kg and charge 1.6×10^{-19}C is to be held motionless between two parallel horizontal plates. Find the distance between the plates when the potential difference of 6×10^{-9} volts is applied across the plates. **(5.86 cm)**

2012

Q2(xiii) Two point charges of $+2 \times 10^{-4}$ C and -2×10^{-4} C are placed at a distance of 40 cm from each other. A charge of $+5 \times 10^{-5}$ C is placed midway between them. What is the magnitude and direction of force on it?

P

2013

Q2(xi) The surface charge density on a vertical metal plate is $25\times10^{-6}\ C/m2$. find the force experienced by a charge of $2\times10^{-10}C$ placed in front close to the sheet. ($\varepsilon_o = 8.85\times10^{-12} C/Nm^2$)

2014

Q2(viii) A 10μF capacitor is charged to a potential difference of 220V. It is then disconnected from the battery. Its plates are connected in parallel to another capacitor and it is found that the potential difference falls to 100V. What is the capacitance of the second capacitor?

2015

Q2(x) A thin sheet of positive charge attracts a light charged sphere having a charge -5×10^{-6} C with a force 1.69N. Calculate the surface charge density of the sheet.
($\epsilon_o = 8.85\times10^{-12}\ C^2/Nm^2$) **($5.98\times10^{-6}$coul/m^2)**

Q2(xiv) How many electrons should be removed from each of two similar spheres each of 10 gm so that electrostatic repulsion may be balanced by gravitational force (Gravitational constant = G = $6.67\times10^{-11}Nm^2/Kg^2$ and K = $9\times10^{911}Nm^2/C^2$)? **(5.4×10^6 electrons)**

CHAPTER 13

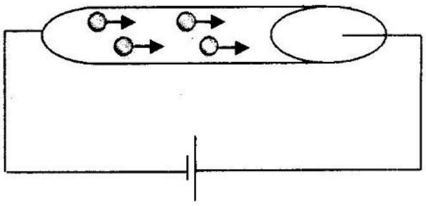
Current Electricity

CURRENT:

"Rate of flow of charges due to some potential differences is called current."

Mathematically,

$$I = \frac{q}{t}$$



UNIT: The S.I unit is Ampere (A).

DIRECTION OF CURRENT:

ELECTRONIC CURRENT: Normally current (in solids) forms due to flow of electrons which move from negative terminal (low potential) to the positive terminal (high potential) of a battery, this is called electronic current.

CONVENTIONAL CURRENT: We take the direction of current from positive terminal (high potential) to negative terminal (low potential) of the battery this is called conventional current.

OHM'S LAW:

STATEMENT:

"If physical state and temperature of the conductor remains constant then current passing through the conductor is directly proportional to the potential difference applied across the conductor"

MATHEMATICAL FORM:

Consider a conductor in which current "I" passes due to some potential difference "V" applied across the conductor then according to the law

$$I \propto V$$

$$I = KV$$

$$I\left(\frac{1}{K}\right) = V$$

Where *K* called conductance of a conductor and "***1/ K=R***" and "R" is called resistance of the conductor.

$$IR = V$$

or,

$$V = IR$$

LIMITATION OF THE LAW:

The limitations of Ohm's law are,

1) Dimensions of conductor must be same
2) Temperature of conductor must be same
3) It holds only for metallic conductor

RESISTANCE:

"The opposition in the flow of current is called resistance."

Resistance in a conductor is due to collisions of electron with the vibrating atoms of the conductor. If the temperature of the conductor increases then the amplitude of vibration of atoms increases which results in increase of resistance.

UNIT: The S.I unit is ohm (Ω).

RESISTIVITY/SPECIFIC RESISTANCE

"The resistance of unit cubic (one cubic meter) of a material is called resistivity."

Unit: S.I unit is "Ω-m".

MATHEMATICAL FORM

Consider a conductor of length 'L' cross sectional area 'A' and resistance 'R' then it is experimentally proved that resistance of the conductor depends on following factors.

- Resistance of conductor is directly proportional to the length of conductor.

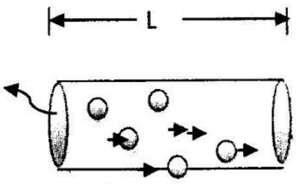
$$R \propto L \quad \text{----------} \ (1)$$

Resistance of the conductor is inversely proportional to the cross sectional area of the conductor

$$R \propto 1/A \quad \text{------------} \ (2)$$

- Nature of the conductor

Comparing (1) and (2) we get,



$$R \propto L / A$$

$$R = \rho \ L / A$$

$$? = \frac{??}{?}$$

Where, 'ρ' represents the resistivity of the conductor.

UNIT:

The S.I unit of resistivity is "Ω - m"

EFFECT OF TEMPERATURE ON RESISTIVITY

As we know that in solids the molecules are vibrating about their mean position. So when a conductor is heated, the K.E of its molecules increases and it causes increase in amplitude of vibration. The number of collision suffered by free electrons decreases the drift velocity of these free electrons and so increases the resistance of conductor.

Consider a conductor whose resistance at 0°C is R_0. If the temperature rises to T °C then resistance increases to R_T,

It is experimentally proved that change in resistivity is directly proportional to the change in temperature

$$\Delta R \propto \Delta T \quad \text{----------------} \quad (1)$$

Similarly change in resistance is directly proportional to the initial resistance.

$$\Delta R \propto R_0 \quad \text{--------} \quad (2)$$

Combining (1) and (2)

$$\Delta R \propto \Delta T \, R_0$$

$$\Delta R = \alpha R_0 \Delta T$$

Where, α is called *temperature coefficient of resistance* **or** *temperature coefficient of resistivity*.

But, $\Delta R = R_T - R_0$

$$R_T - R_0 = \alpha R_0 \Delta T$$

$$R_T = R_0 + \alpha R_0 \Delta T$$

$$R_T = R_0 (1 + \alpha \Delta T)$$

Since Resistance is directly proportional to Resistivity there we may derive as,

$$\rho_T = \rho_0 (1 + \alpha \Delta T)$$

TEMPERATURE COEFFICIENT OF RESISTIVITY

"Fractional change in resistivity per degree rise in temperature is called temperature coefficient of resistivity."

Mathematically, $\alpha = \dfrac{\Delta R}{R_O \, \Delta T}$ or $\alpha = \dfrac{\Delta \rho}{\rho_O \, \Delta T}$

UNIT: The S.I unit is K^{-1} or $°C^{-1}$.

COMBINATION OF RESISTORS:

PARALLEL COMBINATON:

"When the resistors have two terminals common and share the same potential difference then combination is called parallel combination."

EQUIVALENT RESISTANCE:

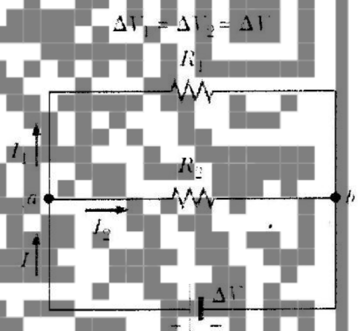
Consider "n" Resistors having resistance R_1, R_2 to R_n are connected to a battery of potential difference "V" in parallel combination.

Since all resistors are directly joint to the battery, therefore their voltage will be equal to the voltage of the battery.

$$V_1 = V_2 = V_3, \ldots\ldots\ldots, V_n = V \text{ ---------- } (1)$$

Different magnitude of current pass through each resistor according to its resistance and their sum gives the total current, If I_1 ,I_2 , I_3,..........,I_n are the currents flowing through different resistors then we can write

$$I = I_1 + I_2 + \ldots\ldots\ldots + I_n$$



But according to Ohm's law $I = V / R$ hence,

$$\frac{V}{R_e} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} + \ldots\ldots + \frac{V}{R_n}$$

Using equation (1) we have,

$$\frac{V}{R_e} = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots + \frac{1}{R_n}\right)$$

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots + \frac{1}{R_n}$$

RESULT:

This equation shows that reciprocal of equivalent resistance of parallel combination is equal to sum of reciprocal of all resistance.

SERIES COMBINATION

"When resistors have one terminal in common and share different potential difference then combination is called series combination."

EQUIVALENT RESISTANCE:

Consider "n" resistors having resistance R_1, R_2 ---------, R_n are connected to a battery of potential difference V in series combination.

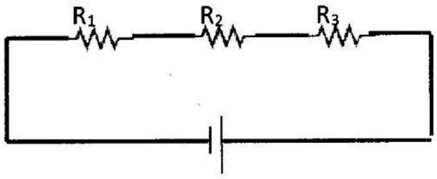
Since all resistors are joint in a row to the battery, therefore their current will be same.

$$I_1 = I_2 = I_3 = \text{-------------} = I_n = I; \text{ ---------- } (1)$$

Different potential differences appear across each resistor according to its resistance and their sum gives the total potential difference of the battery then we can write,

$$V = V_1 + V_2 + \text{-------------} + V_n$$

But $V = IR$ hence,



$$I\,R = I_1R_1 + I_2R_2 \text{-----------} + I_nR_n$$

Using equation (1) we have,

$$I\,R = I\,(R_1 + R_2 + \text{--------------} + R_n)$$

$$\mathbf{R_e = R_1 + R_2 + \text{---------} + R_n}$$

RESULT: This equation shows that equivalent resistance of series combination is the sum of all resistance.

INTERNAL RESISTANCE:

"When current passes through a source of potential difference, such as a battery, then it experiences some opposition within the source this opposition in the flow of current is called internal resistance."

ELECTROMOTIVE FORCE (emf):

"It is the energy supplied to a unit charge to move through an electrical circuit."

OR

"It is the potential difference appears across the two terminals of a source (battery) when no any external resistance (or infinite resistance) is connected across it."

MATHEMATICAL FORM

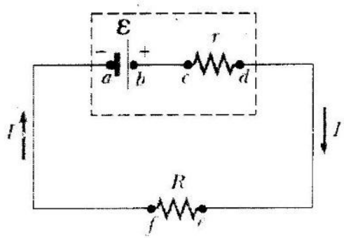
Let us considering a circuit with source E in which resistance R is connected across it. The current I flows through resistance R and internal resistance of source.

By using Ohm's Law current I through the circuit can be expressed as

$$I = \frac{\xi}{R + r}$$

$$\xi = I\,(R + r)$$

$$\xi = I\,R + I\,r$$



- ⇨ ξ = Electromotive force (emf)
- ⇨ IR = Voltage (Terminal Voltage) to derive the current I through the external resistor.
- ⇨ Ir = Voltage loss across internal resistance (r) of the battery to derive current across it

P

$$E = V + I r$$

TERMINAL VOLTAGE:

"The potential difference appears at the two terminal of a source in the presence of internal resistance and a current is passing through it, is called terminal voltage."

$$V = \xi - Ir$$

POWER DISSIPATION IN RESISTORS:

When a resistor conductor is connected to a battery its electrons acquire energy and Start to move. During motion they collide with other electrons and the atoms of resistors. In this way Potential Energy of electrons is converted into vibrational energy of the atoms.

According to Law of Conservation of energy, the energy lost by electrons is gained by the atoms of conductor (resistor) in the form of heat. The energy lost is,

$$Power = \frac{Work}{Time}$$

But work done by the battery on charge "*q*" with a potential difference "*V*" is equal to qV therefore,

$$P = \frac{qV}{t}$$

We know that I = Q / t hence,

$$P = IV \text{ ------- } (i)$$

This expression gives the Electrical Power supplied to an electrical instrument.

Using ohm's law $(V = I R)$ we can write (*i*) as,

$$(i) \Rightarrow P = I(I R)$$

$$P = I^2 R \text{ ------ } (ii)$$

(Or) By Using ohm's law $\left(I = \frac{V}{R}\right)$ we can write (*i*) as

$$(i) \Rightarrow P = \frac{V}{R} V$$

$$P = \frac{V^2}{R} \text{ ------- } (iii)$$

Equation (*ii*) and (*iii*) gives the Power Dissipated by electrical instrument or conductor.

CHAPTER-13 **MULTIPLE CHOICE QUESTIONS**

From Past Papers

2000

Q#4 (a) (i) Resistors of 2ohms, 3ohms and 4ohms are connected in series. If the current flowing through one of tem is One ampere, what is the current through other resistors: ____________. (*Fill in the Blank*) *{1 Ampere}*

Q#4 (a) (ii) When 'V' volts battery is connected across the bulb and if current 'I' is passed through it then its power will be:

* VI * V/I * V^2I * VI^2

Q#4 (a) (iii) Resistivity is reciprocal of conductivity. (*True or False*)

2001

Q#4 (a) (i) If the wire of a uniform area of cross section is cut into two equal parts, the resistivity of each part will be:

* Halved * Doubled * Remain the same * NOTA

Q#4 (a) (ii) All electrical appliances are connected in parallel to each other between the main line and the neutral wire to get:

* same current

* same potential difference

* different current and same potential differences

* none of the above

Q#4 (a) (iii) The terminal potential difference of a battery is equal to its e.m.f when its internal resistance is:

* Zero * Very high * Very low * None of above

2002 (Pre Medical)

Q#4 (a) (i) The rate of transfer of charge through a circuit is called:

* Resistance * Current * Potential difference * Energy

Q#4 (a) (ii) Kilowatt hour is unit of:

P

* Power *Conductivity *Electrical energy *Receptivity

Q#4 (a) (iii) With the increase of temperature the resistance of semi-conductor:

* increases *decreases * remains constant

2003 (Pre Medical)

Q#4 (a) (ii) Total potential difference across the combination of three cells becomes maximum when:

* All the three cells are connected in series.
* All the three cells are connected in parallel.
* Two cells are connected in series and the third cell in series with the combination.
* Two cells are connected in series and the third cell in series with the combination.

Q#5 (a) (iii) One-Kilo-Watt-Hour is equal to

* 3.6×10^5 J * 36×10^5 J * 36×10^6 J * 3.6×10^4 J

2003 (Pre Engineering)

Q#3 (a) (iii) A resistor carries a current I. The power dissipated as P. The power dissipated if the same resistor carries the current 3I is:

* P * 3P * P/3 * 9P

Q#4 (a) (iii) Ohm's law is obeyed in:

*electron tube *semiconductor *metallic conductor *all of above

2004

Q#4 (a) (i) The resistance of 3Ω, 5Ω and 7Ω are connected in parallel. If 0.3V be the potential difference between the ends of 3Ω resistor, the potential difference across other resistors is:

* 0.5 V * 0.7 V * 1.2 V * 0.3 V

Q#6 (a) The dimension of resistance is $ML^2T^{-3}A^{-2}$ (*True or False*) *{True}*

2005

Q#4 (a) (ii) The maximum resistance in an A.C circuit is offered by:

Ph

* Capacitor * Solenoid * Electromagnet * Electric Bulb

Q#6 (a) (i) The power dissipated in a resistance is given by:

* IV * V^2/R * I^2R * All of these

Q#6 (a) (iii) The commercial unit of electrical energy is:

* joule * kilowatt * kilowatt hour * mega watt

2006

Q#3 (a) (i) The rate of transfer of charge through a circuit is called:

* Resistance * Current *Potential difference * All of the above

Q#4 (a) (i) The power dissipated in a resistance is given by

* P = V R * $P = V^2/R$ * $P = I R^2$ * None of these

2007

Q#3 (a) (iii) When a resistor carries a current "I" the power dissipated by it is "P". if the same resistor carries the current of "3 I" the power dissipation will be

* P * P/3 * 3P * None of the above

Q#4 (a) (ii) One-Kilo-Watt-Hour is equal to

* 3.6×10^5 J * 360×10^6 J * 3.6×10^4 J * 36×10^5 J

Q#5 (a) (iii) If the wire of a uniform area of cross section is cut into two equal parts, the resistivity of each part will be:

* Halved * Doubled * Remain the same * NOTA

2008

Q#5 (a) (ii) The resistance of 2Ω, 5Ω, 7Ω and 9Ω are connected in parallel. If the potential difference across the 5Ω resistance is 5V, the potential difference across 9Ω resistance will be:

*9 V *5 V *2.5 V *1.5 V

Q#5 (a) (iii) In a house circuit all the electrical appliances are connected in parallel with the phase and the neutral to get:

* same current, and different potential difference

* different current but same potential difference

* different current and different potential differences

* same current and same potential differences

2009

Q#3 (a) (iii) The E.M.F. of three cells, each of 2 volts, in parallel will be:

* 6 V   * 2 V   * 8 V   * Zero V

Q#6 (a) (ii) In the relation I = KV, K stands for:

* Conductance   * Resistivity

* Specific Resistance   * Permeability

Q#6 (a) (iii) The electrical energy dissipated as heat in a resistor is given by:

* I^2R * V^2R * I^2Rt * V^2Rt

2010

Q#1 (xi) The commercial unit of electrical energy is:

* ohm   * watt   * kilowatt-hour * ampere

Q#1 (xiii) The electrical energy dissipated as heat in a resistor is given by:

* I^2R * I^2Rt * V^2R * V^2Rt

2011

Q#1 (ii) Two wires of resistance R_1 and R_2 are connected in a series in a circuit. If R_1 is greater than R_2 the heating would be:

* more in R_1 * same in R_1 and R_2

* more in R_2 * all of these

Q#1 (xvii) A copper wire having resistivity ρ is stretched in such a way that its diameter reduces to half of that of the original wire the new resistivity will be:

* halved   * doubled   * the same   * four fold.

2012 Resistors of 2Ω, 3Ω, 4Ω and 5Ω are connected in series. If the current flowing through 2Ω resistor is 1 A, the current through the other resistors will be

*4 A   *1 A   *14 A   *0.1 A

2013 (xiv) Resistors of 3Ω, 5Ω and 7Ω are connected in parallel. If the potential difference Across5Ω resistors 6 V, the potential difference across the other resistors is:

*4 volt *6 volt * 8 volt *10 volt

(v) A wire of uniform cross-sectional area is cut into three equal segments, then the resistivity ρ of each segment will be

* ½ρ * ⅓ ρ * 3 ρ * same as the hole wire

2014

(v) Resistance of a wire does not depends on the:

*Temperature *Length *Area *Electric current

2015

(vii) Resistors of 5Ω and 10Ω are connected in parallel. If the P.D. across 5Ω resistor is 6 volts, the P.D. across resistor will be:

* 3 volts * 6 volts * 9 volts * 12 volts

(viii) A battery of e.m.f.(E) has an internal resistance (r). If a current (I) is drawn from it, then its terminal potential drop (V) is given by:

* V=E-Ir *V=E+Ir *V=IR *V=Er

CHAPTER-13

NUMERICALS

FROM PAST PAPERS

1995

Q.3(c) A platinum wire of diameter 0.2mm is wound to make a resistor of 4 Ω. How long a wire is needed for this purpose? (ρ =11x10^{-8}Ωm) **(1.1424m)**

1996

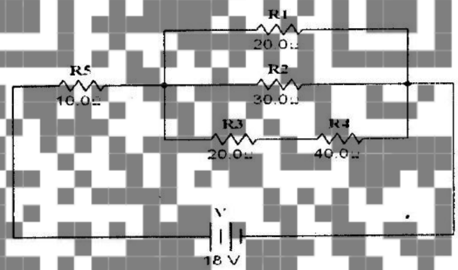
Q.4(c) The resistance of a copper wire is 1.27Ω at 20°C. Find its resistance at 0°C and at 100°C. The temperature coefficient of resistivity of copper is α = 0.0039°C^{-1} **(1.178 Ω, 1.637Ω)**

2000

Q.4(d) You are given three resistors each of 2 ohms. How would you arrange these resistors to obtain the equivalent resistances of (i) 1.33 ohms (ii) 3 ohms (iii) 6 ohms? Also prove the result mathematically.

2001

Q.3(d) Find the equivalent resistance and the current through R_3& R_4. Given R_1 = 20Ω, R_2 = 30Ω, R_3 = 20Ω, R_4 = 40Ω, R_5 = 10Ω **(20Ω, 15A)**



2002 (Pre Med. group)

Q.6(d) A battery of 24V is connected to a 10Ω load and current of 2.2 amp is drawn; find the internal resistance of the battery and its terminal voltage. **(0.9Ω, 22V)**

2002 (Pre Engg. group)

Q.3(d) The resistance of a tungsten wire used in a filament of a 60 watt bulb is 240Ω when the bulb is hot at a temperature of 2020°C, what would you estimate its resistance at 20°C? (The temperature coefficient of tungsten α 0.0046/°C) **(25.4Ω)**

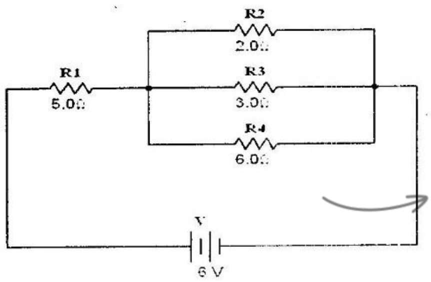
2003 (Pre Med. group)

Q.3(d) Find the equivalent resistance in the given circuit, current I and potential difference between 'a' and 'b':

R_1 = 5Ω

R_2 = 2Ω

R_3 = 3Ω



$R_4 = 6\Omega$

$V = 6$ volts **(1A, 5V, 6Ω)**

2003 (Pre Engg. group)

Q.3. (d) A 50 ohm resistor is to be wound with platinum wire, 0.1 mm in diameter. How much wire is needed ($\rho = 11 \times 10^{-8}\ \Omega m$)? **(3.57 m)**

2005

Q.6. (d) Two resistances of 10Ω and 50Ω are connected in series with a 6 volt battery. Calculate:

i) The charges drawn from the battery per minute

ii) The power dissipated in 10Ω resistance. **(6C, 0.1W)**

2006

Q.4. (d) A 50 ohm resistor is required from a copper wire, 0.2 mm in diameter. What is the length of the wire needed? ($\rho = 1.6\times10^{-8}\ \Omega$-m) **(98.125m)**

2008

Q.3. (d) A rectangular block of iron has the dimensions 1.2cmx1.2cmx15cm.

(i) What is the resistance of the opposite square ends?

(ii) What is the resistance between two of the rectangular faces?

(The resistivity for iron at room temperature is 9.6x10–8Ωm) **($1 \times 10^{-7}\Omega$, $6.4 \times 10^{-8}\Omega$)**

2009

Q.6. (d) In the given diagram $R_1 = R_2 = 4\ \Omega$ and $R_3 = 6\Omega$. Calculate the current in the 6Ω resistor. **(0.37A)**

2010

Q.2. (xi) A water heater that will deliver 1 kg of water per minute is required. The water is supplied at 20°C and an output temperature of 80°C is desired. What should be the resistance of the heating element in water if the line voltage is 220V? (Sp. Heat of water = 4200 J/kg K). **(11.52Ω)**

2011

Q.2. (x) A rectangular bar of iron is 2 cm x 2 cm in cross –section and 20 cm long. What is the resistance of the bar at 500°C if $\rho = 11\times10^{-8}\Omega$-m and $\alpha = 0.0052K^{-1}$? **($1.98 \times 10^{-4}\Omega$)**

2012 You are given three resistors each of 2Ω. How would you arrange these to obtain equivalent resistance of: (a) 1.33Ω (b) 3Ω (c.) 6Ω. Verify the results mathematically.

2013 Two resistors of 5Ωand 2Ω are connected in parallel with a 9V battery. Calculate the current and power dissipated in each resistance.

2014

Q2(ii) A rectangular bar of iron is 2 cm X 2cm in cross section an 20 cm long. What will be its resistance at 500°C? If $\alpha = 0.0052\ K^{-1}$ and $\rho = 11 \times 10^{-8}\Omega m$

2015

Q2(vii) A 50 ohm resistor is to be wound with platinum wire, 0.1 mm in diameter. How much wire is needed ($\rho = 11 \times 10^{-8}\ \Omega m$)? **(3.57 m)**

Chapter 14

Magnetism and Electromagnetism

Magnet:

It is a natural substance which attracts the things made up of iron, cobalt and nickel. If it is suspended freely it always points towards geographical north and south.

Magnetic poles:

Every magnet has two poles, a North seeking pole and a South seeking pole on its opposite ends. If a magnet is allowed to rotate freely it will come to a rest position with one end facing geographical North and the other end facing geographical South. Like electric charges, opposite poles attracts each other and same poles repel each other.

Magnetic Substances:

Those substances which are attracted by magnet or can be magnetized are called magnetic substances. There are three magnetic substances.

I) Iron
i) Cobalt
iii) Nickel

Ferromagnetic Substances Or Ferro-magnets:

Those substances which behave like a magnet in the presence of a strong magnetic field are called "Ferromagnetic Substances" or "Ferro-magnets".

Soft Ferromagnetic Substances:

Those ferromagnetic substances which lose their magnetic effect when removed from the magnetic field are called soft ferromagnetic substances. e.g. soft iron.

Hard Ferromagnetic Substances:

Those ferromagnetic substances which retain their magnetic effect when removed from magnetic field are called hard ferromagnetic substances. e.g. steel.

Magnetic Field:

The region around the magnet in which its effect can be experienced is called magnetic field.

Magnetic Force:

The force experienced by a magnetic substance due to a magnet is called magnetic field.

Magnetic Lines of Force:

In the magnetic field the effect of magnet is caused by special lines of force which are called magnetic lines of force.

Properties of Magnetic Lines of Force:

i) The magnetic lines of force start from the north pole and end at south pole.
ii) Inside the magnet, these lines continue from the South Pole to the North Pole.
iii) They do not intersect each other.
iv) They pass through iron more easily as compared to air.

Magnetic Field of a Straight Wire:

When a current is flowing in a straight wire, a magnetic field is produced around the wire. It consists of concentric circular magnetic lines.

Experimental Proof:

A wire is passed vertically though a hole in a cardboard. The two ends of wire are connected to the

P

terminals of a cell. Fine iron fillings are sprinkled on the cardboard. The current is switched on and the cardboard is tapped gently. The iron fillings set in a series of concentric circles about the wire as centre. It is clear that the magnetic field is formed due to the current carrying wire in the form of circular lines of force as shown in figure.

Note:

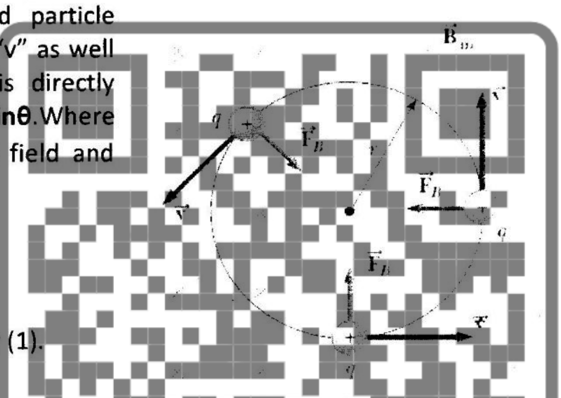
When electric charges are at rest they exert electrostatic force of attraction or repulsion on each other. When the charges are in motion they still exert these electrostatic forces but, in addition, magnetic forces appear because of motion. Isolated moving positive or negative charges create both electric and magnetic fields but an electric current through a conductor produces only a magnetic field because the electric field of moving electron is neutralized by the field of fixed protons in the conductors.

Force On A Moving Charge In A Magnetic Field:

X (cross) => Directed Into paper

• (dot)=>Directed out of paper

Let an isolated point charge "+q" moving with velocity "*v*" be projected across a uniform magnetic field of flux denitty "*B*". It has been observed experimentally that the charged particle experiences a force which is perpendicular to velocity "v" as well as magnetic field "B".The magnitude of this force is directly proportional to the magnitudes of "**q**", "**v**", "**B**" and **Sinθ**.Where "**θ**" is the angle between the directions of magnetic field and velocity of the charge.



ACTIVE FIGURE 29.7

Wh... cle is perpendicular to a uniform magnetic field, the particle moves in a circular path in a plane perpendicular to $\vec{B}$. The magnetic force $\vec{F}_B$ acting on the charge is always directed toward the center of the circle.

$$F \propto qvBSin\theta$$

$$F = (constant)qvBSin\theta$$

In this case the constant of proportionality is unity (1).

$$F = (1)qvBSin\theta$$

$$\boxed{F = qvBsin\theta}$$

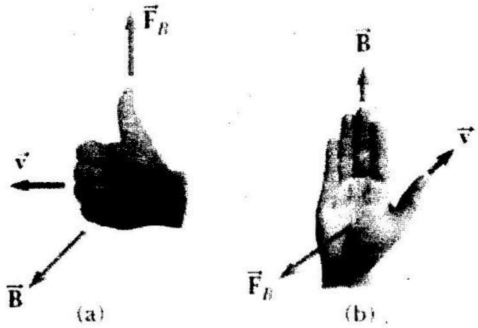
Vector Form:

In vector form, above expression can be written as:

$$\vec{F} = q(\vec{V} \times \vec{B}) - - - - - - - - (i)$$

Equation (i) applies to a positive charge, for a negative charge particle, force will be given as:

Direction of force:



Two right-hand rules for determining the direction of the magnetic force $\vec{F}_B = q\vec{v} \times \vec{B}$ acting on a particle with charge q moving with a velocity $\vec{v}$ in a magnetic field $\vec{B}$. (a) In this rule, your fingers point in the direction of $\vec{v}$, with $\vec{B}$ coming out of your palm, so that you can curl your fingers in the direction of $\vec{B}$. The direction of $\vec{v} \times \vec{B}$, and the force on a positive charge, is the direction in which your thumb points. (b) In this rule, the vector $\vec{v}$ is in the direction of your thumb and $\vec{B}$ in the direction of your fingers. The force $\vec{F}_B$ on a positive charge is in the direction of your palm, as if you are pushing the particle with your hand.

Magnetic Force Provides Centripetal Force To A Moving Charge. WHY???

Force of magnetic field on a moving charge is perpendicular to velocity; therefore this force cannot change the speed (magnitude of velocity). It only changes the direction of motion. Hence this force provides centripetal force to a moving charge due to which the charge describes a circular path in a uniform magnetic field.

Minimum And Maximum Magnetic Force On A Moving Charge:

The magnitude of magnetic force is: $F = qvB\sin\theta$

i. If the charge particle moves parallel to (or) opposite to the direction of magnetic field i.e. ($\vartheta = 0°$ or $180°$) $\because \sin 0° = \sin 180° = 0$

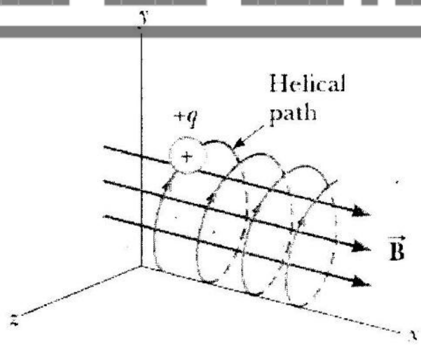
Then, $\because F = 0$. (No force experience by the charge particle)

ii. If the charge particle is moving at right angle (perpendicular) to the magnetic field, i.e.($\vartheta = 90°$). $\because \sin 90° = 1$

Then, $F = qvB$ (Maximum force experience by the particle).

Radius of The Circular Path Followed By The Moving Charge Particle In a Magnetic Field:

When a charged particle having "q" magnitude of charge, "m" mass moving with a velocity "v" enters into a magnetic field whose strength is "B". If ϑ be the angle between v and B then due to the component of v parallel to B (i.e. $v\cos\vartheta$) particle moves parallel to B and due to the component of v perpendicular to B (i.e. $v\sin\vartheta$) the particle experiences a magnetic force in a direction perpendicular to both v and B which provides necessary



ACTIVE FIGURE 29.8

A charged particle having a velocity vector that has a component parallel to a uniform magnetic field moves in a helical path.

centripetal force in this way it moves along a circular path.

Derivation for Radius:

$$F_m = F_{cp}$$

$$q\,v\,B\sin\theta = \frac{m\,(v\sin\theta)^2}{r}$$

$$r = \frac{mv\sin\theta}{qB}; \;-------(i)$$

Due to the superposition of linear and circular motion of the charged particle its path is found in a helical shape whose radius is described by equation (*i*).

Magnetic Induction:

Consider a positive charge which is entered in a magnetic field perpendicularly with velocity "*v*" if the strength of magnetic field is "B", then force of induction is given by;

$$F_m = qvB\sin 90^0$$

$$F_m = qvB(1)$$

$$F_m = qvB$$

$$\frac{F_m}{qv} = B$$

$$B = \frac{F_m}{qv}$$

If q = 1coulomb and v = lm/s

Then:

$$B = \frac{F_m}{(1)(1)}$$

$$B = F_m$$

Hence;

"when a particle having 1coulomb charge on it and it enters perpendicularly in a magnetic field with velocity lm/s, then magnetic force acts on this particle is called "Magnetic Induction".

Unit of Magnetic Field of Induction:

Unit of "B" is Tesla (also Weber/m^2).

Force on a charge particle in a magnetic field is:

$$F = qvBSin\theta$$

$$B = \frac{F}{qvSin\theta}$$

Hence

$$1Tesla = \frac{1Newton}{1Coulomb \times 1m/s}$$

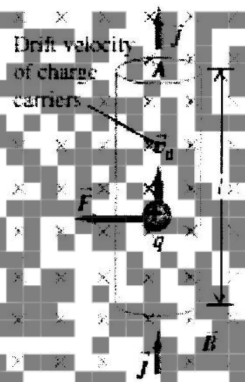
$$1Tesla = \frac{1Newton}{\frac{1Coulomb}{s} \times 1m}$$

$$1Tesla = \frac{1Newton}{1ampere \times 1m}$$

$$1Tesla = 1\frac{N}{A.m}$$

Force On A Current Carrying Conductor In A Uniform Magnetic field:

In order to derive a formula for force experienced by a current carrying conductor, consider a straight current carrying conductor of length "L" and area of cross-section "A" subjected to a uniform magnetic field of induction "B" such that the magnetic field makes a certain angle "θ" with the direction ofcurrent "I"



$$\therefore \text{Volume of the conductor} = A \times L$$

Let "n" be the number of free electrons per unit volume of the conductor causing current "I, then the total number of free electrons flowing through the conductor will

$$\text{Total number of free electrons} = n\,AL$$

If "e" is the charge on each electron, then the total charge flowing through the conductor is given by:

$$q = nALe$$

Force experienced by charge "q" flowing through the conductor or in this case force experienced by the conductor is given by:

$$\vec{F} = q(\vec{V} \times \vec{B})$$

$$\vec{F} = nALe(\vec{V} \times \vec{B})$$

Straight current carrying conductor subjected to a uniform magnetic field at some angle

If charge "q" takes "t" seconds to move from one end of conductor to the other then its velocity "$\vec{V}$" is given by:

$$\vec{v} = \frac{\vec{L}}{t}$$

$$\vec{F} = nALe\left(\frac{\vec{L}}{t} \times \vec{B}\right)$$

$$\vec{F} = \frac{nALe}{t}\left(\vec{L} \times \vec{B}\right)$$

$$\frac{nALe}{t} = \frac{q}{t} = I \qquad \text{(q = total charge passed)}$$

Where, "I" is the current flowing through the conductor.

$$\because \vec{F} = I\left(\vec{L} \times \vec{B}\right)$$

As the magnitude of force changes with the inclination of theconductor with respect to the magneticfield, therefore, $\vec{L}$ is taken as a vector, its magnitude is equal to length of the conductor and its direction is same as the direction of conventional current.
The magnitude of force experienced by a straight current carrying conductor in a uniform magnetic field is given by

$$F = ILB \sin\theta$$

When conductor is perpendicular to the field $\theta = 90^\circ$, force experienced by the conductor will be maximum and is given by:

$$F = ILB \qquad (Sin 90^\circ = 1)$$

When the conductor is held parallel to the field $\theta = 0^\circ$ then;

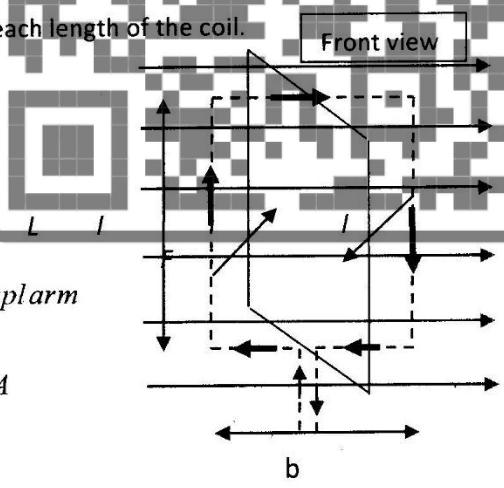
$$F = 0 \qquad (Sin 0^\circ = 0)$$

"Force experienced by a current carrying conductor in a magnetic field is always perpendicular to length of the conductor as well as the magnetic field and its direction can be determined by right hand rule".

Torque on a Current Carrying Coil In A Uniform Magnetic Field:

When current is passed through a coil placed in a magnetic field, acouple is developed which rotatesthe coil. A coil "ABCD" is placed in auniform magnetic field $\vec{B}$ and capableof rotation about an axis xx'.

Let,
L=lengthof coil
b = breath of the coil.
As current I passes through the coil, force is produced on each length of the coil.



$$\because \vec{F} = I\left(\vec{L} \times \vec{B}\right)$$

$$F = BIL \sin 90^\circ$$

$$F = BIL\ (1)$$

$$F = BIL$$

Torque of couple is given by,

$$\tau = Force \times Couplarm$$

$$\tau = F \times b$$

$$\tau = BIL \times b = BIA$$

For coil of N turns;

$$\tau = BIA \times N$$

$$\tau = BINA \ldots\ldots\ldots\ldots\ldots\ldots (i)$$

Eq(i) applies when the plane of the coil is parallel to the direction of magnetic field. When the plane of coil makes an angle "α" with the direction of magnetic field then;

$$\tau = \text{Force} \times \text{Couple arm}$$
$$\tau = \text{BIL} \times \text{b} \cos\alpha$$
$$\tau = \text{BIA} \cos\alpha \qquad (\because \text{A} = \text{Lb})$$

For N turns;

$$\tau = BINA \cos\alpha$$

- Torque is maximum when the plane of coil is parallel to the magnetic field i.e. when $\alpha=0$.
- Torque is zero when the plane of the coil is perpendicular to the direction of magnetic field i.e. $\alpha= 90$.

Magnetic Flux:

The number of magnetic lines of force passing normally through the surface is called "Magnetic flux".

Mathematical Definition:

Magnetic flux is equal to the dot product of magnetic field of induction "$\vec{B}$" and the vector area "$\Delta\vec{A}$" of the surface, provided the magnetic field of induction is uniform over the given area of the surface. It is denoted by "ϑm".

$$\boxed{\Delta\Phi_m = \vec{B}.\Delta\vec{A}}$$

$$\Delta\Phi_m = B\,\Delta A \cos\theta$$

The unit of magnetic flux is "Weber".

Magnetic Flux Density:

"The magnetic flux per unit area of a surface which is held normal to the field is called Magnetic Flux Density"

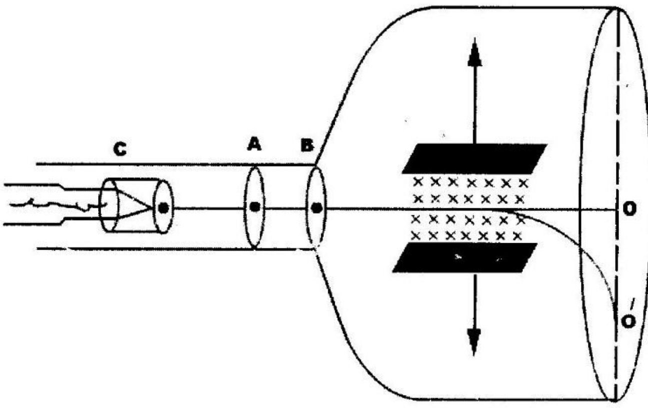
It is denoted by "B".

$$B = \frac{\Delta\Phi_m}{\Delta A}$$

The Unit of magnetic flux density is "W/m^2" or "Tesla".

J.J Thomson's Experiment:

In 1897, Sir J.J Thomson derived an expression for ratio between the charges of electron to the mass of electron. For this he used a device which is shown in following figure.A tungsten filament is connected at one end of device which is heated up with a low tension battery. Electrons are emitted out in dispersive form from the filament. These electrons passed through from a cylinder "A" to make them inform of a line. A negative potential is applied across the cylinder "A" to make electrons in a line, then these electrons again passed through to two plates which have narrow hole on it. After passing through the plates, the electrons are in form of a straight line.



A magnetic field "$\vec{B}$" is applied perpendicularly in the tube. J.J Thomson assumed that, when electrons emit out from plates "C" their velocity is zero, and

P

K.E. is also zero. i.e. KE= 0. A voltage "V" is applied between plate "C" and cathode, after this the KE of electrons will be "1/2mv²" and their velocity is "v".

According to law of conservation of energy:

$$\Delta KE = \Delta PE \qquad \because V = \frac{\Delta PE}{q}$$

$$\left(\frac{1}{2}mv^2 - 0\right) = Ve \qquad Vq = \Delta PE$$

$$\frac{1}{2}mv^2 = Ve \qquad \because Ve = \Delta PE$$

$$v^2 = \frac{2Ve}{m}$$

$$v = \sqrt{\frac{2Ve}{m}} \ldots\ldots\ldots\ldots(i)$$

This eq shows the velocity of electrons. When these electrons enter in magnetic field, a force of induction acts on these electrons. This force is given by;

$$\vec{F}_m = q(\vec{v} \times \vec{B})$$

Since: $\vec{v} \perp \vec{B}$, therefore: θ = 90°

$$F_m = e(vBSin\theta)$$

$$F_m = evBSin90$$

$$F_m = evB(1)$$

$$F_m = evB$$

When electrons enter in magnetic field they move on a circular path of radius "r". Magnetic force provides a centripetal force.

i.e.

$$F_m = F_c$$

Putting F_m= *evB and* $F_c = \frac{mv^2}{r}$

$$evB = \frac{mv^2}{r}$$

$$eB = \frac{mv}{r}$$

$$\frac{e}{m,} = \frac{v}{Br} \ldots\ldots\ldots\ldots(ii)$$

Putting $v = \sqrt{\frac{2Ve}{m}}$

$$\frac{e}{m}=\frac{\sqrt{\frac{2Ve}{m}}}{Br}$$

$$\frac{e}{m}=\sqrt{\frac{2Ve}{m}}\times\frac{1}{Br}$$

Squaring ob both sides.

$$\frac{e^2}{m^2}=\frac{2Ve}{m}\times\frac{1}{B^2r^2}$$

$$\frac{e^2}{m^2}=\frac{e}{m}\times\frac{2V}{B^2r^2}$$

$$\frac{e}{m}=\frac{2V}{B^2r^2}\ldots\ldots\ldots\ldots(iii)$$

Particle Selector Method To Find Velocity Of Electrons:

J.J Thomson assumed that when electrons emitted out from plate "C" their velocity is zero. Later scientists rejected this assumption. To find the correct value of velocity of electron a method is designed, which is called "Particle Selector Method".

In this method an electric field also applied in the tube which is opposite in direction of magnetic field. This field is set such a way that its strength is equal to the strength of magnetic field.

i.e $F_m = F_e$

$\therefore E=\frac{F_e}{q}$, $Eq=F_e$, $\therefore Ee=F_e$

$$evB = Ee$$

$$v=\frac{E}{B}$$

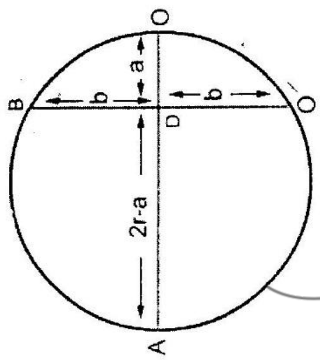
This value of "V" putting eq(ii)

$$\frac{e}{m}=\frac{v}{Br}$$

(ii)=> $$\frac{e}{m}=\frac{\frac{E}{B}}{Br}$$

$$\frac{e}{m}=\frac{E}{B}\times\frac{1}{Br}$$

$$\frac{e}{m}=\frac{E}{B^2r}\ldots\ldots\ldots\ldots(iv)$$



Eq (iii) and Eq (iv) reoresent the ratio between charge and mass of an electron.

P

Determination For radius of circular path

If r is the radius of curvature of circular path, 'a' is the distance b/w 'O' and 'O/', and 'b' is the length of region of magnetic field and screen then by using the property of chord:

$$AD \times OD = BD \times DO$$
$$(2r-a)(a)=(b)(b)$$
$$2r\,a - a^2 = b^2$$

Since 'a' is very small as compared to '2r', so we neglect a^2

$$2r\,a = b^2$$
$$r = \frac{b^2}{2a}$$

M.T

Ampere's Law:

Statement:
"The sum of the product of the tangential component of magnetic field of induction and the length of an element of a closed curve taken in a magnetic field is "ι" times the current which passes through the area bounded by this curve".

Mathematical Representation:

$$\sum_{i=1}^{i=n} \left(\vec{B}.\Delta\vec{L}\right)_i = \mu_0 \times I_{enclosed}$$

Proof:

Consider **a** straight current carrying conductor through which current "1" is flowing. Experimentally, it has been observed that the strength of the magnetic field produced at any point near the conductor is directly proportional to twice the current "I" and inversely proportional to the distance "r" from the conductor.

$$B \propto I$$
$$B \propto \frac{1}{r^2}$$

by combining both observations,

$$B \propto \frac{I}{r}$$
$$\mathrm{B} = (\text{constant})\frac{\mathrm{I}}{\mathrm{r}}$$
$$B = \frac{\mu_0}{2\pi}.\frac{I}{r}$$

$\frac{\mu_0}{2\pi}$ Is the constant of proportionality, is known as permeability of free space. The value of "μ_0" is $4\pi \times 10^{-7}$ Web/Amp-m

$$B = \frac{\mu_0 I}{2\pi r} \ldots\ldots\ldots\ldots(i)$$

The above relation shows that the value of "B" at all the points on the circle will be the same if a straight conductor is at the center of the circle. Hence the magnitude of magnetic field of induction "B" at any point on the surface of a circular closed path can be calculated with the help of equation (*i*) the above formula is valid only for a circular closed path surrounding the conductor.

In order to derive a general formula we will divide the circle into a large number of small elements each of length "Δl". The tangential component of magnetic field of induction for an element is "$B\cos\theta$" hence, the product of tangential component of "B" and length of an element "Δl" is given as;

$$(B\cos\theta)\Delta l = B\Delta l\cos\theta$$

But,

The sum of these products for all the elements is given by:

$$\sum \vec{B}.\Delta\vec{l} = \sum B\Delta l Cos\theta$$

In this case the angle θ between $\vec{B}$ and $\Delta\vec{l}$ each and every point is zero, because the circular path coincides exactly with the magnetic field.

$$\sum \vec{B}.\Delta\vec{l} = \sum B\Delta l Cos\theta$$

$$\sum \vec{B}.\Delta\vec{l} = \sum B\Delta l$$

$$\sum \vec{B}.\Delta\vec{l} = B\sum \Delta l$$

$\sum \Delta l = 2\pi r$ (Total length of the circular closed path), But, $B=\frac{\mu_0 I}{2\pi r}$ circular closed path, from equation (i).

$$\sum \vec{B}.\Delta\vec{l} = \frac{\mu_0 I}{2\pi r} \times 2\pi r$$

$$\sum_{i=1}^{i=n} (\vec{B}.\Delta\vec{L})_i = \mu_0 I \ldots\ldots\ldots\ldots\ldots\ldots(ii)$$

Equation (ii) is the general form of Ampere's circular law. It is independent of the distance of elements form the conductor; therefore, it is applicable to closed curve of any shape taken in the magnetic field.

Application of Ampere's Law:

With the help of Ampere's law the magnetic field of induction B due to a current can be determined provided $\sum \vec{B}.\Delta \vec{l}$ for an imaginary closed curve around the conductor is known.

Determination of "B" Inside A Long Solenoid:

A straight cylinder covered by loops of insulated wire, is called "Solenoid". When a strong current passes through the loops a magnetic field is formed inside the "Core" of Solenoid. Outside the core, the field is very weak so that the force of induction is negligible outside the core.
Consider rectangular amperian loop "abcda", the length of its sides are l_1, l_2, l_3 and l_4.

To Determine The Line Integral of Magnetic Induction "$\sum \vec{B}.\Delta \vec{l}$".

The line integral of magnetic induction on Amperian loop "abcda" is given by;

$$\sum \vec{B}.\Delta \vec{l} = \vec{B}.\vec{l_1} + \vec{B}.\vec{l_2} + \vec{B}.\vec{l_3} + \vec{B}.\vec{l_4} ....(i)$$

Now, For $\vec{B}.\vec{l_1}$

since $\vec{B}$ and $\vec{l_1}$ are parallel, therefore (i.e. θ = 0°)

$$\vec{B}.\vec{l_1} = B l_1 \cos 0^o$$

$$\vec{B}.\vec{l_1} = B\, l_1 (1)$$

$$\vec{B}.\vec{l_1} = B l_1$$

Now For $\vec{B}.\vec{l_2}$

since $\vec{B}$ and $\vec{l_2}$ are perpendicular, (i.e. θ = 90°)

$$\vec{B}.\vec{l_2} = B l_2 \cos 90^o$$

$$\vec{B}.\vec{l_2} = B\, l_2 (0)$$

$$\vec{B}.\vec{l_2} = 0$$

Now For $\vec{B}.\vec{l_3}$

since $\vec{B}$ and $\vec{l_3}$ are anti- parallel, therefore (i.e. θ = 180°)

$$\vec{B}.\vec{l_3} = B l_3 \cos 0^o$$

Since at l_3 the field strength is zero (i.e. B = 0)

$$\vec{B}.\vec{l_3} = (0)\, l_3(-1)$$

$$\vec{B}.\vec{l_3} = 0$$

Now For $\vec{B}.\vec{l_3}$

Since, $\vec{B}$ and $\vec{l_4}$ are perpendicular, (i.e. θ = 90°)

$$\vec{B}.\vec{l_4} = B\, l_4 \cos 90^o$$

$$\vec{B}.\vec{l_4} = B\, l_4\, (0)$$

$$\vec{B}.\vec{l_4} = 0$$

Now;

$$\sum \vec{B}.\, \Delta \vec{l} = Bl_1 + 0 + 0 + 0$$

$$\sum \vec{B}.\, \Delta \vec{l} = Bl_1$$

<u>To Determine the Total Current Passes Through Amperian Loop:</u>

Suppose the no. of turns per unit length of solenoid is "n", therefore the no. of turns on "l_1" is "nl_1". If "I" be the current passes through "one" turn, hence the total current enclosed by the rectangular Amperian loop will be "nl_1I".

Now; applying Ampere's Law;

$$\sum \vec{B}.\, \Delta \vec{l} = \mu_0 (I_{enclosed})$$

$$Bl_1 = \mu_0 (nl_1 I)$$

$$B = \mu_0 n I$$

(or)

$$\boxed{B = \frac{\mu_o N I}{L}\ ; \quad \left(\therefore n = \frac{N}{L}\right)}$$

Where, "N" and "L" are the number of turns and length of solenoid respectively.

If a medium other than vacuum is present at the core of the solenoid the value of "B" is given by;

$$B = \mu_m\, n\, I$$

where "μ_m" is the permeability of the medium.

P

$$B = \mu_m n I = \frac{\mu_r \mu_o N I}{L}$$

Toroid:

A toroid or a circular solenoid is a coil of insulated copper wire wound on a circular core with close turns. If acurrent passes through the loops then a strong magnetic field formed inside the core of toroid, its value outside the core is negligible.

Determination of "B" Inside aToroid:

Consider a toroid consist of N closely packed turns and carry a current *I*. imagine a closed circular Amperian loop of radius r inside the coreof toroid. It is evident from symmetry that the field at all points of the closed loop must have the same magnitude and it should be tangential to the loopat all points.

To determine flux density inside the toroid apply Ampere's law which states,

$$\sum \vec{B}.\Delta\vec{l} = \mu_0 (I_{enclosed}) ------ \Rightarrow (i)$$

To Determine The Line Integral of Magnetic Induction "$\sum \vec{B}.\Delta\vec{l}$".

The line integral of magnetic induction on closed circular Amperian loop

$$\sum \vec{B}.\Delta\vec{l} = \sum B\,\Delta l \cos(0^0); \quad \left(\because \vec{B} \,||\, \Delta\vec{l}, \quad \because \theta = 0^0\right)$$

$$\sum \vec{B}.\Delta\vec{l} = \sum B\,\Delta l (1)$$

$$\sum \vec{B}.\Delta\vec{l} = B \sum \Delta l. -------- (ii)$$

Here, $\sum \Delta l$ represents the circumference of Amperian circular loop.

i.e. $\sum \Delta l = 2\pi r$ Substituting this in equation (*ii*)

$$\sum \vec{B}.\Delta\vec{l} = B(2\pi r)$$

To determine The Total Current Passes Through Amperian Loop:

Asthe number of turns enclosed byAmperian loop is "N" and current passes through one loop is "I", then total current enclosed the Amperian loop will be "*NI*".

i.e. Total current$I_{enclosed}$=*NI*

By substituting values of $I_{enclosed}$ and $\sum \vec{B}.\Delta\vec{l}$ in eq (*i*), we get

$$(i) \Rightarrow B(2\pi r) = \mu_0 (NI)$$

$$\boxed{B = \frac{\mu_0 NI}{2\pi r}}$$

This equation shows the value of "B" inside a toroid.

Electromagnetic Induction:

Changing magnetic flux in a coil or loop produces an emf in it. This emf is called induced emf and the phenomenon is knownas electromagnetic induction. Induced emf causes current in the loop which is called inducedcurrent.

Faraday's Law:

According to faraday's law of electromagnetic induction,

1. "An emf is induced in a coil through which the magnetic flux is changing".
2. The magnitude of induced emf depends only upon the number of turns and the time rate of change of flux linked with the circuit.
   Hence,
3. $\xi = -N\dfrac{\Delta\phi}{\Delta t}$

Where "N" represents the number of turn of coil, $\Delta\phi$ is the change of magnetic flux in time Δt. The negative sign is introduced according to Lenz's Law, to indicate the direction of induced emf. "$N\Delta\phi$" is called Flux Linkage.

The emf will be induced as long as there is a change of magnetic flux, no emf will be induced if flux either becomes zero or becomes constant.

Lenz's Law:

According to Lenz's Law, "The direction of induced emf and hence the direction of induced current is always such that it opposes the change which produces it".

P

Mutual Induction:

"When current is changed in coil an emf is induce in a neighboring coil this phenomenon is KNQWN as Mutual Induction".

Consider two coils of insulated wire lying close to each other such that one of the coils is connected to a battery though a rheostat. This coil is known as "primary coil", the other coil is called a "secondary coil".When current in the primary coil is changed with the help of rheostat, the magnetic field produced also changes resulting in a change in magnetic flux passing through the secondary coil. An emf is therefore induce in the secondary coil due to which the galvanometer connected across it shows deflection.The average emf induced in the secondary coil is directly proportional to the rate of change of current in theprimary coil.

$$\xi \propto -\frac{\Delta I}{\Delta t}$$

$$\xi = -M\frac{\Delta I}{\Delta t}$$

Where "M" is the constant of proportionality it is known as "Mutual Inductance". "ΔI_p" Is the change in current in to primary in the time Δt, The negative sign indicates the direction of induce emf in according to Lenz's law, the phenomenon of mutual induction plays an important role in the design of transformers and other heavy electrical machinery.

Mutual Inductance:

"The ratio of emf induced in the secondary coil to the rate of change of current in the primary coil is called Mutual Inductance". Value of mutual inductance depends upon following;

1. No. of turns of the two coils.
2. Distance between two coils.
3. Shape of the coil.
4. Cross-sectional area of coils.
5. Magnetic properties of medium present between coils.

Unit of Mutual Inductance:

The unit of mutual inductance is "Henry".

"Mutual inductance of a pair of coils is said to be 1Henry if an emf of one volt is induced in the secondary coil when current in the primary is changed at the rate of lAmpere per second".

Self Induction:

If the current passes through a coil is suddenly changed then the magnetic flux linked with the coil itself also changes as a result which an emf is induced in it. This phenomenon is known as self induction. The emf induced in the coil also known as back emf because its direction is always such that it opposes the cause of its induction (Len's Law). The magnitude of back emf or self inducedemf is directly proportional to the rate of change of current in the coil:

$$\xi \propto -\frac{\Delta I}{\Delta t}$$

$$\xi = -L\frac{\Delta I}{\Delta t}$$

Where "L" is the constant of proportionality known as self inductance" of the coil.

Self Inductance:

"The ratio of back emf to the rate of change of current in the coil is called Self Inductance".

The value of self inductance depends upon the following;

1. The no. of turns in coil.
2. Area of cross section of the coil.
3. The magnetic properties of the material of coil.

Unit of Self Inductance:

The unit of self inductance is "Henry".

"Self Inductance of a coil is said to be 1 Henry if a back emf of 1Volt is induced in it when the current is changed at the rate of 1 ampere per second".

Motional E.M.F:

When a conductor is moved across a magnetic field, a potential difference is established between its ends. The potential difference is called motional emf.

Explanation:
When the conductor is moved with velocity i3, the free electrons in the conductor also move along with it with same velocity. A force acts on each electron which is given by;

$$\vec{F} = e(\vec{B} \times \vec{v})$$

This force pushes the free electrons from end "b" to end "a" of the wire. As a result upper end becomes more and more positive and lower end negative. Transfer of electrons stops when force F is balanced by the electrostatic attraction between ends "a" and "b". Hence, under given conditions, a certain value of emf is obtained.

Derivation of Formula:

Suppose;

q = Total charge transferred from end "b" to "a".

B =Flux density of uniform magnetic field.

θ =Angle between $\vec{v}$ and $\vec{B}$.

l=Length of the conductor.

Force on charge "q" is;

$$\vec{F} = q(\vec{B} \times \vec{v})$$

$$F = qBv \sin\theta$$

Work done on the charge from "b" to "a"

$$W = F\ l$$

$$W = qBv\sin\theta \times l$$

Motional emf is;

$$\xi = \frac{W}{q} = \frac{qBv\sin\theta \times l}{q}$$

$$\xi = Bvl \sin\theta$$

<u>Electromechanical Device:</u>

An electromechanical device is that which converts electrical energy into mechanical energy or mechanical energy into electrical energy.

<u>Electric Motor:</u> A motor is an electromechanical device which converts electrical energy into mechanical energy:.

<u>Generator:</u> A generator is a device which converts mechanical energy into electrical energy.

<u>A.C Generator:</u>

Principle:

When a coil is rotated in a magnetic field an emf is induced in it. This emf is of alternating nature.

Construction:

A simple A.C Generator consists of a coil of insulated wire which is wound on a soft iron cylinder. It is known as "armature". The ends of the coil are connected to two slip rings. The slip rings are in contact with two separate carbon brushes. The contact with external circuit is made through these carbon brushes. Armature can be rotated freely between poles of a permanent, strong horse shoe magnet.

Working:

When the coil is rotated in the magnetic field such that at a particular instant, its plane is perpendicular to magnetic field, then its longer side will move parallel to the field, at this instant no emf is induced in it. As the coil continues the motion, component of linear velocity of longer side's perpendicular to the field increases and becomes maximum when plane of the coil is parallel to the field. During this quarter revolution, emf increases from zero to maximum value. Maximum emf is induced when plane of the rotating coil is parallel to the field. During the next quarter revolution emf decreases to zero when the plane of the coil again becomes perpendicular to the field. During the remaining half revolution emf induced varies in the same manner but in opposite direction. Emf induced in the longer sides of the coil is in opposite direction and sends current in the same direction through the coil hence they add up whereas emf induced in the shorter sides is in the same direction and sends the current through the coil in opposite direction hence the net emf induced in shorter sides is zero. In one rotation of the coil one cycle of alternating emf is obtained. The number of cycles of alternating current obtained per second is called "frequency of A.C".

Derivation:

Let "L" be the length, "b" be the breadth of the coil and "v" be the instantaneous linear velocity of the longer side of the coil in the magnetic field of flux density "B", then emf induced in each longer side loop of wire is given by:

$$\xi = BvI\sin\theta$$

Hence the total emf induced at any instant in each turn of the coil will

$$\xi = 2BvI\sin\theta$$

If the coil has "N" turns, then total emf induced in it given by:

$$\xi = 2NBvI\sin\theta ------(i)$$

If "w" is the constant angular speed of the coil then:

$$v = rw$$

Putting $r = \frac{1}{2}(b)$

$$v = \frac{1}{2}(b\omega)$$

$$0 = \omega t \qquad \because \omega = \frac{\theta}{t}$$

On substituting the above values of v and θ in equation (i), we get:

$$\xi = 2NB\frac{1}{2}b\omega I \sin\theta$$

$$\xi = BN\omega lb \sin\omega t$$

But *Lb=A*

$$\xi = BN\omega A \sin\omega t --------(ii)$$

Similarly angular velocity "ω" is related to frequency "ξ" by the following relation:

$$\omega = 2\pi f$$

Equations (i), (ii) and (iii) give us the emf induced in the rotating coil at any instant.

Expression For Maximum emf:

The emf induced in the coil will be maximum when *sin ωt*=1, which is possible when the angle *"ϑ"* between $\vec{v}$ and $\vec{B}$ is 90°, at this particular moment plane of the coil will be exactly parallel to the magnetic field,

$$\xi_{max} = N\omega AB$$

Relation Between Instantaneous emf "ξ" and maximum emf "ξ_{max}"

The instantaneous and maximum emf induced in the coil are related by:

$$\xi = \xi_{max} \sin\omega t$$

$$\omega = 2\pi f$$

In the rotating coil emf induced changes in magnitude and direction with time, such an emf is known as alternating emf. The current caused by alternating emf will also change continuously in magnitude and direction. Under the influence of alternating emf free electrons of the conductor will simply vibrate about their mean position.

Transformer:

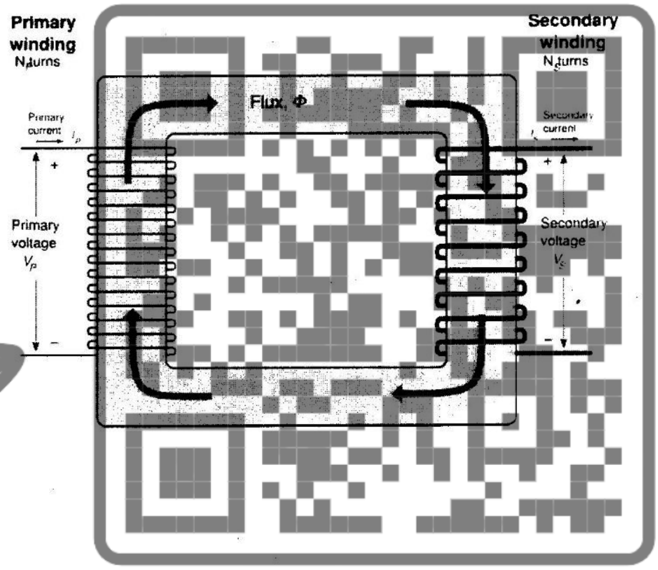
Transformer is an electric device which is used either to step up or step down an alternating en (Voltage). It works on the principle of "Mutual Induction".

Construction & Working:

A transformer consists of two coils known as "primary" and "secondary". These coils of insulated copper wires are wound one on top of the other on a laminated soft iron core. On one of the coils, known as the "primary coil", an alternating emf (Voltage) is applied. Due to self induction an emf (ξ_P) Is induced in the primary coil, given by;

$$\xi_P = -N_P \frac{\Delta\phi_m}{\Delta t} ....(i)$$

where "Np" is the no. of turns in primary coil $\frac{\Delta\phi_m}{\Delta t}$ and is the rate of change of flux through primary coil. Since, the secondary coil is wound on top of the primary coil; therefore the flux linked with the two coils will be practically equal. In other words the rate of change of flux $\frac{\Delta\phi_m}{\Delta t}$ for both coils is same. Due to mutual induction, emf Induced ξ_S in the secondary coil is given by;



$$\xi_S = -N_S \frac{\Delta\phi_m}{\Delta t} ....(ii)$$

Where, "Ns' is the no. of turns in secondary coil.
Dividing eq. (ii) by eq. (i)

$$\frac{\xi_S}{\xi_P} = \frac{-N_S \frac{\Delta\phi_m}{\Delta t}}{-N_P \frac{\Delta\phi_m}{\Delta t}}$$

$$\frac{\xi_S}{\xi_P} = \frac{N_S}{N_P}$$

Efficiency of Transformer:

Efficiency may be defined as;
"The ratio of power output to power input".

Power Output'= $\xi_S I_S$

Power Input = $\xi_P I_P$

P

If the power loses in a transformer are neglected then,

Power Output = Power Input

$$\xi_S I_S = \xi_P I_P$$

$$\frac{\xi_S}{\xi_P} = \frac{I_P}{I_S}$$

This relation shows that in a step up transformer for which $(\xi_S > \xi_P)$, "I_P" " will greater than "I_S".

Step Up Transformer:

If $N_S > N_P$ then "ξ_S" also be greater than "ξ_P", A transformer in which $(\xi_S > \xi_P)$ is known as "Step Up Transformer". It increases the applied voltage, whereas $(I_S < I_P)$.

Step Down Transformer:

A transformer in which $N_S < N_P$, gives lower emf through the secondary coil i.e. $(\xi_S < \xi_P)$ is known as "Step down Transformer". It decreases the applied voltage whereas $(I_P < I_S)$.

Uses of Transformer:

1. Step up transformer is used for sending electricity to long distance.
2. Step down transformer is used to decrease the large voltage up to 220 volts.
3. In electric bell the step down transformer is used to set the voltage up to 4 volts.

Power Loses In A Transformer:

1. Power loses in transformer is mainly due to resistance of its wires.
2. To minimize this source of power loss, thick copper wire is used in the coil which carries larger current.
3. Eddy current induced on the surface of iron core due to the changing magnetic flux, produce heating effect.
4. To minimize this effect core is made up of thin sheets of soft iron separated by a thin layer of varnish.

CHAPTER-14 **MULTIPLE CHOICE QUESTIONS**

From Past Papers

1999

Q.4. (a) (iii) Which of the two charged particles of the same mass will be deflected most in a magnetic field?

* Fast moving * Slow moving

Q.5. (a) (i) Henry is the unit of mutual inductance. True

(ii) Back e.m.f is the effect of self inductance in a coil when a alternate current passes. True

2000

Q.5. (a) (iii) The device which converts mechanical energy into electrical is called Generator. *{True}*

2001

Q.5. (a) (i) The maximum magnetic force will act on a current carrying conductor in a magnetic field when it is placed:

* At 60° to field * Parallel to the field

* Perpendicular to the field * At an angle of 45° to the field

Q.5. (a) (ii) The current produced by moving the loop of a wire across the magnetic field is called:

* Electric current * A.C. current
* D.C. current * Induced current

Q.5. (a) (iii) The phenomenon of producing e.m.f. in the coil due to the change of the force experienced by a current-carrying conductor when it is placed in a magnetic field is:

* F = I (V X B) * F = I (L X B) * F = B (I X L) * NOTA

Q.6. (a) (ii) The phenomenon of producing e.m.f. in the coil due to the change of current in the coil itself is called:

* Mutual induction * Self induction
* Magnetic flux * None of the above

2002(Pre-Medical)

Q.3. (a) (i) A steady current passing through a conductor produces:

- An electric field only
- A magnetic field only
- Both electric and magnetic fields
- Neither electric nor magnetic field

Q.5. (a) (i) If a straight conductor of length 'L' carrying a current 'I' is placed parallel to a magnetic field 'B', the force experienced by the conductor is:

* BIL * BIL cosΘ * Zero * Infinite

'Q.5. (a) (iii) When a charged particle enters a uniform magnetic field perpendicularly, its path is:

* Spiral * Circular * Parabolic * Straight line

2002(Pre-Engineering)

Q.4. (a) (ii) Transformer works on:

* Ohms Law * Self induction * Mutual induction * Gauss's law

Q.4. (a) (iii) The deflecting torque on a current carrying coil placed in a magnetic field is maximum when the angle between magnetic field and the plane of the coil is:

* zero° * 90° * 60° * 45°

2003(Pre-Engineering)

Q.4. (a) (i) The force acting on a charged particle projected into a magnetic field of induction B is maximum when the angle between B and the velocity of the particle is:

* 0° * 90° * 60° * 45°

Q.5. (a) (ii) A transformer is used to change:

* Capacitance * Frequency * Voltage * Power

2003(Pre-Medical)

Q.4. (a) (iii) One Tesla is equal to:

* 1 weber/meter^2 * 2 weber^2/meter^2
* weber/meter^2 * Newton/ampere

Q.5. (a) (ii) An electric current through a conductor produces around it:

* An electric field * A magnetic field
* An electric and a magnetic field

* First a magnetic field and then an electric field.

Q.6. (a) (ii) When the north pole of a bar magnet approaches the face of a closed coil the face becomes:

* South pole * First north pole and then south pole
* North pole * No effect is observed

Q.6. (a) (iii) In step-down transformer:

* $N_S > N_P$ * $N_S < N_P$ * $N_S = N_P$

2004

Q.4. (a) (iii) The unit of Magnetic Flux is Weber. True

Q.5. (a) (ii) Ampere's law can be used to find electric intensity. *(False)*

Q.5. (a) (iii) Henry is the unit of mutual inductance. True

2005

Q.3. (a) (iii) The direction of induced current is given by:

* Ampere's law * Faraday's law * Lenz's law * Snell's law

Q.4. (a) (ii) The maximum resistance in an A.C. circuit is offered by:

* Capacitor * Solenoid * Electromagnetic * Electric bulb

Q.4. (a) (iii) The path of a neutron moving normal to a magnetic field is a/an:

* Straight line * Circular * Oval * Sinusoidal

Q.5. (a) (i) SI unit of induction is:

* Tesla * Henry * Watt * Weber

Q.5. (a) (iii) The force per unit length of a current carrying conductor in a uniform magnetic field is given by:

* $IBL\sin\Theta$ * $IBL\cos\Theta$ * $IB\sin\Theta$ * $IB\cos\Theta$

2006

Q.4. (a) (ii) Which is not a magnetic material?

* Iron * Nickel * Cobalt * Silver

Q.4. (a) (iii) The SI unit of magnetic flux is:

* Tesla * Weber * Gauss * Ohm

Q.5. (a) (ii) The path of a neutron moving normal to a magnetic field is:

* A straight path * A circular path
* An oval path * A sinusoidal path

2007

Q.5. (a) (ii) A device which converts the electrical energy to mechanical energy is called:

* Transformer * Capacitor * Galvanometer * Electric motor

2008

Q.4. (a) (iii) In a conventional transformer:

* The current moves from primary to the secondary windings without any change.
* E.M.F. is induced in the secondary by the changing magnetic flux.
* The heat is transferred from primary to secondary
* None of the above

Q.6. (a) (ii) A charged particle moving in the magnetic field B experiences a resultant force:
* Proportional to the kinetic energy * In the direction of the field
* In the direction perpendicular to its motion and field * None of these

2009

Q.4. (a) (ii) Which one is not a unit of magnetic flux density?
* NA^{-1} * Wb/m^2 * Tesla * $VA^{-1}S$

Q.4. (a) (iii) When an A.C. generator is converted into a D.C. generator, slip rings are replaced by:
* A dynamo * A split ring * A field coil * An inductor

Q.6. (a) (i) The practical application of the phenomenon of mutual inductance is:
* A.C. generator * Transformer * Rectifier * Dynamo

2010

Q.1. (xii) The motional e.m.f. induced in a coil is independent of:
(a) Change of flux (b) Number of turns (c) Time (d) Resistance

Q.1. (xiv) Transformers are used in circuits containing:
(a) d.c. alone (b) a.c. alone c) both a.c. and d.c.(d) non-inductive winding

2011

Q.1. (iii)T he core of a transformer is laminated to reduce the loss of energy caused by
* NAØ * heating * Eddy current * all of these

Q.1. (ix) Two free parallel wires carrying current in the opposite direction
* do not affect each other * attract each other
* repel each other * none of these

Q.1(xiv) If the number of turns in a coil is doubled its self inductance will be
* doubled * halved * the same * four fold

2012

Q.1.xv) The practical application of phenomenon of mutual inductance is:
* A.C generator * transformer * rectifier * dynamo

Q.1(xiv) An electric current on passing through a conductor, produces around it
* an electric field * a magnetic field
* Both electric and magnetic field * first a magnetic field then an electric field

2013

Q.1(xv) The practical application of phenomenon of mutual inductance is:
* A.C generator * transformer *rectifier * dynamo

Q.1(xiii) The direction of induced current is given by
* Ohm's law * Lenz's law *Coulomb's law * Ampere's law

Q.1 (i) When an AC generator is converted into DC generator the alip ring are replaced by
* An Inductor *A field coil *A split ring * A dynamo

2014

(xiii) When A.C generator is converted into D.C generator slip ring is replaced by:
*a dynamo *a split ring *a field coil * an inductor

(xiv) The path of neutron, moving perpendicularly through a magnetic field is:

P

*Straight line *Circular *Oval *Sinusoidal

2015

(iii) If the number of turns in a coil is doubled, its self-inductance will become:

* halved * doubled * threefold * fourfold

(ix) When an electron moves in a magnetic field (B) with a velocity (V), the magnetic force acting on it is perpendicular to:

* V but not on B * B but not on V * neither V nor B * both V and B

CHAPTER-14 **NUMERICALS**

From Past Papers

1985

Q.4. (c) A toroidal coil has 300 turns and its mean radius 12cm. Calculate the magnetic field of induction 'B' inside the coil when a current of 5 amperes passes through it. **($2.5 \times 10^{-3} Wb/m^2$)**

Q.5. (c) Current of 2 amperes passes through an inductive circuit. What is the self-inductance of the circuit if the current falls to zero in 0.1 seconds? The average value of induced e.m.f. is 20 volts. **(1.0 Henry)**

1986

Q.5. (c) A train is moving directly towards south with a uniform speed of 10m/s, if the vertical component of the earth's magnetic field induction is 5.4×10^{-5} Tesla. Compute the e.m.f. induced in the axle 1.2m long. **(6.48×10^{-4} volts)**

1987

Q.4. (c) An electron having a speed of 1.6×10^6 m/s is moving along a circle of radius 1.82×10^{-6}m entering perpendicularly in a uniform magnetic field. Find the value of magnetic field. **(5 Tesla)**

1988

Q.5. (c) A solenoid of diameter 5.0cm is 25cm long and has 250 turns. If the current flowing in it is 5 amperes, find B inside the solenoid. **(6.28×10^{-3} web/m^2)**

1990

Q.4. (c) Find the current required to produce a field of induction B = 2.51×10^{-3} web/m^2 in a 50cm long solenoid having 4000 turns of wire. **(0.25A)**

1992

Q.4. (c) A current of 2 amperes is passing through a solenoid. If the solenoid has 24 turns per cm of its length, find the value of B. **(6.03×10^{-3} web/m^2)**

Q.6. (c) A transformer has 1000 turns in its primary coil. If the input voltage of the transformer is 200 volts, what should be the number of turns of the secondary coil to obtain an output of 6.0 volts? **(30 turns)**

1993

Q.5. (c) A 10eV electron is moving in a circular orbit in a uniform magnetic field of strength 10^{-4} weber/m^2. Calculate the radius of the circular path. **(0.107m)**

Q.6. (c) A coil having an area of cross section 0.05m^2 and number of turns 100 is placed perpendicular to the magnetic field of induction 0.08 weber/m^2. How much e.m.f. will be induced in it if the field is reduced to 0.02 weber/m^2 in 0.01 seconds? **(30 volts)**

1994

Q.6. (c) A solenoid 25cm long has a cross-section of 5 square cm with 250 numbers of turns on it. If a current if 5 amperes is passed through it, find "B" in it. **(6.28×10^{-3} web/m^2)**

1995

Q.4. (c) An electron is moving along a circle of radius 1.8×10^{-7}m. Calculate the speed of the electron on entering perpendicularly in a uniform magnetic filed of 5.0 Tesla. **(15.81×10^4 m/s)**

1996

Q.4. (c) A coil of 100 turns and area (4cm x 2cm) is placed in a uniform magnetic field of 0.45 T. The coil carries a current of 1.5 amperes. Calculate the torque on the coil when the plan is at 60° with B. **(0.0054 Nm)**

Q.5. (c) An airplane is flying in a region where the vertical component of earth's magnetic field is 3.2×10^{-4}T. If the wingspan of the airplane is 50m and its velocity is 360 km/hour, find the potential difference between the tips of the wing of airplane. **(1.6V)**

1997

Q.4. (c) An α particles are accelerated from rest at a P.D. of 1 KV. They then enter a magnetic field B=0.2T perpendicular to their direction. Calculate the radius.
Given $m = 6.68 \times 10^{-27}$ kg & q = 2e. **(0.032m)**

1998

Q.4. (c) A solenoid 20 cm long has three layers of windings of 300 turns each. If a current of 3 amperes is passed through it, find the value of the magnetic field of Induction. **(0.016 web/m^2)**

Q.5. (d) A 500 turn coil in A.C. Generator having an area of 1000 cm^2 rotates in a magnetic field of value 50 Tesla. In order to generate 220 volts maximum, how fast is the coil to be rotated? Express your answer in terms of the number of revolutions per second. **(0.088 rad/sec, 0.014rev/s)**

1999

Q.5. (d) A 10eV electron is moving in a circular orbit in a uniform magnetic field of strength 10^{-4} weber/m^2; calculate the radius of the circular path. **(0.107m)**

Q.6. (d) A transformer has 1000 turns in the primary coil. If the input voltage of the transformer is 200 volts, what should be the number of turns of the secondary coil to obtain an output of 6.0 volts? **(30 turns)**

2001

Q.5. (d) What will be the mutual inductance of two coils when the change of a current of a 3 amperes in one coil produces the change of flux of 6×10^{-4} Weber in the second coil having 2000 turns? **(400mH)**

Q.6. (d) An electron is accelerated by the potential difference of 1000 volts. It then enters into a uniform magnetic field of induction B = 2.5, weber/m^2 at an angle of 45° with the direction of the field, find the value of the path described by the electron. **(6.04×10^{-5} m)**

2002 (Pre–Med)

Q.5. (d) A long solenoid is wound with 10 turns per cm and carries a current of 10 amperes; find the magnetic flux density within it. **(0.0125 web/m^2)**

2002 (Pre–Engg)

Q.5. (d) An e.m.f. of 45 milli-volts is induced in a coil of 500 turns, when the current in a neighboring coil changes from 10 amperes to 14 amperes in 0.2 seconds.

- **a)** What is the Mutual Inductance of the coils?
- **b)** What is the rate of change of flux in the second coil? **(2.25mH, 9×10^{-5} web/sec)**

2003 (Pre–Med)

Q.5. (d) The current in a coil of 325 turns is changed from zero to 6.32 amperes thereby producing a flux of 8.46×10^{-4} Webers. What is the self-inductance of the coil? **(43.2mH)**

2003 (Pre-Engg)

Q.5. (d) Calculate the speed of an electron entering perpendicularly in a uniform magnetic field of 5.0 w/m^2 which moves along a circle of radius 1.8×10^{-6} m in the field. **(1.58×10^6 m/sec)**

Q.6. (d) A coil of 50 turns is wound on an ivory frame 3cm x 6 cm which rotates in a magnetic field of induction B = 2 web/m^2. What will be the torque acting on it if a current of 5 amp passes through it and the plane of the coil makes an angle of 45° with the field. **(0.6363 Nm)**

2004

Q.5. (d) How fast must a proton of mass 1.67×10^{-27} kg be moving if it is to follow a circular path of radius 2.0 cm in a magnetic field of 0.7 Tesla? **(1.34×10^6 m/sec)**

Q.6. (d) The current in a coil of 500 turns is changed from zero to 5.43 amps. There by producing a magnetic flux of 8.52×10^{-4} Webers. What is the Self-Inductance of the coil? **(78.45mH)**

2005

Q.5. (d) A proton accelerated through 1000 volts is projected normal to a 0.25 Tesla magnetic field. Calculate the following:

a) The Kinetic energy of the proton on entering the magnetic field.

b) The radius of the circular path of the proton **(1.6×10^{-16} J, 0.0182 m)**

Q.6. (d) A step-down transformer having 4000 turns in primary is used to convert 4400 volts to 220 volts. The efficiency of the transformer is 90% and 9KWatt output is required. Determine the Input power, the Number of turns in the secondary coil and the current in the primary and secondary coils? **(10000W, 200turns, 2.23A, 40.9A)**

2006

Q.5. (d) A long solenoid is wound with 35 turns in 10cm, and carries a current of 10A. Find the magnetic field in it. **(4.3×10^{-3} wb/m^2)**

2007

Q.4. (d) An airplane is flying in a region where the vertical component of earth's magnetic field is 3.2×10^{-4}T. If the wingspan of the airplane is 50m and its velocity is 360 km/hour, find the potential difference between the tips of the wing of airplane. **(1.6V)**

2008

Q.5. (d) A step down transformer reduces 1100V to 220V. The power output is 12.5KW and overall efficiency of the transformer is 90%. The primary winding has 1000 turns. How many turns do the secondary have? What is the power input? What is the current in each coil?

(200 turns, 13.8×10^3 Watt, 12.6A, 56.81A)

2009

Q.4. (d) A pair of adjacent coil has a mutual inductance of 850mH. If the current in the primary coil changes from 0 to 20A in 0.1 sec; what is the change in the magnetic flux in the secondary coil of 800 turns? **(2.12×10^{-2}webers)**

2010

Q.2. (x) Find the current required to produce a field of induction B = 2.512×10^{-3} T in a 50 cm long solenoid having 4000 turns of wire.($\mu_o = 4\pi \times 10^{-7} Wb/A\text{-}m$ **(0.785A)**

2011

Q.2. (viii) An alternating current Generator operating at 50 Hz has a coil of 200 turns, while the coil has an area of $120cm^2$. Calculate the magnetic field intensity applied to rotate the coil to produce the maximum voltage of 240V. **(0.31831T)**

Q.2. (xiii) The inner and the outer diameters of the toroid are 22cm and 26cm. If a current of 5.0 amp is passed which produces 0.025 tesla flux density inside the core, find the approximate length of the wire wound on the toroid.($\mu_o = 4\pi \times 10^{-7} Wb/A\text{-}m$). **(226.2m)**

2012

Find the current required to produce a field of induction B = 2.512×10^{-3} T in a 50 cm long solenoid having 4000 turns of wire. ($\mu_o = 4\pi \times 10^{-7} Wb/A\text{-}m$).

2013

An alternating current generator operates inat 79 Hz the area of coil is 500 cm^2. Calculate the number of turns in the coil when a magnetic field of induction 0.06 web/m^2 produces a maximum potential difference of 149 V.

2014

Q.2. (iii) An iron core of solenoid 500 turns has a cross section of 5 cm^2. A current of 2.3 A passing through produces of flux of B = 0.53 T. How large an e.m.f is induced in it, if the current is turned off in 0.1 second? What is the self inductance of the solenoid?

2015

Q.2(ix) An e.m.f. of 45 milli-volts is induced in a coil of 500 turns, when the current in a neighboring coil changes from 15 amperes to 4 amperes in 0.2 seconds.

a) What is the Mutual Inductance of the coils?

b) What is the rate of change of flux in the second coil?

Chapter 15

ELECTRICAL MEASURING INSTRUMENTS

Galvanometer:

It is an electromechanical instrument used for detecting or measuring a very small amount of electrical current in a given circuit.

Moving Coil Galvanometer:

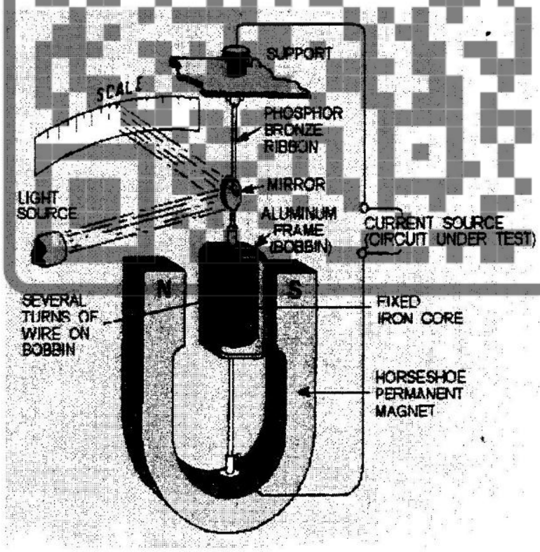
The primitive form of moving coil galvanometer was developed by the French scientist D'Arsonval. Edward Weston improved upon D'Arsonvals original version (in which coil is suspended between the concave pole pieces of magnet) and gave the modern moving coil galvanometer (in which coil is pivoted between the concave pole pieces of magnet).

Principle:

Moving coil galvanometer works on the principle that when an electrical current passes through a coil placed in a magnetic field it experiences a magnetic torque.

Construction of Moving Coil Galvanometer:

The main parts of moving coil galvanometer are discussed below:



(i). Magnetic poles:

Concave type pole pieces of powerful horse shoe magnet are fixed to obtain strong magnetic field.

(ii). Soft Iron Cylinder: -

A soft iron cylinder is set between pole pieces to provide radial magnetic field o the rotating coil. Radial field is a field in which the plane of rotating coil is always parallel to the magnetic field. It is placed inside the coil, but could not move as the coil is rotated, such that the coil can rotate freely about the cylinder without touching it.

(iii). Rectangular Coil:

A number of turns of insulated copper wire are wound on a rectangular ivory frarn2 inform of a rectangular coil. The ends of copper wire are connected with meter

P

movement and spiral spring separately. A thin bronze strip is connected with each end V of wire, acted as input and output lead to the flowing current.

(iv). Meter Movement: S

It consists of a very light pointer and a dial. When rectangular coil is rotated in presence, of couple of magnetic induction, the pointer rotates on dial and hence flow of current is detected.

(v). Spiral Spring:

A soft helical spring is connected with the end of coil which is used to restore the pointer to its initial position when the current is cut off.

Theory of Moving Coil Galvanometer:

To study the theory of moving coil galvanometer, let us consider a rectangular coil inside a radial field of induction, which remains parallel to the plane of coil.Assume that:

i. The length of coil = L
ii. The breadth of coil = b
iii. The area of plane of coil = A = Lb
iv. The total number of turns in coil = N
v. The current passes through the coil = I
vi. The strength of magnetic field =B
vii. The magnitude of deflecting torque on coil due to couple of induction = $BINA\cos\alpha$.
viii. The magnitude of restoring torque on coil due to elasticity of helical spring = $c\theta$

Where "c" is the constant of proportionality, called "Couple per unit angular twist of the suspension wire".(As the coil rotates under the action of deflecting torque, the suspension wire is twisted and an opposing torque is developed which is called restoring torque It depends upon the deflecting angle of the coil.)

In case of a balanced galvanometer, the deflecting torque must be equal to the restoring torque on the coil. Mathematically:

Deflecting Torque= Restoring Torque

$$BINA\cos\alpha = c\theta$$

$$I = \frac{c}{BAN\cos\alpha}\,\theta \;----(i)$$

In case of radial fieldthe angle between plane of coil and direction of $\vec{B}$ always zero, i.e. $\alpha = 0^0$ $\cos\alpha = 1$, and *B*, *A* and*N*are constant. Therefore equation *(i)* reduces to

$$I = \frac{c}{BAN}\,\theta$$

$$\boxed{\therefore I \propto \theta}$$

This relation expresses theory of a moving coil Galvanometer which states, "The angular twist (deflection) of a coil is directly proportional to the strength of current passes through the Turns of coil, provided geometric constants of coil and strength of magnetic field remains same".

Sensitivity of Galvanometer:

"Deflection per unit current is known as Current Sensitivity of Galvanometer".

Mathematically;

$$\because I = \left(\frac{c}{BNA}\right)\theta$$

$$\therefore \frac{\theta}{I} = \frac{BNA}{c}$$

$$\boxed{Current\ Sensitivity = \frac{BNA}{c}}$$

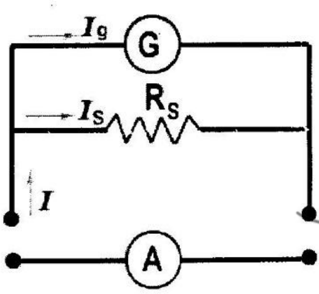
In practice, A sensitive Galvanometer is one in which a small value of current produces large angular deflection.

Ammeter:

It is an electromechanical instrument used for measuring large current. It is symbolized by in electric circuits.

Conversion of Moving Coil Galvanometer into an Ammeter:

To convert a galvanometer into an ammeter a suitable low resistance called shunt is connected in parallel to it.



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To Determine Resistance of Shunt:

For this, let us assume that:

i. The range of ammeter = I

ii. The strength of current passes through the coil of galvanometer = I_g

iii. The resistance of galvanometer = R_g

iv. The PD across the galvanometer = $V_g = I_g R_g$

v. The strength of current passes through the low resistor (shunt) = $I_s = I - I_g$

vi. The resistance of shunt=R_s=?

vii. The P.D across the shunt = $V_s = I_s R_s \Rightarrow V_s = (I - I_g) R_s$

According to the characteristics of parallel combination of resistors,

$$V_s = V_g$$

$$I_s R_s = I_g R_g$$

$$\boxed{R_s = \frac{I_g}{I - I_g} R_g}$$

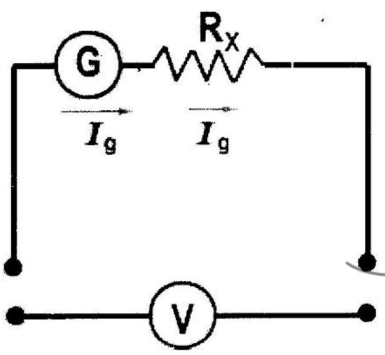
This equation expresses theory of an ammeter. According to this theory, if range of ammeter, resistance of coil and current through the coil of galvanometer are known, the resistance of shunt can be determined.

Voltmeter:

It is an electromechanical instrument used for measuring the potential difference between any two points in a given circuit through which a current is flowing.

Conversion of Moving Coil Galvanometer into a Voltmeter:

To convert a galvanometer into a voltmeter a very high resistance is connected in series to it.



To Determine Resistance of Series Resistor:

For this, let us assume that:

i. The range of voltmeter = V

ii. The strength of current passes though the coil of galvanometer = I_g

iii. The resistance of galvanometer = R_g

iv. The P.D across the galvanometer = $V_g = I_g R_g$

v. The strength of current passes through the series resistor = I_g

vi. The resistance of series resistor = R_x = ?

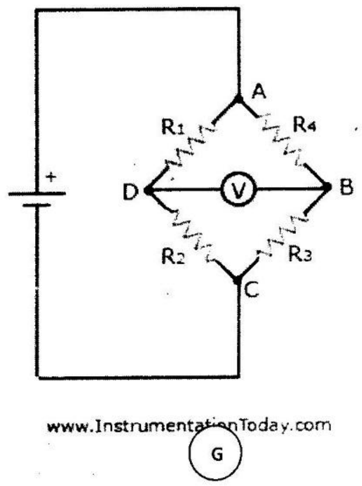
vii. The P.D across the series resistor = $V_x = I_g R_x$

According to the characteristics of series combination of resistors,

$$V = V_g + V_X$$
$$V = I_g R_g + I_g R_X$$
$$V - I_g R_g = I_g R_X$$
$$R_X = \frac{V - I_g R_g}{I_g}$$
$$R_X = \frac{V}{I_g} - \frac{I_g R_g}{I_g}$$
$$\boxed{R_X = \frac{V}{I_g} - R_g}$$

This equation expresses theory of a voltmeter. According to this theory, if range of voltmeter, resistance of coil and current through the coil of galvanometer are known, the series resistance can be determined.

Wheatstone bridge



Wheatstone Bridge: A most accurate method for determining an known resistance Was proposed by Charles Wheatstone in 1843. The electric circuit used for this purpose is often called, "Wheatstone Bridge".

Construction:

The Wheatstone bridge consists of four wires of resistance "R_1", "R_2", "R_3" and "R_4" that are stretched on a wooden bench inform of a quadrilateral loop,

P

"ABCDA". In this closed loop, the terminal "A" and terminal "C" are connected with a key (K_1) and battery of low P.D whereas; the terminal "B" and terminal "D" are connected with another key (K_2) and a Galvanometer.

Balanced Wheatstone Bridge: If electric potential at terminal "B" andterminal "D" is set at the same value i.e. $V_B = V_D$, then no current will be passedthrough the coil of Galvanometer and thus pointer of Galvanometer shows null deflection. At this state, a Wheatstone bridge is said to be "Balanced".

Theory of Wheatstone Bridge:

At the state of balanced Wheatstone bridge, $V_B = V_D$, therefore;

$$\Delta V_{AB} = \Delta V_{AD}$$

$$I_1 R_1 = I_2 R_3 \text{ ----------- } (i)$$

Similarly

$$\Delta V_{BC} = \Delta V_{CD}$$

$$I_1 R_2 = I_2 R_4 \text{ ----------- } (ii)$$

Now dividing eq*(i)* by eq*(ii)*

$$\frac{I_1 R_1}{I_1 R_2} = \frac{I_2 R_3}{I_2 R_4}$$

$$\boxed{\frac{R_1}{R_2} = \frac{R_3}{R_4}}$$

This expression represents theory of a balanced Wheatstone bridge. According to this expression; if any three resistances of the bridge are known, then fourth unknown resistance can be determined,

Meter Bridge:

It is an electrical measuring instrument used to determine an unknown resistance after noting down lengths of wire and known resistance at balanced state of the circuit.

Principle:

It is based on Wheatstone bridge principle.

The apparatus has unknown resistance "*X*" between point A and B, a known resistance "R" from resistance box between points B and C, a high resistance wire of uniform thickness and 1m long between points A and C, a galvanometer between points B and D with a jockey K_2 and a cell between point A and C with key K_1.

Suppose no current passes through the galvanometer when key K_2 is at point D. then $R_1 = X$, $R_2 = R$, $R_3 = \rho\, l_x$, $R_4 = \rho\, l_R$;

Where; ρ = resistance per unit length of wire

$$\because R \propto L$$
$$R = (constant)L$$
$$R = \rho L$$
$$\rho = \frac{R}{L}$$

l_x= length of wire on the side of unknown resistance *X*

l_R= length of wire on the side of known resistance *R*

According to Wheatstone bridge principle;

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$
$$\frac{X}{R} = \frac{\rho\, l_X}{\rho\, l_R}$$
$$\boxed{\frac{X}{R} = \frac{l_X}{l_R}}$$

Thus by measuring the length l_x and l_R the value of unknown resistance *X* can be calculated.

IMPORTANT SCIENTIFIC REASONS

Q.1 Why must an ammeter connected to a circuit in series and a voltmeter in parallel?

Ans. An Ammeter is a device of low resistance and it must be connected in series to measure full scale deflection of the current passing through circuit. In this way we observe the actual current passing through circuit, whether if we connect in parallel it will act like a shunt and we will not observe actual current through circuit.

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In opposite, Voltmeter is always connected in parallel with the circuit or device for which potential difference is required. If we connect the voltmeter in series (which not so) then maximum potential drop will across its terminals due to high resistance and we cannot observe potential drop of the circuit device. (Also draw circuits)

Q.2 Which is the more accurate instrument a meter bridge or a P.O. Box?

Ans: A P.O. Box is more accurate instrument than a meter bridge, because the higher the value of the ratio arm the greater the accuracy in the measurement of the unknown resistance.

CHAPTER-15
MULTIPLE CHOICE QUESTIONS
From Past Papers

1999

Q#5 (a) (iii) To increase the accuracy of a potentiometer __________.
* A uniform wire of a large length should be used.
* A uniform wire of a small length should be used.
* Non uniform wire should be used.

2001

Q#6 (a) (iii) A galvanometer can be used to measure the current by connecting:
* Low resistance in series
* High resistance in series
* Parallel resistance in parallel

2002 (Pre Engineering)

Q#5 (a) (iii) AVO meter is used to measure:
*current * voltage * resistance * all of them

Q#6 (a) (i) A meter bridge is used to measure:
*Voltage * Inductance * Capacitance * Resistance

Q#6 (a) (iii) A galvanometer can be converted into an ammeter by connecting:
* Low resistance in series
* High resistance in series
* Low resistance in parallel
* High resistance in parallel

2003 (Pre Medical)

Q#4 (a) (i) Potentiometer is a device for measuring:
* Potential difference between the two points of a circuit.
* Voltage between the two points of a circuit.
* E.M.F. of the current source.
* All the above

2003 (Pre Engineering)

Q#5 (a) (i) A moving coil galvanometer can be converted into an ammeter by connecting a:
* Low resistance in series
* High resistance in series
* Low resistance in parallel
* High resistance in parallel

Q#5 (a) (iii) To increase the accuracy of a potentiometer __________.
* A uniform wire of a large length should be used.

* A uniform wire of a small length should be used.

* Non uniform wire should be used. * Non of these

Q#6 (a) (ii) The principle of post office box is based on:

* telegraph line * terminal potential difference

* multimeter * Wheatstone Bridge

2006

Q#6 (a) (i) In a Wheatstone Bridge circuit we balance:

* Resistance * Current * Voltage * All of these

Q#6 (a) (ii) The unit of least count on a galvanometer scale represents:

* Division * Ohm * Volt * Henry

Q#6 (a) (iii) I = (C/BNA) θ hence to increase the sensitivity of a galvanometer, we must decrease the value of:

* θ * N * B * C

2007

Q#5 (a) (i) A moving coil galvanometer is converted into an ammeter by connecting to it:

* Low resistance in series * High resistance in series

* High resistance in parallel * Low resistance in parallel

Q#5 (a) (ii) A device which converts electrical energy to mechanical energy is called:

* Transformer * capacitor * galvanometer

2008

Q#6 (a) (i) The sensitivity of a galvanometer can be increased by increasing:

* Magnetic field * area of coil * Number of turns *all of them

2009

Q#5 (a) (ii) The working principle of a post office box is:

* Wheatstone Bridge * Potentiometer * Telegraph Line * None of these

2010

Q#5 (a) (ii) A single device containing ammeter, voltmeter and ohmmeter is called:

* VTVM * CRO * Potentiometer * Millimeter

2011

Q#1 (i) If the length of the wire of potentiometer is increased the accuracy in the determination of null point

* Increases * remains the same * Decreases * becomes zero

2012

Q.1(xvii). AVO meter is used to measure:

* Electric current *voltage *resistance * all of these

2013

Q.1(vii) Meter Bridge is used to measure

* electric current * voltage * resistance * capacitance

2014

Q1.(xvii) This is a high resistance instrument:

*Voltmeter *Ammeter *Galvanometer *Motor

P

2015

(x) An instrument which can measure and compare potentials without drawing any current from the circuit is known as a/an:

* Ammeter * Voltmeter * Potentiometer * AVO-meter

CHAPTER-15 **NUMERICALS**

From Past Papers

1987

Q.3. (c) A moving coil galvanometer has a resistance of 50 ohms and it given a full-scale deflection for P.D of 150 mV. What should be the resistance of the shunt used with the galvanometer in order to use it as an ammeter reading up to 4 amperes?

(0.0375Ω)

1989

Q.4. (c) A galvanometer of resistance of 50Ω gives full-scale deflection with a current of 0.005 amperes. How will you convert it into an ammeter measuring maximum current of 1.0 ampere?**(0.251 Ω)**

1995

Q.4. (d) A galvanometer of resistance 60Ω given full-scale deflection with a current of 4mA, a resistance of 10940 Ω is connected in series with the coil to convert it into voltmeter; find the range of voltmeter obtained. **(44 volts)**

1997

Q.3. (d) A moving coil galvanometer has a resistance of 25Ω and it gives a full-scale deflection for a P.D. of 50 mV. If the galvanometer is to be converted into a voltmeter reading up to 50 volts, what should be the resistance of the series resistor? **(24975 Ω)**

2000

Q.3. (d) A moving coil galvanometer has a resistance of 50Ω and it gives a full-scale deflection for a P.D. of 100 mV. If the galvanometer is to be converted into a voltmeter reading up to 50 volts, what should be the resistance of the series resistor? **(24950 Ω)**

2002 (Pre Engg. group)

Q.3. (d) The coil of a Galvanometer having a resistance of 50 ohms and a current of 500 micro-amperes produces a full-scale deflection in it. Compute:

a) The shunt required to convert it into an ammeter of 5 amperes range.
b) The series resistance required to convert it into a voltmeter of 300 volt range.

(0.005Ω, 599950Ω)

2003 (Pre Med. group)

Q.3. (d) An ammeter deflects full-scale with a current of 5 amperes and has a total resistance of 0.5 ohm. What shunt resistance must be connected to it to measure full scale current up to 30 amperes? **(0.1Ω)**

2003 (Pre Engg. group)

Q.6. (d) A 300 volts voltmeter has a total resistance of 20 kilo-ohms. What additional resistance is required to convert it into a voltmeter, reading up to a maximum of 600 volts? **(20000 Ω)**

2004

Q.6. (d) A 250 volt voltmeter has a total resistance of 20,000Ω. What additional series resistance must be connected to it to increase its range to 400 volts? **(12000Ω)**

2005

Q.6. (d) A maximum 50 milli-ampere current can be allowed to flow through a 19.8ohm coil of a galvanometer. The galvanometer is to be used to measure 5-ampere maximum current. Calculate the length of a copper wire to be used as a shunt. The diameter of the wire is 4mm; the specific resistance (ρ) of copper is 1.6×10^{-8} ohm-m. **(0.2Ω, 157.1m)**

2006

Q.4. (d) An ammeter deflects full-scale with a voltage of 2.5 volts, and has a total resistance of 0.5Ω. What small resistance must be connected to measure 20A full-scale? **(0.166Ω)**

2007

Q.5. (d) A 300 volts voltmeter has a total resistance of 20 kilo-ohms. What additional resistance is required to convert it into a voltmeter, reading up to a maximum of 600 volts? **(20000 Ω)**

2008

Q.6. (d) A galvanometer has a resistance of 100 ohms. A difference of potential of 50mV gives the full-scale deflection. Calculate the shunt resistance to read from 0–5A. What is the value of the series resistance if the galvanometer is to be converted into a voltmeter to read up to 250V? **(0.01 Ω, 499900 Ω)**

2010

Q.2. (ix) A galvanometer whose resistance is 50Ω deflects full-scale for a potential difference 100 mV across its terminals. How can it be converted into a voltmeter of 50V range? **(24950 Ω)**

2012

A galvanometer of resistance of 50 ohms gives full scale deflection with a current of 10 mA. A shunt of 0.05 ohm is connected in parallel to convert it into an ammeter. Find the range of the ammeter.

2013

A voltmeter measuring up to 200 V has a total resistance of 20000 ohms. What additional series resistance must be connected to it to increase its range to 600V.

2014

Q2.(i). A galvanometer having resistance 50Ω, deflects full scale for a potential difference of 100 mV across the terminals. What resistance should be connected in series to increase its range to 50V.

2015

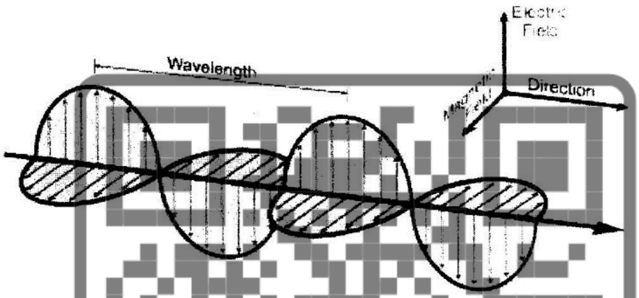
Q2(viii) A galvanometer of resistance of 60Ω gives deflects full-scale for a potential difference of 100 millivolts across its terminals. What shunt resistance must be connected to convert it into an ammeter of 5 ampere range?

Chapter#16

ELECTROMAGNETIC WAVES AND ELECTRONICS

Electromagnetic Waves:

Faraday discovered the phenomenon of electromagnetic induction that a magnetic field, which is changing with time, causes an induced electric field. Maxwell showed that the opposite is also true. A changing electric field causes an induced magnetic field. This symmetrical relationship between changing electric and magnetic fieldscan take place through any region. The electric and magnetic fields will propagate out of the region in the surrounding space. Such moving electric and magnetic fields are known as electromagnetic waves. Another prediction of the Maxwell theory is that "E" and "B" are mutually perpendicular to each other and they both are perpendicular to the direction of propagation of the wave.



Speed of Electromagnetic Wave:

Speed of electromagnetic waves depends upon the permeability 'μ_o'and permittivity '$\mathcal{E}_o$' of the medium through which it travels. In vacuum speed of electromagnetic wave is given by:

$$c = \sqrt{\frac{1}{\mu_o \mathcal{E}_o}}$$

$$c = \sqrt{\frac{1}{4\pi \times 10^{-7} \times 8.85 \times 10^{-12}}}$$

$$c = 2.99 \times 10^8 m/s$$

$$c \cong 3 \times 10^8 m/s$$

Antenna:

"An antenna is a device, which can generate and receive electromagnetic waves."The one which can generate electromagnetic waves is called Transmitting Antenna and the one which can receive electromagnetic wave is called Receiving Antenna.

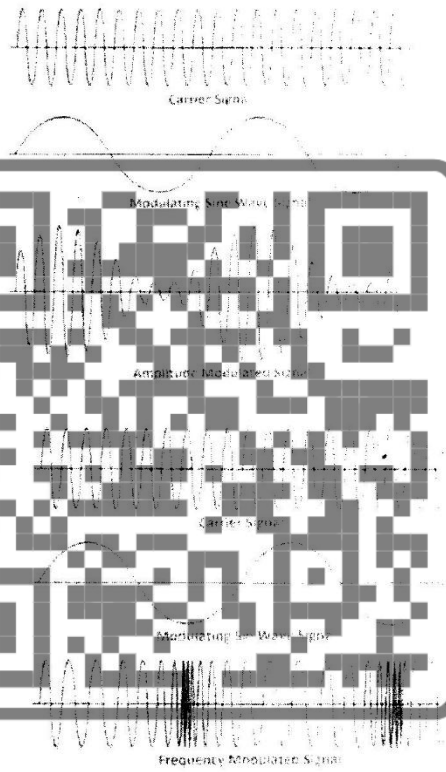
Carrier Waves or Radio Frequency:

The audio-frequency signal cannot be radiated out from the antenna directly. For this purpose, oscillations of very high frequency are produced with the help of oscillators. These electromagnetic waves so produced are of constant amplitude but of extremely high frequency called carrier waves or radio frequency.

Modulation:

The process by which audio frequency signal or information is impressed on the carrier wave is known as modulation. There are two types of modulation.

1. Amplitude Modulation
2. Frequency Modulation



1. **Amplitude Modulation:**
   In amplitude modulation the amplitude of carrier wave is varied in accordance with the modulating signal but the frequency of modulated carrier wave is maintained at its original strength. The outline of the modulated carrier wave is accordingly to the modulating signal, this outlineis called the Modulation Envelope.
2. **Frequency Modulation:**
   In frequency modulation the frequency of carrier wave is varied in accordance with the modulating signal but the amplitude of modulated carrier wave is maintained at its original strength. The frequency of the modulated carrier varies in proportion to the amplitude of the modulating signal.

De-Modulation:

The process by which audio frequency signal or information is separated by the carrier wave is known as de-modulation.

Band Theory:

Every solid contains electrons. The important question for electrical conductivity is how the electrons respond to an applied electric field? The band theory of solids provides the answer of this question as follows.

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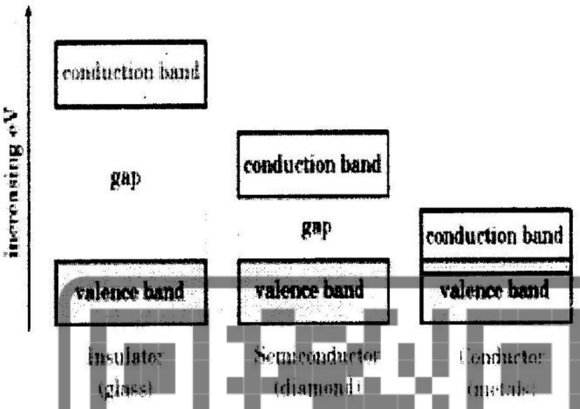
According to Bohr's atomic model, the electrons in an atom can occupy only allowed energy levels. The lowest energy level is called the ground state of atom where as the higher energy levels are called excited states. In solids, atoms are very close to each other so that their outer orbits overlap and spread out into energy bands. These bands are of two types.

1. Valence band
2. Conduction band

1. **Valence Band:**

   Valence band corresponds to the ground state of the atom. In valence band electrons do not gain energy by applying electric filed.



2. **Conduction Band:**

   With the gain of thermal energy, atoms reach at the higher state called the conduction band. In conduction band, electrons gain energy by applying electric field.

Forbidden Gap (Band Gap or Energy Gap):

The region in which electrons cannot occupy any energy levels is called forbidden gap. It lies between the conduction band and valence band.

Classification of solids In The Light of Band Theory:

According to band theory of solids, solids are classified into three types.

1. **Insulators:**

   In an insulator valence band is completely filled with electrons, the conduction band is empty and the two bands are separated by a large forbidden gap (5eV). Under this condition, electrons cannot move freely from valence to conduction band. Hence current cannot be passed through these materials.

   The resistivity of insulators (rubber, wood, plastic, etc.) is high ($\sim 10^4 \Omega m.$). The resistance remains high with the increase of temperature.

2. **Conductors:**

   In conductors valence band overlaps the conduction band and the forbidden gap practically does not exist. Conduction band is partially filled with electrons. Valence band is completely filled with electrons. Under these conditions electrons can move freely causing electric current.

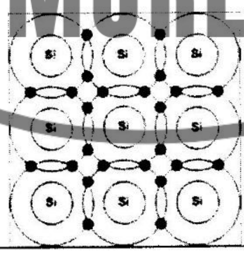
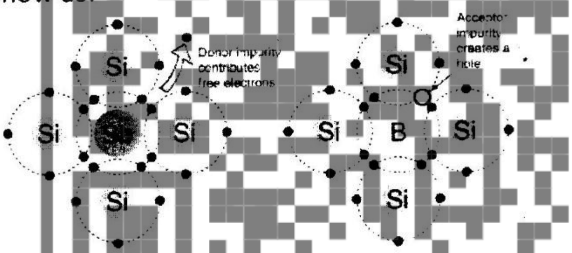
   The resistivity of conductors (metals) is low ($\sim 10^{-8} \Omega m.$). However the resistance increases with the rise of temperature.

3. Semi-conductors:

In semi-conductors there is a narrow forbidden gap (~1eV) between the two bands. A few electrons can be easily transferred from the valance band (which is partially filled) to the conduction band (which is empty). Thus slight electric conduction is possible. With the rise in temperature, as more electrons are excited and transferred into the conduction band, the conductivity increases rapidly.

Semi-conductors (e.g. silicon and germanium) have small resistivity ($\sim 10^{-1}\Omega m$). The resistance decreases with the rise of temperature.

Difference between Intrinsic and Extrinsic Semiconductors:

Intrinsic Semi-conductors	Extrinsic Semi-conductors
Intrinsic semi-conductor is pure semi conductor. Silicon and germanium are the examples of intrinsic semi-conductor.	Extrinsic semi-conductor is an impure semiconductor. N-type and p-type semi-conductors are the example of extrinsic semi-conductor.
Intrinsic semi-conductor does not contain excess electrons and hole.	Extrinsic semi-conductor contains excess electrons and hole.
Intrinsic semi-conductor does not pass electricity.	Extrinsic semi-conductor can pass electricity.
Atomic structure of intrinsic semi-conductor can be show as: 	Atomic structure of extrinsic semi-conductor can be show as: 

Doping:

The important property of semi-conducting materials is that their conductivity can be considerably affected by temperature and by addition of small amount of impurities. This addition of impurity in a semi-conductor is called doping.

Types of Doping: There are two types of doping.

(i) Donor Doping / N-Type Semi-conductor:

When an intrinsic semi-conductor Ge or Si is doped with elements of group V (arsenic,

P

antimony or phosphorus), which have five electrons in their outer most orbit. Each Ge atom has four electrons. Four of five electrons of antimony form bonds with four electrons of Ge, while the fifth electron will remain as free. When an electric field is applied, this free electron will be easily excited to conduction band. Thus addition of antimony increase the number of free electrons and hence the conductivity of material. In this case, antimony is called Donor Doping.

The donor doping makes an intrinsic semi-conductor n-type. In n-type material majority charge carriers are electrons.

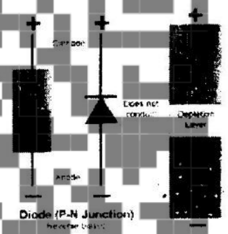
(ii) **Acceptor Doping / P-Type Semi-conductor:**

When an intrinsic semi-conductor Ge or Si is doped with the elements of group III (boron, aluminum or gallium), which have three electrons in the outer most orbit, there is a deficiency of electrons in the crystal structure called hole. Due to this deficiency material becomes capable of accepting extra electrons and it is called Acceptor Doping.

The acceptor doping makes an intrinsic semi-conductor p-type. In p-type material majority charge carriers are holes.

Semi-Conductor Diode (P-N Junction Diode):

A single crystal of Si or Ge, which has been doped in such a way that one half of it is p-type and the other half is n-type, is called a semi-conductor diode. P-type and n-type regions are separated by a boundary region called junction. This is a two terminal device called p-n junction. In electrical circuits,it is symbolically represented by



Biasing:

Application of voltage across a semi-conducting device is termed as Biasing. There are two types of biasing.

(i) **Forward Biasing:**

If the external voltage is applied across p-n junction in such a way that it cancels the potential barrier and helps current to flow then it is called forward biasing. When p-n junction is forward biased, it offers low resistance to the flow of current. Forward biasing can be done by connecting positive terminal of the battery with p-type and negative terminal of the battery with n-type material.

(ii) **Reverse Biasing:**

If the external voltage is applied across p-n junction in such a way that it offers a potential barrier and resists the current to flow then it is called reverse biasing. When p-n junction is reverse biased, it offers high resistance to the flow of current.

Reverse biasing can be done by connecting negative terminal of the battery with p-type and positive terminal of the battery with n-type material.

Rectification:

The process of converting alternating current or voltage into direct pulsating current or voltage is called rectification.

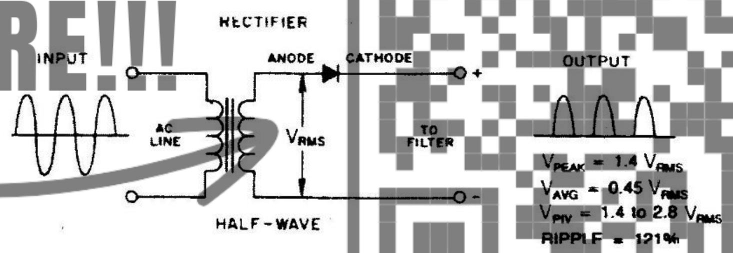
Rectifier:

The device which converts alternating current or voltage into direct pulsating current or voltage is called rectifier. A semi-conductor diode also known as crystal diode can be used for rectification. There are two types of rectification.

(i) Half Wave Rectification
(ii) Full Wave Rectification

(i) **Half Wave Rectification:**

When a diode is connected to a transformer its biasing changes alternately. During one half cycle it is forward biased and during other half cycle it is reverse biased. When forward biased, and it acts as a closed switch, the current flows in the circuit as a pulse of half-sine "wave-form".



During the next half cycle of the transformer voltage, anode of the diode is negative (reverse biased), and it acts as an open circuit. No current exists in the load (resistance R). In this way, current flows in one direction and the output across the load "pulsating D.C". These pulsations in the output are further smoothed with the help of "filter circuits".

(ii) **Full Wave Rectification:**

In a full wave rectification current flows through the load in the same direction for both half cycles of input A.C voltage. Two diodes D_1 and D_2 can produce full wave rectification using a center-tap transformer. A.C voltages of opposite polarity are applied simultaneously to D_1 and D_2. This makes each diode forward biased alternately and the other reverse biased. If in the first self-cycle D_1 is forward biased and D_2 is reverse

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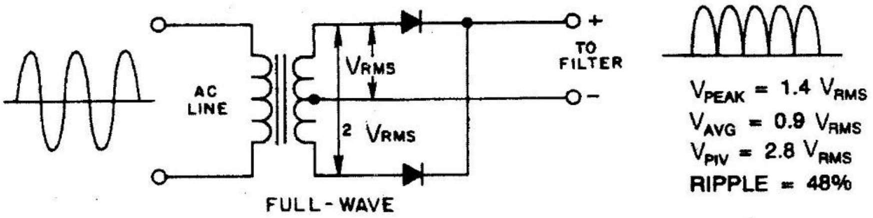
biased: D_1 conducts electric current and D_2 does not. In the next half cycle D_1 does not conduct but D_2 conducts. Hence, unidirectional voltage is obtained as output.

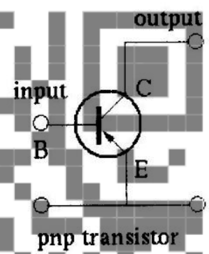


Note: A full wave rectification with four diodes can be produced by using a bridge circuit without using center-tapped secondary. It provides greater D.C output voltage.

Transistor:

In 1947, John Bardeen invented a three terminal semi-conductor device called transistor. It can be defined as, "Transistor is one type of very thin semi-conductor which is sandwiching between relatively thick layers of other type of semi-conductor." It helps us to amplify control and generate electric signals. There are two types of transistors.

(i) PNP Transistor.
(ii) NPN Transistor.

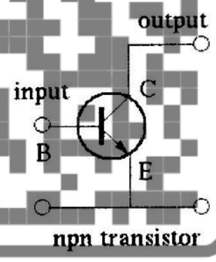


(i) PNP Transistor:

In this type of transistor n-type semi-conductor piece is sandwiched between two pieces of p-type semi-conductor layers.

(ii) NPN Transistor:

In this type of transistor p-type semi-conductor piece is sandwiched between two pieces of n-type semi-conductor layers.



Essential parts of Transistors:

There three essential parts of transistors

Base: It is the central layer denoted by 'b'.

Emitter: It is the outer layer denoted by 'e'.

Collector: It is the outer layer denoted by 'c'.

Principle of Transistor:

Transistor work on the principle that the base emitter junction always forward biased whereas base collector junction is always reverse biased.

Working:

Consider any one type of the transistor for example a pnp transistor. Let the two p-end are connected to two batteries as shown in figure. The forward biasing causes the holes in the p-type emitter to flow toward the base which constituent current I_e. These holes cross into the n-type base, they try to combine with electrons but the base is lightly doped and is very thin.

Therefore, only few holes combine with electronsand the remaining holes cross into the collector and generates collector current I_c. In this way almost the entire emitter current flows into the collector circuit. From the above description it is clear that:

$$I_e = I_b + I_c$$

Thus there are two current paths through a capacitor. One is the base-emitter (input) path and the other is collector-emitter (output) path.

Transistor as an Amplifier:

An amplifier is a device used to increase the amplitude of input signal (current or voltage) without changing the shape of wave. Transistor increases the amplitude of electric signals so it can be used as an amplifier and the process is called Amplification.

The ratio of collector current to emitter current is called "current gain" (β).

$$\beta = \frac{I_c}{I_e}$$

CHAPTER-16

MULTIPLE CHOICE QUESTIONS

From Past Papers

2003 (P.E)

1 The speed of electromagnetic waves is given by:

* $\frac{1}{\sqrt{\mu_o \varepsilon_o}}$ * $\left(\frac{\mu_o}{\varepsilon_o}\right) \times \sqrt{\frac{\varepsilon_o}{\mu_o}}$ * $\sqrt{\mu_o \varepsilon_o}$ * $\mu_o \varepsilon_o$

2 In p-type semi-conductor majority charge carriers are:

* electrons * protons * neutrons * holes

3 Electrical conductors contain:

* only free electrons * only bound electrons

* both free and bound electrons * neither free nor bound electrons

2003 (P.M)

1 The elements of group IV like Ge and Si can be converted into P-type semi-conductor by:

* adding impurity of group V-A elements * adding impurity of group III-A elements

* adding impurity of both group V-A and III-A elements * none of these

2 A semi-conductor diode is used as:

* an amplifier * an oscillator * a rectifier * none of these

2005

1 A semi-conductor diode is used as

* amplifier * rectifier * modulator * oscillator

P

2006

1 A pn- junction can be used as,
* rectifier * amplifier * transformer * ohm-meter

2007

1) The speed of electromagnetic waves is given by:

* $\frac{1}{\sqrt{\mu_o \varepsilon_o}}$ * $\left(\frac{\mu_o}{\varepsilon_o}\right) \times \sqrt{\frac{\varepsilon_o}{\mu_o}}$ * $\sqrt{\mu_o \varepsilon_o}$ * $\mu_o \varepsilon_o$

2) A semi-conductor diode is used as
* an amplifier * an oscillator * a rectifier *none

2008

1) In a semi-conductor,
* Electrons move in the conduction band while the holes move in the forbidden band.
* Holes move in the conduction band while the electrons move in the forbidden band.
* Electrons move in the conduction band while the holes move in the valence band.
* Holes move in the conduction band while the electrons move in the valence band.

2) The potential difference applied across pn-junction which results in the reduction in the barrier potential is
* reverse biases * forward biases * charging Inductor * inductor

2009

1) A diode which gives of visible light when energized, is called
*LCD *photo-diode *LED *photo voltaic cell

2010

(xvi) Donor impurities are:
*Ge and Si * In and Ga * Sb and As * Li and Ga

(xvii) In a semi-conductor, the energy gap between the valence band and the conduction band is:
* narrow * wide * not present * 10^{-6}

2011

(xvii) Emitter Base junction is forward biased in:
*PNP transistor *NPN transistor *both PNP and NPN transistor *Rectifier

(xvi) PN- Junction diode works as an insulator if connected:
*to A.C source *in forward bias *in reverse bias *all of these

(xii) A photoelectric cell transforms light energy into

* Heat energy * Electric energy * Magnetic energy * Sound energy

2012

(xi) With the increase of temperature the resistance of a semi-conductor:

* increase * decrease * remains same * becomes zero

2013

Q1(xii) The speed of electromagnetic waves is given by:

* $\frac{1}{\sqrt{\mu_o \varepsilon_o}}$ * $\left(\frac{\mu_o}{\varepsilon_o}\right)\times\sqrt{\frac{\varepsilon_o}{\mu_o}}$ * $\sqrt{\mu_o \varepsilon_o}$ * $\mu_o \varepsilon_o$

Q1.(ii) A diode which gives of visible light when energized, is called

*LCD *photo-diode *LED *photo voltaic cell

2014

(i) Hole in a semi-conductor is actually the;

*Electron *Positron *Helium nucleus *vacancy in the valance bond

2015

(iv) Donor impurities are:

* Ge and Si * In and Ga * Sb and As * Li and Ga

P

Chapter#17

Advent of Modern Physics

Frame of Reference:

Any three dimensional co-ordinate system with respect to which physical measurements are made is known as a frame of reference. It consists of three mutually perpendicular co-ordinate axes.

Internal Frame of Reference:

An inertial frame of reference is one in which Newton's law of inertia is valid. Such a frame moves with uniform velocity is a non-accelerating frame of reference.

All inertial frames of reference are equivalent from the point of view of making physical measurement.

A physical quantity as measured by different observers moving with respect to each other with different velocities in different frames of reference may have different values, but the basic physical laws governing such measurements always remain the same. For example if two observers in different inertial frames measure the velocity and momentum of two colliding bodies they may get their different values, but the basic laws such as laws of conservation of momentum and energy will remain same for both of them.

Non-Internal Frame of Reference:

A frame of reference having acceleration is called a non-inertial frame of reference. In this frame the law of inertia is not valid.

Theory of Relativity:

Theory of relativity is of two types:

i. Special theory of relativity, which deals with inertial frames of reference.

ii. General theory of relativity, which deals with non-inertial frames of reference.

Postulates of Einstein's theory of relativity:

i. The laws of physics must be the same in all inertial reference frames.

ii. The speed of light in vacuum has the same value, $c = 3\times10^8\ m/s$ in all inertial frames, regardless of the velocity of the observer or the velocity of the source emitting the light.

Results (consequences) of special theory of relativity:

Einstein's special theory of relativity gives the following results.

1. Mass Variation:

If "m_o" is mass of a body at rest in observer's frame of reference, then it's mass "m" as measured by an observer from another frame of reference moving with uniform velocity "v" with respect to the body's frame is given by:

$$m = \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

The above relation shows that mass "m" of the body appears to increase to an observer moving with velocity "v" with respect to the body. Hence mass of a body depends upon whether the body is at rest or is in motion relative to the observer. This effect takes place only if the relative velocity between the object and the observer is comparable to the speed of light.

2. LengthContraction:

If "L_0' is the length of a rod when it is at rest relative to an observer then its new length "L" when it is in motion with velocity "v" relative to the same observer, is given by;

$$L = L_o\sqrt{1-\frac{v^2}{c^2}}$$

Hence length of the rod appears to reduce when there is relative motion between an observer and the rod, provided the relative velocity is comparable to speed of light This effect is known as "Length Contraction".

Length contraction takes place only along the direction of motion of the body. There no change in length of the body perpendicular to the direction of its motion, hence change appears when the length is parallel to direction of motion.

3. Time Dilation:

Let "t_o" be the time interval between two events at some point in space as recorded by an observer at rest with respect to that point. Then the time interval recorded between the same two events by another observer moving with velocity "v" relative to that point is given by;

$$t = \frac{t_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

This effect is known as Time Dilation. "t_0" is called the proper time and "t" is called relativistic time.

Above three effects take place only when the relative velocity "v" approaches the speed of light in vacuum. The relative speed at which these *effects* become noticeable is called "relativist' speed".

Factor $\sqrt{1-\frac{v^2}{c^2}}$ appears in these equations is called "Lorentz Factor". For ordinary relative velocities this factor is practically unity. Hence relativistic effects cannot be detected at ordinary velocities. These effects cannot be neglected if the relative speed is comparable to the speed of light.

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4. Mass Energy Relation:

Mass and energy are inter-convertible. A mass "m" is equivalent to energy "mc^2", where "c" is the speed of light.

If "m_o" is the rest mass of a body then its energy equivalent is m_oc^2.When the body moves with relativistic speed "v" its mass becomes "rn" which is equal to energy "mc^2". This energy is greater than the rest mass energy by amount equal to K.E of the body. i.e.

$$mc^2 = m_oc^2 + K.E$$

$$E = m_oc^2 + K.E$$

Where; *E = relativistic energy*, *m_oc^2= rest mass energy* and *K.E = kinetic energy*

Black Body:

A black body is one which absorbs all the radiation of energy striking on its surface i.e. the absorption power of a black body is 100%. A hole in the wall of a cavity is very nearly a black body because any radiation which gets into this hole is almost completely absorbed in the cavity by multiple reflections. The surface of cavity is painted black to enhance its absorption power.

Black Body Radiation:

When the walls of a cavity are heated from outside then radiation emitted from the hole in the cavity is called black body radiation. Since good absorbers are also good emitters therefore the hole of cavity radiator has nearly emissive power. Spectrum of black body radiation is continuous. It means that black body radiation consists of all wavelengths in a certain range.

Intensity or Monochromatic Emissive Power:

The energy of a particular wavelength emitted per unit time per unit area of a surface is called intensity or monochromatic emissive power. It is denoted by EA. Its unit is W/rn^2.

How does intensity of black body radiation vary with wavelength:

Graph shows the energy among different wavelengths. It is clear that intensity of short wavelengths is low. As wavelength increases, intensity also increases until the intensity becomes maximum for a certain wavelength λ_{max}. The dominant color in black body radiation is due to this wavelength. As wavelengthincreases beyond, then intensity begins to decrease.

Emissive Power:

Total energy of all wavelengths emitted per unit time' per area of a surface at a certain temperature is called emissive power at that temperature. It is denoted by "E" and it is equal to the area under the curve drawn between intensity and wavelength at a certain temperature.

Laws of Black Body Radiation:

Wien's Displacement Law:

This law states that the wavelength that emitted with maximum intensity from a black body is inversely proportional to the absolute temperature of black body.
Hence;

$$\lambda_{max} \propto \frac{1}{T}$$

$$\lambda_{max} = (constant)\frac{1}{T}$$

$$\lambda_{max} \times T = constant$$

Value of Wien's constant is 0.0029mK.

Stefan-Boltzmann's Law or Forth Power Law:

The law states that the total energy of all wavelengths radiated per unit time per unit area of the surface of black body (i.e. emissive power) is directly proportional to the fourth power of absolute temperature of the black body.

$$E \propto T^4$$

$$E = \sigma T^4$$

Where; $\sigma = 5.67 \times 10^8 W/m^2K^4$.

Rayleigh-jean's Law:

The law states that the intensity of a particular radiation emitted froma black body at a certain temperature is inversely proportional to the fourth power of its wavelength.

$$E_\lambda \propto \frac{1}{\lambda^4}$$

$$E_\lambda = \frac{constant}{\lambda^4}$$

The law is obeyed by radiation of longer wavelength but is a failed for shorter wavelength i.e. for ultraviolet radiation.

Plank's Law:

In 1900, after the failure of Rayleigh Jean's law, max plank has made some bold step to explain the phenomenon of absorption or emission of radiation. He firmly believed that a new mechanics should be introduced to explain such a phenomenon instead of applying classical mechanics.
He thus proposed three fundamental postulates to explain the phenomenon of emission of radiation, often called Plank's Law for Radiations.

1^{st} Postulate:
The atoms of cavity behave like tiny harmonic oscillators and they are the origin of emission of radiations from a cavity radiator.

2^{nd} Postulate:
The emission or absorption of energy is not considered as a continuous phenomenon, but infact it is Quantized.

3rdPostulate:
Only those harmonic oscillators emits energy in form of electromagnetic wave whose minimurn energy must be equal to *"hv"* or integral multiple of *"hv"*.Thus, Quantization of energy for nth harmonic oscillator can be written as;

$$\boxed{E_n = nh\nu}$$

Where; n = 1,2,3,4

h= Plank's constant $h = 6.63\times10^{-34}$ J-s

ν = Frequency of harmonic oscillator.

Photoelectric Effect:
In 1887, Heinrich Hertz and Hallwach found that when electromagnetic radiations such as, visible light. Ultraviolet light, x-rays incident on a metal surface, particles are found to emit out of the metal surface.

"The phenomenon of emission of particles from a metal surface when it is illuminated by light of suitable frequency is known as "Photoelectric Emission" whereas the emitted particles are called "Photo Particles". In practice, it was observed that Alkali-Metals like Na, K, Cs etc are sensitive to only visible light, but some other metals like Al, Zn, Cu, Cd etc, are sensitive to ultraviolet and x-rays only.

Later on, Lenard has made an attempt to determine q/rn of photo-particle, equal to e/m of an electron. He thus suggested that photo-particles are infact "Electrons", called "Photo-Electrons".

Experimental Arrangement:
The Hallwach's experiment an arrangement consists of two zinc plates are fixed inside X-Rays an evacuated bulb. The plates are connected with the positive and negative terminal of a battery of known P.D. A micro-Ammeter is connected in the circuit to observe phenomenon of emissionof photo-electrons. When ultraviolet light of suitable frequencyincident on cathode plate, a very feeblecurrent in few micro ampere flow in the circuit but, when the same radiation incident on anodeplates no such current is found in the circuit concern.

Laws of Photoelectric Effect:
After the number of experiment performed by the scientists some fundamental laws were formulated about the emission of photoelectrons. These laws are;

i) To every metal surface there must needed radiations in a particular frequency range, below which no photoelectric emission takes place. The minimum frequency needed to emit photoelectrons from a metal surface, is referred as "Threshold Frequency". It is symbolized by "ν_o". Its value depends on, nature of material of the metal surface.

ii) The strength of photoelectric current directly depends on intensity of radiation, provided $\nu > \nu_o$.

iii) The velocity and hence kineticenergy of photoelectrons emitted out of metal surface directly proportional to the frequency of incident radiations, provided $\nu > \nu_0$.

iv) The photoelectric emission is an instantaneous phenomenon. The time needed for emission of a photo-electron from metal surface, is nomore longer than 3×10^{9} second.

Einstein's, Quantum Theory of Light:

After the failure of classical mechanics, Albert Einstein proposed a new ideology about the nature of light on the basis of Plank's Quantum Theory of Radiation. According to him;

"A light ray of frequency "ν" is composed of tiny packets of energy, called Photons. In radiations of frequency (ν) only those photons exists whose energy remains equal to ($h\nu$) or integral multiple of $h\nu$".

Hence, for quantization of energy in photons of radiations we may write as;

$$E_n = n\,h\nu$$

Where; n = 1,2,3,4

h= Plank's constant = 6.63×10^{-34}J-s

ν = Frequency of Light.

Explanation of Photoelectric Effect On The Basis of Einstein's Quantum Theory of Light:

According to Einstein's ideology;

When a ray of light of frequency "ν" is incident on a metal surface such that $\nu > \nu_o$, then photon of radiations losses its energy completely into two ways.

i. Some parts of photon's energy are utilized in doing work against the lattice-energy of surface.

ii. The rest of photon's energy is used in imparting kinetic energy to the liberated electron. The energy of incident photon which is used to pull an electron out of the metal surface is referred as Photoelectric Work Function. It is symbolized by "ϕ_o".

The magnitude of photoelectric work function directly depends on the threshold frequency needed for metal surface.

Mathematically;

$$\phi_o \propto \nu_o$$

$$\phi_o = h\nu_o$$

Einstein's Equation For Photoelectric Effect:

Let us assume that;

i. The frequency of incident light ν

ii. The energy of incident photon = h ν

iii. The threshold frequency for metal surface = ν_o

iv. The photoelectric work function needed for the metal surface = ($\phi_o = h\nu$)

v. The K.E gained by the librated*electron*

$$K.E_{max} = \frac{1}{2}mv^2_{max}$$

Now, applying law of conservation of energy,

$$h\nu = \phi_o + K.E_{max}$$

$$h\nu = h\nu_o + \frac{1}{2}mv^2_{max}$$

$$h\nu - h\nu_o = \frac{1}{2}mv^2_{max}$$

$$h(\nu - \nu_o) = \frac{1}{2}mv^2_{max} \quad \left(\because \frac{1}{2}mv^2_{max} = V_o e\right)$$

$$h(\nu - \nu_0) = V_0 e \quad \left(\because \nu = \frac{c}{\lambda}\right)$$

$$h\left(\frac{c}{\lambda} - \frac{c}{\lambda_o}\right) = V_o e$$

Where, V_0 is stopping potential (it is the voltage required to stop the fastest photoelectron emitted having maximum K.E) and "e" is the charge on an electron.Where "i" is the wavelength of incident light and "λ_0" is the threshold or cut off wavelength (threshold wavelength or cut off wave .length "λ_0" is the longer wavelength required to initiate photoelectric effect, depends on the nature of the surface) and "c" is the speed of light invacuum.

Photocell:

A photocell is a device used to produce photoelectric current.

Construction:

It consists of an evacuated glass fitted with two Glass Tube electrodes. Cathode plate is made curved andcoated with a thin layer of some photosensitive metal such as "cesium" so that visible light causes Lightphotoelectric emission. The anode is made of a thin rod so as not to obstruct light falling oncathode. A source of light is installed at a fixed distance light from the source falls on cathode and Anode the emitted photoelectrons converge at the anode to produce photoelectric current.

Application or Uses of Photocell:

Photo cells work on the basis of photo electric effect. These are widely used in various devices. Some uses of photo cells are:

i. To count vehicles passing a road or to count the number of articles running on a conveyer belt.

ii. To automatically open doors.

iii. To operate burglar.

iv. To automatically switch on and switch off street lights.

v. Small electric cars even small single sealer planes have been developed which make use of solar panels consisting of a large number of photo cell, that convert solar energy into electrical energy.

Momentum of Photon:

Rest mass of photon is zero. However photon has mass as well as momentum in motion. Its,

velocity is equal to the velocity of light.Energy of a photon may be given by;

$E = h\nu$ (Einstein's Quantum Theory).

And $E=mc^2$ (Theory of Relativity).

Therefore;

$$mc^2 = h\nu$$

$$mc = \frac{h\nu}{c}$$

But $mc = p$ = momentum of photon

Therefore;

$$P = \frac{h\nu}{c}$$

But $c = \nu\lambda$

Therefore;

$$P = \frac{h\nu}{\nu\lambda}$$

Or

$$P = \frac{h}{\lambda}$$

The momentum of photon is directly proportional to the frequency "ν" and inversely proportional to the wavelength "λ" of the radiation.

P

Compton Effect:

In 1922, A.H Compton has made a successful interaction of x-ray's photon and free Electron of material of low atomic number like "Carbon". This Photoelectron interaction is often called "Compton Effect".

Mechanism:

When an x-ray's photon of every sharp frequency is incident on a carbon block, it gets successful collision with a free electron, transfers energy to electron and scatters with rest of energy. In this interaction, the energy and frequency of scattered photon will be less than that of incident photon and hence, the wavelength of scattered photon will be increased than that of incident photon.

The change in wavelengths of scattered photon and incident photon is called "Compton Shift" in wavelength and symbolized by "$\Delta\lambda$".

Derivation for Compton Shift In Wavelength:

The collision between photon and electron is elastic, therefore momentum and energy both are conserved:

Conservation of Energy:

Total initial energy = Total final energy

$$h\nu + m_o c^2 = h\nu' + E$$

$$h\nu - h\nu' + m_o c^2 = E$$

$$h(\nu - \nu') + m_o c^2 = E \text{------}(i)$$

h= Plank's Constant

ν = Frequency of incident photon

ν'= Frequency of scattered photon

m_0c^2= Rest energy of electron

C = speed of light

E = Energy of electron after collision

Conservation of Momentum:

Along original direction:

Total momentum before collision Total momentum after collision

$$\frac{h\nu}{c} + 0 = \frac{h\nu'}{c}\cos\theta + P\cos\phi$$

$$\Rightarrow h\nu = h\nu'\cos\theta + Pc\cos\phi$$

$$\Rightarrow h\nu - h\nu'\cos\theta = Pc\cos\phi \text{------}(ii)$$

θ = Angle t which photon is scattered

ϕ= Angle at which electron is scattered

Perpendicular to original direction:

Total momentum before collision Total momentum after collision

$$0 + 0 = \frac{hv'}{c}\sin\theta - P\sin\phi$$

$$\Rightarrow \frac{hv'}{c}\sin\theta = P\sin\phi$$

$$\Rightarrow hv'\sin\theta = Pc\sin\phi \text{------}(iii)$$

Solving equations (i), (ii) and (iii) simultaneously we get

$$\Rightarrow \frac{1}{v'} = \frac{1}{v} + \frac{h}{m_o c^2}(1-\cos\theta) \text{------}(iv)$$

Now, $$c = v\lambda \Rightarrow \frac{1}{v} = \frac{\lambda}{c}$$

Therefore eq. (iv) gives;

$$(iv) \Rightarrow \frac{\lambda'}{c} = \frac{\lambda}{c} + \frac{h}{m_o c^2}(1-\cos\theta)$$

Multiply throughout by "c"

$$\lambda' = \lambda + \frac{h}{m_o c}(1-\cos\theta)$$

$$\lambda' - \lambda = \frac{h}{m_o c}(1-\cos\theta)$$

$$\boxed{\Delta\lambda = \frac{h}{m_o c}(1-\cos\theta)}$$

Where, $\Delta\lambda$ = *Compton Shift in wavelength*

Pair Production:

Under suitable conditions when a photon passes near a nucleus it disappears and anelectronp3sit1on pair is produced. This phenomenon is known as "Pair Production". Positron is a positively charge particle its charge and mass are equal to the charge and mass of electron, the only difference between the two particle is that positron is positive and electron is a negative particle. Positron is the anti-particle of electron. According to Einstein's mass energy equation,the energy required to create an electron is(called rest mass energy of electron) when *"rn$_0$"* is the rest mass of an electron. Hence the minimum energy required for pair production is *$2m_0c^2$"* which is;

$$2m_oc^2 = 2\ (9.1\times10^{-31})(3\times10^{8})$$

$$2m_oc^2 = \frac{1.638\text{x}10^{-13}\text{J}}{1.6021\text{x}10^{-19}}\ e.V$$

$2m_0c^2 = 1.022\ \text{x}10^6 e.V$

$2m_0c^2 = 1.022\ MeV$

Pair production takes place only if the energy of the photon is equal or greater than 1.022 *MeV*. If the energy of the photon is greater than *"2m0c2"* then during the process *"2m"* energy is used to create the electron=position pair whereas the remaining energy is carried away by the two particles in the form of K.E. the two particles move in opposite direction carrying equal amount of K.E.

$$\therefore h\nu = 2m_0c^2 + K.E_{e^-} + K.E_e$$

If energy of the incident photon is less than *"$2m_0c^2$"* no pair production will take place. During this process energy, momentum and charge are all conserved. Pair production is also known as "Materialization of Energy".

Annihilation of Matter:

If an electron (a particle) and a positron (anti-particle) come close to each other they combine and destroy each other. This process is the reverse process of pair production and is known as "Annihilation of Matter". During this process at least two photons are produced. To conserve momentum these photons move in opposite direction. Charge and energy are also conserved. \

$$(m_oc^2 + K.E)_{e^-} + (m_oc^2 + K.E)_{e^+} = 2h\nu$$

De-Broglie's Concept of Matter Waves:

In 197l.a French physicist Louis-de-Broglie has proposed a new ideology about the nature of light called "Dual Nature of Light". According to him, light has dual nature Le. it exhibits wave nature and matter nature under appropriate conditions E.g. when light exhibits wave nature, it produces phenomenon like Reflection, Refraction, Interference, Diffraction and Polarization etc. Similarly, when light exhibits matter nature, it produces phenomenon like Photoelectric effect and Corn Compton effect etc. He further added that "Matter" which consists of discrete dual nature like radiations (Light). His ideology was based on three basic postulate ate given below.

1. Nature loves symmetry.
2. Strong Parallelism between mechanics and optics.
3. Integral Rules in atom and wave motion.

By the observations De-Broglie found that the momentum of an electron and momentum of photon is equal.

i.e $\quad Particle's\ momentum = Photon's\ momentum$

$$mv = \frac{h}{\lambda}$$

$$\lambda = \frac{h}{mv}$$

Where; m = mass of matter particle like electron

v = velocity of particle

λ= wave length of matter wave.

This equation originally proposed for electrons are equally applicable to any other particle. Hence wave length "A" associated with any moving body can be calculated with the help of above equation. Waves associated with the particles are known as De-Broglie's waves. Wavelength "A" associated with ordinary bodies moving with ordinary velocities (such as car) is very long and hence donot represent any appreciable wav' character. But the wavelength "A" associated with a fast moving light particle (such as electron etc) lies within the range electromagnetic spectrum and cannot he neglected.

Davison and Germer in 1927 experimentally proved the existence of De-Broglie waves associated with fast moving electrons. Experimentally measured value of the wavelength associated with fast moving electrons matched with the value theoretically predicted by r-Brogue. Later on same wave like behavior was observed with other particles such as protons, neutrons and atoms etc.

GermerAnd Davisson Experiment:

In this experiment electrons showed their wave nature. Electrons emitted from a filament pass through voltage "V" and gain K.E. These high speed electrons strike a nickeltarget and reflect at different angles arid the intensity of reflected electron beam is measured by the moveable detectorD.it was found that the intensity of reflectedelectron beam was different at different angles. This behavior of electrons was explained by Davisson and Germer. When they assumed that electrons were not particles but waves, the electrons were showing diffraction and interference by making maxima and minima of intensity.

Wavelength of Electrons:

Through the voltage, electrons gain k.E i.e.

$$K.E. = q\Delta V$$

$$\frac{1}{2}m_o v^2 = eV$$

P

$$v^2 = \frac{2eV}{m_o}$$

$$v = \sqrt{\frac{2eV}{m_o}}$$

Now;

$$\lambda = \frac{h}{m_o v}$$

$$\lambda = \frac{h}{m_o \sqrt{\frac{2eV}{m_o}}}$$

$$\lambda = \frac{h}{\sqrt{m_o^2 \frac{2eV}{m_o}}}$$

$$\boxed{\lambda = \frac{h}{\sqrt{2eVm_o}}}$$

Where "e" is the charge and "m_0" is the rest mass of electron.

Heisenberg's Uncertainty Principle:

For a microscopic particle it is impossible to measure accurately the momentum and position simultaneously. The principle states that, "The product of uncertainty in the momentum of a particle at a certain instant and the uncertainty in the position of the particle at the same instant is equal to or greater than $\frac{h}{2\pi}$

Mathematically;

$$\boxed{\Delta E \times \Delta x \geq \frac{h}{2\pi}}$$

Where; $\Delta p =$ Uncertainty in momentum

$\Delta x =$ Uncertainty in position

h=Plank's constant

Another form of uncertainty principle states that the product of uncertainty in the measurement of energy and the time available for the measurement of energy is equal to Plank's constant.

$$\Delta E \times \Delta t = h$$

CHAPTER-17 **MULTIPLE CHOICE QUESTIONS**

From Past Papers

2001

Q.7. (a) (i) The relativistic changes in mass, length and time in daily life are not observed because:

* The masses of objects are very large
* The size of objects is very large
* The velocity of objects is very small in comparison to the velocity of light
* None of the above

Q.7. (a) (ii) As the temperature of a black body is raised, the wavelength corresponding to the maximum intensity:

* Shift towards longer wavelength
* Shifts towards shorter wavelength
* Greater frequency and greater wavelength
* None of the above

Q.7. (a) (iii) In Compton Effect, the scattered photon has:

* Greater frequency and smaller wavelength
* Smaller frequency and greater wavelength
* Greater frequency and greater wavelength
* None of the above

2002(Pre–Medical)

Q.7. (a) (i) The fast moving electrons stopped by a heavy metallic target in an evacuated glass tube, give rise to the production of:

* α particles
* β-particles
* X-rays
* Protons

Q.7. (a) (ii) The maximum kinetic energy of photoelectron emitted from a metal depends upon:

* the frequency of incident light only
* the wavelength of incident light only
* work function of the metal only
* all of them

2002(Pre–Engineering)

Q.7. (a) (i) Max Planck is well known because of his:

* energy quantization
* energy conservation
* wave particle duality
* momentum conservation

Q.7. (a) (ii) A frame of reference is called inertial if it is:

* rotatory * accelerated * moving with uniform velocity * vibratory

Q.7. (a) (iii) According to Uncertainty Principle:

* $(\Delta x)(\Delta t) = h$ * $(\Delta x)(\Delta p) = \hbar$ * $(\Delta E)(\Delta p) = h$ * $(\Delta x)(\Delta E) = h$

Q.8. (a) (i) The Einstein photo electric equation is:

* $V_o e = hv + \frac{1}{2} mv^2$ * $hv = mc^2 + V_o$
* $V_o e = hv - \hbar v_o$ * $V_o e = [h(1/\lambda - 1/\lambda_o)]$

Q.8. (a) (ii) The absorption of the incident radiation by a perfect black body is:

* 0% * 100% * 90% * 50%

Q.8. (a) (iii) Pair production is only possible when incident photon has the wavelength of the order of:

* 10^{-4}m * 10^{-6} m * 10^{-10} m * 10^{-14} m

2003(Pre–Medical)

Q.7. (a) (i) the reverse of pair production is known as;

* Fusion * annihilation of electrons and positrons
* Fission * annihilation of electrons and protons

2003(Pre-Engineering)

Q.7. (a) (i) the formula for the momentum of photon is:

* hc/λ * h/λ * λ/h * c/λ

Q.7. (a) (ii) If the frequency of light causing photoelectron emission is doubled, the kinetic energy of photoelectron will be:

* increased by a factor $1/\sqrt{2}$ * doubled
* increased by a factor less than 2 * increased by a factor greater than 2

Q.7. (a) (iii) Wein's Law is given as:

* $\lambda_{max}T$ = constant * Ω T = constant
* $\lambda_{max}\sqrt{T}$ = constant * $\lambda_{max}T^4$ = constant

2004

Q.7. (a) (i) The number of photoelectrons emitted from a metal depends upon;

* the frequency of the incident light * the wavelength of the incident light
* thecolour of the incident light * the intensity of the incident light

Q.7. (a) (ii) In pair production we need photons of at least 1.02Mev energy. {*True*}

Q.7. (a) (iii) The energy of each quantum as proposed by Plank is given by *E=hv*.

Q.8. (a) (i) The disintegration of a photon into electron and positron near a heavy nucleus is known as;
* Annihilation * β decay * α decay * Pair Production

Q.8. (a) (iii) The ratio of the mass of proton to the mass of electron is *1:1836*

2005

Q.7. (a) (i) One atomic mass unit is equal to;
* 1.6×10^{-19}J * 9.1×10^{-27}kg * 931×10^{6}eV * 9×10^{9}eV

Q.7. (a) (ii) The frequency of the incident radiation corresponding to the work function is called;
* Fundamental frequency * working frequency
* critical frequency * Threshold frequency

Q.8. (a) (i) The radiation from a black body depends upon the;
* Material of the body * size of the body
* Shape of the body * Temperature of the body

Q.8. (a) (iii) As a result of elastic collision between a photon and an electron the;
* frequency of the photon is increased * wavelength of the photon is increased
* energy of the photon is increased * X-rays are produced

2006

Q.7. (a) (i) The formula for the momentum of photon is:
* h/λ * h/λ * λ/h * c/λ

Q.8. (a) (i) The emissive power of a black body radiation is proportional to:
* T * T^2 * T^4 * T^{-4}

2007

Q.7. (a) (i) A frame of reference is called inertial if it is:
* rotatory * accelerated
* vibratory * moving with uniform velocity

Q.7. (a) (ii) In Compton Effect, the scattered photon has:
* Greater frequency and smaller wavelength

* Greater frequency and greater wavelength
* Smaller frequency and greater wavelength
* None of the above

Q.7. (a) (iii) The wavelength of a material particle of mass 'm' moving with a velocity 'v' is given by:

* $\lambda = \frac{hv}{m}$ * $\lambda = \frac{m}{hv}$ * $\lambda = \frac{v}{hm}$ * $\lambda = \frac{h}{mv}$

Q.8. (a) (i) The absorption of the incident radiation by a perfect black body is:

* 0%   * 50%   * 90%   * 100%

Q.8. (a) (ii) A Compton shift depends only on photon's:

* Greater frequency, smaller wavelength
* Greater frequency, greater wavelength
* Smaller frequency, greater wavelength
* None of the above

2008

Q.7. (a) (i) Galilean transformations are applicable to a frame of reference which is:

* stationary   * moving   * inertial   * non inertial

Q.7. (a) (ii) A perfect black body:

* is a perfect absorber of radiation   * has a unit absorptive power
* is the most efficient radiator   * all of them

Q.7. (a) (iii) The experimental evidence of Einstein's mass energy equation is:

* Photoelectric and Compton effect   * elastic collision
* pair production and annihilation of matter   * radioactive emission

Q.8. (a) (ii) The expression $\lambda_{max} T$ = constant, represents:

* Stefan's Law   * Wein's Displacement Law
* Rayleigh Jean's Formula   * Plank's Law

2009

Q.7. (a) (i) The emissive power of a black body radiation is proportional to:

* T * T^2 * T^4 * T^{-4}

Q.7. (a) (ii) The photoelectric emission takes place if:

* $hv<\phi_o$ * $hv>\phi_o$ * $hv_o<\phi_o$ * $v_o<\phi_o$

P

Q.7. (a) (iii) According to Uncertainty Principle:

* $(\Delta E)/(\Delta t) = h$ * $(\Delta E)=(\Delta t) / h$ * $(\Delta E)(h) = \Delta t$ * $(\Delta E)(\Delta t) = \hbar$...

2010

Q.1. (i) The phenomenon of pair production takes place if the energy of photon is greater than:

(a) 1.0MeV (b) 1.02MeV (c) 0.051MeV (d) None of these

Q.1. (xvii) The emissive power of a black body is proportional to:

(a) T (b) T^5 (c) T^{-4} (d) T^4

2011

Q.1. (vi) As the temperature of the black body is raised, the wavelength corresponding to the maximum intensity shifts towards

* shorter wavelength * longer wavelength
* similar wavelength * lower frequency

Q.1. (x) A photoelectric cell transform light energy into

* Heat energy * Electric energy
* Magnetic energy * Sound energy

Q.1. (xi) De–Broglie's wavelength associated with the particle is given by:

* $\lambda = mv/h$ * $\lambda = h/mv^2$
* $\lambda = h/mv$ * $\lambda = mh/v$

Q.1. (xii) The maximum energy required for a pair production is

* 1.02MeV * 102MeV * 10.2MeV * 1.02 volt

Q.1. (xv) In order to increase the kinetic energy of an ejected photo–electron, there should be an increase in

* frequency of radiation * wavelength of radiation
* intensity of radiation * both wavelength and intensity

2012

Q.1 v. According to Einstein's special theory of relativity, the mass of a particle moving with the speed of light will become:

* zero * double * infinite * ten times

Q.1.xii. The mathematical expression $\lambda_{max} X\ T = constant$, is called

* Stefan's Law * Wien's displacement law
* Rayleigh-Jean's law * Planck's law

Q.1.xiv. According to Uncertainty Principle:
* $(\Delta x)(\Delta t) = h$ * $(\Delta x)(\Delta p) = \hbar$ * $(\Delta x)(\Delta E) = h$ * $(\Delta E)(\Delta p) = h$

2013

Q.1.xvi The rest mass of photon is
* 1 * zero * infinity *-1

Q.1.x As the temperature of Black Body is raised, the wavelength corresponding to the maximum intensity shifts towards:
*similar wavelength *shorter wavelength
*longer wavelength *None of these

2014

(i) The energy radiated per unit area per unit time from the surface of a black body is directly proportional to its absolute temperature raiser to power:
*One *Two *Three *Four

(vii) de-Broglie wavelength is:
*$\lambda = mv/h$ *$\lambda = h/mv^2$ *$\lambda = h/mv$ *$\lambda = mh/v$

(viii) The minimum energy required for a pair production is:
*1.02 MeV *102 MeV *10.2 MeV *1.02 Volt

(x) The mathematical expression $\lambda_{max} \times T$ = constant, is called
*Stefan's Law *Rayleigh-Jeans law
*Wien's displacement law *Planck's law

2015

i) The rest mass of a photon is:
* –1 * zero * 1 * infinite

xi) In Compton's scattering experiment, the scattered photon has a:
* frequency less than that of incident photon.
* frequency greater than that of incident photon.
* same frequency as that of incident photon.
* wavelength shorter than that of incident photon.

P

CHAPTER-17 **NUMERICALS**

From Past Papers

1987

Q.7. (c) Find the cut off wavelength for a given metal whose work function is 4.14eV. **(3002.7A°)**

1989

Q.7. (c) The work function of certain metal is 3.03eV. When this metal is illuminated by the infrared light of 1.2×10^{15} Hz. Find the maximum kinetic energy of the emitted photoelectrons. **(1.9725eV)**

1991

Q.7. (c) A 50 m trailer is moving with relativistic speed. It passes over a bridge of length 40m. To an observer at rest with respect to the bridge at one instant, the trailer seems to overlap the bridge i.e. the ends of the trailer seem to coincide with the ends of bridge. Find the speed of the trailer. **(1.8×10^8m/s)**

1992

Q.7. (c) The work function of a photo emissive surface is 4.0eV. What will be the velocity of fastest photoelectrons emitted from it by an accident light of frequency 3.0×10^{15} Hz. **(1.722×10^6 m/s)**

1994

Q.7. (c) The work function of metal is 2eV. The light of wavelength 3000 A° is made to fall on it. Find the kinetic energy of the fastest emitted photoelectrons. **(2.144eV)**

1996

Q.7. (c) Find the relativistic speed at which the kinetic energy of a particle of rest mass m_o becomes doubles its rest mass energy. Given $m_o = 1.67 \times 10^{-27}$ Kg. Also calculate:

1) Rest mass energy
2) Kinetic energy
3) Total energy

(939.375MeV, 1878.75MeV, 2818.125 MeV)

1998

Q.7. (c) The range of visible light is 4000A° to 7000A°. Will photoelectrons be emitted by a copper surface of work function 4.4eV, when illuminated by visible light? Give the mathematical proof of your answer.

2001

Q.7. (c) When the light of the wavelength 4000°A falls on a metal surface, stopping potential is 0.6 volt. Find the value of the work function of the metal. **(2.5eV)**

2002 (Pre Med. group)

Q.7. (d) Find the speed at which the mass of a particle will be doubled. **(2.56×10^8 m/s)**

2002 (Pre Engg. group)

Q.8. (d) Given $m_oc^2 = 0.511$MeV. Find the total energy E and the kinetic energy K of an electron moving with a speed v = 0.85c. **(0.979MeV, 0.459MeV)**

2003 (Pre Med. group)

Q.7. (d) If a neutron is converted entirely into energy, how much energy is produced? Express your answer in joule and electron – volt. **(9.39×10^8eV)**

Q.8. (d) Sodium surface is shined with the light of wavelength 3×10^{-7}m. If the work function of Na=2.46eV, find the kinetic energy of the photoelectrons. **(1.68eV)**

2003 (Pre Engg. group)

Q.8. (d) A sodium surface is shined with the light of wavelength 3×10^{-7}m, if the work function of sodium is 2.46 eV, find the kinetic energy of the photoelectron. **(1.68eV)**

2004

Q.7. (d) What minimum energy is required in an X-ray tube in order to produce X-rays with a wavelength of 0.1×10^{-10}m. **(12.43 eV)**

Q.8. (d) Compare the energy of a photon of wavelength 2×10^{-6}m with the energy of X-ray photon of wavelength 2×10^{-10}m. **(10^{-4})**

2005

Q.8. (d) Estimate the relativistic mass and the wavelength associated with an electron moving at 0.9c. **(2.087×10^{-30}kg, 1.176×10^{-12} m)**

2006

Q.7. (d) An electron exists within a region of 10^{-10}m, find its momentum uncertainty and approximate kinetic energy. **(1.05×10^{-24} Ns, 3.78eV)**

2007

Q.8. (d) In Compton Scattering process the fractional change in wavelength of X-Rays Photon is 1% at an angle 120°, find the wavelength of X – rays used in this experiment. **(3.63×10^{-10} m)**

2008

Q.7. (d) Calculate the relativistic speed at which the mass of a particle becomes double its rest mass **(2.59×10^8 m/s)**

2009

Q.7. (d) A sodium surface is shined with the light of wavelength 3×10^{-7}m, if the work function of sodium is 2.46 eV, find the kinetic energy of the photoelectron and also cutoff wavelength. **(1.68eV, 5061A°)**

2010

Q.2, (xiv) If the electron beam in a television picture tube is accelerated by 10,000 V what will be the de Broglie's wavelength? ($h = 6.63 \times 10^{-34}$ J.s., $m = 9.1 \times 10^{-31}$ kg). **(1.28×10^{-11} m)**

2011

Q.2. (xii) What will be the relative velocity and momentum of a particle whose rest mass is m_o and kinetic energy is equal to twice of its rest mass energy.

$$\left(\frac{2\sqrt{2}}{3}c,\ 2\sqrt{2}\,m_o c\right)$$

P

Q.2. (xv) If the electron beam in a television picture tube is accelerated by 10 kVolt. What will be the de Broglie wavelength of an electron? ($h = 6.63 \times 10^{-34}$Js, $m = 9.1 \times 10^{-31}$ kg).

(1.28×10^{-11} m)

2012

Q.2 (iv) Given m_oc^2=0.511 MeV. Find the total energy "E" and the kinetic energy K of an electron moving with speed $v=0.85c$. $m_o = 9.1 \times 10^{-31}$ kg, $c=3 \times 10^8$ m/s.

Q.2 (xv) A sodium surface is shined with the light of wavelength 3×10^{-7}m, if the work function of sodium is 2.46 eV, find the kinetic energy of the photoelectron and also cutoff wavelength. $h=6.63 \times 10^{-34}$ J-s, $c = 3 \times 10^8 m/s$

2013 Q2 (vi)

Pair annihilation occurred due to a head-on-collision of an electron and positron having the same kinetic energy, produce pair of photons each having energy of 2.5 MeV. What were their kinetic energies before collision? Given $m_oc^2=0.511MeV$.

2014

Q2. (iv) What will be the velocity and momentum of a particle whose rest mass is mo and kinetic energy is equal to twice of its rest mass energy.

Q2. (ix) In a TV picture tube, an electron is accelerated by a potential difference of 12000V. Determine de-Broglie wavelength.

Given that ($h = 6.63 \times 10^{-34}$ J.s $e=1.6 \times 10^{-19}$ C, $m_e=9.11 \times 10^{-31}$ kg).

Chapter # 18

THE ATOMIC SPECTRA

Bohr's Atomic Model:

In 1913, after the failure of Rutherford's atomic theory, Neil Bohr has suggested another ideology about the structure of an atom, called Bohr's atomic theory. This ideology was based on three principles stated below.

1. Electrostatic (or) Stationary State Principle:

In an atom, all electrons revolve around the nucleus in circular orbits under the action of coulomb's electrostatic force.

An electron while in circular motion never emits energy and hence principles of classical mechanics cannot applied to the revolving electrons. The orbits of such electrons are called "Bohr's Stationary Orbits".

2. Angular Momentum Principle:

An electron while rotation in a circular orbit has specific angular momentum. Infact, only those electrons occupy Bohr's stationary orbits whose angular momentum remains equal to "$\frac{h}{2\pi}$" (or) integral multiple of "$\frac{h}{2\pi}$"

Hence, the angular momentum of an electron occupies nth Bohr's orbit is given by;

$$L_n = \left(\frac{nh}{2\pi}\right)$$

Where, n = 1,2,3,4,.... It is often called Principle Quantum Number. $h = 6.63 \times 10^{-34}$ J-s.

3. Frequency Rule Principle:

According to this, when atom gets excited state, its electron will be shifted from ground state orbit to an excited state orbit. It instantaneously returns back to its ground state orbit after emitting energy inform of radiations. The amount of radiation energy would be equal to the difference of energies of the two orbits in which transition of electron takes place.

If "E_i" and "E_f" be the energy of an excited state orbit and ground state orbit respectively, then by the Frequency Rule Principle we may write as;

$$E_i - E_f = h\nu$$

Where; $E_i > E_f$ and ν is the frequency of emitted radiations.

Radius of nth Orbit of Hydrogen Atom:

Consider Bohr's Hydrogen Atom in which an electron is revolved around nucleus in nth circular orbit.

Assume that:

1. The magnitude of charge on electron = e.
2. The mass of electron = m.
3. The magnitude of charge on nucleus = Ze = (1) e = e.
4. The tangential velocity of revolving electron = v.
5. The radius of nth orbit=r=?

When an electron revolves around the nucleus in circular orbits, the electrostatic pull provides the necessary centripetal force to the revolving electron.

P

Mathematically:

$$F_e = F_c \text{---------} (i)$$

$$\therefore F_e = \frac{kq_1q_2}{r^2} = \frac{kee}{r^2} = \frac{ke^2}{r^2}$$

$$\therefore F_c = \frac{mv^2}{r}$$

$$(i) \Rightarrow \frac{ke^2}{r^2} = \frac{mv^2}{r}$$

$$\frac{ke^2}{r} = mv^2$$

$$r_n = \frac{ke^2}{mv^2} \text{------} (ii)$$

In this equation, "k", "e" and "m" are the known values. Thus if tangential velocity of revolving electron is obtained, the radius of nth stationary orbit can be determined.

To find velocity, applying angular momentum principle which states,

$$L_n = n\left(\frac{h}{2\pi}\right)$$

$$mvr_n = \frac{nh}{2\pi}$$

$$v = \frac{nh}{2\pi m r_n}$$

$$v^2 = \frac{n^2h^2}{4\pi^2 m^2 r_n^2}$$

Substituting "v^2" in eq (i)

$$r_n = \frac{ke^2}{m\left(\frac{n^2h^2}{4\pi^2 m^2 r_n^2}\right)}$$

$$r_n = \frac{4\pi^2 ke^2 m r_n^2}{n^2h^2}$$

$$1 = \frac{4\pi^2 ke^2 m r_n}{n^2h^2}$$

$$r_n = \frac{n^2h^2}{4\pi^2 ke^2 m r_n}$$

$$\boxed{r_n = n^2\left(\frac{h^2}{4\pi^2 ke^2 m}\right)}$$

Hence,

$$\frac{h^2}{4\pi^2 k e^2 m} = \frac{(6.63\times10^{-34})^2}{4\times(3.142)^2(9\times10^9)(1.6\times10^{-19})^2(9.1\times10^{-31})}$$

$$\frac{h^2}{ke^2 4\pi^2 m} = 0.53\times10^{-10}\,m \Rightarrow 0.53\,\overset{o}{A}$$

Now;

$$r_n = n^2\left(0.53\,\overset{o}{A}\right)$$

This expression represents radius of nth Bohr's stationary orbit for hydrogen atom.

Energy of nth Orbit of Hydrogen Atom:

Suppose that an electron is revolving in a circular orbit of radius, "rn". The revolving electron has some kinetic energy due to its tangential velocity and some potential energy due to its work which is done against the electrostatic force of attraction of nucleus.

The electrostatic attraction between electron and proton is given by;

$$F_e = \frac{1}{4\pi\varepsilon_o}\cdot\frac{e.e}{r^2}\left[\therefore F_e = \frac{1}{4\pi\varepsilon_o}\cdot\frac{q_1 q_2}{r^2}\right]$$

$$F_e = \frac{1}{4\pi\varepsilon_o}\cdot\frac{e^2}{r^2} ------(i)$$

Because electron is revolving in a circular obit with the velocity "v" thus centripetal force is equal to electrostatic force.

i.e.

$$F_e = F_c$$

$$F_e = \frac{mv^2}{r} -----(ii)$$

Now comparing eq (i) and eq (ii)

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_o}\frac{e^2}{r}$$

$$mv^2 = \frac{1}{4\pi E_o}\frac{e^2}{r}$$

$$\frac{1}{2}mv^2 = \frac{1}{2}\frac{1}{4\pi\varepsilon_o}\frac{e^2}{r}$$

$$K.E = \frac{1}{8\pi\varepsilon_o}\frac{e^2}{r}$$

P

Potential energy of electron is given by;

$$P.E = -qV$$

For electron, q = $-e$ and electric potential due to nucleus at n[th] orbit

$$V = \frac{1}{4\pi\varepsilon_o}\frac{q}{r} = \frac{1}{4\pi\varepsilon_o}\frac{e}{r}$$

Now;

$$P.E = -e.\frac{1}{4\pi\varepsilon_o}\frac{e}{r}$$

$$P.E = -\frac{1}{4\pi\varepsilon_o}\frac{e^2}{r}$$

According the law of conservation of energy, total energy of electron is given below;

$$E = K.E + P.E$$

$$E = \frac{1}{8\pi\varepsilon_o}\frac{e^2}{r} - \frac{1}{4\pi\varepsilon_o}\frac{e^2}{r}$$

$$E = \frac{e^2 - 2e^2}{8\pi\varepsilon_o r}$$

$$E = -\frac{e^2}{8\pi\varepsilon_o r}$$

$$E = -\frac{1}{8\pi\varepsilon_o r}.\frac{e^2}{r}$$

$$E = -K.E$$

Energy br nth orbit is given by;

$$E_n = -\frac{1}{8\pi\varepsilon_o}.\frac{e^2}{r_n}$$

As we know that radius of hydrogen atom for nth orbit is;

$$r_n = \frac{n^2h^2}{4\pi^2ke^2m}$$

Now

$$E = -\frac{1}{8\pi\varepsilon_o}.\frac{e^2}{\frac{n^2h^2}{4\pi^2ke^2m}}$$

$$E_n = -\frac{1}{2\varepsilon_o}\frac{e^2(\pi k e^2 m)}{n^2h^2}$$

$$E_n = -\frac{\pi e^4 m}{2\varepsilon_o n^2 h^2}.k$$

$$E_n = -\frac{\pi e^4 m}{2\varepsilon_o n^2 h^2} \cdot \frac{1}{4\pi\varepsilon_o}$$

$$E_n = -\frac{e^4 m}{8\varepsilon_o^2 h^2}$$

$$E_n = -\left(\frac{e^4 m}{8\varepsilon_o^2 h^2}\right) \cdot \frac{1}{n^2}$$

$$E_n = -(13.6\, eV) \cdot \frac{1}{n^2}$$

$$\boxed{E_n = -\frac{13.6}{n^2} eV}$$

Wave Length of Light Emitted By Hydrogen Atom:

According to Bohr's theory when an electron jumps from an inner to an outer orbit it absorbs energy but when it jumps from an outer to an inner orbit it emits energy. The difference of energy between the two orbits is emitted in the form of a photon of energy *"hv"*. Hence if *"Ei"* and *"E_f"* represent the energy of the electron in its initial (outer orbit) and final (inner orbit) energy states respectively then,

$$E_i - E_f = hv$$

$$v = \frac{E_i - E_f}{h} \text{ ----- } (i)$$

The energy of nth orbit is given by;

$$E_n = -\frac{e^4 m}{8E_o^2 n^2 h^2}$$

Or

$$E_i = -\frac{e^4 m}{8E_o^2 n_i^2 h^2} \quad and \quad E_f = -\frac{e^4 m}{8E_o^2 n_f^2 h^2}$$

By using the expressions of E_i and E_f, equation (*i*) reduced to

$$(i) \Rightarrow v = \frac{1}{h}\left[-\frac{e^4 m}{8E_o^2 n_i^2 h^2} + \frac{e^4 m}{8E_o^2 n_f^2 h^2}\right]$$

$$\Rightarrow \frac{c}{\lambda} = \frac{1}{h}\frac{e^4 m}{(8E_o^2 h^2)}\left[-\frac{1}{n_i^2} + \frac{1}{n_f^2}\right] \qquad \left(\because v = \frac{c}{\lambda}\right)$$

$$\Rightarrow \frac{1}{\lambda} = \frac{e^4 m}{8E_o^2 h^3 c}\left[-\frac{1}{n_f^2} + \frac{1}{n_i^2}\right]$$

Here;

$$\frac{e^4 m}{8E_o^2 h^3 c} = R_H = 1.097\times10^7 m^{-1}$$

"R_H" is known as Rydberg constant

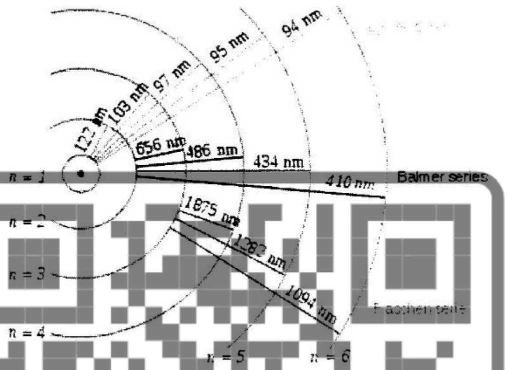
Now;

$$\frac{1}{\lambda} = R_H\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$$

This expression gives the wavelength of radiation emitted from Hydrogen atom when a transition take place from n_{ith}orbit to n_{fth}orbit

where $n_i > n_f$.

Spectral Series of Hydrogen Atom:



The experimentally measured values of wavelength of light emitted in different spectral series of hydrogen can also be calculated by the wavelength formula obtained on the basis of Bohr's theory of atomic structure. This is done by giving different values to **"nf"** for each spectral series.

1. **Lyman Series:**

   This series lies in the ultraviolet region of the spectrum of hydrogen. In Lyman series a We transitions from outer orbits end at the first orbit, so that $n_f = 1$. Hence wavelength of light obtained in this series can be calculated by giving different values to n1.

$$\frac{1}{\lambda} = R_H\left[\frac{1}{1^2} - \frac{1}{n_i^2}\right]$$

   Where $n_i = 2,3,4,5,6,7,8, ...,\infty$

2. **Balrner Series:**

   Balmer series lies in visible part of spectrum of hydrogen. In this series all the transition from outer orbits end at the second orbit (i.e. nf= 2)

$$\frac{1}{\lambda} = R_H\left[\frac{1}{2^2} - \frac{1}{n_i^2}\right]$$

   Where ii, -- 3, 4, 5,6,7,8,....,∞

3. **Paschen Series:**

   This series lies in infra red region of hydrogen spectrum, this series is obtained when the electron jumps from outer orbits to the third orbit of hydrogen atom.

$$\frac{1}{\lambda} = R_H\left[\frac{1}{3^2} - \frac{1}{n_i^2}\right]$$

   Where n = 4, 5,6,7,8,.....,∞

4. **Bracket Series:**
This series lies in the far infra red region of hydrogen spectrum. Bracket series is obtained when the electron jumps from outer orbits to the fourth orbit of hydrogen atom.

$$\frac{1}{\lambda} = R_H\left[\frac{1}{4^2} - \frac{1}{n_i^{\,2}}\right]$$

Where n1= 5,6,7,8,......., ∞

5. **Pfund Series:**
This series also lies in the far infra red region of hydrogen spectrum. This series is obtained from the transition of electron from outer orbits to the fifth orbit of hydrogen atom.

$$\frac{1}{\lambda} = R_H\left[\frac{1}{5^2} - \frac{1}{n_i^{\,2}}\right]$$

Where n= 6,7,8.

Excitation Energy and Excitation Potential:

To move an electron from ground state to an excited state energy must be supplied to it. The energy supplied is equal *to* the difference of energy between the two states of the atom. Amount of energy required to move an electron from ground state (for hydrogen atom n = 1) to an excited state (n =2, 3) is called excitation energy of the state.

An atom of gas can be excited by different methods such as by heating the gas, by passing an electric discharge through the gas or by illuminating the gas by light of suitable frequency etc. Usually atoms are excited by passing an electric discharge through a gas. In this method free electrons are accelerated by suitable potential difference. These accelerated electrons on colliding the electrons in the atom transfer energy required to excited them. Accelerating potential difference required to move an electron from ground state to an excited state is called excitation potential for the state.

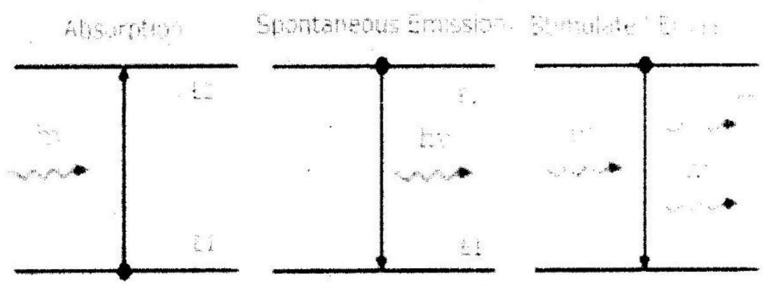
Energy of the electron in the ground state of hydrogen atom is -13.6 ev. Whereas in the second orbit its energy is -3.4ev, hence to send the electron from ground State to the first excited state (second orbit) of hydrogen atom energy needed will be -3.4-(-13.6) = 10.2ev. In other words excitation energy for the second orbit of hydrogen atom is 10.2eV. The corresponding potential difference through which a free electron must be accelerated so that it transfers 10.2 e.V energy to the electron in the ground state of hydrogen will be 10.2 Volt. In other words the excitation potential for the second orbit with respect to the first orbit of hydrogen atom is 10.2volt.

Ionization Energy And Ionization Potential:

When an electron is completely removed from an atom, it is said to be ionized. The amount of energy required to ionize an atom is called ionization energy and the corresponding accelerating potential is called ionization potential and denoted by I.P. Energy of electron in the ground state of hydrogen atom is -13.6 ev. If 13.6 ev energy is supplied to the electron it will jump to such an orbit for which n = and it will no longer be bound to the atom. Hence the ionization energy for hydrogen atom is 13.6 ev and the ionization potential will be 13.6 volts.

LASER:

Laser is an acronym of light amplification by stimulated emission of radiation.



E1: Lower Energy State E2: Higher Energy State

Principle of Laser:

Laser works on the principle of stimulated emission. The concept of stimulated emission was first introduced by Einstein in 1917.

Properties of Laser:

A laser beam possesses the following special characteristics:

i. It is monochromatic i.e. it consists of a single wavelength only.
ii. It is coherent i.e. all parts of beam are in phase.
iii. It is highly collimated i.e. all part travel in the same direction.
iv. It is sharply focused.

IMPORTANT TERMS:

1. STIMULATED ABSORPTION:

If a beam of photons is incident on a sample of atoms in the ground state E_1, atoms absorb the photon and reach the exciting state E_2. This process is known as stimulated or induced absorption.

2. SPONTANEOUS EMISSION:

If an atom is in exciting state E_1, it will remain in this state for a limited time called lifetime of the state (usually of the order of 10^{-8} sec). After remaining there for this time, the atom falls back to ground state. This process is called spontaneous absorption.

3. STIMULATED EMISSION:

Stimulated emission is a process in which an incoming photon of energy hv can simulate an atom in a high energy state E_2 to jump a low energy state E_1, where $E_2 - E_1 = hv$. The photon resulting from this process has the same frequency as the stimulating photon and travels in the same direction.

Production of Laser beam depends on stimulated emission.

4. POPULATION INVERSION:

Usually in a sample of atoms, the numbers of atoms in ground state are always greater than the number of atoms excited. But artificially condition can be achieved where the numbers of excited atoms are greater than in the ground state. This is termed as population inversion.

5. METASTABLE STATE:

The mean life τ for an ordinary excited state is of the order of 10^{-8} sec. However, there are some states for which τ are much longer i.e. of the order of 10^{-3} sec or more. Such long-lived states are called metastable.

THE LASER OPERATION:

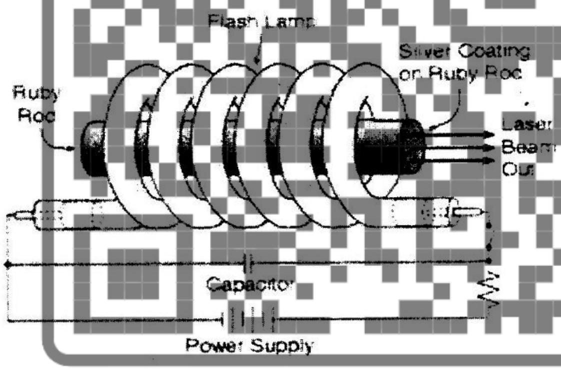
For laser action or lasing (i.e. the production of an intense coherent beam of light), we consider three energy level system of atoms as shown, where

E_1 = ground state
E_2 = metastable state
E_3 = short-lived state

From these three levels, laser light is obtained as follows:

1. Atoms from ground state E_1 are pumped to an excited state E_3, for example by the absorption of light energy from an intense, continuous spectrum source. This is known as optical pumping.
2. As E_3 is a short-lived state, atoms decay rapidly to a state of energy E_2. Since E_2 is a metastable, therefore under suitable condition it becomes heavily populated. This provides the required population inversion.
3. After population inversion is obtained, state E_2 is exposed to beam of photons of energy, $h\nu = E_2 - E_1$, which causes induced emission, resulting in production of laser light.

In order to maintain stimulated emission events, the emitted radiations are confined in an assembly. The ends of this assembly are fitted with mirrors. One mirror is totally reflecting whereas the other is partially reflecting for the laser beam to be taken out.



RUBY LASER:

Ruby laser was the first type of laser invented. Ruby is the name of a crystal of Aluminium Oxide (Al_2O_3) in which a few (one in every 3500) of Aluminium atoms are replaced by Cr^{+++} (chromium ion).

CONSTRUCTION:

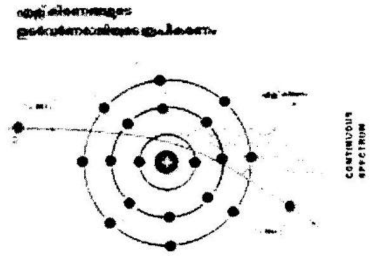
A ruby laser consists of a synthetic ruby crystal having cylindrical shape, generally 5cm long and 1cm in diameter. A high intensity helical xenon flash lamp surrounds the crystal to provide pumping light. The ends of the crystal rod are made optically flat and parallel. These ends are silvered, with one end completely and other only partially.

WORKING:

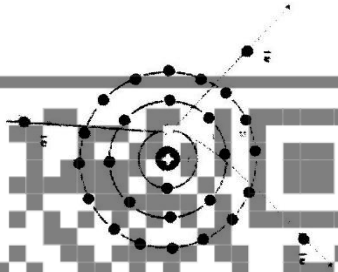
Ruby is a type of three-state laser. The pumping radiation, produced by xenon flash lamp, raises the Cr atoms from ground state E_1 to short lived state E_3. From there, they fall spontaneously to metastable state E_2 where they remain for approximately 10^{-3} sec. this prolonged stay of atoms in E_2 creates population inversion. A few Cr atoms make transitions spontaneously from state E_2 to state E_1 and emit photons. These photons are reflected back and forth between mirror ends of ruby rod. In this process, these photons stimulate other Cr atoms to fall to E_1 from E_2 and after a few microseconds a large pulse of red coherent laser (wavelength 694.3 nm) is given out from partially silvered end.

APPLICATION OF LASER:

Some of the important applications of laser technology are as follows:



1. It is used as a surgical tool in "welding" detached retina. It is also used in removing tumors and breaking stones in kidney.
2. It is used for precision cutting, welding and drilling of tiny holes in various materials.
3. It is used in telephone communication along optical fibre to transmit both sound and picture at speed of sound.
4. It is used for precision measurement of length and surveying.
5. It is used to read digitally coded music on CDs and retrieve data from computer disks. It is also used in high-speed computer printer.
6. It is used in the production of holograms (three dimensional images), called holography.



X-Rays (Unknown Mysterious Radiation):

When high speed electrons impinge on a metal surface then photon of ultraviolet light are produced. This ultraviolet light is called X-rays.

Principle:

When high speed electrons are made to stop, their K.E is released in the form of photons.

Apparatus:

The apparatus consists of an evacuated glass tube. Filament F is heated by battery E to emit electrons. The emitted electrons pass through very high voltage V supplied between filament F and target T. The electrons gain K.E and hit the target and X-Rays are produced.

Spectrum of X-Rays is continuous. It shows that X-Rays consist of all wavelengths in a certain range.

X-Rays of shortest wavelength and maximum frequency are produced by those electrons which come to stop in one collision. For such electrons we have;

K.E of electron = Energy of photon

$$eV = h\nu_{max}$$

$$\nu_{max} = \frac{eV}{h}$$

$$\frac{c}{\lambda_{min}} = \frac{eV}{h}$$

$$\frac{1}{\lambda_{\min}} = \frac{eV}{hc}$$

$$\lambda_{\min} = \frac{hc}{eV}$$

This shows that the wavelength of X-Rays is inversely proportional to applied P.D. The range of wavelength of X-Rays is 1A° to 10A° or 0. I nm to mm.

Uses of X-Rays:

Some uses of X-Rays are given below:

1. In medical science e.g. to check fracture of injured bones.
2. In Airports for checking and security purpose.
3. In industry e.g. for checking the quality control in rubber tyre and tube manufacturing.
4. X-Rays are also used to check the quality of welded parts of a machine or tool.
5. Scientific research labs e.g. to study the crystalline structure of solids.

CHAPTER-18 MULTIPLE CHOICE QUESTIONS

From Past Papers

2001

Q.8. (a) (i) Balmer Series is obtained when all the transitions of electrons terminate on:

* 3rd orbit * 4th orbit * 2nd orbit * 1st orbit

Q.8. (a) (ii) The laser is a device which can produce:

* An intense beam of light * A coherent beam of light

* A monochromatic beam of light * All of the above

2002(Pre – Medical)

Q.8. (a) (i) The fast moving electrons stopped by a heavy metallic target in an evacuated glass tube, give rise to the production of:

* α particles * β-particles * X-rays * Protons

2003(Pre – Medical)

Q.8. (a) (ii) According to Bohr's postulates, the electron revolving around the nucleus in a fixed orbit radiates;

* energy * no energy * γ-rays * α-rays

2003(Pre – Engineering)

Q.8. (a) (i) In a hydrogen atom Balmer series lines are emitted as the electron falls to the orbit having:

* n=1 * n=2 * n=3 * n=4

Q.8. (a) (iii) The laser is a device which can produce:

P

* an electron beam of light
* a neutron beam of light
* a coherent beam of light
* all of these

2006

Q.8. (a) (ii) The frequencies in spectral lines emitted in Lyman series are in the ________ region:

* Visible * Infrared * X rays * Ultraviolet

2008

Q.8. (a) (iii) Hydrogen atom spectrum consists of lines in:

* Ultraviolet region * Visible region * Infrared region * All of them

2010

Q.1 (ii) Brackett series of hydrogen atom spectrum lies in:

* Ultraviolet region
* Visible region
* Infrared region
* All of these

Q.1(iv) The wavelength of X-ray is in the range:

* 0.01 nm to 0.1 nm
* 1A° to 100A°
* 0.1A° to 1m
* 0.1 nm to 1.0 nm

2012

Q.1.vii LASER produces:

* an electron beam
* a neutron beam
* a coherent beam of light
* all of these

2013

Q.1.iv When an electron jumps from 3rd orbit to the 1st orbit in Hydrogen atom the line spectrum belongs to

*Bracket *Lyman *Balmer *Paschen

2014

(iii). The life time of the electron is excited state is:

*10^8 sec *10^{-8} sec *10^{-3} sec *10^3 sec

(ix) LASER produces:

*An electron beam *A neutron beam *A coherent beam of light *None of these

2015

(xii) In Laser, the life time of an electron in a metastable state is:

* 10^{-8} sec. * 10^{-5} sec. * 10^{-3} sec. * 10^8 sec.

(xvii) Balmer series is obtained when the transitions of electrons terminate on:

* 1st orbit * 2nd orbit * 3rd orbit * 4th orbit

CHAPTER-18 **NUMERICALS**

FROM PAST PAPERS

1990

Q.7. (c) A blood corpuscle has diameter about 9×10^{-6} m. In which excited orbit should a hydrogen atom so that it is just about as big as the blood corpuscle. **(291)**

1993

Q.7. (c) The energy of the lowest level of hydrogen atom is –13.6 eV. Calculate the energy of the emitted photons in transition from n = 4 to n = 2. **(2.55eV)**

1995

Q.7. (c) Find the wavelength of light which is capable of ionizing a hydrogen atom. **(911.5A°)**

1997

Q.7. (c) The energy of an electron in an excited hydrogen atom is –3.4 eV. Calculate the angular momentum of the electron according to Bohr's Theory. **(2.1×10^{-34}Js)**

2000

Q.7. (c) What is the wavelength of the radiation that is emitted when hydrogen atom undergoes a transition from the state $n_2 = 3$ to $n_1 = 2$. **(6.5×10^{-7} m)**

2002 (Pre Med. group)

Q.8. (d) What is the longest wavelength of light capable of ionizing a hydrogen atom? What energy in electron volt is needed to ionize it? **(9.12×10^{-8} m/s, 13.6eV)**

2002 (Pre Engg. group)

Q.7. (d) A photon of 12.1 eV absorbed by a hydrogen atom originally in the ground state raises the atom to an excited state. What is the quantum number of this state?(E_1 = –13.6 eV) **(3)**

2003 (Pre Engg. group)

Q.7. (d) An electron in the hydrogen atom makes a transition from the n = 2 energy state to the ground state (corresponding to n = 1) find the wavelength in the ultraviolet region. **(1.21×10^{-7} m)**

2005

Q.7. (d) In a hydrogen atom an electron experiences transition from a state whose binding energy is 0.54 eV to the state whose excitation energy is 10.2 eV.

a) The quantum numbers of the two states
b) The wavelength of the photon emitted **(5, 2, 4.342×10^{-7} m)**

2007

Q.7. (d) Calculate the Binding Energy of a hydrogen atom. **(–13.6 eV)**

2008

Q.8. (d) Calculate the longest and shortest wavelengths of emitted photons where $R_H = 1.097 \times 10^7$ m^{-1}. **(656.33 nm, 364.6nm)**

2010

Q.2. (xii) Find the shortest wavelength of photon emitted in the Balmer series and determine its energy in eV. ($R_H = 1.097 \times 10^7\ m^{-1}$). **(3646A°, 3.41eV)**

2011

Q.2. (xi) Calculate the energy of the longest wavelength radiation emitted in the Paschen series in hydrogen atom spectra. ($R_H = 1.0968 \times 10^7\ m^{-1}$, $h = 6.63 \times 10^{-34}$Js, m c = 3×10^8 m/s).

(1875.6 nm)

2012

Q2(xi) Find the value of shortest and the longest wavelength of emitted photon in hydrogen spectra in Balmer series. (Rydberg constant = $1.097 \times 10^7\ m^{-1}$)

2013

Q2(v) A hydrogen atom in the ground state gets excited by absorbing a photon of 12.15 eV. Find the Quantum number of this state,

2014

Q2. (x) Determine the longest and shortest wavelength of photons emitted in the Lyman series. (R_H=$1.097 \times 10^7\ m^{-1}$)

2015

Q2(xi) Find the shortest wavelength of photon emitted in the Balmer series and determine its energy in eV. ($R_H = 1.097 \times 10^7\ m^{-1}$). **(3646A°, 3.41eV)**

Chapter # 19

THE ATOMIC NUCLEUS

Charge Number of Nucleus:

The number of proton present in the nucleus of an atom is called "Charge Number". It is denoted by "z".

Mass Number of Nucleus:

Total number of protons and neutrons present in the nucleus of an atom is called "mass Number". It is denoted by A". Any Nucleus X is represented as $_ZX^A$, for example sodium nucleus is $_{11}Na^{23}$. No. of neutrons in a nucleus is given by;

$$N = A - Z$$

Nuclear Mass:

"Total mass of nucleons present inside the nucleus is called "Nuclear Mass".

Or

"The sum of the mass of neutrons and the mass of the protons is called nuclear mass. It is denoted by M".

Isotopes:

All such nuclei having same charge number Z but different values of mass number A are called Isotopes.

For example hydrogen has three isotopes;

i. Protium ($_1H^1$); Z=1, A=1, and N=0.
ii. Deuterium ($_1H^2$); Z=1, A=2, and N=1.
iii. Tritium ($_1H^3$); Z=1, A=3, and N=2.

Radioactivity:

The spontaneous emission of invisible rays from the elements having atomic number greater than 82 is called radioactivity. The emitted rays are called radioactive rays and the elements which emit such rays are called radioactive elements.

In 1896 Henry Becquerel discovered that uranium atom emits radiation these radiations cause blackening of photographic plates they can penetrate into glass water and thin layers of metal. The nuclei of such heavy elements are unstable and disintegrate spontaneously.

Radioactive Rays:

Radioactive elements emit three types of rays;

(i)Alpha rays
(ii) Beta rays
(iii) Gamma rays

Properties of Alpha-Radiations:

Some essential properties related to the α-rays are discussed below:

i. The α-rays are composed of positively charged particles called, "α -Particles". Each α-particle carries two units of positive charge i.e. $\alpha = 3.2 \times 10^{-19}$C.
ii. An α-particle is a helium nucleus consists of two protons and two neutrons.

iii. The mass of a α-particle is four times greater than that of a proton i.e. mass of α-particle m= 6.68×10^{-27}kg.
iv. The speed of a-particles was found from 1.4×10^{7} m/s to 1.7×10^{7}m/s.
v. A-particles produces intense ionization phenomenon when they are passed through the gases.Their ionizing power is about 100 times greater than that of β-rays and about 10,000 times greater thanthat of γ-rays.
vi. α-particles shows very low penetration power. They hardly penetrate 7.0 cm through the air.
vii. The ratio of charge and mass *(elm)* of α —particle is calculated to be one-half of the (e/m) of aproton.
viii. A-particles produce fluorescence when they are incident on zinc sulphide and BariumPlatinocyanide.
ix. α-particle produces heating effects when they are incident on a metal surface.
x. α-particle affect a photographic plate, but their effects on plate are very feeble.
xi. α-particle can be deflected under the action of an electric field and magnetic field. This characteristic shows that α-particles are infact, charged particles.

Properties of β-Rays:

Some essential properties related to the fl-rays are discussed below;

i. β-rays are composed of negatively charged particles called, "β-Particles". Each β-particlecarries one unit of negative charge i.e. $q = e = 1.6 \times 10^{-19}$C.
ii. The mass of β-Particleis equal to mass of an electron i.e. $m_\beta = m_e = 9.1 \times 10^{-31}$kg.
iii. The ratio of charge and mass (q/m) of a β-Particle is equal to that of electron, when velocity of *β*-Particle is non-relativistic.
iv. The speed of *β*-Particle was found in the range from 0.3*c* to 0.99*c*.
v. *B*-Particle shows low ionization phenomenon when it is passed through gases. Its ionizing power is about 100 times less than that of α-Particle.
vi. β-Particle shows high penetration power. They can penetrate through 1.0cm aluminum sheet.
vii. β-Particle produces fluorescence when it incidents on calcium tungstate and bariumplatinocyanide.
viii. β-Particle affects a photographic plate more effectively. Their effect on photographic plate isfound more prominent than that of a-Particles.
ix. β-Particle can be detected under the action of an electric field and magnetic field. The direction ofits deflection shows that it is negatively charged particles.
x. The magnitude of charge and mass of β-Particles shows that β-Particles are identical with"Electrons".

Properties of γ-Rays:

Some essential characteristics related to the γ-rays are discussed below;

i. The γ-rays are composed of packets of very high energy called, "γ-Photons".
ii. γ-rays are the radiations of very shorter wavelength range from 0.005A° to 0.5A°.
iii. γ-rays does not show any deflection under the action of either electric field or magnetic field.This properties verify that γ-rays are electromagnetic radiations.

iv. γ-rays can travel in space with the speed of light, 3×10^{8} m/s

v. γ-rays shows very poor ionization phenomenon when they are passed through the gases, theirionization power is about 10,000 times less than that of cc-particles.

vi. γ-rays shows very high penetration power. They can penetrate through an iron plate of *f* 30cmthickness.

vii. γ-rays produces fluorescence when they are incident on cadmium tungstate, zinc sulphide and barium platinocyanide.

viii. γ-rays effects a photographic plate.

ix. γ-rays are diffracted by crystals and obey Bragg's Equation for diffraction.

x. γ-rays shows line spectrum consists of sharp spectral lines these lines indicates existence of a number of energy levels in the nucleus.

Law of Radioactivity:

In the process of radioactive disintegration the original radio-atom (parent atom) disintegrates into a new radio-atom (daughter atom) with the emission of nuclear radiation. In 1913, Soddy and Fajan formulated some basic principles to explain the radioactive changes called, "Displacement Law". These principles are given below;

i. In all know radioactive series either an alpha particle or a beta particle is emitted. It simply means neither more than one of each particle nor both particles are emitted at the same instant.

ii. When an alpha particle is emitted from a radio atom, it disintegrates into a new daughter atom whosemass number is less by four units and atomic number is less by two units.

i.e. $_{Z}X^{A} \rightarrow {}_{Z-2}Y^{A-4} + {}_{2}He^{4}$ (Alpha Particle)

(Parent Nucleus)(Daughter Nucleus)

e.g: $_{92}U^{238} \rightarrow {}_{90}TH^{234} + {}_{2}He^{4}$ (Thorium)

iii. When a beta particle is emitted from a radio-atom, it disintegrates into a new daughterwhose mass number remains same but atomic number is increased by one unit.

i.e.

$$_{Z}X^{A} \rightarrow {}_{Z+1}Y^{A} + {}_{-1}\beta^{o}$$

$$_{90}Th^{234} \rightarrow {}_{91}Pa^{234} + {}_{-1}\beta^{o} \text{ (Protactinium)}$$

iv. When a positive beta particle is emitted from a radio-atom, it disintegrates into a new daughter atom whose mass number remains same but atomic number is decreased by one unit.

i.e. $_{Z}X^{A} \rightarrow {}_{Z-1}Y^{A} + {}_{+1}\beta^{0}$

$_{90}Th^{234} \rightarrow {}_{89}Ac^{234} + {}_{+1}\beta^{0}$ (Actinium)

P

v. When a gamma photon is emitted from a radio atom, it returns to the ground state with same mass number and atomic number.

$$\left({}_{Z}X^{A}\right)^{*} \rightarrow {}_{Z}X^{A} + \gamma$$

(Excited State) (Ground State)

Law of Radioactive Decay or Disintegration:

Soddy and Rutherford analyzed that the rate of which a radio element disintegrates was independent of any physical or chemical change, but depends on the total number of radio atoms contained by the radioactive sample at the time of disintegration.

According to them,

"The rate of decay of radioactive atoms at any instant is directly proportional to the total number of radio atoms that exist at that instant".

If "N" be the total number of radio atoms that present at any instant of "t", then the rate of radio atoms that have decayed can be expressed mathematically as;

$$-\left(\frac{dN}{dt}\right) \propto N$$

Here, negative sign shows that number of radio atoms decreases with the passage of time.

$$-\left(\frac{dN}{dt}\right) = \lambda N$$

Where, "λ" is the constant of proportionality, called "Radioactive decay constant" or "Decrease in activity" of the radio element. Its value depends on the nature of radio element.

Definition of Radioactive Decay Constant:

According to the law of radioactive disintegration,

$$-\left(\frac{dN}{dt}\right) = \lambda N$$

$$\lambda = \frac{\left(-\frac{dN}{dt}\right)}{N}$$

According to this equation, "The ratio of rate of radio atoms that have decayed to the total number of radio atoms that exist at the time of decay, is called Radioactive decay constant.

Unit of Radioactive Decay Constant:

As,

$$\lambda = \frac{\left(\frac{dN}{dt}\right)}{N}$$

$$\lambda = \frac{\left(\frac{atoms}{\sec}\right)}{atoms}$$

$$\lambda = \frac{atoms}{\sec} \times \frac{1}{atoms}$$

$$\lambda = \frac{1}{\sec} = s^{-1}$$

Hence, the radioactive decay constant is measured by "per second".

Activity:

The number of disintegrations per second is called activity "A" and is taken as a positive number. Hence, the activity at any time "t" may be expressed as;

$A = \lambda N$

Relative Activity:

The ratio N/N_0 is called relative activity. Where N_0 is the number of parent nuclei at time t=0 whereas N is the number of parent nuclei at any instant.

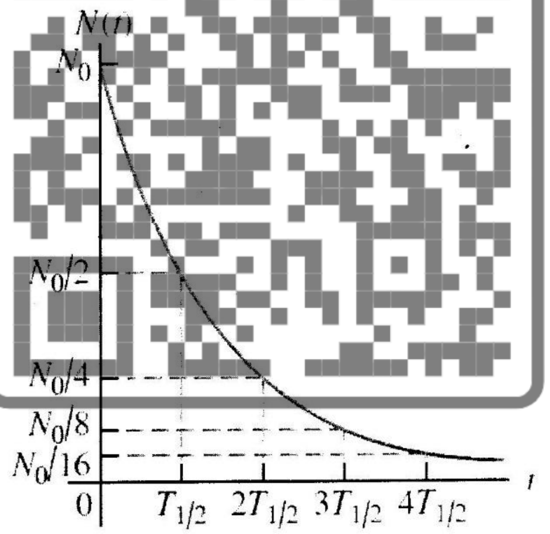
Relative activity decreases as time passes.

Exponential Law of Radioactive Decay:

A graph is plotted between time and relativeactivity N/N_0. At the start the value of N/N_0 is N/N_0 equal to 1. Graph shows that the radioactive decay is fast in the beginning and as time passé, it shows down. This is exponential behavior.The exponential behavior is mathematically expressed as;

$$N = N_0 \ e^{-\lambda t}$$

Where, e = 2.7 18 and A = decay constant.



The number of nuclei in a sample of a radioactive element as a function of time. The sample's activity has an exponential decay curve with the same shape.

Half Life of Radioactive Element:

Half life of a radioactive element is the time in which half of the existing parent nuclei decay into daughter nuclei. It is denoted by $T_{\frac{1}{2}}$.

Determination of Half Life of A Radioactive Element:

Suppose that we have radioactive sample of a radio element which contains "N_0' number of radio atoms at t=0. If "N" be the total number of radio atoms that exist after any instant of "t", then according to the law of exponential disintegration we may write as;

$N = N_o e^{-\lambda t}$ ______(i)

P

$$\text{If } N = \frac{N_o}{2} 2 \text{ then } t = T\frac{1}{2}$$

$$\text{Eq(1)=>} \frac{N_o}{2} = N_o \times e^{-\lambda T} \tfrac{1}{2}$$

$$\tfrac{1}{2} = e^{-\lambda T \frac{1}{2}}$$

$$2 = e^{\lambda T \frac{1}{2}}$$

Taking "In" both sides,

$$\ln(2) = \lambda T_{\frac{1}{2}}$$

$$0.693 = \lambda T_{\frac{1}{2}}$$

$$T_{\frac{1}{2}} = \frac{0.693}{\lambda}$$

According to this equation, if radioactive decay constant of a radio element is known to us, the half life of that element can be determined.

Note:

Noted that, radio elements have different range of their half lives e.g. Uranium has half life of about 4.9×10^9 years, polonium has a half life of about 140 day and "Ra" has a half life of about 10 seconds. It means some radio elements have very high, some have moderate and some have very short range of half lives.

Nuclear Force:

In order to hold positively charged protons and neutral neutrons together inside a nucleus a very strong force exists between them. This force is known as nuclear force, it is stronger than the repulsive coulomb force between the positively charged protons. Nuclear force is short range and is independent of charge on the particle. It means that this force is effective over a very short distance (its range is of the order of size of the nucleus). Hence inside a nucleus each nucleon is attracted by the other irrespective of its charge with a very strong short range nuclear force.

Mass Defect:

Mass of a stable nucleus is less than the combined mass of its constituent particles in Free State. This difference in mass is called mass defect.

Example: A deuterium nucleus (deuteron) is made up of one proton and one neutron. Combined mass of one proton and one neutron in Free State is greater than the mass of deuteron.

Calculation of Mass Defect:

Miss of one proton $1.6724\text{X}10^{-27}$kg

Mass of one neutron $1.6748\text{X}10^{-27}$kg

combined mass of proton and neutron = $3.3472\text{X}10^{-27}$g

Mass of deuteron = $3.343X10^{-27}$kg
Mass defect = $3.3472X10^{-27}-3.343X10^{-27}$
$\Delta m = 0.0042X10^{-27}$kg

Binding Energy:

The amount of energy released during the formation of a nucleus is called binding energy of atnucleus. It is the energy equivalent of mass defect. If Δ m is mass defect then binding "energy is Δmc^2.

Example: mass defect of deuterium nucleus is;

$$\Delta m = 0.0042X10^{-27}\text{kg}$$

Therefore binding energy of deuteron is;

$$B.E = \Delta mc^2$$

$$B.E = (0.0042X10^{-27})(3X10^8)^2$$

$$B.E = 3.69X10^{-13}\ J$$

$$\text{Or } B.E = 3.69X10^{-13}/1.6X10^{-19}$$

$$B.E = 2.3X10^6 ev$$

B.E = 2.3 Mev

Unified mass: *Mass Number is represented in atomic mass unit (a.m.u) or u unified mass.*

$$1u = 931.5\ MeV$$

Packing Fraction:

"Binding energy per nucleon is called packing fraction"

$$P.F = \frac{B.E}{A}$$ Where *A* is Mass Number

. For example binding energy of deuteron is 2.3 Mev. It is the energy of two nucleons (one proton and one neutron). Therefore packing fraction of deuteron is;

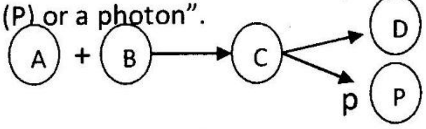
$$P.F = \frac{2.3}{2} = 1.5Mev$$

Nuclear Reaction:

The nuclear reaction means, "Transmutation of a stable nucleus into another stable nucleus by interaction with a particle or proton".

Bohr's Scheme For Nuclear Reaction:

After successful completion of some nuclear reactions, Neil Bohr suggested a general scheme for nuclear reaction. According to him,
"When a projectile (A) hits a target nucleus (B), it combines to form a new unstable nucleus, called compound nucleus (C). The unstable nucleus spontaneously disintegrates into a stable nucleus (D) and outgoing particle (P) or a photon".



Reaction:

P

B+A C D+P

Symbolic Form:

B(A,P)D

The nuclear reaction is often denoted by two symbols inside a parentheses, (A,P); first symbol represents the projectile and second expresses an outgoing particle. E.g. (oc,P) nuclear reaction shows that projectile is an "cc particle" and outgoing particle is a "proton".

In a nuclear reaction, projectile may be neutral or charge particle or photon. Neutron is the most effective one, as it can easily enter into a nucleus without experiencing any repulsion. Whereas; proton, deuteron and cc particle etc, has to be accelerated before they are able to overcome then repulsion of target nucleus.

Types of Nuclear Reactions:

Some essential types of nuclear reactions are discussed below;

1. Elastic Scattering:

In this type, the projectile gets elastic collision with the target nucleus and leaves the target nucleus without any loss of energy. Anyhow, the direction of motion of projectile may change. An interesting example of this nuclear reaction is the scattering of particle from a thin gold foil.

$$_{79}Au^{197} + \ 2He^{4} \rightarrow {}_{79}Au^{197} + {}_{2}He^{4}$$

Here, projectile and target nucleus remains unchanged.

2. Inelastic scattering:

In this type, the projectile gets inelastic collision with the target nucleus and transfers some of its energy into the target nucleus. The excited target nucleus instantaneously decays into a stable nucleus by radiating excess energy in form of photon of γ Rays. The inelastic scattering of proton from nucleus of lithium is given by;

$$_{3}Li^{7} + {}_{1}H^{1} \rightarrow {}_{3}Li^{7*} + {}_{1}H^{1}$$

$$_{3}Li^{7} \rightarrow {}_{3}Li^{7} \quad + \quad \gamma$$

3. Radioactive Capture:

In this type, the incident projectile is captured by the target nucleus and a new nucleus is formed. The newly formed nucleus has excess amount of energy and thus it decays into a stable nucleus by emitting one or more photons of γ rays.

A radioactive capture of proton by carbon nucleus is given by;

$$_{6}C^{12} + {}_{1}H^{1} \rightarrow {}_{7}N^{13*}$$

$$_{7}N^{13*} \rightarrow {}_{7}N^{13} + \ \gamma$$

4. Disintegration:

In this type, projectile is absorbed by the target nucleus and disintegrate into new stable nucleus by emitting a particle of different nature. An interesting example is the disintegration of beryllium by oc particle. It produces carbon nucleus and a neutron.

$$_{4}Be^{9} + {}_{2}He^{4} \rightarrow {}_{6}C^{12} + {}_{0}n^{1}$$

5. Photo-Disintegration:

In this type, a photon is absorbed by the target nucleus and it gets excited state. The target nucleus decay into a new stable nucleus by emitting a particle different from incident projectile

(Photons).
An interesting example of photon disintegration is given below;

$$_1H^2+\gamma \rightarrow {}_1H^{2*}$$

$$_1H^{2*} \rightarrow {}_1H^1+{}_0n^1$$

Note: The photo disintegration of "deuteron" takes place when photon of γ rays has energy equal to 2.225Mev.

Q-Value of Nuclear Reaction:

In general, a nuclear reaction is expressed by the following scheme;

$$X+a \rightarrow Y+b+Q$$

Where, "a" is the incident projectile. "X" is the target nucleus. "Y" is the product nucleus. 'b' is the outgoing particle. "0" is the energy either released or absorbed during nuclear reaction, called "Q-Value of the nuclear reaction". The Q-Value may be positive or negative, depends on the condition whether energy is evolved out of the nuclear reaction or absorbed into the nuclear reaction.

i. If K.E of the products of nuclear reaction is greater than the K.E of the reactants, then energy is evolved out of the nuclear reaction and thus it is referred as "Exothermic" or "Exoergic" nuclear reaction. In this case, Q-Value of nuclear reaction will be "Positive".

ii. If K.E of the reactants of nuclear reaction is less than the K.E of the products, then some energy must be needed to initiate the nuclear reaction and thus it is referred as "Endothermic" or "Endoergic" nuclear reaction. In this case, Q-Value of nuclear reaction will be "Negative".

Nuclear Fission Reaction:

"The process of splitting a nucleus into smaller nuclei with the release of energy is known as nuclear fission".

During the fission of $_{92}U^{235}$ with a slow neutron krypton and barium of roughly equal size are produced along with three neutrons and large amount of energy.

$$_{92}U^{235}+{}_0n^1 \rightarrow {}_{36}Kr^{89}+{}_{56}Ba^{144}+3{}_0n^1 + \text{energy}$$

$_{36}Kr^{89}$ and $_{56}Ba^{144}$ are called fission fragments.

In general fission reaction may be written as;

$$_0n^1+{}_{92}U^{235} \rightarrow ({}_{92}U^{36})^* \rightarrow X + V+Y+ \text{neutrons + energy}$$

$(_{92}U^{236})^*$ is exited or compound nucleus of uranium form after the capture of a neutron, whereas X and V are the fission fragments. Fission fragments may also be radioactive and may decay in number of ways into stable nuclei.

Due to mass defect between Uranium and fission fragments the total mass of fission fragments is less than the mass of uranium nucleus. This loss of mass (mass defect) is converted into energy according to Einstein's mass energy relation. In the above reaction about 200 Mev energy per fission is released.

Fission Chain Reaction:

During each fission reaction some neutrons are also emitted. These neutrons are of high energy, hence if they are slowed down then on colliding with other uranium nuclei they will produce further fission. This continuous fission process in known as nuclear "Chain Reaction". Material used for slowing down fast moving neutrons is known as a Moderator. Graphite or ordinary water are commonly used as moderators, while heavy water is the best moderator. Number of neutrons available for fission reaction will keep on increasing. In this manner a chain reaction is established. Chain reaction is, therefore, a self sustaining reaction. The rate of reaction or in other words, the speed with which chain reaction proceeds can be controlled by controlling the number of neutrons available. This can be done by using suitable neutron absorbing rods.

The minimum quantity of fissionable material required to sustain nuclear fission at a uniform rate is known as Critical Mass. Chain reaction will die if mass of Uranium is less than the critical mass, similarly it proceeds at a faster rate and releases more energy if mass of uranium is more than its critical mass.

Nuclear Reactor:

In a nuclear reactor energy released during nuclear fission is converted into useful electrical energy. During fission reaction energy released is in the form of heat. The rate of fission reaction is controlled by using suitable neutron absorbing boron or cadmium rods, so that heat is obtained at a steady rate. Huge quantity of heat released is removed with the help of a coolant. The choice of coolant material depends upon type of reactor. Usually ordinary water, heavy water, mercury, liquid sodium etc, are used as coolants. Heat carried by the coolant is then used to operate turbines to produce electricity. Neutron absorbing rods used to control the rate of reaction are called control rods.

Fission of ($_{92}U^{235}$) takes place with slow neutrons, hence fast moving neutron released during fission reaction are to be slowed down before they can produce further fission. A suitable material, such as heavy water, used for slowing down fast moving neutrons is known as Moderator.

Nuclear reactors are intense source of neutron and gamma radiations which are extremely dangerous for life. Hence two kinds of shielding is required. Biological shielding and thermal shielding. Biological shield is required to protect scientists working in the reactor area. Six to eight feet thick concrete layer can be used as biological shield, it absorbs neutrons and gamma rays. Thermal shield is required for reactors operating at high power.

The atomic bomb:

An atom bomb the rate of fission reaction is left uncontrolled. This is done by taking mass of uranium more than its critical mass. Under these conditions fission reaction proceeds at such a rapid uncontrolled rate that the large amount of energy released produces an explosion. The atomic bomb explosion can easily destroy a small city.

Strong shock waves produced during atom bomb explosion destroys buildings etc. whereas large quantities of storing nuclear radiations (Gamma rays) emitted are extremely harmful for life.

Nuclear Fusion:

"The process of combining two or more light nuclei to form a heavier nucleus with the release of energy is called nuclear fusion".

heavier nucleus formed after combining lighter nuclei has more mass defect in other words mass of the heavier nucleus is less than the sum of masses of the lighter nuclei. Mass lost during this process is converted into energy according to Einstein's mass energy relation. During a nuclear fusion more energy per nucleon is released as compared with the energy released

during fission reaction.
Consider the fusion reaction between a deuterium and a tritium nucleus,

$$_1H^2+_1H^3 \rightarrow {}_2He^4 + {}_0n^1 + \text{energy}$$

During the above fusion reactions a helium nucleus is produced along with a release of about 17.6 Mev energy.
Fusion reaction can therefore produce abundant energy using deuteron as raw material. It is a very difficult to produce fusion reaction because the positively charged smaller nuclei repel each other before they can fussed and the repulsive force increases as they are brought close to each other.
Fusion reaction takes place at a very high temperature (more than a million degrees centigrade). Hydrogen bomb utilizes fusion reaction, releases more energy, therefore, it has more destructive power than an atom bomb. Scientists have not been able to control fusion reaction as yet, hence the enormous amount of energy released could not be converted into electricity.

Fusion Reaction In Sun And Stars:

The enormous amount of energy produced by the sun aiid other stars is due to fusion reaction. Temperature on the surface of the sun and other stars is very high (more than million degrees centigrade). Under these conditions fusion reaction can easily take place. To explain fusion reaction taking place on the sun and other stars proton-proton cyclic process was proposed. In each such cycle energy released is estimated to be about 25 Mev.
Another cyclic fusion process, called carbon cycle, assumed to be taking place on the surface of the sun was proposed by Bethe. In this cycle energy released is estimated to be about 26.7Mev. The reaction which takes place in the sun utilizes four hydrogen nuclei to from a helium nucleus in the following manner.

i. $_1H^1+{}_1H^1 \rightarrow {}_1H^2+{}_1\beta^{\circ}+\nu$ (neutrino)
ii. $_1H^1+{}_1H^2 \rightarrow {}_2He^3+\gamma$
iii. $_1H^1+{}_2He^3 \rightarrow {}_2He^4+{}_1\beta^0+\nu$

Carbon cycle:

Bethe proposed solar fusion to occur in the following manner.

i. $_6C^{12}+{}_1H^1 \rightarrow {}_7N^{13}+$
ii. $_7N^{13} \rightarrow {}_6C^{13}+{}_1\beta^0+\nu$
iii. $_6C^{13}+{}_1H^1 \rightarrow {}_7N^{14}+\gamma$
iv. $_6N^{14}+{}_1H^1 \rightarrow {}_8O^{15}+$
y. $_8ON^{15} \rightarrow {}_7N^{15}+{}_1\beta^0+$
vi. $_7N^{15}+{}_1H^1 \rightarrow {}_6C^{12}+{}_2He^4$

In this cycle carbon acts as catalyst.

IMPORTANT SCIENTIFIC REASONS

Q.1 It is more difficult to start a fusion reaction than fission. Why?

Ans: Fission is caused by the capture of neutrons by heavy nuclei. Neutron, being electrically neutral, is highly penetrating particle for nuclei. But in fusion of two light nuclei, the positively charged nuclei are repelled by the Coulomb repulsive forces. So work has to be done against the repulsive forces of the two nuclei.

Q.2 Why do most moderators, used in nuclear reactors, are light atoms like H1, H2, C12 to slow down the neutrons instead of using heavier atoms?

Ans: Fast moving neutrons can be stopped when they make elastic collision with stationary particle of the same mass.

Q.3 Why are heavy nuclei unstable?

Ans: The stability of nucleus depends upon binding per nucleon (B.E/A) where A is mass number for Heavy nuclei the binding energy per nucleon less than lighter nuclei or those lying at the Middle portion of the periodic table. Since the heavy nuclei have lesser value of B.E per Nucleon they are unstable. So less energy is required to break heavy nuclei.

Q.4 A particle which produces more ionization is less penetrating why?

Ans: Ionization may be (i) due to direct collision of the particle (ii) due to coulombs force. Attractions or repulsion in both cases the ionizing particles losses its energy .so **α** And **β** particles losses its energy during each ionization. A particle which produces More ionization is less penetrating because it losses all its energy rapidly in ionizing the atoms. Thus it fails to penetrate greater depth. Thus a particle has more ionizing Ability cannot penetrate more. It is less penetrating for example **α** particle is more ionizing but less penetrating while **β** is less ionizing but more penetrating.

Q.5 Do α, β and γ-rays come from the same element. Why do we find all three in many radioactive samples?

Ans: A radioactive element either emits **α**-particles or **β**-particles, but never both. Gamma radiations generally accompany **β**-emission and in some cases with **α**-emission. A radioactive element (or sample) is a mixture of various nuclides of different relative abundances and with different modes of disintegration. Hence we can find all the three activities in a radioactive sample at the same time. For example, Ra-226 is an α -emitter, but Ra-225 is a B-emitter.

Q.6 Why is heavy water more efficient moderator than ordinary water?

Ans: Heavy water (D_2O) has much lower probability of capturing neutrons but it can slow down neutrons. In fact, heavy water is 1600 times more efficient as moderator than ordinary water (H_2O).

P

CHAPTER-19 **MULTIPLE CHOICE QUESTIONS**

From Past Papers

2001

Q.8. (a) (iii) The nuclei having the same mass number but different atomic numbers are called:

* Isotopes * Isobars * Isotones * Isomers

2002(Pre – Medical)

Q.8. (a) (ii) Breeder reactor is used to convert:

* $_{92}U^{235}$ into $_{92}U^{236}$ * $_{92}U^{238}$ into $_{94}Pu^{239}$
* $_{92}U^{235}$ into $_{92}U^{237}$ * $_{92}U^{235}$ into $_{56}Ba^{144}$ and $_{36}Kr^{89}$

Q.8. (a) (iii) The process in which heavier nucleus is formed from the combination of lighter nuclei is called:

* Fission * Fusion
* Radioactivity * mass defect

2003(Pre – Medical)

Q.7. (a) (ii) The process of β-particle emission from a nucleus involves the change in:

* mass number * charge number
* mass and charge number * no change occurs

Q.8. (a) (i) The process of the splitting of a heavy nucleus into smaller fragments is called:

* Fusion * Fission
* Pair production * Annihilation of matter

2003(Pre – Engineering)

Q.8. (a) (ii) In the nuclear reaction $_{7}N^{14} + {}_{2}He^{4} \rightarrow {}_{8}O^{17}$ + _______, the missing particle is:

* Proton * Neutron * Electron * α-particle

2004

Q.8. (a) (iii) the ratio of the mass of proton to the mass of electron is ________. *{1836}*

2005

Q.7. (a) (i) One atomic mass unit is equal to:

* 1.6×10^{-19}J * 9.1×10^{-27}kg * 931×10^{6}eV * 9×10^{9}eV

Q.7. (a) (iii) the energy equivalent to the mass reduced in the formation of a nucleus is called:

* Nuclear Energy * Binding Energy
* Fusion Energy * Potential Energy

Q.8. (a) (ii) The atomic number of an element is increased as a result of;

* A-radiation * β-radiation
* Pair production * photoelectric effect

2006

Q.7. (a) (ii) The atomic number of a radioactive element is increased as a result of:

* A-radiation * γ-radiation * B-radiation * pair production

Q.7. (a) (iii) In the nuclear reaction ${}_7N^{14} + {}_2He^4 \rightarrow {}_8O^{17}$ + ________, the missing particle is:

* Proton * Neutron * Electron * α-particle

2007

Q.8. (a) (iii) in radioactive decay law, $N = N_o e^{-\lambda t}$, λ represents:

* Wave Length * Half Life
* Mass Radioactive Sample * Decay Constant

2008

Q.8. (a) (i) the rate of decay of a radioactive substance:

* Increases with increasing time
* remains constant with increasing time
* Decreases exponentially with the increasing time
* None of these

2009

Q.8. (a) (ii) The half-life of radium is 1600 years. After 6400 years, the sample of the surviving radium would be its:

* 1/4 * 1/8 * 1/16 * 1/2

Q.8. (a) (iii) When a nucleus emits a Beta Particle, its atomic number:

* Increases * Decreases
* Remains constant * None of them

2010

Q.1. (iii) The radioactive decay law is:

(a) $\frac{N}{N_o} = e^{-t\lambda}$ (b) $N = N_o\ e^{-t\lambda}$

(c) $\frac{N_o}{N} = e^{-t\lambda}$ (d) $N_o = \Delta N_o\ e^{-t\lambda}$

2012

Q.1.vi. After alpha-decay, the nucleus has its:

* charge number decreased by four * charge number increased by four
* mass number decreased by four * mass number increased by four

2013

Q.1.xiii. In radioactive decay law $N = N e^{-t\lambda}$, λrepresents

*wavelength *half life *decay constant *None of these

P

Q.1.vi. This was the first experimental verification of Einstein's Mass-Energy relation

*Deuteron-induced reaction *Proton-induced reaction

*Gamma-induced reaction *none of these

2015

(xiii) The product of decay constant λ and half life $T_{1/2}$ of a radioactive source is:

* 0.369 * 0.396 * 0.693 * 0.963

(xv) A small quantity of radioactive Iodine $_{53}I^{151}$ is taken in food, most of it is deposited in the:

* Thyroid glands * Bones * Brain * Stomach

CHAPTER-19

NUMERICALS
From Past Papers

1994

Q.8. (c) Find the binding energy of $_{52}Te^{126}$ in MeV if the mass of a proton = 1.0078U, mass of a neutron = 1.0086U, mass of a Te atoms = 125.9033U. **(1061 MeV)**

2001

Q.8. (d) Find the binding energy of $_{52}Te^{126}$ in MeV if the mass of a proton is 1.0078U, mass of a neutron is 1.0086U, mass of a Te atoms = 125.9033U. **(1061 MeV)**

2006

Q.8. (d) The half-period of $_{104}Po^{210}$ is 140 days. By what percent does its activity decrease per week? **(3.465 % per week)**

2007

Q.7. (d) Calculate the binding energy of hydrogen atom.

Given that: $m = 9.1 \times 10^{-31}$Kg $e = 1.6 \times 10^{-19}$Coul

$\epsilon_o = 8.854 \times 10^{-12}$Coul^2/Nm^2 $h = 6.63 \times 0^{-34}$J s **(–13.6 eV)**

2009

Q.8. (d) If the number of atoms per gram of $_{88}Ra^{236}$ is 2.666×10^{21} and it decays with a half life of 1622 years, find the decay constant and the activity of the sample.

(1.35×10^{-11} sec^{-1}, 3.61×10^{11} disintegration/ sec)

2010

Q.2. (xiii) A deuteron (3.3431×10^{-27} kg) is formed when a proton (1.6724×10^{-27} kg) and a neutron (1.6748×10^{-27}) combine; calculate the mass defect and binding energy (in MeV).

(4.1×10^{-30} kg, 2.3MeV)

2012

Find the binding energy of $_{52}Te^{126}$ in MeV if the mass of a proton is 1.0078U, mass of a neutron is 1.0086U, mass of a Te atoms = 125.9033U. **(1061 MeV)**

2013

The number of atoms per gram of $_{88}Ra^{226}$ is 2.666×10^{21} and it decays with a half life of 1622 years. Find the activity and decay constant of the sample.

(1.35×10^{-11} sec^{-1}, 3.61×10^{11} disintegration /sec)

2014

Q2(v) Find the binding energy of $_{52}Te^{126}$ in MeV if the mass of a proton is 1.0078U, mass of a neutron is 1.0086U, mass of a Te atoms = 125.9033U. **(1061 MeV)**

2015

Q2(v) Find the binding energy and packing fraction (B.E per neucleon) of $_{52}Te^{126}$.

Given that: m_p=1.0078U m_n=1.0086U m_{Te}=125.9033U 1U=931.5MeV

CHAPTER 20

NUCLEAR RADIATION

"Physics in itself is not a factor of material progress but also an element in the spiritual evolution of man."

Biological and Medical Uses of Radiation:

the application of radiations to human beings and other organisms may be divided into two categories:"tracer techniques" and 'medical diagnostics and radiation therapy'

Tracer Techniques:-The location and concentration of radioactive isotope can be detected easily by measuring the radiations emitted radioactive isotope thus acts as a *tracer* that makes it possible to follow the course of a chemical and biological process. The following radio nuclei are used

I. **Radioactive carbon (C-14):** It has made it possible to understand the complex process of photosynthesis by autoradiography by placing a leaf on a photographic film (using S-35).
II. **I-131**: When takes **in food deposits in the thyroid glands.**
III. **Ca-45**: When taken orally or by injection, nearly 90% of it deposits in the bones of the young men or animals while only 40% In the old individuals.
IV. **Na-24**: It helps to **trace the rate of flow of the blood, food or water, etc**in the body.
V. **Fe-59**: It is used as a **traced in mechanical systems such as engines to trace the flow of lubricating oil.**
VI. **P-32**: it is used in **leukemia**.

Detectors:

The devices which are used to detect nuclear radiations are called "Radiation detectors". There are three main devices that are studies at intermediate level. They are

- Wilson Cloud Chamber
- Geiger Muller Counter
- Solid state detector

Wilson Cloud Chamber:

In 1911, C.T.R Wilson developed a condensation chamber for detection and measurement of moving charged particles.

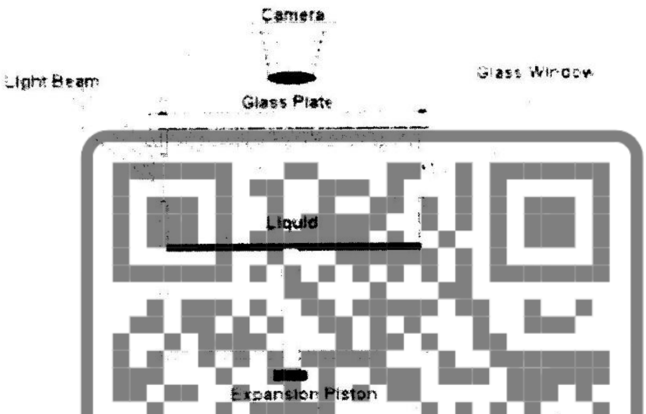
Principle:

A chamber contains super cooled vapors in a dust-free atmosphere. When radiations pass through the chamber, ions are formed, which serve as nucleation centres. The supersaturated vapors get condensed on them, so the path shoes up as a fog trail. In this way, the instrument is used to visualize the tracks of charged particles.

Construction:

Wilson cloud chamber is a funnel shaped transparent vessel. The components of this device are depicted in the figure.

A chamber: A closed (air tight) chamber that contains a moveable piston at its bottom and a glass top. It also contains windows for light and nuclear particles on each side. The chamber is well insulated.



Liquid: A mixture of alcohol (low boiling point) and water vapors is used.

Camera: A camera is used to take photograph of the tracks of the particles.

Working:

The cloud chamber is filled with a mixture of alcohol and water. The air chamber formed between moveable piston and glass top contains saturated vapors.

If the volume of chamber is increased (about 1.38 times its original volume) by suddenly moving the piston downwards, the *adiabatic expansion* causes cooling. The already saturated vapors now become *super saturated*, because the air now contains more vapors than is necessary for saturated at this temperature.

If an ionizing particle enters into the chamber immediately after the expansion, the ions left in its path act as condensation nuclei. Hence a close array of fine droplets (or track) is formed. The track is the path taken by a particle. It appears like a white line on a black background. The tracks can be photographed. The length of the track is a measure of ionizing power of the incident radiation.

Different particles produce different type of marks:

- The α-particles produce short, broad (dense) and continuous tracks.

- The β-particles produce thin, 1tortuous (zigzag) and discontinuous tracks.
- The γ particles produce no ionization, but when γ particles pass through the chamber, they produce photoelectrons. These particles produce irregular and beaded paths.

Uses:

- For measuring the range and energy of the particles
- To determine the sign of the charge
- For studying about the collisions between particles.
- For studying disintegration and nuclear reaction
- To distinguish particles by determining its specific ionization.

DrawBacks:

- It has a relatively large recovering time
- It is not continuously sensitive

Importance:

- Cloud chamber has helped to discover many new particles.

Geiger Muller Counter:

G.M counter is a very efficient device for counting individual particles and detecting nuclear radiation (α,β,γ rays).It was constructed by Geiger & Muller in 1928 in Germany.

Construction:

(1) **A metal Tube:** of aluminum or copper (it is 5-100cm long and 1-5 cm in diameter). One end of the tube is closed by an insulator. The other end is covered with a thin foil of mica. It serves as an entrance for particles.

(2) **A thin wire tungsten:** it lies along the axis of metal cylinder (tube). It passes through the insulated end, it serves as anode.

(3) **A mixture:** Of argon(90%) and alcohol gas at 10% is filled at low pressure (5-10cm of Hg)

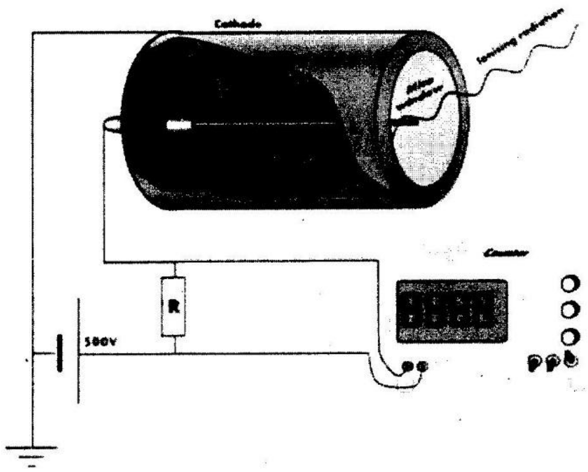
(4) **Potential difference:** Of 600V to 1000V is applied across the metal cylinder and anode wire.

(5) **A high resistor:** Of the order of $10^9\ \Omega$ is connected in series with a battery and anode wire.

(6) **Amplifier:** It amplifies small pulses of current.

(7) **Recorder:** It is a scalar/rate meter/counter/loudspeaker to register particles.

P|



Principle:

Geiger Muller counter is a special type of ionizing chamber. It is based on the phenomenon of production of ions by the incident radiations. An 'avalanche' of electrons that reaches the anode produces a *current pulse* which is recorded.

Working:

When an ionizing particle (α or β particle) enters the tube through the window, it ionizes the gaseous mixture. A few electrons and ions are produced. These positive and negative ions travel through the tube towards the electrodes. The accelerated ions suffer collisions with the gas molecules. They produce further ionization. If voltage (V) is above the breakdown potential for the gas, the numbers of ions are multiplied enormously. The ions are accelerated towards their respective electrodes. They collide with the gas molecules. Thus an *'avalanche'* of electrons-ion pairs produced. This gives rise to a sudden discharge in the tube. The gas, therefore, becomes conducting. The resulting current pulse is passed to a resistor to produce a voltage pulse (~10uV).This pulse is implied (up to 50V0) and is fed to:

1. To a loudspeaker to produce a loud click; or
2. To a scalar which gives record of the total number of pulses received; or
3. To a rate meter which indicates the number of counts per second received(i.e. it measures the rate of the incident radiations)

Advantages:

It is sensitive for counting of electrons and for γ rays.

Disadvantages:

- It cannot distinguish amongst the particles

- It is not suitable for fast counting.
- It cannot measure the energies of the incident particles.

Uses:

- It is used for the detection of radioactivity
- It helps in measurement of intensity of radiation
- It has been used to investigate cosmic-ray.

Solid –State Detector:

It is a device that makes use of solid state semi-conductor diode to detect nuclear particles.

***Principle*:**

When an energetic ionizing particle passes through a reverse biased PN junction, reverse current pulse passes through the junction. This can be detected.

***Construction*:**

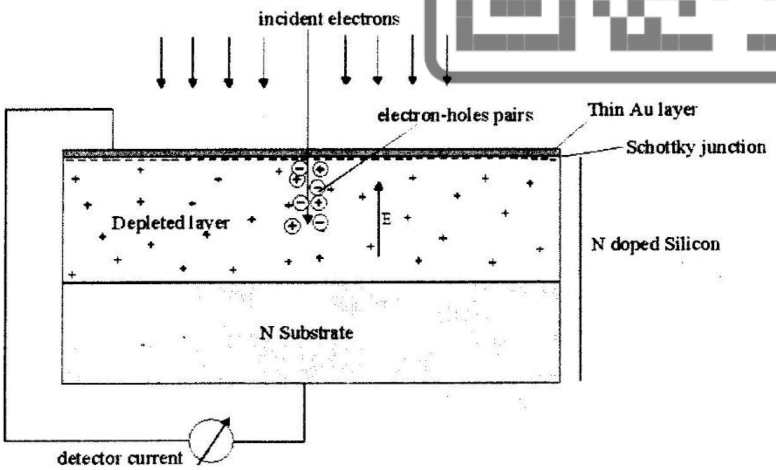
(1) **A semi-conductor diode:** The back of the detector consist of a thick layer of P-type material connected to the negative terminal of a battery. The front surface is made of thin layer on N-type material over which a very thin layer of gold is coated. It serves as positive electrodes.

(2) **A battery of low voltage (3-9V):** A diode is reverse biased with it.

(3) **A high resistor (MΩ):** It is connected in series with the diode and the battery.

(4) **Amplifier:** It amplifies small pulses of current.

(5) **Recorder:** A scalar or counter or loud speaker is used to register particles.



Working:

When a PN junction is reversed biased, the thickness of the *depletion* layer (which has high resistance) increases. When ionizing particle falls in the N-type side, it is absorbed in the depletion region (charge free region). Thus more electron-hole pairs are created. These charge carriers move under the influence of biasing potential. The electrons move towards the positive side of the battery and the holes are swept towards the negative side of the battery. The arrivals of these charges at two layers produce a *potential drop* across the junction. This results in a current pulse of small magnitude and extremely short duration (of the order of a nanosecond). The current pulse is fed to an amplifier. The amplifier pulse is applied to a counter to register the particle.

Advantages:

- It is more accurate and efficient than the G.M counter
- It is suitable for fast counting.
- The size and cost of the detector is very much reduced.
- No high voltage is used. Hence no precaution of earthing is REQUIRED.

Disadvantages:

- It can detect particles having energy of only few electron volts.

CHAPTER 20
IMPORTANT SCIENTIFIC REASONS

Q.1 In a cloud chamber photograph, the path of an α -particle is a thick and continuous line whereas that of a β -particle is a thin and broken line. Why?

Ans: An α -particle is highly ionizing than a β -particle.

Q.2 In what way does a neutron produce ionization of an atom?

Ans: A neutron collides with a substance containing a large number of hydrogen atoms and knocks out a proton. In this way, it causes ionization.

Q.3 Why do gamma rays not give a line track in the cloud chamber photograph?

Ans: Gamma rays do not produce ionization directly. They interact with atoms to eject electrons. These electrons like β-particles, produce irregular cloud tracks of their own which branch out from the direction of gamma rays.

Q.4 In how many ways can γ -rays produce ionization of the atoms?

Ans: Gamma rays only ionize an atom by collision. Being high energy photon, it can produce ionization in three ways:

(1) It may lose all its energy in a single collision with the electron of an atom (photoelectric effect);

(ii) It may lose only a part of its energy in a collision (Compton Effect);

(iii) It may be stopped by a heavy nucleus giving rise to electron-positron pair (Materialization of energy).

Q.5 Which of α , β and γ -rays would you advise for the treatment of (i) skin cancer (ii) the cancer of flesh just under skin (iii) a cancerous tumor deep inside the body?.

Ans: (i) For the treatment of skin cancer we use α -particles; as their penetration is small.

(ii) For the treatment of cancer, of flesh just under skin, β -particles should be used because of their medium penetration power.

(iii) For the treatment of deep infection in the body, gamma rays should be used; as they are highly penetrating.

CHAPTER-20

MULTIPLE CHOICE QUESTIONS
From Past Papers

2003

In treating a localized cancerous tumor a narrow beam of

* Alpha-rays from Cobalt-60 * beta-rays from Cobalt-60
* Electrons from Cobalt-60 * gamma-rays from Cobalt-60

If a small quantity of radioactive iodine $_{53}I^{131}$ is taken in food most of it is deposited in:

* Kidneys * Brain * Thyroid glands * All glands

2004

The track formed in Wilson cloud chamber due to gamma rays is a thick and continuous line

*TRUE *FALSE

2006

In treating a localized cancerous tumor a narrow beam of

* Alpha rays from cobalt. * Beta rays from cobalt.
* Gamma rays from cobalt. * Laser from cobalt.

2009

A Geiger Muller counter contains:

* Argon and Alcohol * alcohol only
* ions * super cooled water vapors

2012

Q.1.xiii. This narrow beam from Cobalt-60 is used to treating localized cancerous tumor,

* Alpha *rays* * Beta *rays* * Gamma *rays* * all of these

2013

Q.1.xvii. The rate of flow of blood in the body can be traced by using this radio isotope:

*$_{20}Ca^{45}$ *$_{11}Na^{24}$ *$_{1}H^{3}$ *$_{6}C^{12}$