CBCS SCHEME

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BPHYM102/202

First/Second Semester B.E./B.Tech.Degree Examination, June/July 2023

Applied Physics for ME Stream

Time: 3 hrs. Max. Marks: 100

Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. VTU Formula Hand Book is permitted.
3. M : Marks , L: Bloom's level , C: Course outcomes.

		Module – 1	M	L	C
Q.1	a.	Define force constant. Derive the expressions for equivalent force constant for two springs connected in series and parallel combination.	9	L2	CO1
	b.	Describe the construction and working of Reddy shock tube with the help of a diagram.	7	L2	CO1
	c.	The distance between the two pressure sensors in shock tube is 100 mm. The time taken by a shock wave to travel this distance is 195 microsecond. If the velocity of sound under the same condition is 340 m/s. Find the Mach number of the shock wave.	4	L3	CO1
		OR			
Q.2	a.	Obtain a differential equation for a body undergoing forced oscillation and mention expression for amplitude and phase of forced oscillation.	8	L2	CO1
	b.	What are shock waves? Mention three characteristics and applications of shock waves.	7	L2	CO1
	c.	In series resonance experiment, a 50 μF capacitor, when connected in series with a coil having a resistance of 40 Ω, resonates at 1000 Hz. Calculate the inductance of the coil for the resonant circuit.	5	L3	CO5
		Module – 2			
Q.3	a.	Define bending moment. Derive the expression for bending moment interms of moment of inertia.	10	L2	CO1
	b.	Explain the nature of elasticity with the help of stress-strain diagram.	6	L2	CO1
	c.	The Bulk modulus for a material is 60×10^9 N/m^2 and its modulus of rigidity is 40×10^9 N/m^2. Calculate its Young's modulus for the given material.	4	L3	CO1
		OR			
Q.4	a.	Define Young's modulus, Bulk modulus and rigidity modulus. Derive the relation between Y, η and σ.	9	L2	CO1
	b.	Explain the various types of beams and mention their engineering applications.	6	L2	CO1
	c.	Calculate the force required to produce an extension of 1 mm in steel wire of length 2 m and diameter 1 mm. (Given : Young's modulus of wire, $Y = 2\times10^{11}$ N/m^2).	5	L3	CO1
		Module – 3			
Q.5	a.	Discuss the Seebeck effect and Peltier effect with their coefficients.	8	L2	CO2
	b.	Describe the construction and working of Thermoelectric Generator (TEG).	7	L2	CO2

			Marks	Level	CO
	c.	The thermo emf of a thermocouple is 1200 μV when the cold junction is at $0^{\circ}C$ and hot junction at $100^{\circ}C$. Calculate the constants a and b if the neutral temperature is $300^{\circ}C$.	5	L3	CO2
		OR			
Q.6	a.	Describe the construction and working of Thermocouples. Mention their advantages.	9	L2	CO2
	b.	Explain the application of thermoelectricity on Refrigerator.	6	L2	CO2
	c.	The emf in microvolts of a thermocouple, one junction of which is at $0^{\circ}C$ is given by $e = 1600\,T - 4T^2$ where $T^{\circ}C$ is the temperature of hot junction. Find the neutral temperature and Peltier coefficient.	5	L3	CO2
		Module – 4			
Q.7	a.	Derive $\Delta T = \frac{(P_1 - P_2)}{C_P}\left[\frac{2a}{RT} - b\right]$ and hence discuss three cases.	9	L2	CO3
	b.	Describe the construction and working of Platinum Resistance Thermometer.	7	L2	CO3
	c.	In Joule-Thomson experiment temperature changes from $100^{\circ}C$ to $150^{\circ}C$ for pressure change of 20 MPa to 170 MPa. Calculate Joule-Thomson coefficient.	4	L3	CO3
		OR			
Q.8	a.	Describe the construction and working of Porous plug experiment. What conclusions have been drawn from it.	9	L2	CO3
	b.	Explain the construction and working of Lindey's air Liquefier.	7	L2	CO3
	c.	In a diffraction grating experiment the laser light undergoes second order diffraction for diffraction angle 1.48°. The grating constant $d = 5\times10^{-5}$ m and the distance between the grating and screen is 1 m, find the wavelength of LASER light.	4	L3	CO5
		Module – 5			
Q.9	a.	With a neat diagram, explain the principle, construction and working of Scanning Electron Microscopy.	8	L2	CO4
	b.	Explain the construction and working of X-ray diffractometer.	7	L2	CO4
	c.	Determine the crystal size when the peak width is 0.5° and peak position 30° for a cubic crystal. The wavelength of X-rays used is 100 Å and the Scherrer's constant K = 0.92.	5	L3	CO4
		OR			
Q.10	a.	Describe the principle, construction and working of Atomic Force Microscopy with the help of a neat diagram.	8	L2	CO4
	b.	Describe the principle, construction and working of Transmission Electron Microscopy.	8	L2	CO4
	c.	A beam of monochromatic X-rays is diffracted by NaCl crystal with a glancing angle of 12° for first order. Calculate the wavelength of X-rays if interplanar spacing of the crystal is 2.82 Å.	4	L3	CO4

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Applied Physics for ME Stream
BPHYM 102/202.
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Module - 1.

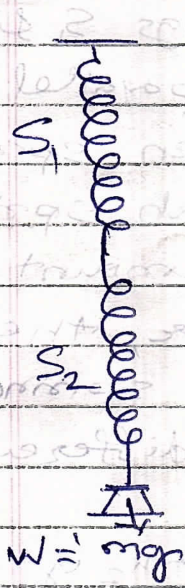
Q.1
(a) Define force constant. Derive the expression for equivalent force-constant for two springs connected in series and parallel combination. - (9M).

Soln According to Hooke's law, restoring force acting on a body is directly proportional to the displacement from its equilibrium position & is given by

$$F \propto -x$$
$$F = -kx$$

Here k is constant of proportionality called force constant & is measured in Nm^{-1}.

Springs in series.



Let us suppose S_1 & S_2 are connected in series, when weight 'mg' is attached to the series combination, the restoring force in each spring will be the same, (F, say) but increase in length will be different. If y_1 & y_2 are the extensions in the length of the springs S_1 & S_2 then

$$F = -k_1 y_1 \quad \text{and} \quad F = -k_2 y_2$$
$$y_1 = \frac{-F}{k_1} \qquad y_2 = -\frac{F}{k_2}$$

The total extension in series combination is given by

$$y = y_1 + y_2$$
$$= \frac{-F}{k_1} + \left(\frac{-F}{k_2}\right)$$

$$y = -F\left[\frac{1}{k_1} + \frac{1}{k_2}\right]$$

$$y = -\left[\frac{k_1+k_2}{k_1k_2}\right]F$$

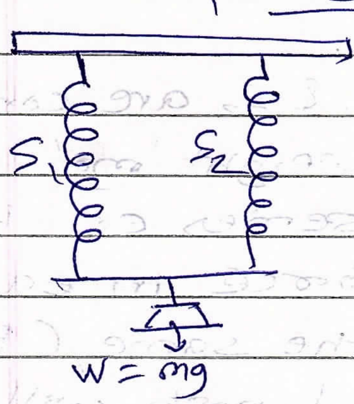
$$F = -\left[\frac{k_1k_2}{k_1+k_2}\right]y.$$

If k_s is the resultant spring constant in series, then

$$\boxed{k_s = \left(\frac{k_1k_2}{k_1+k_2}\right)}$$

$$\therefore F = -k_s y.$$

Springs in Parallel



Suppose two springs S_1 & S_2 are connected in parallel combination. When springs are in parallel, each spring will undergo same amount of extension 'y'. However, the restoring force developed in two springs will be different as they have different spring constants

$$\therefore F_1 = -k_1 y \quad \& \quad F_2 = -k_2 y$$

The resultant restoring force (F) is given by

$$F = F_1 + F_2$$
$$F = -k_1 y + (-k_2 y)$$

$$F = -(k_1+k_2)y$$

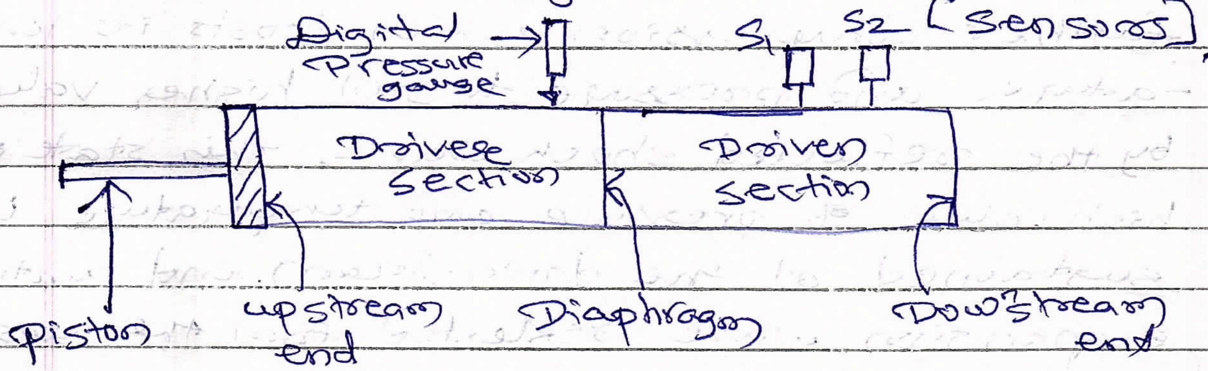
If k_p is the force constant of the parallel combination, then

$$\boxed{k_p = k_1 + k_2}$$

i.e. $F = -k_p y$.

Q.1 (b) Describe the construction & working of Reddy shock tube with the help of a diagram — (7M).

Soln. Reddy's tube is a hand operated tube capable of producing shock waves using human energy.



Construction:- Reddy's tube consists of a cylinder made of stainless steel tube of about 30mm in diameter & of length nearly 1m. It is divided into two section each of length 50cm. The two are separated by 0.1mm aluminium or paper diaphragm. The tube has a piston fitted at far end of the driver section whereas the far end of the driven section is closed.

A digital pressure gauge is mounted in the driver section next to the diaphragm & two piezoelectric sensors S_1 & S_2 are mounted ~~...~~ far apart towards the closed end of the driven section.

Working: The driver gas is compressed by pushing the piston hard into the driver tube until the diaphragm ruptures. Following the rupture, the driver gas rushes into the driven section and pushes the driven gas towards far downstream end. This generates a moving shock wave that traverses the length of the driven section. The shock wave instantaneously raises the tempera-ture & pressure of the driven gas as the shock moves over it.

The propagating primary shock wave is reflected from the downstream end. After the reflection, the test gas undergoes further compression which boosts its temper-ature and pressure to still higher values by the reflected shock waves. This state of high values of pressure and temperature is sustained at the downstream end until an expansion wave reflected from the upstream end of the driver tube arrives there and neutralises the compression partially.

The pressure rise caused by the primary shock waves & also reflected shock wave are sensed as signals by the sensors S_1 & S_2 respectively, and they are recorded in digital CRO.

From the recording in the CRO, the shock arrival times are found out by the associated time base calculations. Using the data so obtained, Mach number, pressure & temperature can be calculated.

Q.1 (c) The distance between two pressure sensors in tube is 100mm. The time taken by the shock wave to travel 100mm is 195 µs. Find the Mach number? Given $V_s = 340\,ms^{-1}$ — (4M)

DATE

Sol(2) Distance between two pressure sensors $d = 100 \times 10^{-3}$ m

time taken to travel $(t) = 195 \times 10^{-6}$ s

Velocity of sound $V_s = 340\ ms^{-1}$

Mach number, M = ?

Shock speed $U_s = \frac{d}{t} = \frac{100 \times 10^{-3}}{195 \times 10^{-6}}$

$= 0.512 \times 10^{3}\ ms^{-1}$

$U_s = 512\ ms^{-1}$

Mach number, $M = \frac{U_s}{V_s} = \frac{512}{340}$

$M = 1.50$

Q2

(a) Obtain a differential equation for a body undergoing forced oscillation and mention expression for amplitude & phase of forced oscillation — (8M).

Soln: Forced oscillations can be defined as the oscillations in which the body oscillates with a frequency other than its natural frequency under the action of an external periodic force.

Theory of forced oscillations

In this case, a particle is subjected to three kinds of forces

(i) a restoring force proportional to the displacement but oppositely directed

$F_{re} = -ky$ — (1)

(2) A frictional force proportional to velocity but oppositely directed

$F_{fr} = -r\frac{dy}{dt}$ — (2)

DIAMOND

iii) The external periodic force represented by

$$F_{ext} = F \sin(pt) \quad \text{—— (3)}$$

where

$F \rightarrow$ max. value of force,

$p/2\pi$ is its frequency

So the total force acting on the particle is given by

$$F = F_{re} + F_{fr} + F_{ext} \quad \text{—— (4)}$$

$$F = -ky - r\frac{dy}{dt} + F\sin(pt)$$

$$m\frac{d^2y}{dt^2} = -ky - r\frac{dy}{dt} + F\sin(pt)$$

$$m\frac{d^2y}{dt^2} + ky + r\frac{dy}{dt} = F\sin(pt)$$

$$\frac{d^2y}{dt^2} + \frac{k}{m}y + \frac{r}{m}\frac{dy}{dt} = \frac{F}{m}\sin(pt)$$

$$\frac{d^2y}{dt^2} + \omega^2 y + 2b\frac{dy}{dt} = f\sin(pt) \quad \text{—— (5)}$$

[$\because$ $\omega^2 = \frac{k}{m}$, $2b = \frac{r}{m}$, $f = \frac{F}{m}$]

Eqn (5) is a differential equation of motion of the particle.

The soln of Eqn (5) must be of the type

$$y = A\sin(pt - \theta) \quad \text{—— (6)}$$

Differentiating Eqn (6), we get

$$\frac{dy}{dt} = Ap\cos(pt - \theta)$$

$$\frac{d^2y}{dt^2} = -Ap^2\sin(pt - \theta)$$

Substituting the above relations in Eqn (5) we get

$$-Ap^2 \sin(pt-\theta) + 2b.Ap\cos(pt-\theta) + \omega^2 A\sin(pt-\theta) = f\sin pt$$

$$A(\omega^2-p^2)\sin(pt-\theta) + 2bAp\cos(pt-\theta) = f\sin[(pt-\theta)+\theta]$$

$$-A(\omega^2-p^2)\sin(pt-\theta) + 2bAp\cos(pt-\theta) = f\sin(pt-\theta).\cos\theta + f\cos(pt-\theta).\sin\theta$$

If this relation holds good for all values of 't' then the coefficient of $\sin(pt-\theta)$ & $\cos(pt-\theta)$ terms on both sides of this equation must be equal i.e.

$$A(\omega^2-p^2) = f.\cos\theta \quad \text{--- (7)}$$

$$2bAp = f.\sin\theta \quad \text{--- (8)}$$

Squaring Eqn (7) and (8) and then adding, we get

$$A^2(\omega^2-p^2) + 4b^2A^2p^2 = f^2$$

$$A^2[(\omega^2-p^2) + 4b^2p^2] = f^2$$

$$A = \frac{f}{\sqrt{(\omega^2-p^2)+4b^2p^2}} \quad \text{--- (9)}$$

while on dividing Eqn (7) by (8), we get

$$\tan\theta = \frac{2bAp}{A(\omega^2-p^2)}$$

$$\theta = \tan^{-1}\left[\frac{2bAp}{A(\omega^2-p^2)}\right] \quad \text{--- (10)}$$

Eqn (9) gives Amplitude & Eqn (10) represents phase of a body under forced oscillation.

Q 2 (b) What are shock waves? Mention three characteristics and applications of shock waves. — (7M)

Soln: Any fluid that propagates at super-sonic speed gives rise to shock wave. Shock waves can be produced by a sudden dissipation of mechanical energy in a medium enclosed in a small space. A shock wave is a surface that manifests as a discontinuity in a fluid medium in which it is propagating with supersonic speed.

Characteristics

1. They always travel in the medium with Mach number exceeding 1
2. The effects caused by shock waves result in increase of entropy.
3. Shock waves obey the laws of fluid dynamics

Applications:

1. Shock waves are used in wood preservation.
2. They are used to treat kidney stones.
3. Shock waves are also used for needleless drug delivery
4. They are used in the treatment of borewells.

Q. 2 (c) In a series resonance experiment, a 50 μF capacitor, when connected in series with a coil having a resistance of 40 Ω, resonates at 1000 Hz. Calculate the inductance of the coil for the resonant circuit. — (5M)

Sol^n Given $f_r = 1000\,Hz$

$C = 50 \times 10^{-6}\,F$

$R = 40\,\Omega$

$L = ?$

W.K.T

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad ; \quad f_r^2 = \frac{1}{4\pi^2 LC}$$

$$L = \frac{1}{4\pi^2 f_r^2 C} = 0.000506\,H$$

$L = 506\,\mu H.$

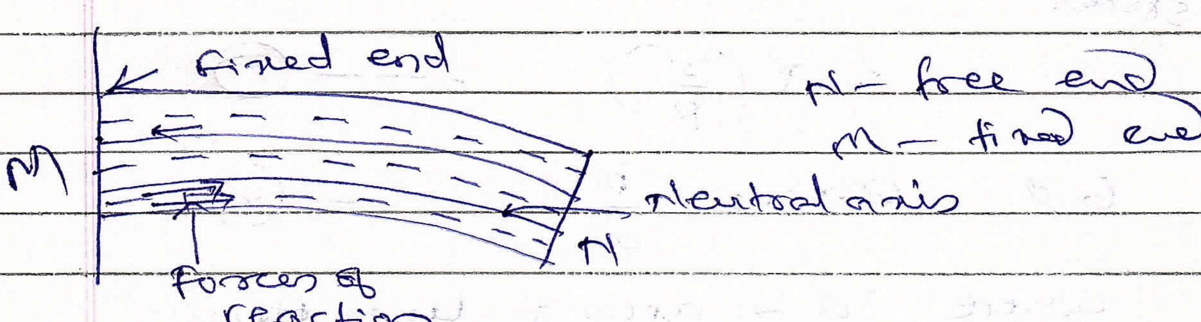
Module - 2

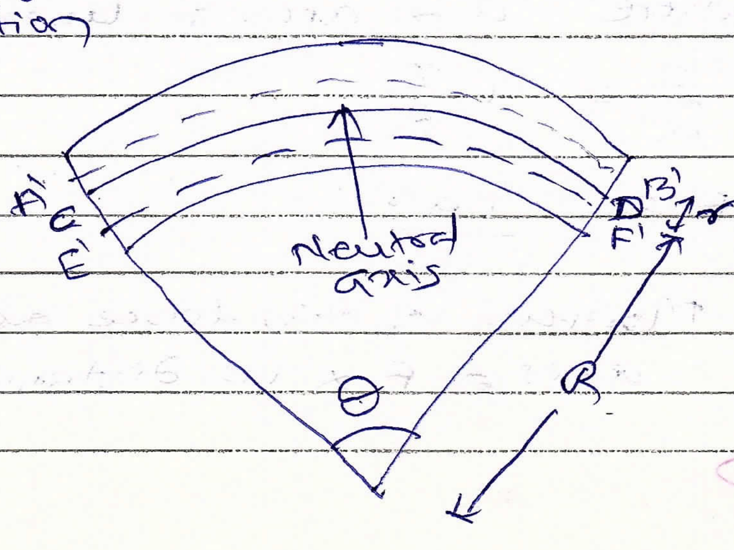
Q3 (a) Define bending moment. Derive the expression for bending moment interms of moment of inertia - 10M

Sol^n: A bending moment, in solid mechanics refers to the twisting force (or turning effect) experienced by a structural element (like a beam) when an external force or moment is applied, causing it to bend.

It represents the reaction developed within the element to counteract the applied force & prevent it from rotating.

Expression for bending moment.





Consider a long uniform beam MN whose one end is free at N. The beam can be thought of as made up of a number of parallel layers like AB, CD, EF ... etc.
If a load is attached to N, the beam bends. the layer AB elongates to A'B' & EF will be contracted to E'F'. CD is the neutral surface which does not change in length.
Let 'R' be the radius of the circle to which the neutral surface forms a part.

$\therefore CD = R\theta$

change in length $= A'B' - AB$

$AB = CD = R\theta$

If layers are separated by a distance 'r' then

$A'B' = (R+r)\theta$

$\therefore$ change in length $= (R+r)\theta - R\theta$

$= r\theta$

But original length $= R\theta$

Linear strain $= \frac{r\theta}{R\theta} = \frac{r}{R}$ —— (1)

But Young's modulus $Y = \frac{\text{Long. stress}}{\text{Linear strain}}$

Longitudinal stress $= Y \times$ Linear strain

$= Y\left(\frac{r}{R}\right)$ —— (2)

But stress $= \frac{F}{a}$ —— (3)

where 'a' → area of layer AB

$\therefore \frac{F}{a} = Y\frac{r}{R}$

or $F = \frac{Yar}{R}$

$\therefore$ Moment of this force about the neutral axis $= F \times$ its distance from neutral axis

$= F \times r = \frac{Y a r^2}{R}$

∴ Moment of the force acting on the entire beam $= \sum \frac{Y a r^2}{R}$

$$= \frac{Y}{R} \sum a r^2 \quad \text{---} \quad (4)$$

The Bending moment $= \frac{Y}{R} I_g$

where I_g - Geometric moment of inertia

$I_g = \sum a r^2 = A K^2$

A → area of cross section of beam

& K → Radius of gyration about the neutral axis.

(a) for rectangular cross section

$I_g = \frac{bd^3}{12}$

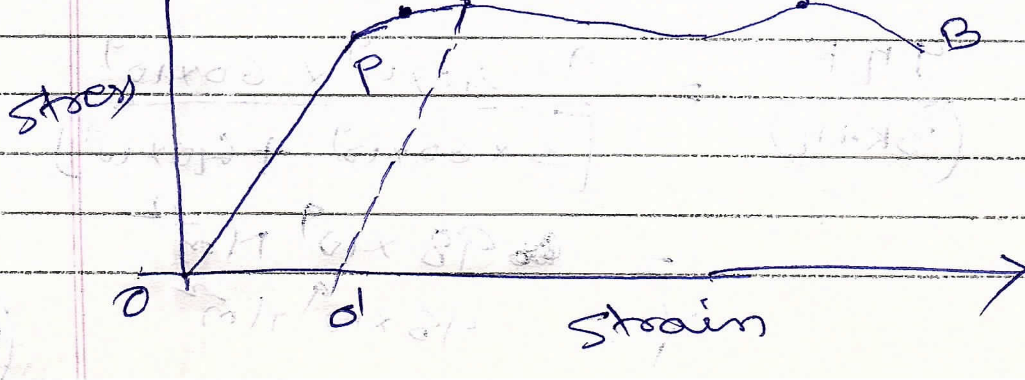
∴ Bending moment $= \frac{Y}{R} \frac{bd^3}{12}$

(b) for a beam of circular cross section

$I_g = \frac{\pi r^4}{4}$, r → radius of beam

Bending moment $= \frac{Y}{R} \frac{\pi r^4}{4}$

Q.3 (b) Explain the nature of elasticity with the help of stress-strain diagram. - 6M



If a metal wire is loaded & stress is plotted vs strain, then graph obtained is of the shape as shown in figure.

(i) The portion 'OP' of the graph is straight showing that stress ∝ strain, Hooke's law is obeyed. P → is called proportional limit.

(ii) Beyond 'P', the graph little bit deviates from straight line. Hooke's law is not obeyed between P & E. the point E is called elastic limit.

(iii) If the wire is loaded beyond point 'E', the strain increases much more rapidly with stress. If the wire is unloaded at 'A', the graph between stress vs strain will be along the dotted line AO'. It is called permanent set

(iv) Beyond point 'A', the length of the wire start increasing virtually for increase in stress. the point 'A' is referred to as Yield point.

(v) At point 'C' the wire breaks & enters into plastic region.

Q3 (c) The bulk modulus of the material is $60\times10^9\ Nm^{-2}$ & its modulus of rigidity is $40\times10^9\ Nm^{-2}$. Calculate its Young's modulus for the given material. — (4M)

Soln K or $B = 60\times10^9\ Nm^{-2}$

$\eta = 40\times10^9\ Nm^{-2}$

$$Y = \frac{9\eta K}{(3K+\eta)} = \frac{9\times40\times10^9\times60\times10^9}{[3\times60\times10^9+40\times10^9]}$$

$= 98\times10^9\ Nm^{-2}$

$Y = 98\times10^9\ Nm^{-2}$

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Q.4 (a) Define Youngs modulus, Bulk modulus, Rigidity modulus. Derive the relation bet Y, σ & η. — 9M

Soln:

(i) Young's modulus (Y) :- The ratio of longitudinal stress to the longitudinal strain within elastic limit is called Young's modulus of elasticity (Y)

$$Y = \frac{\text{Longitudinal stress}}{\text{Longitudinal strain}} = \frac{F/a}{l/L} = \frac{FL}{al}$$

$= \ldots Nm^{-2}$

(ii) Bulk modulus (K) :- The ratio of volume stress to the volume strain within elastic limit is called Bulk modulus of elasticity (K)

$$K = \frac{\text{Volume stress}}{\text{volume strain}} = \frac{F/a}{v/V}$$

$= \ldots Nm^{-2}$

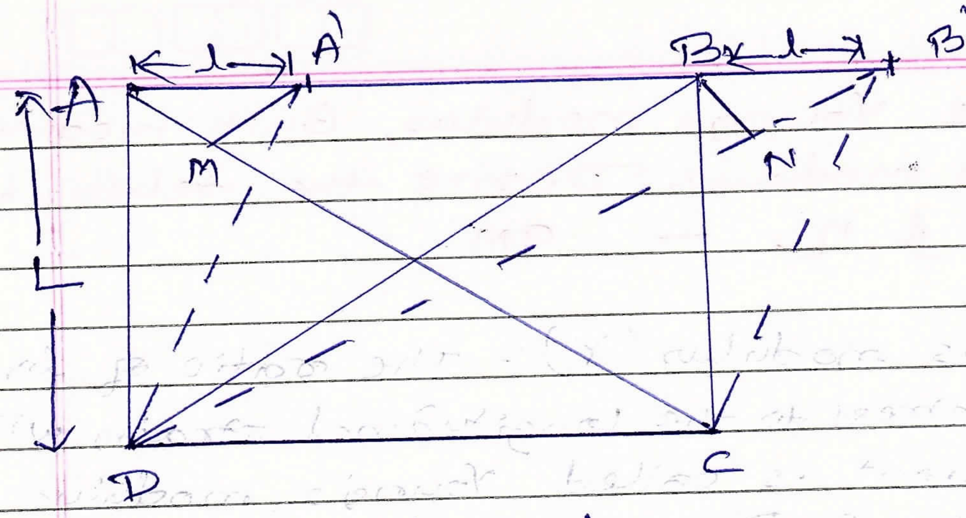
(iii) Rigidity modulus (η) :- The ratio of tangential force per unit area to the angular deformation produced is called modulus of rigidity (η).

$$\therefore \eta = \frac{\text{Tangential stress } (T)}{\text{shearing strain } (\theta)}$$

$= \ldots Nm^{-2}$.

Relation between Y, η & σ.

It should be noted that 'σ' represents Poisson's ratio & is defined as the ratio of lateral strain to the longitudinal strain.



In the above diagram,

ABCD → one face of the cube

L → length of the cube

CD → fixed surface

Extension produced → BB'

Compression → AA'

Shearing strain along AB can be treated as equivalent to longitudinal strain along diagonal DB' & an equal lateral strain along A'C.

If α → longitudinal strain / stress

β → lateral strain / stress

T → applied stress

Extension produced for length DB due to tensile stress = DB. T. α

Extension produced for DB due to compressive stress = DB. T. β

∴ Total extension along DB = DB. T. (α+β)

From figure, it is clear that, total extension in DB is approximately equal to B'N when BN is drawn perpendicular to DB'.

∴ $B'N = DB.T.(\alpha+\beta)$

$= \sqrt{2}L\, T(\alpha+\beta)$

W.K.T

$B'N = \frac{BB'}{\sqrt{2}} = \frac{l}{\sqrt{2}}$

$\therefore (r_2 L)\, T(\alpha+\beta) = \frac{l}{r_2}$

Rearranging above eqn

$$2(\alpha+\beta) = \frac{l}{TL}$$

Inverting above Eqn

$$\frac{1}{2(\alpha+\beta)} = \frac{TL}{l}$$

$$= \frac{T}{(l/L)} = \frac{T}{\theta} = \eta$$

$$\therefore \eta = \frac{1}{2(\alpha+\beta)}$$

$$= \frac{1}{2\alpha\left[1+\frac{\beta}{\alpha}\right]}$$

$$\eta = \frac{1}{2\alpha(1+\sigma)}$$

$$\eta = \frac{1/\alpha}{2(1+\sigma)}$$

But $Y = \frac{\text{stress}}{\text{Long. strain}} = \frac{1}{\frac{\text{Long. strain}}{\text{stress}}}$

$$= \frac{1}{\alpha}$$

$$\therefore \eta = \frac{Y}{2(1+\sigma)}$$

& $\boxed{Y = 2\eta(1+\sigma)}$ //.

The above equation gives relation between Y, η & σ.

Q.4 (b) Explain various types of beams & mention their engineering applications. — 6M

Sol^n: A homogenous body of uniform cross section whose length is large compared to its other dimensions is called a beam.

Different types of beams

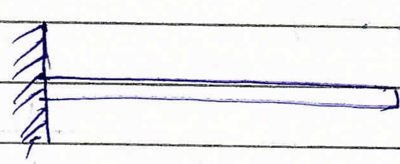
(i) Simple beam:-

A simple beam is a bar resting upon supports at its ends.

(2) Continuous beam

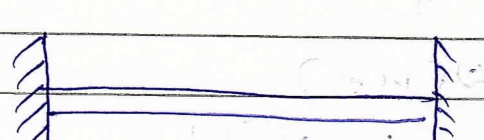
A Continuous beam is a bar resting upon more than two supports.

(iii) Cantilever beam



A cantilever beam is a beam whose one end is fixed & the other is free

(4) Fixed beam:- A beam fixed at its both ends is called fixed beam.



Engineering Application

Beams are used in

(1) the Elevators.
(2) the Construction of bridges
(3) the fabrication of trolley ways

Q.4(c) Calculate the force required to produce an extension of 1mm in steel wire of length 2m & diameter 1mm. (Given $Y = 2\times10^{11}\ Nm^{-2}$) — (5M)

Soln:

Extension to be produced, $x = 1mm = 10^{-3}\ m$

Length, $L = 2m$

Diameter $d = 1mm = 10^{-3}\ m$

$Y = 2\times10^{11}\ Nm^{-2}$

Force required to produce an extension = ?

Radius of the wire $R = \frac{d}{2} = \frac{10^{-3}}{2} = 0.5\times10^{-3}\ m$

$$Y = \frac{FL}{ax}$$

where $a \rightarrow$ area of cross section of wire

$$a = \pi R^2$$

$$\therefore Y = \frac{FL}{\pi R^2 x}$$

$$\text{or } F = \frac{\pi R^2 x Y}{L}$$

$$= \frac{\pi\times(0.5\times10^{-3})^2\times 2\times10^{11}\times10^{-3}}{2}$$

$$F = 78.54\ N.$$

Module - 3

Q.5(a) Discuss the Seebeck effect and Peltier effect with their coefficients — (8M)

Soln **Seebeck Effect:-**

The Seebeck effect is the build up of electric potential across a temperature gradient.

A thermocouple measures the difference in potential across a hot and cold end for two dissimilar materials. This potential difference is proportional to the temperature difference between hot & cold ends.

The Seebeck effect is a classic example of an electromotive force (EMF) & leads to measurable currents or voltages in the same way as any other EMF. The total current density is given by

$$J = \sigma(-\nabla V + E_{emf})$$

where V → local voltage, σ = local conductivity, E_{emf} – Electromotive force

The Seebeck effect is described locally the creation of an emf field

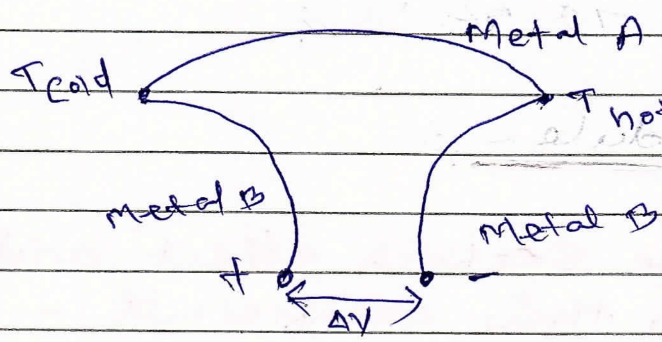
$$E_{emf} = -S\nabla T$$

where S – Seebeck coefficient.
∇T – Temperature gradient.

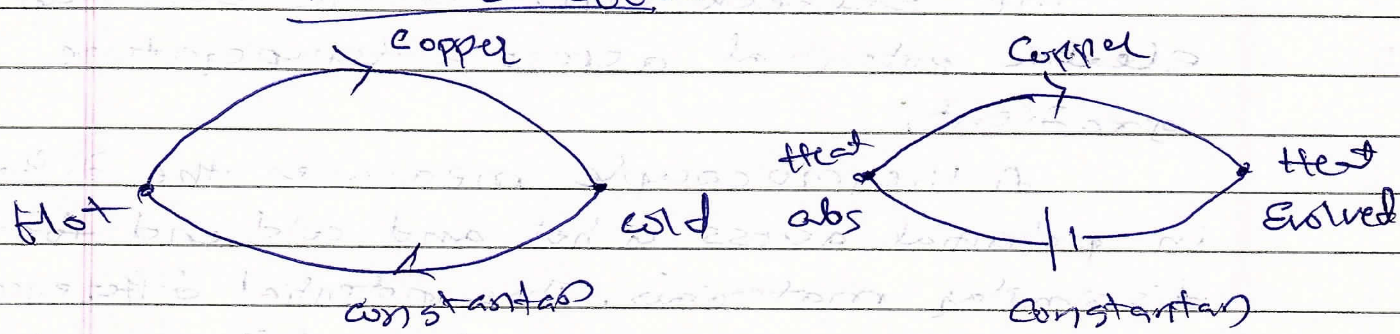
$$\Delta V = S\Delta T$$

$$S = \frac{\Delta V}{\Delta T}$$

This simple relationship, which does not depend on conductivity is used in the thermocouple to measure a temperature difference.



Peltier Effect.



If a current flows through a circuit containing junction of two dissimilar metals, it leads to an absorption or liberation of heat at the junctions. Heat is given out or absorbed depending on the pairs of metals & the direction of the current. The phenomenon of heat evolution is different from the Joule heat as Peltier effect is a reversible process while Joule loss is irreversible.

If the direction of the current at the junction is same as the direction of the seebeck current, heat is liberated if the Seebeck junction is a hot junction & is absorbed if the junction is cold. Thus for a copper-constantan thermocouple, if the current flow at the junction is from copper (+) to constantan (−), heat is absorbed. On changing the direction of the current, heat will be liberated at the same junction, showing that the phenomenon is reversible.

The amount of heat Q liberated to the surroundings in order that the junction may be kept at the same temperature is proportional to the current I passing through the junction

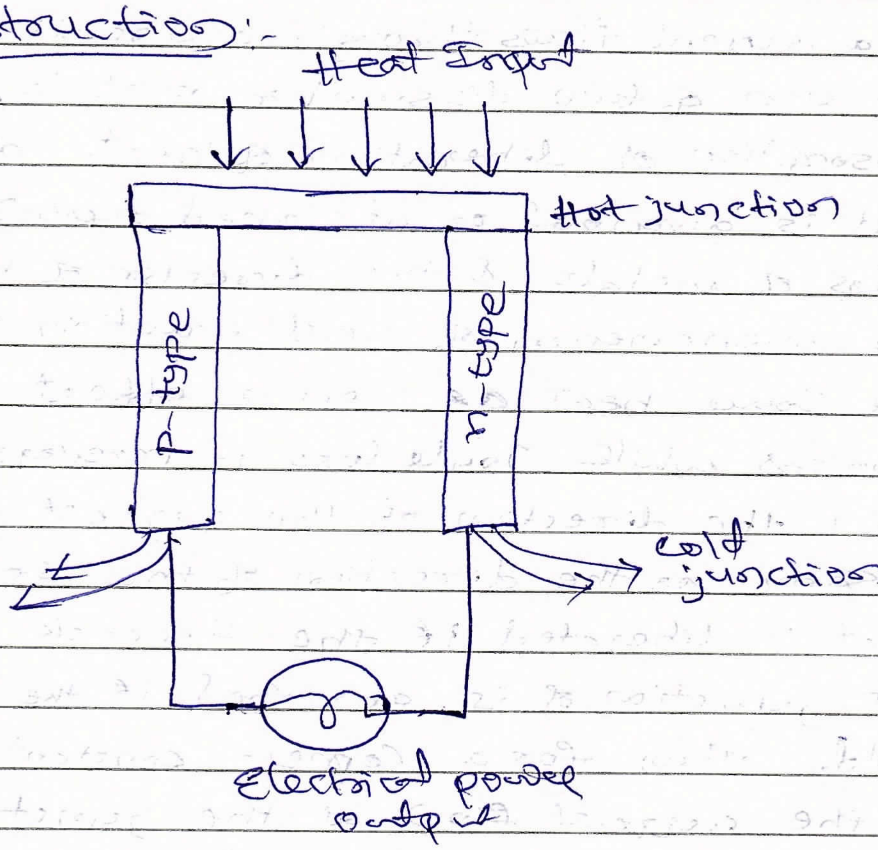
$$Q = \pi_{AB} I$$

where constant π_{AB} is called Peltier coefficient. The Peltier coefficient depends on the pair of materials A & B of the junction and also on the junction temperature.

Q.5(b) Describe the construction & working of Thermoelectric Generator (TEG) — (7M).

Sol^{n}: Principle:- The seebeck effect forms the basis for power generation; Thermoelectric generator converts heat energy to electricity.

Construction:-



The simplest TEG consists of a thermocouple comprising a p-type & n-type thermo-element connected electrically in series and thermally in parallel. The p-type & n-type semiconductor are interconnected through a metal. Load is connected to free end of p & n-type semiconductors.
To design such thermoelectric generators, semiconductors are used which have high electrical conductivity and low thermal conductivity.

Working:-
Heat is pumped into one side of the couple and rejected from the opposite side. The electrons present at the hot end would be at a high energy level as compared electrons present at the cool end side. This means that the hot electrons will tend to move towards the cool end due to the temperature gradient. When a temperature gradient is produced between two ends, the electrons starts flowing from one end to another end and create a potential

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difference, An electrical current is produced proportional to the temperature gradient between the hot and cold junctions.
Examples for best TE materials are BiTe, PbTe, Si-Ge alloys.

Q.5 (c) The thermo emf of a thermocouple is 1200 μV when the cold junction is at 0°C and hot junction at 100°C. Calculate the constant 'a' & 'b' if the neutral temperature is 300°C

Soln

EMF of a thermocouple $e = 1200 \times 10^{-6}$ V.

$t = T_2 - T_1$

$t = 100°C$

Neutral tempr $T_n = 300°C$

$e = at + \frac{1}{2} bt^2$

$(1200 \times 10^{-6}) = a(100) + \frac{1}{2} b(100)^2$

$a + 50b = 12 \times 10^{-6}$ ——— (i)

$T_n = \frac{-a}{b}$

$300°C = \frac{-a}{b}$

or $a = -300b$ ——— (ii)

From Eqn (i)

$-300b + 50b = 12 \times 10^{-6}$

$b = \frac{12}{-2.5} \times 10^{-8} = -4.8 \times 10^{-8}$

From Eqn (ii)

$a = (-300) \times (-4.8 \times 10^{-8})$

$a = 14.4 \times 10^{-6}$

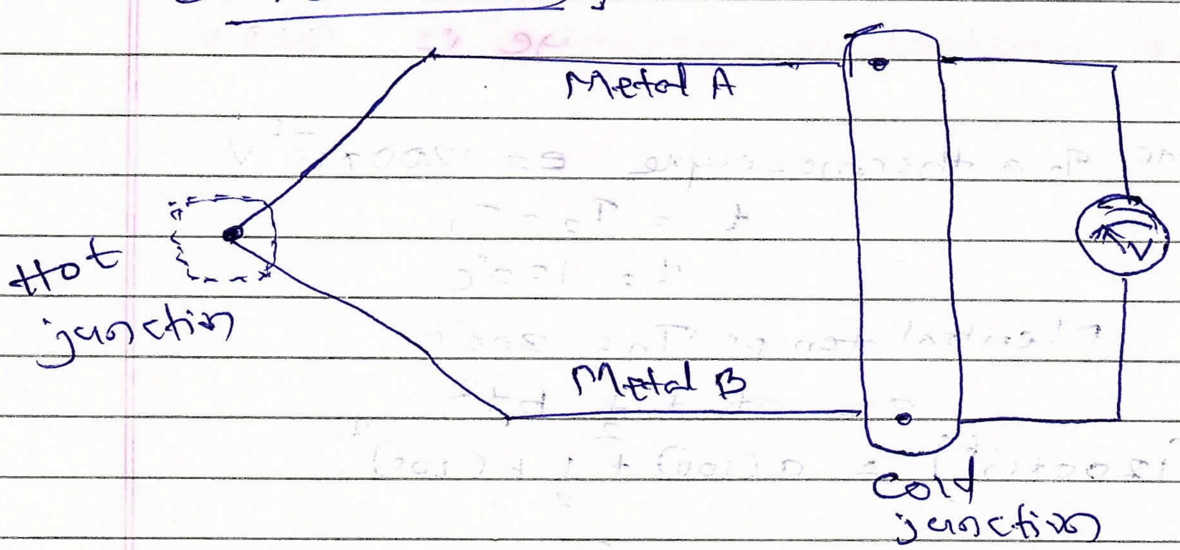
$\therefore$ $a = 14.4 \times 10^{-6}$ & $b = -4.8 \times 10^{-8}$

DIAMOND

Q.6 (a) Describe the construction & working of thermocouples. Mention their advantages. — 9M

Soln: The thermocouple can be defined as a kind of temperature sensor that is used to measure the temperature at one specific point in the form of the EMF or an electric current.

Construction:-



Thermocouple is constructed by joining wires made from dissimilar metals to form a junction. Voltage is produced when the temperature of the junction changes. Sensitive voltmeter is used to measure thermo EMF.

Working:-

First the thermocouple is calibrated by studying the variation of thermo EMF as a function of temperature of HOT junction keeping the temperature of cold junction constant say 0°c. A graph of thermo EMF Vs Temperature of hot junction is plotted. The graph is known as calibration graph. Next, the hot junction is placed in a bath of unknown temperature & the EMF developed in the thermocouple is noted. The temperature corresponding to this EMF is read from the calibration graph.

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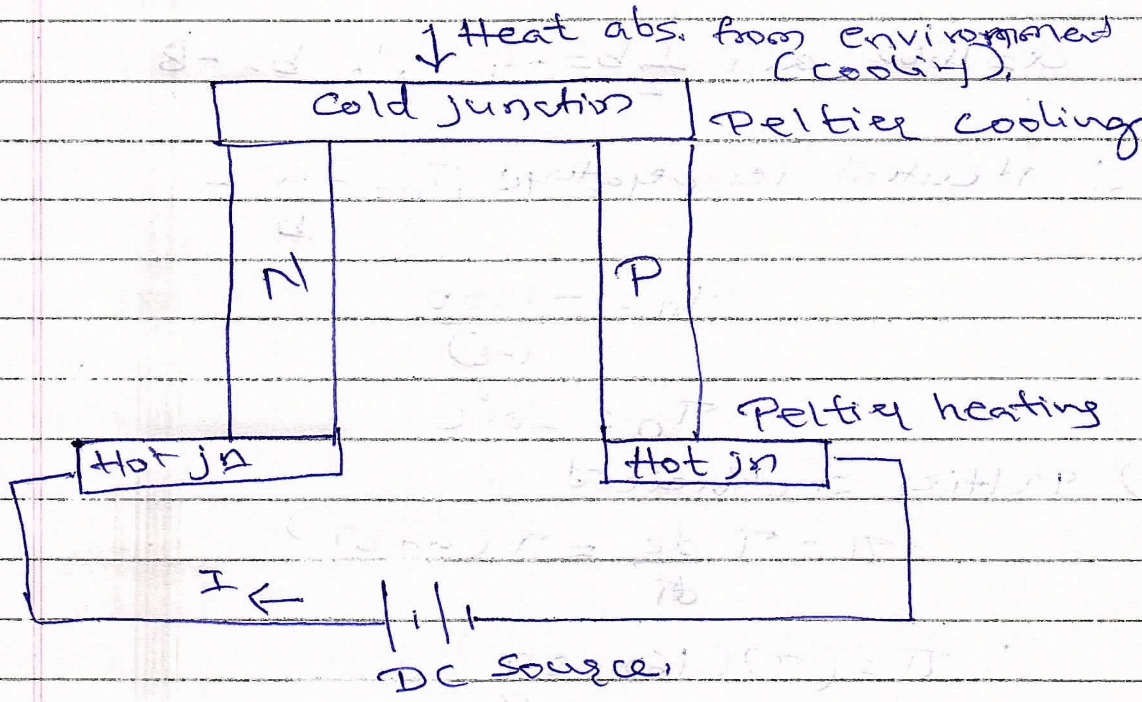
Advantages:

1. It is an active transducer i.e. it operates without any external power source.
2. Measurement of wide ranges of temperature from 200°c to 2800°c
3. The response time is fast, which can measure fast changing temperatures.
4. Able to measure temperatures at desired points.

Q.6 (b) Explain the application of thermo electricity on Refrigerator. (6 M).



Thermoelectric cooling is a way to remove thermal energy from a medium, device or component by applying a voltage of constant polarity to a junction between two dissimilar semiconductors. Thermoelectric cooling uses the Peltier effect to create heat flux between the junction of two different type of materials. The device has 2 sides & when a DC electric current flows through the device, it brings heat from one side to the other, so that one side gets cooler while the other gets hotter.

The main advantages of this thermo electric refrigeration system are the absence of moving parts & ease of automatic control by controlling the magnitude of current.

Q. 6 (c) The e.m.f in micro volts of a thermocouple, one junction of which is at 0°C is given by $e = 1600T - 4T^2$ where T°C is the temperature of the hot junction. Find (i) neutral temperature & (ii) Peltier coefficient.

Soln:

(i) $e = aT + \frac{1}{2}bT^2 = 1600T - 4T^2$

$a = 1600$ and $\frac{1}{2}b = -4$ ∴ $b = -8$

∴ Neutral temperature, $T_n = -\frac{a}{b} =$

$$T_n = \frac{-1600}{(-8)}$$

$$T_n = 200°C$$

(ii) Peltier coefficient

$$\pi = T\frac{de}{dT} = T(a + bT)$$

$$\therefore \pi = (T)(1600 - 8T)$$

$$\pi = 1600T - 8T^2$$

MODULE – 4

Q. 7 (a) Derive $\Delta T = \frac{P_1 - P_2}{C_p}\left[\frac{2a}{RT} - b\right]$ & hence discuss three cases.

Soln: Joule-Thomson effect is the change in temperature that accompanies expansion of a gas without production of work or transfer of heat.

Explanation:- If a gas initially at constant high pressure is allowed to suffer throttle expansion through the porous plug of silk, wool or cotton wool having a number of of fine pores, to a region of constant low pressure adiabatically, a change in temperature of gas (either cooling or heating) is observed. This effect is called as Joule-Thomson effect.

Theory:-

Consider a gas which expands through fine pores. Let the initial state & final states of the gas be (P_1, V_1, T_1) and (P_2, V_2, T_2). The change in temperature $T_1 - T_2 = \partial T$ is due to Joule-Thomson effect.

The external work done by the gas is given by

$$W_1 = P_2 V_2 - P_1 V_1 \quad \text{--- (1)}$$

The internal work done by the gas, to overcome the intermolecular gases is given by

$$W_2 = \frac{-a}{V_2} - \frac{a}{V_1} \quad \text{--- (2)}$$

The total work done by the gas is given by

$$W = W_1 + W_2$$

$$W = P_2 V_2 - P_1 V_1 - \frac{a}{V_2} + \frac{a}{V_1} \quad \text{--- (3)}$$

Vander Waals state equation for the gas is given by

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT \quad \text{--- (4)}$$

Neglecting $\frac{ab}{V^2}$, the eqn (4) could be reduced to

$$PV = RT + Pb - \frac{a}{V} \quad \text{--- (5)}$$

Thus for the initial & final states of the gas we can write

$$P_1 V_1 = RT_1 + P_1 b - \frac{a}{V_1} \quad \text{--- (6)}$$

$$P_2 V_2 = RT_2 - P_2 b - \frac{a}{V_2} \quad \text{--- (7)}$$

Substituting Eqs (6) & (7) in (3), & on simplification, we get

$$W = R(T_2 - T_1) - b(P_1 - P_2) + \frac{2a}{V_1} - \frac{2a}{V_2} \quad \text{--- (8)}$$

for very small values of a & b in Vander Walls equation, it reduces to $PV = RT$ and thus $V = \frac{RT}{P}$. Thus substituting for V_1 & V_2 in Eqn (8) we get

$$W = R(T_2 - T_1) - b(P_1 - P_2) + \frac{2aP_1}{RT} - \frac{2aP_2}{RT}$$

$$W = R(T_2 - T_1) - b(P_1 - P_2) + \frac{2a}{RT}(P_1 - P_2)$$

Since $\partial T = T_1 - T_2$ and re-organizing the terms we get

$$W = -R\partial T - b(P_1 - P_2) + \frac{2a}{RT}(P_1 - P_2) \quad \text{--- (9)}$$

$$W = -R\partial T + (P_1 - P_2)\left(\frac{2a}{RT} - b\right)$$

$$W = (P_1 - P_2)\left(\frac{2a}{RT} - b\right) - R\partial T \quad \text{--- (10)}$$

Since the gas is thermally insulated the expansion leads to reduction in temperature ∂T and the heat lost by the gas is given by

$$W = C_v \partial T \quad \text{--- (11)}$$

Thus Eqn (10) becomes,

$$C_v \partial T = (P_1 - P_2)\left(\frac{2a}{RT} - b\right) - R\partial T$$

$$(C_v + R)\partial T = (P_1 - P_2)\left(\frac{2a}{RT} - b\right) \quad \text{--- (12)}$$

The change in pressure $(P_1 - P_2) = \partial P$ and $C_p - C_v = R$, Eqn (12) could be written as

$$\boxed{\partial T = \partial P \frac{1}{C_p}\left(\frac{2a}{RT} - b\right)}$$

the three cases

1) If $\frac{2a}{RT} > b$ then ∂T is positive and there will be cooling effect.

2) If $\frac{2a}{RT} < b$ then ∂T is negative & there will be heating effect.

3) If $\frac{2a}{RT} = b$ then $\partial T = 0$ indicating neither cooling nor heating.

Q7(b) Describe the construction & working of Platinum Resistance Thermometer. (7M)

Soln. The Platinum Resistance Thermometer (PRT) uses platinum for determining the temperature. It works on the principle of positive temperature coefficient of resistance. The platinum is a chemically inert metal and can easily be drawn into fine wires. Because of these properties, platinum is used as a sensing element in thermometer.

Construction:

Fig (C)

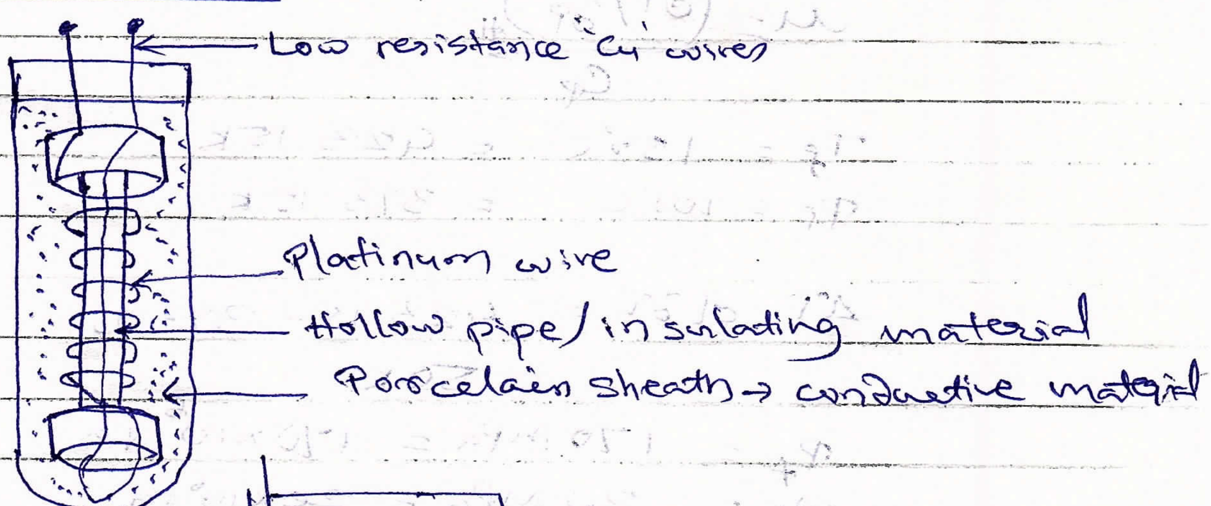
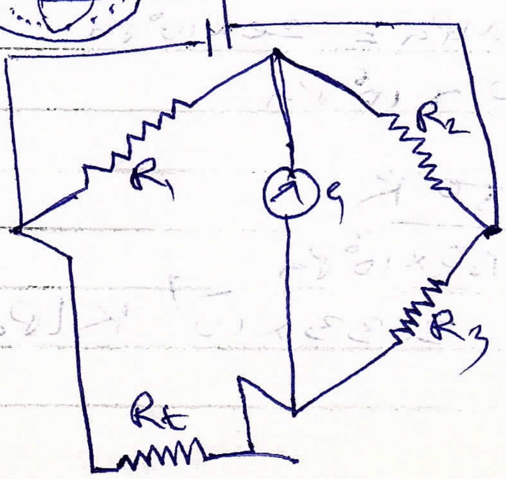


Fig (2)



The PRT consists of pure platinum wire wound on hollow pipe made up of insulating mica or ceramic, which is placed in porcelain sheath. Free ends of the platinum wire are attached to long leads of low resistance copper wires. To measure change in resistance, Wheatstone bridge is used. Two long extension leads form one arm of wheatstone bridge.

Working :-

When Platinum resistance thermometer is subjected to temperature variation, the wheatstone bridge gets unbalanced due to change in resistance R_t of platinum resistance. This makes the pointer move over circular scale of galvanometer, which is directly calibrated to give measured value of temperature.

Q 7 (c) In Joule-Thomson experiment, temperature changes from 100°C to 150°C for pressure change of 20 MPa to 170 MPa. Calculate Joule-Thomson coefficient.

Soln.

$$\mu = \frac{(\partial T/\partial P)_H}{C_P}$$

$T_f = 150°C = 423.15 K$

$T_i = 100°C = 373.15 K$

ΔT or $\partial T = 423.15 - 373.15$

$= 50 K$

$P_f = 170 MPa = 170 \times 10^6 Pa$

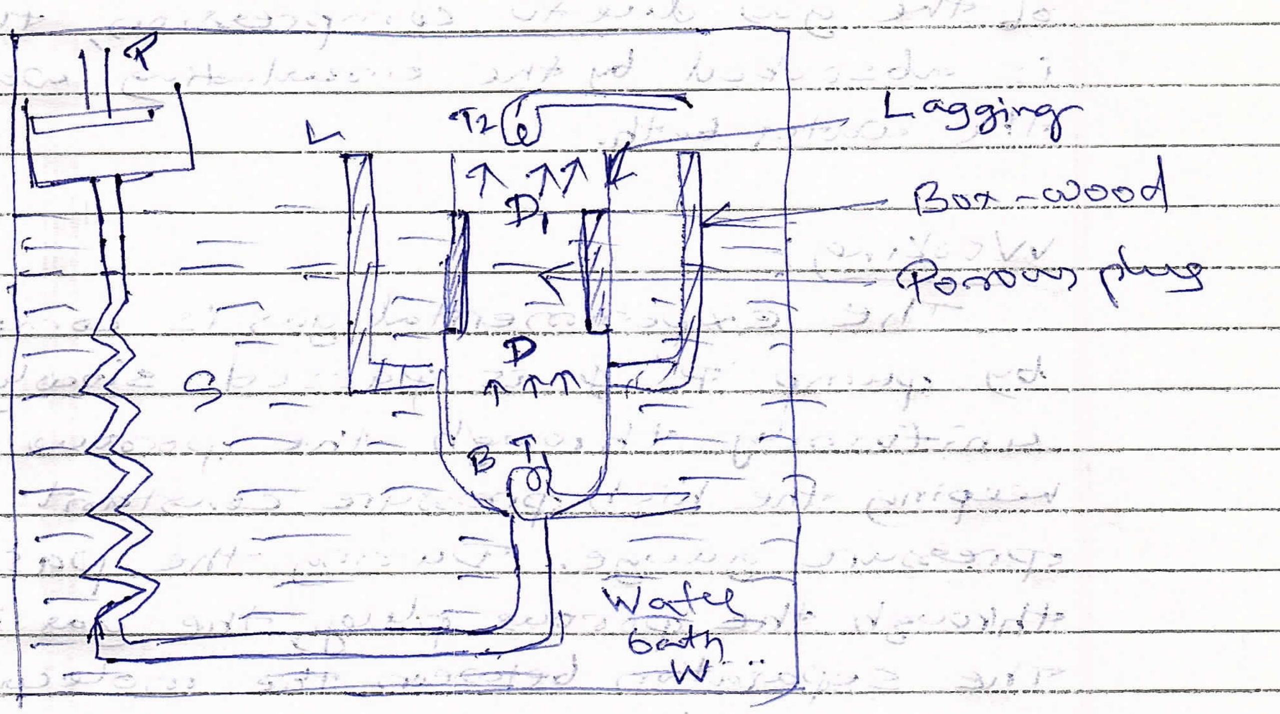
$P_i = 20 MPa = 20 \times 10^6 Pa$

$\Delta P = 150 \times 10^6 Pa$

$$\mu = \frac{\Delta T}{\Delta P} = \frac{50 K}{150 \times 10^6 Pa}$$

$$\mu = 3.33 \times 10^{-7} K/Pa.$$

Q.8 (a) Describe the construction & working of Porous-plug experiment. What conclusions have been drawn from it. [9M]



Construction:- Joule in collaboration with Thomson devised a very sensitive technique known as porous plug experiment. The experiment is set up to study Joule-Thomson effect.

Construction:-

1. A porous plug having two perforated brass discs D & D₁
2. The space between D & D₁ is placed with cotton wool or silk fibers.
3. The porous plug is fitted ~~with~~ in a cylindrical box-wood 'W' which is surrounded by a vessel containing cotton wool. This is to avoid loss or gain of heat from the surroundings.
4. T_1 & T_2 are two sensitive platinum resistance thermometers and they measure the temperature of the incoming and outgoing gas.
5. The gas is compressed to a high pressure with the help of piston P & is placed

through a spiral tube immersed in water bath maintained at a constant temperature. If there is any heating of the gas due to compression, this heat is absorbed by the circulating water in the water bath.

<u>Working</u>:-

The experimental gas is compressed by pump 'P' & is passed slowly & uniformly through the porous plug keeping the high pressure constant read by pressure gauge. During the passage through the porous plug, the gas is throttled. The separation between the molecules increases. By passing through the porous plug, the volume of the gas increases against the atmospheric pressure. As there is no loss of gain of heat during the whole process, the expansion of the gas takes place adiabatically. The initial & final temperatures are noted by platinum resistance thermometers T_1 & T_2.

The behaviour of large number of gases was studied at various initial temps & the results are as follows.

(1) At sufficiently low temperatures, all gases show a cooling effect.

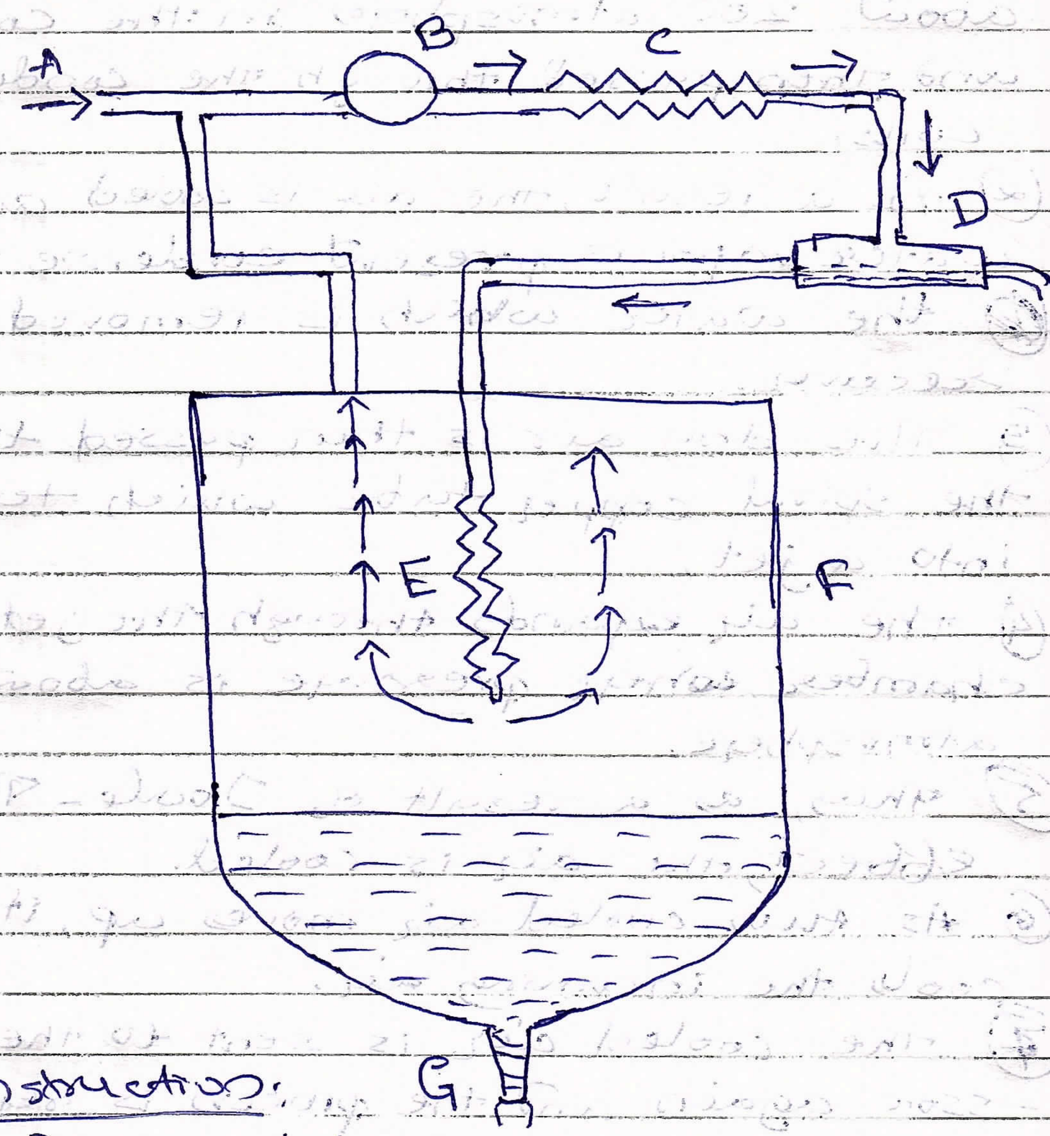
(2) At ordinary temperatures, all gases except hydrogen & helium, show cooling effect.

(3) The fall in temperature is directly proportional to the difference in pressure on the two sides of porous plug.

(4) The fall in temperature for a given difference of pressure, decreases with the rise in the initial temperature of the gas.

Q.8(b) Explain the construction and working of Lindey's air liquefier (7M)

Sol:-



Construction:

A → inlet of air
B → Compressor
C → Condensing coils
D → Receiver for water
E → Copper spiral with Jet J
F → Outer chamber
G → Out let for Liquefied air.

Principle:- Linde's process is known as adiabatic expansion of compressed gas. The process is based upon the combined effect of Joule-thomson effect and regenerative cooling. The compressed gas is made to expand adiabatically & repeatedly.

Working :-

① The air is first compressed to about 200 atmospheres in the compressor and then passed through the condensing coils.

② As a result, the air is cooled and the water vapours present condense to form ② the water which is removed from receiver.

③ The dry air is then passed through the spiral copper tube which terminates into a jet,

④ The air expands through the jet into the chamber where pressure is about 50 atmosphere.

⑤ Thus, as a result of Joule-Thomson effect, the air is cooled.

⑥ As this cooled air moves up, it further cools the incoming air.

⑦ The cooled air is sent to the compre-ssor again and the process is repeated a number of times till ultimately the air is cooled to such an extent that it liquefies

⑧ The liquefied air gets collected at the bottom of the outer chamber and can be drawn off. Any uncondensed air is recirculated.

Q.8 ⓔ In a diffraction grating experiment, the laser light undergoes second order diffraction for diffraction angle 1.48°. The grating constant $d = 5 \times 10^{-5}$ m & the distance between the grating & the screen is 1m. Find the wavelength of LASER light.

Soln:-

$m = 2 \quad d = 5 \times 10^{-5} \quad \theta = 1.48°$

$$\lambda = \frac{d \sin\theta}{m}$$

$$= \frac{5\times10^{-5} \times \sin(1.48^{\circ})}{2}$$

$$= \frac{5 \times 0.026 \times 10^{-5}}{2}$$

$$= 0.065 \times 10^{-5}$$

$$= 650 \times 10^{-9}\ m$$

$$= 650\ nm.$$

MODULE - 5

Q.9 (a) With a neat diagram, explain the principle, construction & working of Scanning Electron Microscope (8M)

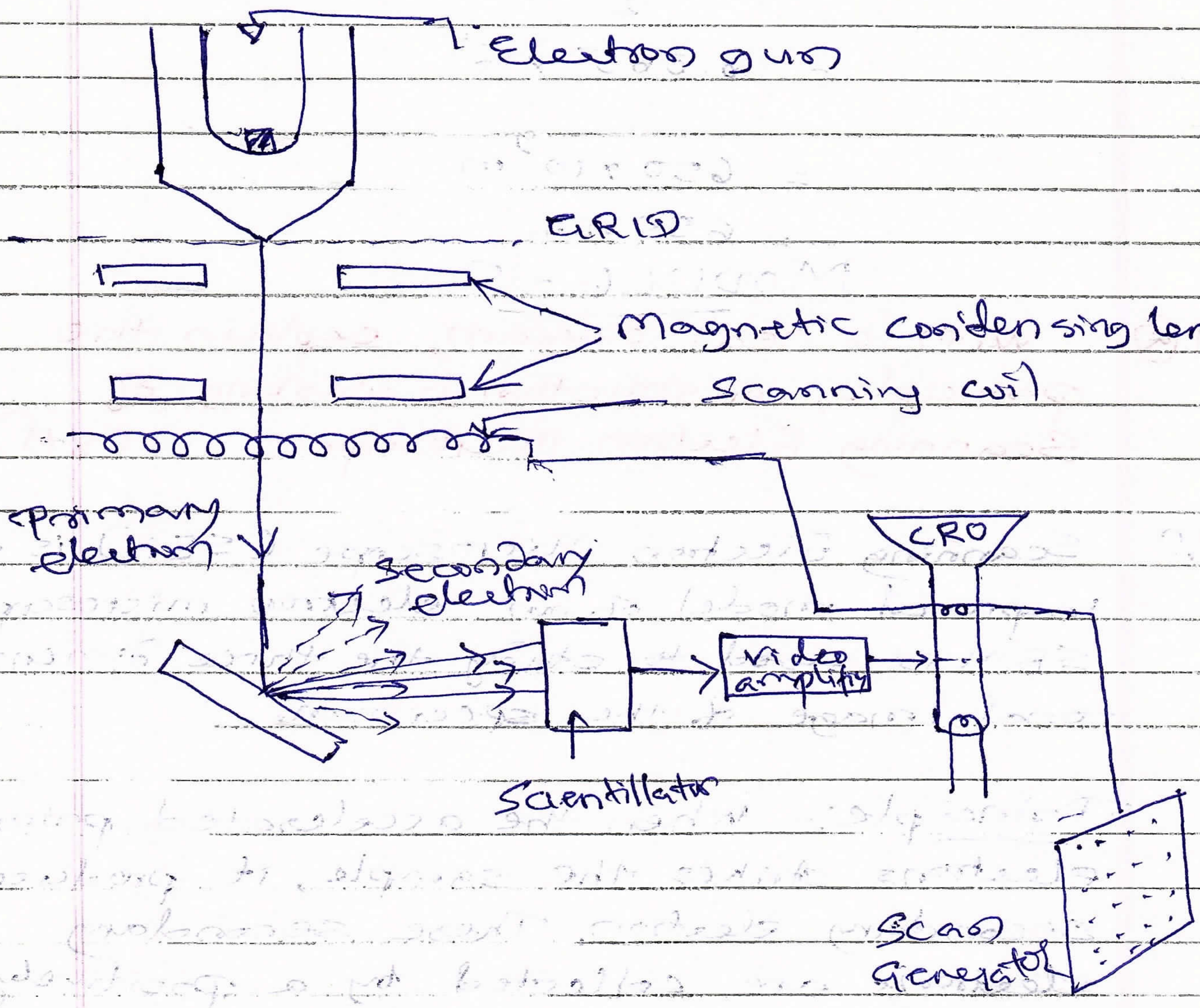
Sol) Scanning Electron Microscope (SEM) is an improved model of an electron microscope. SEM is used to study the three dimensional image of the speciman.

Principle:- When the accelerated primary electrons strikes the sample, it produces secondary electron. These secondary electrons are collected by a positively charged electron detector which in turn gives a three dimensional image of the sample.

Construction:-

It consists of an electron gun to produce high energy electron beam. Magnetic condensing lens is used to condense the electron beam & scanning coil is arranged inbetween the magnetic condensing lens and the sample.

The electron detector scientillator is used to collect the secondary electrons & converted into electrical signal, these signals can be fed into CRO through video amplifier, as shown in figure below.



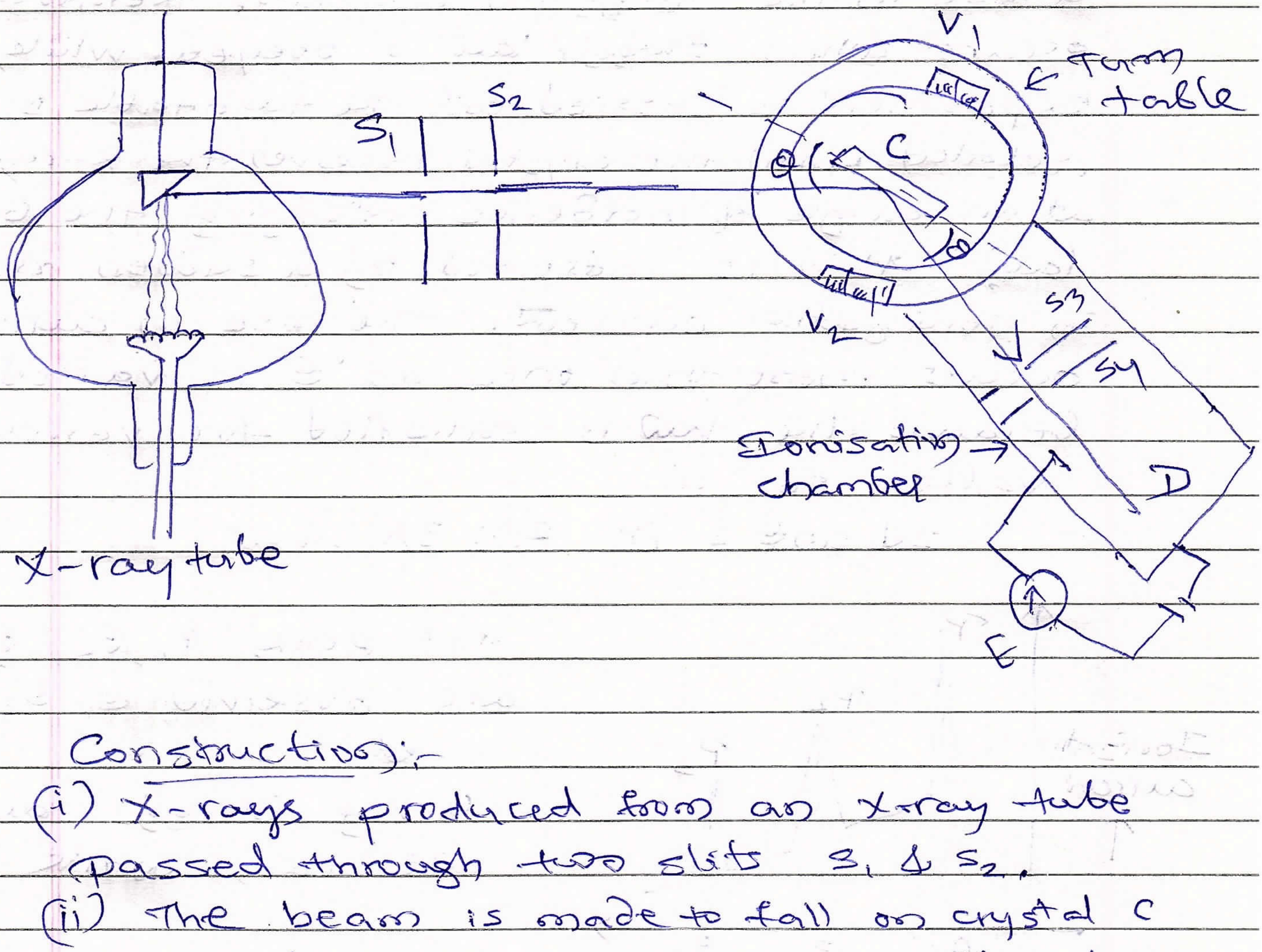
Working :-

1. Stream of electrons are produced by the electron gun and the primary electrons are accelerated by the grid and anode.
2. These primary accelerated electrons are made to fall on the sample through the condensing lens and scanning coil.
3. The high speed primary electron on falling over the sample produces low energy secondary electrons.
4. The low energy secondary electrons are difficult to collect. Hence high voltage is applied to the collector.

(5) The collected electrons are converted into electrical signals are are amplified by the amplifier & is then fed to CRO.
(6) Through CRO image of the sample can be known.

Q.9(b) Explain the construction and working of x-ray diffractometer. (7M)

Soln



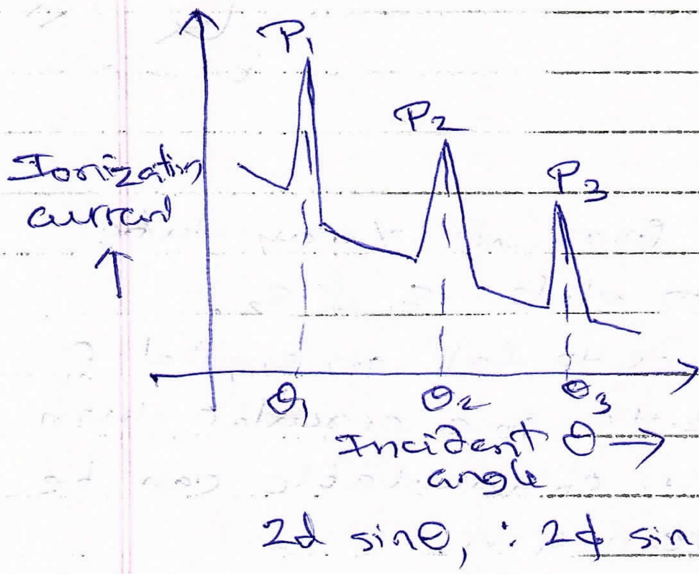
Construction:-
(i) X-rays produced from an X-ray tube passed through two slits S_1 & S_2.
(ii) The beam is made to fall on crystal C mounted at the center of a circular turn-table. The position of the table can be read by means of vernier V_1.
(iii) The X-ray beam after reflection enters ionization chamber D filled with gas. They are again made into narrow beam by means of slit S_3 & S_4. The position of the arm carrying the chamber read by the vernier V_2.

(iv) The x-rays produce ionization of the gas in the chamber D. The ionization current is measured by the electrometer E. If more x-rays enters the chamber, there will be an increase in the ionization current.

Working:

When the reflected rays from the crystal reinforce, the intensity of x-rays entering the ionization chamber increases causing a rise in the ionization current. Reinforcement occurs when Bragg's law is obeyed. While the experiment is carried out, the turntable is rotated until the crystal receives the x-ray beam at an angle of incidence satisfying the Bragg's law. This is indicated by a sudden rise in ionization current. The rise in current occurs more than once as 'θ' is varied, because the law is satisfied for various values of 'θ'

$$2d \sin\theta = \lambda : 2\lambda : 3\lambda \ldots$$



The peaks P_1, P_2, P_3 .. etc are observed $\theta_1\ \theta_2\ \theta_3$, etc

Using Bragg's law, we can write

$$2d \sin\theta_1 : 2d \sin\theta_2 : 2d \sin\theta_3 = \lambda : 2\lambda : 3\lambda$$

This helps in assessing the accuracy of measurement of θ_1, θ_2 & θ_3 .. One can measure the important crystal parameter, the interplanar spacing 'd', through the relation $2d \sin\theta = n\lambda$.

Q.9 (c) Determine the crystal size when the peak width is 0.5° and peak position 30° for a cubic crystal. The wavelength of X-rays used is 100 Å & the Scherrer constant K = 0.92.

Sol:

$$D = \frac{k\lambda}{\beta \cos(\theta)}$$

D → mean crystal size

β → Full width at half maxima

θ → Bragg's angle

k → Scherrer's constant = k = 0.92

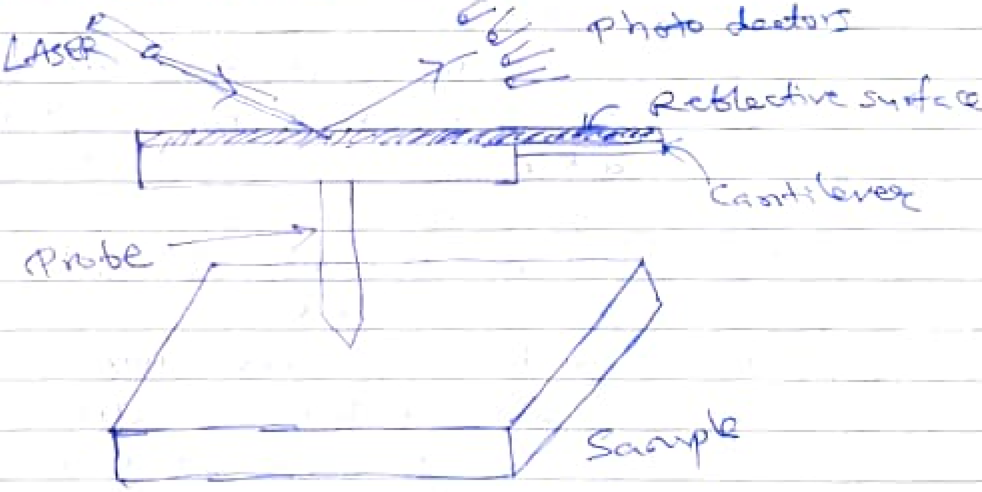
$\beta = 0.5° = 0.5 \times \pi/180 = 0.00873$ rad.

$$D = \frac{0.92 \times 100 \times 10^{-10}}{0.00873 \times \cos(\frac{31°}{2})}$$

$= 1.09 \times 10^{-6}$ m.

Q.10 (a) Describe the principle, construction & working of Atomic Force Microscopy with the help of neat diagram. (8M)

Sol:



Principle:- Atomic Force Microscope (AFM) produces image by physically pushing a cantilever probe against the sample. The probe movement is analyzed & converted into 3D image of the sample surface.

Construction:-

(1) A typical AFM consists of a cantilever around 100-500 microns in length with a small tip/probe of radius 3-15 microns at the free end.

(2) A laser source & photo detectors are used.

(3) Sample stage is attached to a piezo-electric sensor.

Analyzer:- The light collected by photo detectors is analyzed with computer controlled devices and 3D image of the sample surface is constructed.

Working:-

(1) When a cantilever probe is brought into proximity of the sample surface, the forces such as Vander waal's forces, electrostatic forces, magnetic forces and other forces which arise due to the physical interaction between the surface atoms, cause the cantilever tip to deflect.

(2) The cantilever can be thought of as a spring. The quantity of the generated force between the probe & the surface depends on the spring constant of the cantilever & the distance between the probe & the surface.

(3) This force can be characterized with Hooke's law $F = -kx$

(4) The deflection of the cantilever is detected by the help of a laser beam & deflection sensor.

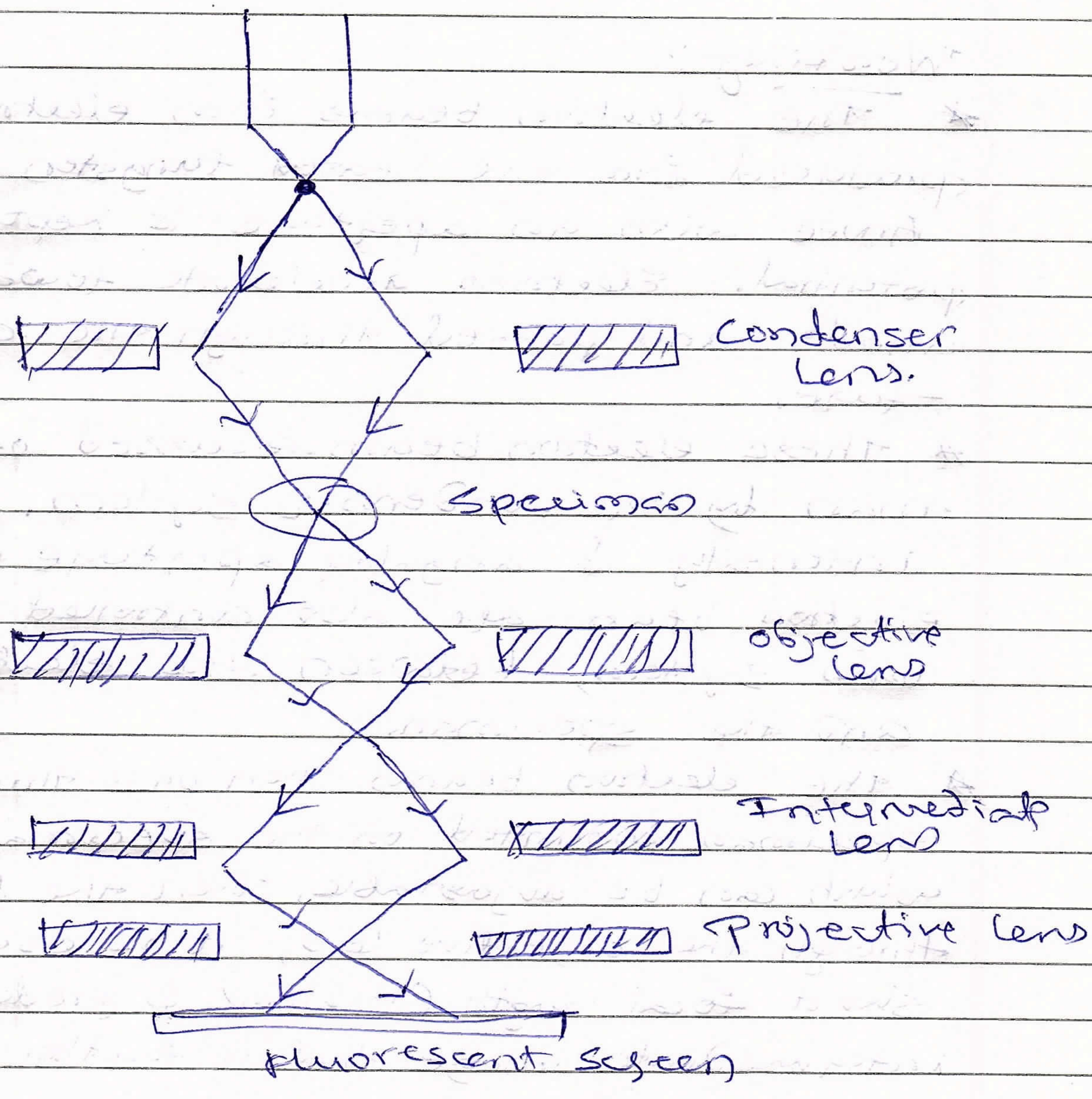
(5) The displacement of the probe is measured & a topographical image is obtained.

(6) In AFM both conducting & non-conducting samples can be analyzed.

Q.10 (b) Describe the principle, construction and working of Transmission Electron Microscopy (TEM) — (8M)

Soln:-

Principle:- Transmission Electron Microscope (TEM) works on the principle of wave nature and tunnelling effect of electrons.



Construction:- TEM is an electron microscope that has four main parts

(1) An electron gun → It produces electron beam.

(2) The condenser system → It focuses the electron beam on the sample

(3) The image-producing system: It consists of the objective lens, moveable specimen stage and intermediate and projector lenses to form a real & highly magnified image.

(4) The image-recording system: This converts the electron image into the format that can be seen by the human eye.

Working:-

* The electron beams from electron gun are produced from the heated tungsten filament. Anode with an aperture is kept at positive potential. Electrons accelerate toward the anode and passed through the central aperture.
* These electron beam focussed on the specimen by the condenser system. The intensity & angular aperture of the electron beam are also controlled by these lens system, between the electron gun and the speciman.
* The electron beams then pass through the speciman mounted on the speciman stage which can be adjustable. Then the beam passes through the objective lens, it is usually of short focal length (1-5mm) & produces a real intermediate image that is further magnified by the projector lenses.
* Modern instruments employ two projector lenses to permit a great range of magnification without increase in the physical length of the microscope.
* The intermediate electron image that is formed at the projector lenses are converted into the format that can be seen by the human eye by the image recording system.

This consists of a fluorescent screen for viewing and focussing the image, the higher magnification may be obtained by photographic or digital enlargement.

Q.10 (b) (c) A beam of monochromatic X-rays is diffracted by NaCl crystal with a glancing angle of 12° for first order. Calculate the wavelength of X-rays if interplanar spacing of the crystal is 2.82 Å

Soln:-

$\lambda = \frac{2d \sin\theta}{n}$

$d = 2.82 \times 10^{-10}$ m

$n = 1$

$\theta = 12°$

$\lambda = \frac{2.82 \times 10^{-10} \times \sin 12° \times 2}{1}$

$= 2.82 \times 10^{-10} \times 0.2079 \times 2$

$= \sout{0.5863 \times 10^{-10} m = 0.586 Å}$

$\lambda = \sout{5.863 \times 10^{-11} m}$ 1.172×10^{-10} m

QP-Solution Prepared by
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