CBCS SCHEME

1BPHYM102

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First Semester B.E./B.Tech. Degree Examination, Dec.2025/Jan.2026

Physics of Materials

Time: 3 hrs. Max. Marks: 100

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

			M	L	C
		Module – 1			
Q.1	a.	Define force constant. Derive the expression for equivalent force constant for two springs connected in series and parallel combination.	8	L2	CO1
	b.	Define Simple harmonic motion. Derive the differential form of expression for Simple Harmonic motion.	6	L2	CO1
	c.	A mass of 0.4 Kg causes an extension of 0.02m in a spring and the system is set for oscillations. Find the force constant of the spring, angular frequency and period of resulting oscillations.	6	L3	CO1
		OR			
Q.2	a.	Discuss the different types of springs used for various applications. Obtain the differential form of expression for a body undergoing forced oscillations and mention the expression for amplitude and phase of oscillations.	10	L2	CO1
	b.	Discuss the condition for amplitude resonance and hence emphasize on sharpness of resonance.	5	L2	CO1
	c.	Calculate the resonance amplitude of the vibration of the system whose natural frequency is 1000 Hz when it oscillates in the resistive medium for which the value of damping per unit mass is 0.008 rad/s under the action of an external periodic force/unit mass of amplitude 5 N/kg, with tunable frequency.	5	L3	CO1
		Module – 2			
Q.3	a.	Define Young's modulus (Y), Rigidity modulus (η) and Poissons ratio (σ). Derive the relation between them.	10	L2	CO2
	b.	With a neat diagram explain the stress- strain curve for elastic materials.	6	L2	CO2
	c.	In a stretching experiment, the extension produced in a wire for a load of 1.5 Kg is 0.2×10^{-2} m. If length and radius of cross section of the wire are 2m and 0.013 cm respectively, determine Young's modulus of materials of the wire.	4	L3	CO2
		OR			
Q.4	a.	Derive the expression for bending moment in terms of moment of inertia and hence arrive at the expression for bending moment for the beams with circular and rectangular cross sections.	9	L2	CO2

	b.	Explain different mechanisms of failure of engineering materials.	6	L2	CO
	c.	Calculate the force required to produce an extension of 1mm in steel wire of length 2m and diameter 1mm. Given young's modulus of the wire $Y = 2 \times 10^{11} N/m^2$.	5	L3	CO
		Module – 3			
Q.5	a.	Derive the expression for thermo emf in terms of temperatures of hot and cold junctions.	8	L2	CO3
	b.	Describe the construction and working of a thermoelectric generator.	7	L2	CO3
	c.	The e.m.f of a lead-iron thermocouple, one junction of which is at 0°C, is given by $E = 1784\,T - 2.4\,T^2$ (in μ volts), T being temperature in °C. Find the neutral temperature and Peltier coefficient.	5	L3	CO3
		OR			
Q.6	a.	Describe the construction and working of a thermocouple. Mention their advantages.	9	L2	CO3
	b.	Explain the application of thermoelectricity for refrigerators.	6	L2	CO3
	c.	EMF of a thermo couple is 1200 μV, when working between 0 °C and 100 °C. If its neutral temperature is 300 °C, find the value of coefficients a and b.	5	L3	CO3
		Module – 4			
Q.7	a.	Explain the liquification of oxygen by cascade process.	7	L2	CO4
	b.	Deduce the equation $\Delta T = \Delta P \frac{1}{C_P}\left[\frac{2a}{RT} - b\right]$ and hence discuss three cases.	9	L2	CO4
	c.	Mention the properties and uses of liquid Helium.	4	L3	CO4
		OR			
Q.8	a.	Describe the experimental arrangement and working of porous plug experiment. What are the conclusions drawn from it?	9	L2	CO4
	b.	Explain the construction and working of platinum resistance thermometer.	7	L2	CO4
	c.	In a Joule-Thomson experiment, temperature changes from 100°C to 150° C for pressure changes of 20Mpa to 170Mpa. Calculate Joule- Thomson coefficient.	4	L3	CO4
		Module – 5			
Q.9	a.	Describe the construction and working of an X-ray diffractometer.	7	L2	CO5
	b.	Discuss the motion of a particle in 1D potential well of infinite height and hence obtain it eigen function and eigen values.	9	L2	CO5

	c.	Determine the crystal size, when the peak width is 0.5 and peak position 30 for a cubic crystal. Given that, wavelength of the X-rays used is 100^0A and the Scherrer's constant K=0.92.	4	L3	CO5
		OR			
Q.10	a.	Explain quantum confinement in 0, 1, 2 and 3 dimensions and give the graphical representation of density of states.	8	L2	CO5
	b.	Describe the principle, construction and working of an atomic force microscope with a neat diagram.	8	L2	CO5
	c.	A beam of monochromatic X-rays is diffracted by a cubic crystal with a glancing angle of 12° for first order. Calculate wavelength of the X-rays, if the inter planar spacing of the crystal is 2.82 ^{0}A.	4	L3	CO5

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Physics of Materials

First Semester B.E, Jan, 2026, 1BPHYM102.

Q.1 (a) Define force constant, Derive the expression for equivalent force constant for two springs connected in series and parallel combination – 8M

Sol^n:- The force constant (k), also known as the spring constant, is a measure of the stiffness of an elastic material or object, such as springs. It quantifies the relationship between the applied force & the resulting deformation (displacement) from the equilibrium position

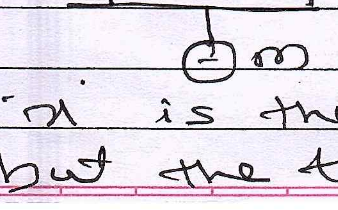
According to Hooke's law, the restoring force F produced by the spring is directly proportional to the displacement

$$F = -kx$$

The -ve sign indicates that the force is restorative, opposing the displacement.

$x \rightarrow$ is the displacement in meters

Equivalent of force constant for two springs in parallel.



Let two springs with force constants k_1 & k_2 are connected in parallel, the total displacement 'x' is the same for both springs. but the total force F is the is the sum of the individual forces.

For 1^{st} spring

$$F_1 = -k_1 x$$

For 2^{nd} spring

$$F_2 = -k_2 x$$

The equivalent force

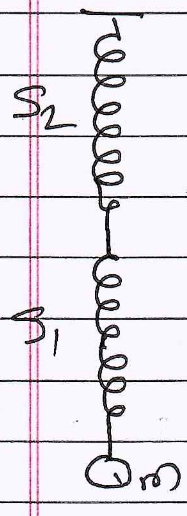
$$F_{eq} = F_1 + F_2$$
$$= -k_1 x + (-k_2 x)$$
$$= -k_1 x - k_2 x$$
$$= -(k_1 + k_2)\, x.$$

Thus equivalent force constant k_{eq} is

$$k_{eq} = k_1 + k_2.$$

Parallel springs act like a single stiffer spring.

Equivalent force constant for two springs in series combination



When two springs with force constant k_1 & k_2 are connected in series (end to end), the total force F is the same through both springs, but the total displacement 'x' is the sum of individual displacements x_1 & x_2

For 1^{st} spring

$$x_1 = -\frac{F}{k_1}$$

For 2^{nd} spring

$$x_2 = -\frac{F}{k_2}$$

The total displacement

$$x = x_1 + x_2$$
$$= F\left(\frac{1}{k_1} + \frac{1}{k_2}\right)$$

$$F = -\frac{x}{\left(\frac{1}{k_1} + \frac{1}{k_2}\right)}$$

The equivalent force constant k_{eq} satisfies $F = k_{eq} x$

$$k_{eq} = \frac{1}{\frac{1}{k_1} + \frac{1}{k_2}} = \frac{k_1 k_2}{k_1 + k_2}.$$

This shows that series springs are less stiff overall, as the equivalent constant is always less than the smaller individual constant

Q.1b Define simple harmonic motion. Derive the differential form & expression for simple harmonic motion. (6M)

Soln:- Simple harmonic motion (SHM) is a type of periodic motion in which the restoring force (or acceleration) acting on a particle is directly proportional to its displacement from the mean position & is always directed towards the mean position.

$$F \propto -x.$$

-ve sign indicates that the force is directed opposite to the displacement.

Derivation of differential equation of SHM

Consider a particle of mass 'm' performing SHM along a straight line

Let

x = displacement from mean position

a = acceleration

F = restoring force

By definition

$$F \propto -x$$

$$F = -kx$$

Applying Newton's 2nd law

$$F = ma$$

$$ma = -kx$$

$$m\frac{d^2x}{dt^2} = -kx$$

$$\frac{d^2x}{dt^2} = -\frac{k}{m}x$$

Let $\omega^2 = \frac{k}{m}$; $\omega \rightarrow$ angular frequency

Final differential equation of SHM

$$\boxed{\frac{d^2x}{dt^2} + \omega^2 x = 0}$$

Q.1(c) A mass of 0.4kg causes an extension of 0.02m in a spring system & the system is set for oscillation. Find the force constant of the spring, angular frequency & period of resulting oscillation. (6M)

Sol^{n} Given data

$m = 0.4$ kg

$x = 0.02$ m

$g = 9.8$ ms^{-2}

when the mass is suspended, the spring extends due to weight

$$mg = kx$$

$$k = \frac{mg}{x}$$

$$k = \frac{0.4 \times 9.8}{0.02}$$

$$= \frac{3.92}{0.02}$$

$$k = 196 \text{ N} m^{-1}$$

Angular frequency : $\omega = \sqrt{\frac{k}{m}}$

$$\omega = \sqrt{\frac{196}{0.4}}$$

$$\omega = \sqrt{490}$$

$$\omega = 22.14 \text{ rad/s}$$

Time period $T = \frac{2\pi}{\omega}$

$$= \frac{2\pi}{22.14} = \frac{6.283}{22.14}$$

$$T = 0.284 s$$

force constant $k = 196$ Nm^{-1}

Angular Frequeny $\omega = 22.14$ rad s^{-1}

Time period $T = 0.284$s

SCORE

Q2(a) Discuss the different types of springs used for various applications obtain the differential form of expression for a body undergoing forced oscillations & mention the expression for amplitude & phase of oscillations.

Soln:- Springs are elastic mechanical elements that store energy when deformed & release it when the load is removed.

(1) Helical spring:-
- Made of wire wound in a helix
- Works under tension or compression
- Follows Hooke's law within elastic limit.

Applications:- Vehicle suspension system, spring balances shock absorbers

(2) Leaf spring:-
- Consists of flat metal strips stacked together
- Provides large load-bearing capacity

Application:- Heavy vehicles, railway wagons

(3) Spiral Spring
- Flat strip wound in spiral form
- Stores rotational energy.

Application:- Mechanical watches, toys

(4) Torsion Spring
- Operates by twisting
- Stores energy as torque.

Application:- door hinges, clips

SCORE

5. Conical / volute spring

- Coils of varying diameter
- Prevents solid height problem.

Application:- High load condition, vibration isolators.

Forced Oscillation:-

Consider a particle of mass 'm' attached to a spring of force constant k, subjected to

- Damping force proportional to velocity ($b\frac{dx}{dt}$)
- External periodic force
  $F = F_0 \sin\omega t$

forces acting

1. Restoring force $= -kx$
2. Damping force $= -b\frac{dx}{dt}$
3. Driving force $= F_0 \sin\omega t$

Applying Newton's 2nd Law

$$m\frac{d^2x}{dt^2} = -kx - b\frac{dx}{dt} + F_0 \sin\omega t$$

$$\boxed{m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = F_0 \sin\omega t}$$

This is the standard differential eqn of a damped forced oscillator.

The steady-state solution is
$x = A \sin(\omega t - \phi)$

Amplitude of forced oscillation

$$A = \frac{f_0/m}{\sqrt{(\omega_0^2 - \omega^2)^2 + (2\beta\omega)^2}}$$

$$\omega_0 = \sqrt{\frac{k}{m}} \ ; \ \beta = \frac{b}{2m}$$

phase angle

$$\tan\phi = \frac{2\beta\omega}{\omega_0^2 - \omega^2}$$ //

Q.2(b) Discuss the condition for amplitude resonance and hence emphasize on sharpness of resonance. - 5M

Soln:- For a damped forced oscillator

$$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = f_0 \sin\omega t$$

The steady-state amplitude is

$$A = \frac{f_0/m}{\sqrt{(\omega_0^2 - \omega^2)^2 + (2\beta\omega)^2}}$$

where

$$\omega_0 = \sqrt{\frac{k}{m}} \qquad \beta = \frac{b}{2m}$$

Amplitude resonance occurs when the amplitude A becomes maximum.
Since A is maximum, when the denominator is minimum, we

SCORE

differentiate the denominator term w.r.t. ω & set it equal to zero.

On solving, the condition for resonance is

$$\omega_r = \sqrt{\omega_0^2 - 2\beta^2}$$

Thus

- For light damping ($\beta << \omega_0$)

$$\omega_r \approx \omega_0$$

- for no damping ($\beta = 0$)

$$\omega_r = \omega_0$$

Hence, resonance frequency is slightly less than natural frequency when damping is present.

Sharpness of resonance

Sharpness of resonance refers to how rapidly the amplitude falls on either side of the resonance frequency.

It depends on damping

(1) Light damping

- Resonance curve is tall & narrow
- Very large amplitude at resonance
- Highly sharp resonance

(2) Heavy damping

- Resonance curve is broad & flat
- Amplitude is smaller
- Resonance is less sharp.

Quality factor

$$Q = \frac{\omega_0}{2\beta}$$

Large $Q \Rightarrow$ Sharp resonance

Small $Q \Rightarrow$ Broad resonance

Q.2 (E) Calculate the resonance amplitude of the vibration of the system whose natural frequency is 1000 Hz, when it oscillates in the resistive medium for which the value of damping per unit mass is 0.008 rad/s under the action of an external periodic force/unit mass of amplitude 5 N/kg with a tunable frequency. (5M)

Soln: Natural frequency

$$f_0 = 1000 \text{ Hz}$$

$$\omega_0 = 2\pi f_0$$

$$= 2\pi \times 1000$$

$$\omega_0 = 2000\pi = 6283.19 \text{ rad/s}$$

Damping per unit mass

$$\beta = 0.008 \text{ rad/s}$$

Driving force/unit mass $\frac{F_0}{m} = 5 \text{ N/kg}$

For a damped forced oscillator

$$A = \frac{F_0/m}{\sqrt{(\omega_0^2 - \omega^2)^2 + (2\beta\omega)^2}}$$

At amplitude resonance,

$$\omega_r = \omega_0$$

The max. amplitude is approximately

$$A_{max} \approx \frac{F_0/m}{2\beta\omega_0}$$

$$A_{max} = \frac{5}{2 \times 0.008 \times 6283.19}$$

$$= \frac{5}{0.016 \times 6283.19}$$

$$A_{max} = 0.0497 \text{ m}$$

$A \approx 0.05$ m //

Q.3(a) Define Young's modulus (Y), Rigidity modulus(η) & Poissons ratio (σ). Derive the relation between them. (10M)

Soln: Young's modulus is defined as the ratio of longitudinal stress to longitudinal strain within the elastic limit

$$Y = \frac{\text{Longitudinal stress}}{\text{Longitudinal strain}}$$

$$= \frac{F/A}{\Delta L/L} \quad N m^{-2}$$

$F \rightarrow$ Applied force, $A \rightarrow$ cross sectional area, L - original length, $\Delta L \rightarrow$ change in length.

Rigidity modulus (η):-

It is the ratio of shear stress to shear strain

$$\eta = \frac{\text{shear stress}}{\text{shear strain}} = \frac{F/A}{\theta}$$

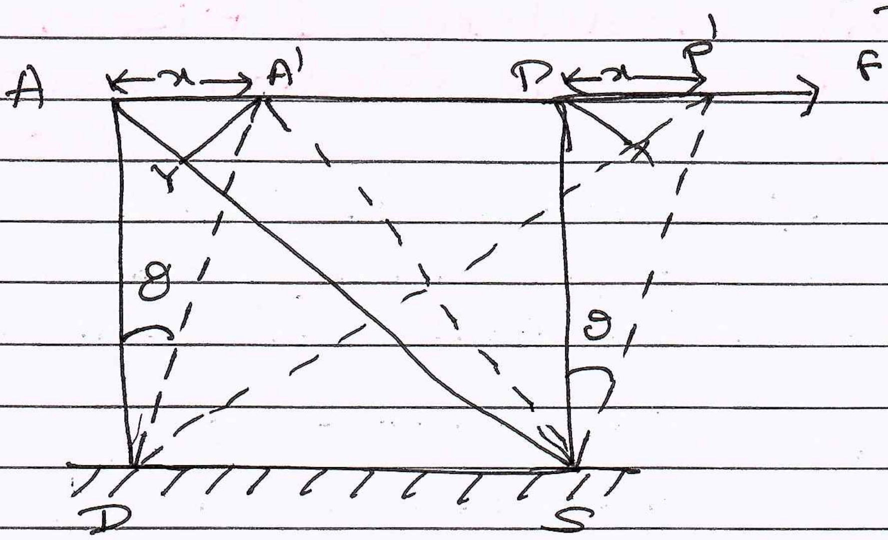
$\theta \rightarrow$ shear angle.

unit $\rightarrow N m^{-2}$

Poisson's ratio (σ):- It is defined as the ratio of lateral strain to longitudinal strain

$$\sigma = \frac{\text{lateral strain}}{\text{Longitudinal strain}} = \frac{\Delta d/d}{\Delta L/L}$$

Relation between Y, η & σ



Consider a cube of length L whose lower surface is fixed & a tangential force F is applied at the upper surface.

If 'α' is the longitudinal strain coefficient then extension produced for length DP due to tensile stress $= DP\,\alpha T$ --- (1).

If 'β' is the lateral strain coefficient, then the compression produced for length DP due to compressive ~~tensile~~ stress $= DP\,\beta T$ — (2).
where T is the applied stress.

$\therefore$ Total extension along

$$DP = DP\,T(\alpha+\beta)$$

The diagonal DP changes to DP' due to stress

$\therefore$ P'X is the total extension

$$\therefore P'X = DP\,T(\alpha+\beta)$$

But diagonal $DP = \sqrt{2}\,L$ & $P'X = \frac{x}{\sqrt{2}}$ —(3).

$\therefore$ Eqn (3) $\Rightarrow \frac{x}{\sqrt{2}} = \sqrt{2}\, L T (\alpha + \beta)$

$$\frac{x}{LT} = 2(\alpha+\beta)$$

Inversing

$$\frac{1}{2(\alpha+\beta)} = \frac{LT}{x}$$

$$\frac{T}{\left(\frac{x}{L}\right)} = \frac{T}{\theta} = \eta \quad \text{(Rigidity modulus)}$$

where $\frac{x}{L}$ = shear strain (θ).

$$\therefore \eta = \frac{1}{2(\alpha+\beta)} \quad \text{--- (4)}$$

Rearranging Eqn (4)

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

$$\eta = \frac{1/\alpha}{2(1+\sigma)} \quad \left(\because \frac{\beta}{\alpha} = \sigma\right) \quad \text{--- (5)}$$

Young's modulus $Y = \frac{\text{stress}}{\text{long. strain}} = \frac{1}{\frac{\text{long. strain}}{\text{stress}}}$

$$= \frac{1}{\alpha} \quad \text{--- (6)}$$

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

Putting Eqn (5) in 6

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

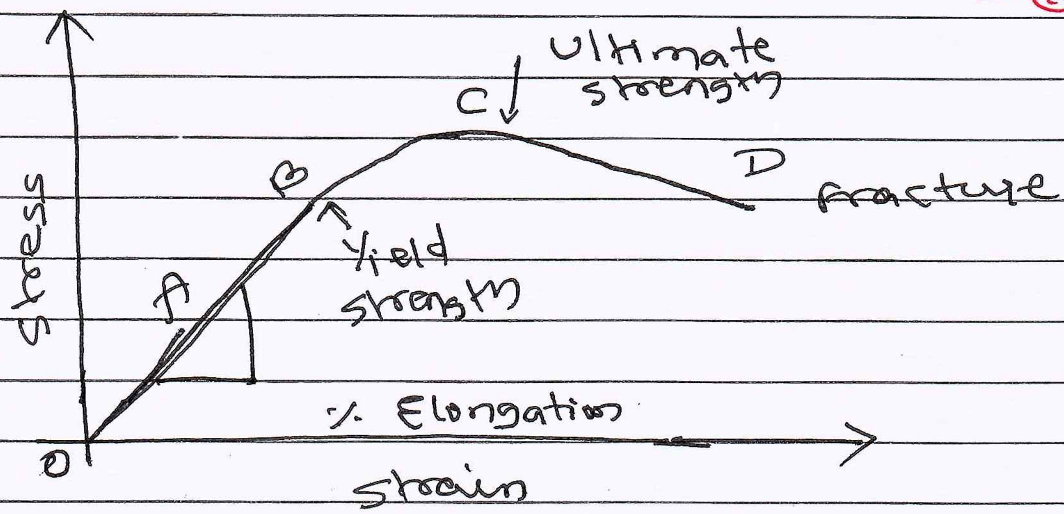
$$\boxed{Y = 2\eta(1+\sigma)} \quad \text{--- (7)}$$

This is the relation between

Y, η & σ

Q.3 (b) With a neat diagram, explain the stress-strain curve for elastic materials -6M.

Soln



The stress-strain curve describes how a material deforms under an applied load. It provides information about elasticity, plasticity, strength & ductility.

(1) OA → Proportional limit
- stress ∝ strain
- obey's Hooke's law

(2) AB → Elastic limit
- slight deviation from linearity
- still elastic
- If load is removed material returns to original shape
- B - represents Elastic limit

(3) BC → Yield point
- Sudden increase in strain with little or no increase in stress
- Material begins plastic deformation.

(4) CD → Plastic region
- stress increases with strain
- Material undergoes permanent deformation
- No longer follows Hooke's law

(5) DE → Fracture point
- Stress decreases due to necking
- Material finally breaks at E.

Q3(c) In stretching experiment, the extension produced in a wire for a load of 1.5 kg is 0.2×10^{-2} m. If length & radius of cross section of the wire are 2m and 0.013cm respectively, determine Young's modulus of the wire.

Soln Given Data

$m = 1.5$ kg

$\Delta L = 0.2\times10^{-2}$ m $= 2\times10^{-3}$ m

$L = 2$m

$r = 0.013\times10^{-2}$ m $= 1.3\times10^{-4}$ m

$g = 9.8\ ms^{-2}$

$$Y = \frac{\text{stress}}{\text{strain}} = \frac{F/A}{\Delta L/L}$$

$$Y = \frac{FL}{A\cdot\Delta L}$$

$F = mg$ & $A = \pi r^2$

$= 1.5\times9.8$ $\quad A = 3.142\times(1.3\times10^{-4})^2$

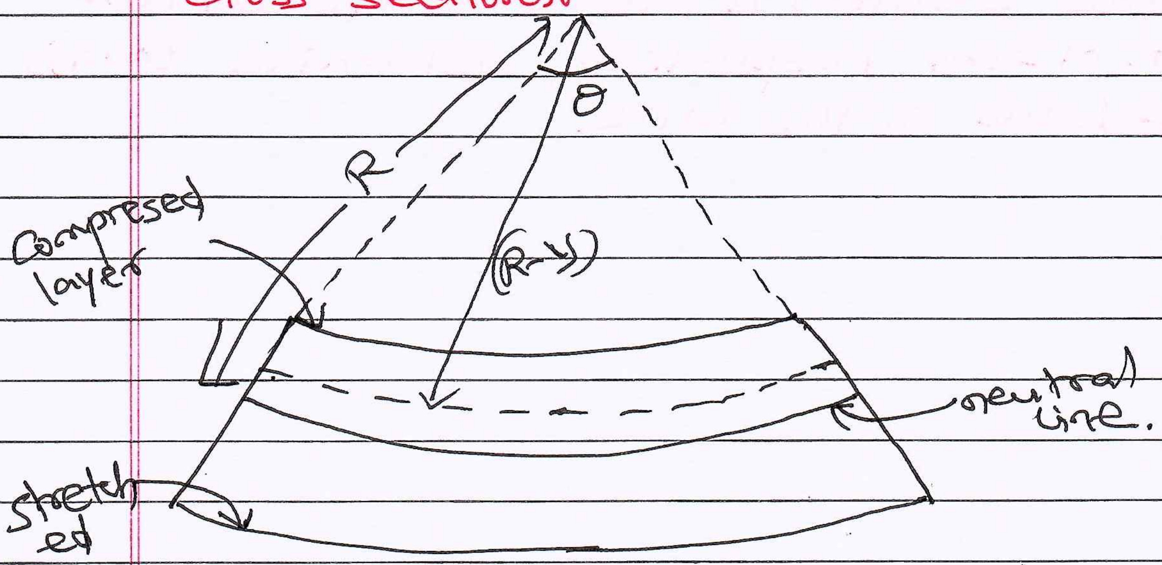
$= 14.7$ N $\quad = 5.31\times10^{-8}\ m^2$

$$Y = \frac{14.7 \times 2}{(5.31 \times 10^{-8}) \times (2 \times 10^{-3})}$$

$$= \frac{29.4}{1.062 \times 10^{-10}}$$

$$Y = 2.77 \times 10^{11} \ N m^{-2}$$

Q.4(a) Derive the expression for bending moment in terms of moment of inertia & hence arrive at the expression for bending moment for the ~~pt~~ beam with circular & rectangular cross sections.



Assumptions of simple bending Theory

1) Beam material is homogeneous & isotropic
2) Hooke's law is valid
3) Plane sections remain plane after bending
4) Radius of curvature is large compared to beam depth

- Upper layers → Compression
- Lower layer → Tension
- Neutral surface → No stress

SCORE

· Radius of curvature = R

Consider a beam bent into an arc of radius R
Let y = distance from neutral axis.

Original length of neutral layer

$$L = R\theta$$

Length of a layer at distance y

$$L_y = (R+y)\theta$$

Strain in the layer

$$\text{strain} = \frac{L_y - L}{L}$$

$$\text{strain} = \frac{(R+y)\theta - R\theta}{R\theta}$$

$$= \frac{y}{R}$$

Stress in the layer

$$\text{stress} = Y \times \text{strain}$$

$$\sigma = Y \frac{y}{R}$$

Force on an elemental area dA

$$dF = \sigma\, dA$$

$$= \frac{Y y\, dA}{R}$$

Bending moment

Moment of this force about neutral axis

$$dM = y\, dF$$

$$dM = y\left(\frac{Y y\, dA}{R}\right)$$

$$dM = \frac{Y}{R} y^2 dA$$

$$M = \frac{Y}{R} \int y^2 dA$$

But

$$\int y^2 dA = I$$

wher $I \Rightarrow$ moment of inertia of cross section

Find Bending Equation

$$M = \frac{YI}{R}$$

$$\frac{M}{I} = \frac{Y}{R}$$

Bending moment of different cross section

(1) Rectangular Section

Bredth = b, Depth = d

Moment of Inertia

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

$$\therefore M = \frac{Y}{R} \times \frac{bd^3}{12}$$

$$= \frac{Y\, bd^3}{12R}$$

(2) Circular cross section

Radius = r

$$I = \frac{\pi r^4}{4}$$

$$\therefore M = \frac{Y}{R} \times \frac{\pi r^4}{4}$$

$$\therefore M = \frac{Y \pi r^4}{4R}$$

Q.4(b) Explain different mechanisms of failure of engineering materials (6M)

Soln:- Failure of engineering materials occurs when a component loses its ability to perform its intended function due to excessive stress, environmental effects or time-dependent degradation.

1. Fracture failure

Fracture is the separation of a material into two or more parts under stress

(a) Ductile fracture

- Large plastic deformation
- Necking observed
- Rough, fibrous surface
- High energy absorption

Ex:- Mild steel.

(b) Brittle fracture

- Sudden failure without plastic deformation
- Flat & shiny fracture surface
- Low energy absorption

Ex: Glass, cast iron

2. Fatigue failure.

- Occurs under cyclic or fluctuating stresses
- Failure happens even below yield

• Crack initiates at stress concentration pt

3. Creep failure
   • Time-dependent permanent deformation under constant stress
   • occurs at high temp.
   Ex. Turbine blades, boiler tubes

4. Corrosion failure
   • Chemical or electrochemical reaction with environment
   • Leads to material weakening
   Ex. Rusting of iron.

Q4 (c) Calculate the force required to produce an extension of 1mm in steel wire of length 2m and diameter 1mm. Given $Y = 2\times10^{11}\ N m^{-2}$.

Soln:- Extension

$$\Delta L = 1mm = 1\times10^{-3} m$$

length of wire

$$L = 2m$$

diameter of wire

$$d = 1\times10^{-3} m$$

radius

$$r = \frac{d}{2} = 0.5\times10^{-3} m$$

$$= 5\times10^{-4} m$$

$$Y = 2\times10^{11}\ N m^{-2}$$

$$Y = \frac{FL}{A\Delta L}$$

$$F = \frac{YA\Delta L}{L}$$

$$A = \pi r^2$$
$$= \pi (5\times10^{-4})^2$$
$$= 7.854 \times 10^{-7}\ m^2$$

$$\therefore F = \frac{(2\times10^{11})(7.854\times10^{-7})(1\times10^{-3})}{2}$$

$$F = 78.54\ N.$$

Module - 3

Q5 (a) Derive the expression for thermo emf in terms of temperatures of hot & cold junctions. — (8 M)

Soln: When two dissimilar metals form a closed circuit & their junctions are maintained at different tempr, an emf is produced. This is called thermo emf.

Let

$T_h \Rightarrow$ tempr of hot junction

$T_c \rightarrow$ tempr of cold junction

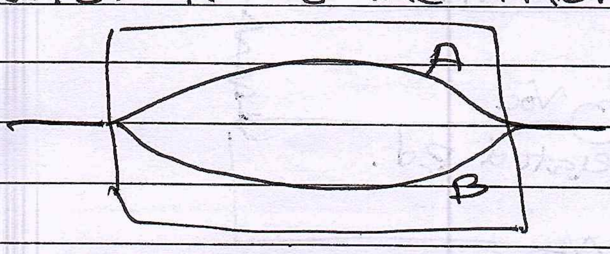
Thermoelectric power (P) is defined as

$$P = \frac{dE}{dT}$$

Exptly, thermo electric power varies linearly with temperature

$$P = a + bT$$

where a & b are thermoelectric constants of the thermo couple.



Since

$$\frac{dE}{dT} = a + bT$$

$$dE = (a+bT)\,dT$$

Integrating between T_c & T_h

$$E = \int_{T_c}^{T_h} (a+bT)\,dT$$

$$E = \left[aT + \frac{bT^2}{2}\right]_{T_c}^{T_h}$$

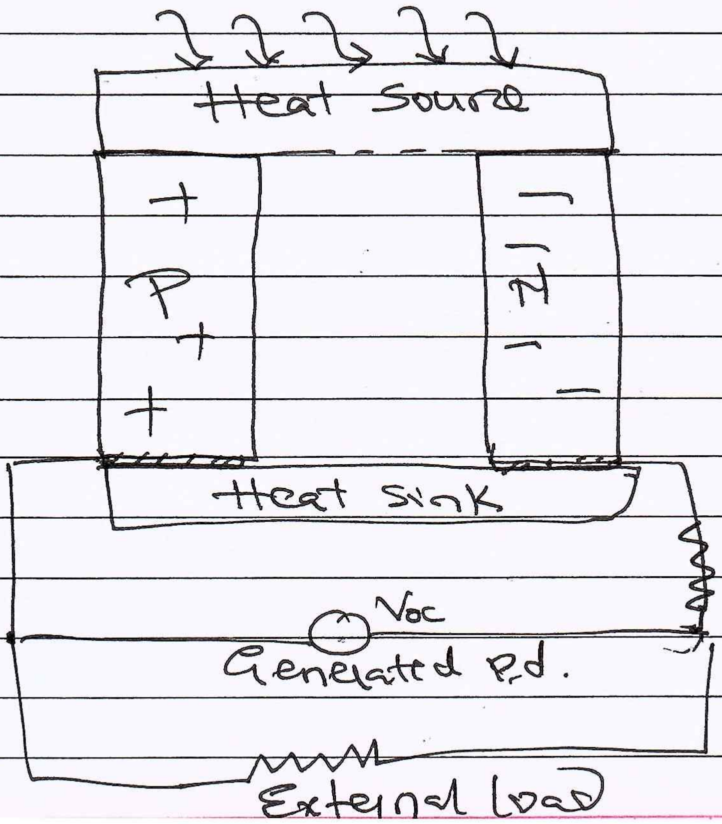
$$E = \left(aT_h + \frac{bT_h^2}{2}\right) - \left(aT_c + \frac{bT_c^2}{2}\right)$$

$$E = a(T_h - T_c) + \frac{b}{2}(T_h^2 - T_c^2)$$

This is the required expression for thermo-emf in terms of hot & cold junction.

Q.5(b) Describe the construction & working of thermoelectric generator —(7m)

Soln:-



Principle :- Thermoelectric generators are the devices that convert the tempr difference that is generated between the two sections in to the electrical form & energy (DC voltage). When a load is properly connected electrical current flows

Main parts. - Construction

- P-type semiconductor
- N-type "
- Metallic connectors
- Hot plate (Heat source)
- Cold plate (Heat sink)
- External load.

Description :- A number of P-type & N-type semiconductor pellets are connected electrically in series & thermally in parallel.

Working :-

When the hot sides is maintained at tempr T_h & cold side at T_c

$$\Delta T = T_h - T_c$$

Due to temperature difference

- Charge carriers diffuse from hot side to cold side
- In P-type holes move
- In N-type electrons move.

This creates potential difference

$$E = \alpha \Delta T$$

$\alpha \rightarrow$ Seebeck coefficient

Advantages :- No moving parts, Silent operation, Reliable, Long life, Eco friendly

Q.5 (c) The emf of a lead-Iron thermocouple, one junction of which is at 0°c is given by $E = 1784T - 2.4T^2$ (μ volts) T being tempr in °C. Find the neutral tempr & Peltier coefficient. — (5M)

Soln. Thermo-emf of lead-iron thermocouple

$$E = 1784T - 2.4T^2$$

where

E is in μV

T is tempr in °c

Cold junction at 0°c

Neutral tempr is the tempr at which thermo-emf is maximum

$$\frac{dE}{dT} = 0$$

$$\frac{dE}{dT} = 1784 - 4.8T$$

$$1784 - 4.8T = 0$$

$$4.8T = 1784$$

$$T_n = \frac{1784}{4.8}$$

$$T_n = 371.67°C$$

Peltier coefficient

$$\Pi = T\frac{dE}{dT}$$

At cold junction $T = 0°C$

$$T = 273K$$

At $T = 0°C$

$$\frac{dE}{dT} = 1784 - 4.8(0)$$

$$= 1784 \ \mu V/°C$$

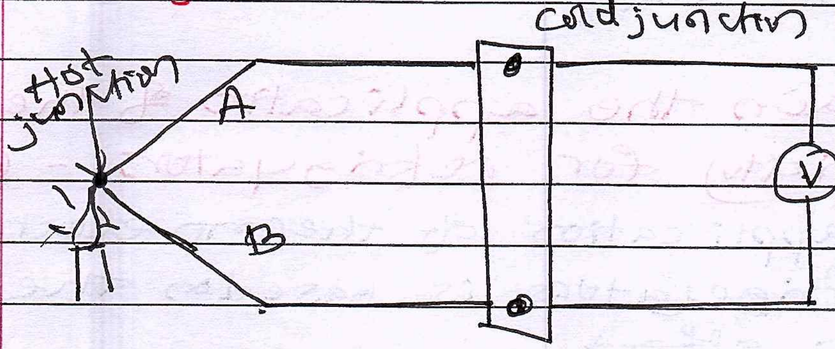
SCORE

$1784\,\mu V = 1784 \times 10^{-6}\,V$

$\pi = 273 \times 1784 \times 10^{-6}$
$= 0.487\,V.$

Q.6(a) Describe the construction & working of a thermocouple. Mention their advan-
-tages. (9M)

Soln,



A thermocouple consists of
(1) Two dissimilar metal wires (A & B)
(2) Two junctions
· Hot junction
· Cold junction.

· The two metals are joined at one end to form the hot junction.
· The other side are connected to measuring device forming the cold junction

Working:-

when two junctions are maintained at different tempr

$T_h \neq T_c$

An emf is generated in the circuit

Reason:-

· Charge carriers move from hot region to cold region.

- Due to difference in electron density & energy levels in two metals.
- This produces thermo emf.

Advantages

(1) simple construction (2) low cost
(3) wide temp range (4) Rugged durable
(5) fast response.

Q.6 (b) Explain the application of thermo-electricity for refrigerators. - 6M

Soln: The application of thermo electricity in refrigerators is based on the Peltier effect

Principle: The Peltier effect occurs when an electric current is passed through a junction of two dissimilar conductors (usually n-type & p-type semiconductors). Depending on the direction of the current, heat is either absorbed or released at the junction.

Advantages: (1) No moving parts.
(2) Compact & light weight
(3) Eco friendly
(4) Precise temp control

Disadvantages: (1) Lower efficiency
(2) Limited cooling power.

Q.6 (c) EMF of a thermocouple is 1200 μV, when working between 0°C & 100°C. If its neutral temp is 300°C, find the value of coefficients a & b.

SCORE

Soln EMF between 0°C & 100°C

$E = 1200\ \mu V$

Neutral tempr $T_n = 300°C$

$$E = aT + \frac{b}{2}T^2$$

$$\frac{dE}{dT} = a + bT$$

at $T = T_n$

$a + bT_n = 0$

$a + 300b = 0$

$a = -300b$

$$E = a(100) + \frac{b}{2}(100)^2$$

$1200 = 100a + \frac{b}{2}\,10000$

$1200 = 100a + 5000b$

$(\because a = -300b)$

$1200 = 100(-300b) + 5000b$

$$b = \frac{-1200}{25000}$$

$b = -0.048\ \mu V/°C^2$

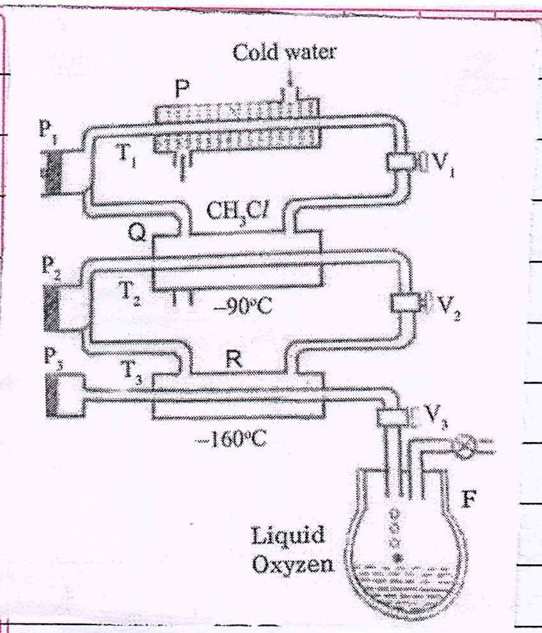
$a = -300b$

$a = -300(-0.048)$

$a = 14.4\ \mu V/°C$ //.

Q.7(a) Explain the liquification of oxygen by cascade process - (7M)

Soln:



The cascade process is based on the principle that a gas can be liquefied by successive cooling using other gases having progressively lower boiling points.

Since oxygen has a very low critical tempr (-118°C), it must be cooled below this tempr before it can be liquefied by pressure.

Construction: The system consists of 3 stages

1. Sulphur dioxide (SO_2) circuit.
2. Carbon dioxide (CO_2) circuit
3. Oxygen circuit

Each gas is compressed, cooled & expanded in sequence.

Working of Cascade Process:

Stage 1:- Sulphur Dioxide (SO_2)

- SO_2 is compressed & cooled with water.
- On expansion, it produces cooling (-10°C)
- This cools the CO_2 gas in the next stage

Stage 2:- Carbon Dioxide (CO_2)

- CO_2 is compressed & precooled by SO_2
- On expansion, it produces much lower tempr (-78°C)
- This cools oxygen gas in the third stage

Stage 3:- Oxygen (O_2)

- Oxygen is compressed & precooled by CO_2.
- Since its tempr is now below its critical tempr ($-118°C$) further expansion leads to liquefaction.

Thus liquid oxygen is obtained.

Q-7(b) Deduce the equation

$$\Delta T = \Delta P \frac{1}{C_p}\left[\frac{2a}{RT} - b\right]$$ & hence discuss three cases. (9m)

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

Theory:- when a gas expands adiabatically through a porous plug

- No heat exchange $\rightarrow q = 0$
- No external work
- Enthalpy remains constant $\rightarrow H = const$

The tempr change with pressure at constant enthalpy is called Joule-Thomson coefficient.

$$\mu = \left(\frac{\partial T}{\partial P}\right)_H$$

For small changes

$$\Delta T = \mu \Delta P$$

A thermodynamic identity gives

$$\mu = \frac{1}{C_p}\left[T\left(\frac{\partial V}{\partial T}\right)_P - V\right]$$

For one mole of a vander walls gas

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

For low pressure, we approximate

$$V \simeq \frac{RT}{P} + b - \frac{a}{RT}$$

$$\left(\frac{\partial V}{\partial T}\right)_P = \frac{R}{P} + \frac{a}{RT^2}$$

$$\mu = \frac{1}{C_p}\left[\frac{RT}{P} + \frac{a}{RT} - \frac{RT}{P} - b + \frac{a}{RT}\right]$$

$$\mu = \frac{1}{C_p}\left[\frac{2a}{RT} - b\right]$$

for small pressure changes

$$\Delta T = \Delta p \frac{1}{C_p}\left[\frac{2a}{RT} - b\right]$$

~~Q7(c) Mention the properties & uses of Liquid helium. --(4m)~~

Discussion of 3 cases

(i) $\frac{2a}{RT} > b$

$\mu > 0$

$\Delta T > 0$ when $\Delta P < 0$

So the tempr decreases

- Gas cools on expansion
- Intermolecular attraction dominates
- Occurs at low tempr.

Case (2) $\frac{2a}{RT} < b$

$\mu < 0$,

$\Delta T < 0$ when $\Delta P < 0$

So tempr increases

· Gas warms on expansion

· Molecular size effect dominates

Case (3) $\frac{2a}{RT} = b$

$\mu = 0$

$\Delta T = 0$

No tempr change

This defines the inversion tempr.

Q.7 (c) Mention the properties & uses of liquid Helium. — (4M)

Soln: (1) Properties

(1) Extremely low boiling point

(2) very low density & viscosity

(3) very high thermal conductivity

(4) chemically inert & non-flammable

Uses

(1) Cryogenics

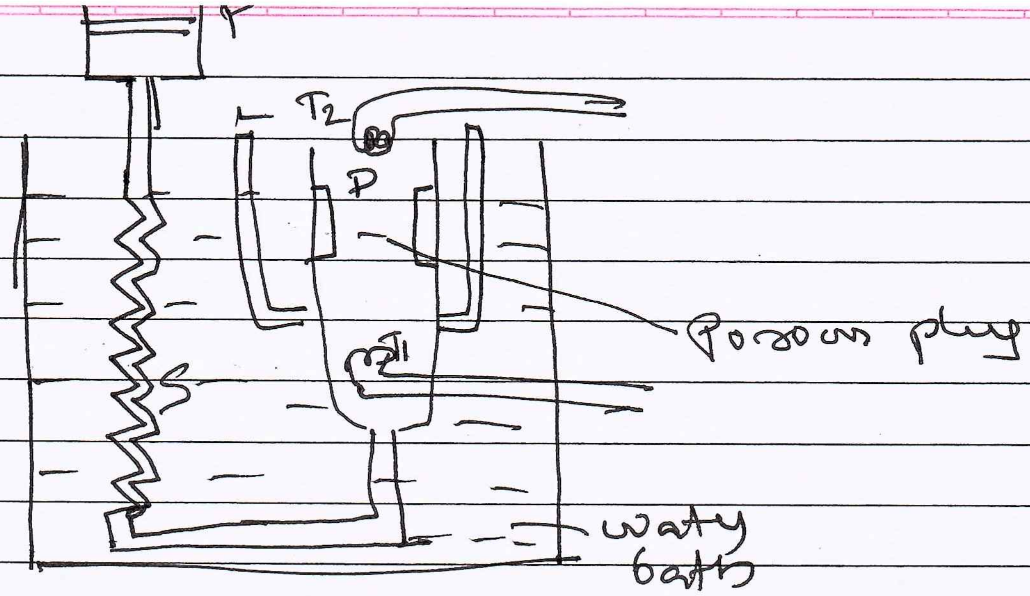
(2) Superconducting magnets cooling

(3) space research & infrared detectors

(4) Low-tempr physics

Q.8 (a) Describe the experimental arrangement & working of porous plug experiment. What are the conclusions drawn from it — 9M.

Soln



Experimental arrangement:-

- A gas at high pressure is allowed to pass through a prous plug fitted inside a thermally insulated tube.
- Pressure gauges measure high pressure (P_1) & Low pressure (P_2) on either side of the plug
- thermometers are placed near the plug to measure tempr T_1 & T_2 (after expansion)
- The system is well insulated so that no heat exchange occurs

Working:-

- Gas expands from high pressure to low pressure through the porous plug
- The process is called throttling.
- No heat exchange & no external work is done.
- Hence the process is isenthalpic

$$H_1 = H_2$$

- Joule coefficient is

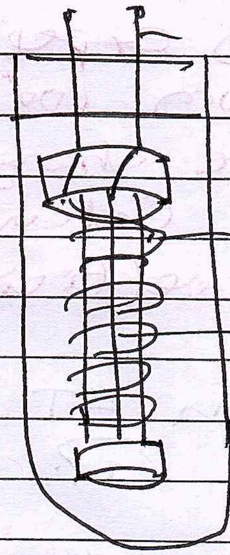
$$\mu = \left(\frac{\partial T}{\partial P}\right)_H$$

Conclusion:

1. Real gases show tempr change on expansion.
2. Ideal gas shows no tempr change.
3. There exists an inversion tempr
   Below it – gas cools on expansion
   Above it → gas warms on expansion.

Q8(b) Explain the construction & working of platinum resistance thermometer – (7m)

Soln



Construction:-

1. It consists of a fine platinum wire wound in the form of a coil.
2. The platinum coil is wound on mica
3. The coil is enclosed inside a protective glass.
4. Two or four connecting leads are attached to measure resistance.
5. The thermometer is connected to a Wheatstone bridge to measure resistance accurately.

Working:

1. It works on the principle that electrical resistance of platinum increases with temperature.
2. The resistance at a tempr T is given by

$$R_T = R_0(1+\alpha T)$$

3. As tempr increases, resistance increases
4. The change in resistance is measured using a wheatstone bridge

Q.8 (c) In a Joule Thomson experiment, tempr changes from 100°C to 150°C for pressure changes of 20MPa to 170 MPa. Calculate Joule-Thomson coefficient.

Soln

$$\mu = \left(\frac{\partial T}{\partial P}\right)_H \quad \text{or} \quad \frac{\Delta T}{\Delta P}$$

tempr changes from 100°C to 150°C

$$\Delta T = 150 - 100$$
$$= 50°C$$

Pressure changes from 20MPa to 170 MPa

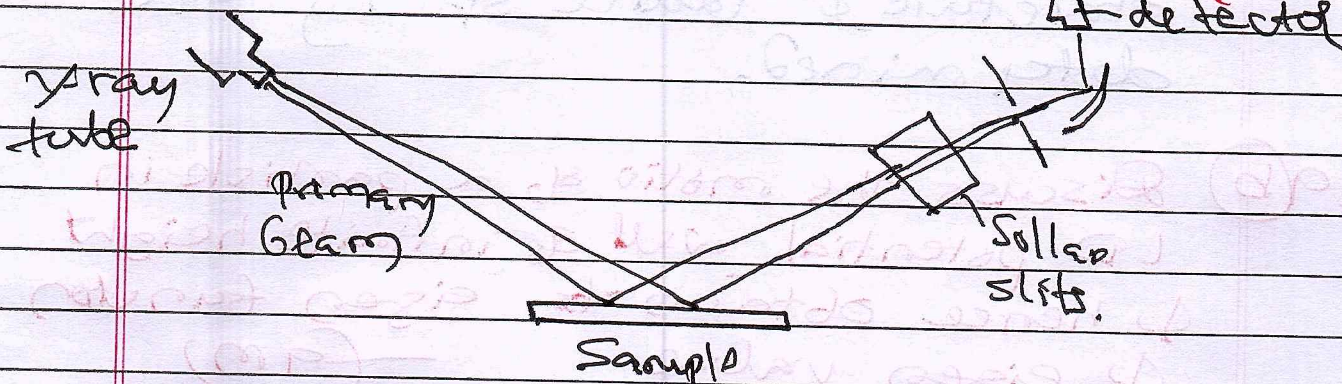
$$\Delta P = 170 - 20$$
$$= 150 \text{ MPa}$$

$$\mu = \frac{50}{150} = \frac{1}{3} = 0.333 \text{ K/MPa}$$

$$\therefore \mu = 0.333 \text{ K MPa}^{-1}$$

SCORE

Q 9(a) Describe the construction and working of X-ray diffractometer — (7M)



Construction:

An X-ray diffractometer consists of
1. X-ray tube
2. Collimator / slits
3. Sample holder
4. Goniometer (Rotates the sample & detector to vary angle θ)
5. Detector
6. Computer.

Working:

- X-ray falls on the crystalline sample
- At certain angles X-rays are diffracted by crystal planes
- Diffraction occurs according to Bragg's law

$$n\lambda = 2d \sin\theta$$

where λ – wavelength
d – dist. between crystal planes
θ – angle of diffraction

- The detector measures intensity of diffracted rays at different angles

· A graph of intensity vs 2θ is obtained.

· From peak positions, crystal structure & lattice spacing are determined.

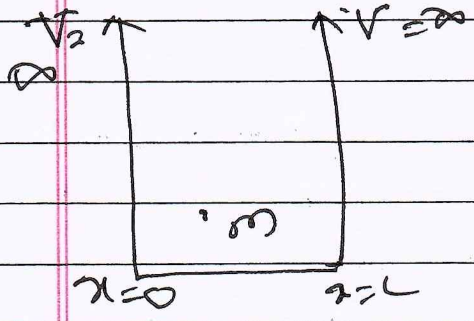
Q.9(b) Discuss the motion of a particle in 1D potential well of infinite height & hence obtain its eigen function & eigen value — (9M)

Soln. Consider a particle of mass 'm' confined in a one-Dimensional box of length L

$$V(x) = \begin{cases} 0 & 0 < x < L \\ \infty & x \leq 0 \ \& \ x \geq L \end{cases}$$

Since the potential is infinite outside the box, the particle cannot exist outside. Thus, the wave function must satisfy

$$\psi(0) = 0 \qquad \psi(L) = 0$$



Inside the well (V=0), time-independent Schrodinger Eqn is

$$-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} = E\psi$$

Rewriting

$$\frac{d^2\psi}{dx^2} + k^2\psi = 0$$

where

$$k^2 = \frac{2mE}{\hbar^2}$$

General soln.

$$\psi(x) = A\sin kx + B\cos kx$$

Applying boundary condn.

At $x=0$

$$\psi = 0 \Rightarrow B = 0$$

So

$$\psi(x) = A\sin kx$$

At $x=L$

$$\psi(L) = 0 \Rightarrow \sin(kL) = 0$$

$$kL = n\pi$$

$$k = \frac{n\pi}{L}, \quad n = 1, 2, 3 \ldots$$

Since

$$k^2 = \frac{2mE}{\hbar^2}$$

$$E_n = \frac{n^2\pi^2\hbar^2}{2mL^2}$$

$$E_n = \frac{n^2h^2}{8mL^2}$$

Thus energy is quantized

Normalization gives

$$\psi_n(x) = \sqrt{\frac{2}{L}}\sin\left(\frac{n\pi x}{L}\right) //$$

Q.9(b) Determine the crystal size, when the peak width is 0.5 and peak position 30 for a cubic crystal. Given that λ of x-rays is $100 A^0$ & Scherrer' constant $K = 0.92$

Sol:

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

peak width $\beta = 0.5^\circ$

peak position $2\theta = 30^\circ$; $\theta = 15^\circ$

$K = 0.92$

$\lambda = 100\ \text{Å}$

$$\beta = 0.5^\circ \times \frac{\pi}{180}$$

$$= 0.008727\ \text{rad}$$

$$D = \frac{0.92 \times 100 \times 10^{-10}}{0.00872 \times \cos 15^\circ}$$

$$= 1091.4\ \text{Å}$$

$D \approx 1.09\ \mu m$

Q. 10 (a). Explain quantum confinement in 0, 1, 2 and 3 dimensions & give graphical representation of density of states — (8M).

Sol: Quantum confinement occurs when the size of a material becomes comparable to the de Broglie wavelength of electrons.

As dimensions reduce, energy levels become discrete instead of continuous

i) 3D system

- Electrons are free to move in all 3 directions (x, y, z)

SCORE

- energy levels are almost continuous.

Density of states

$$g(E) \propto \sqrt{E}$$

2D system :- (Quantum well)

- Motion confined in 1 Direction, ~~only~~ free in 2-direction
- Energy is quantized in one direction.

$$g(E) = \text{constant}$$

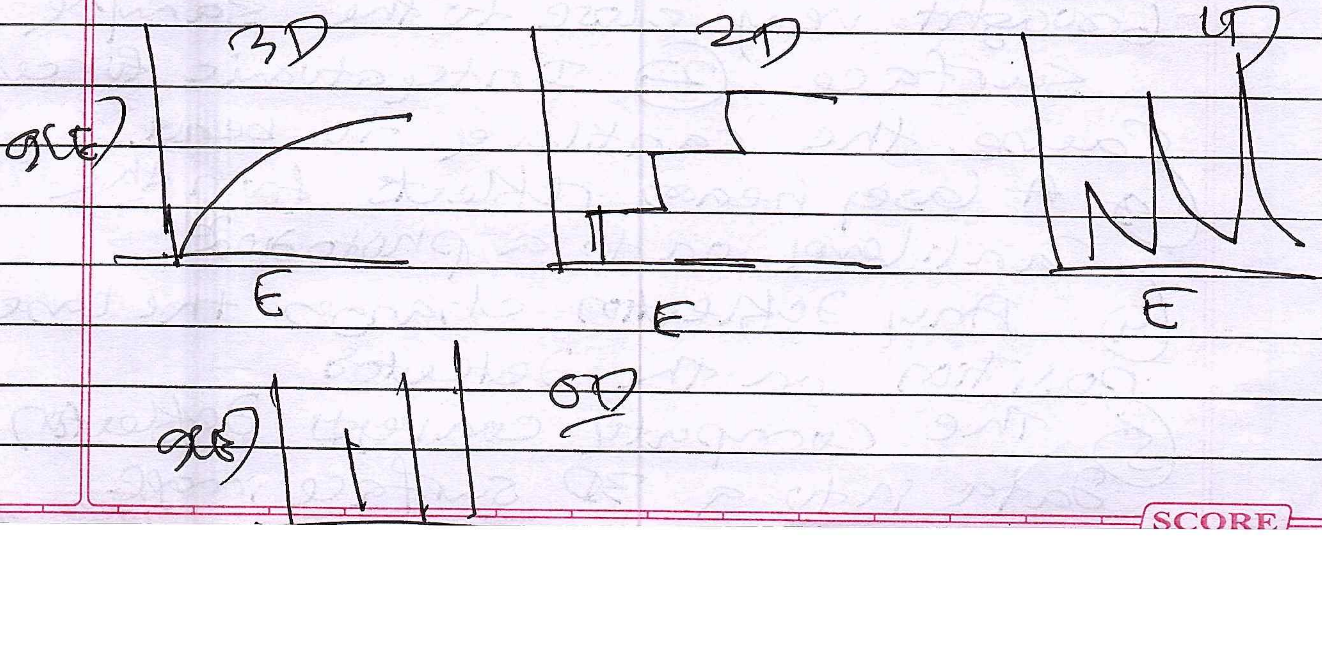
1D system (Quantum wire)

- Motion confined in two direction free in one
- Energy is quantized

$$g(E) \propto \frac{1}{\sqrt{E}}$$

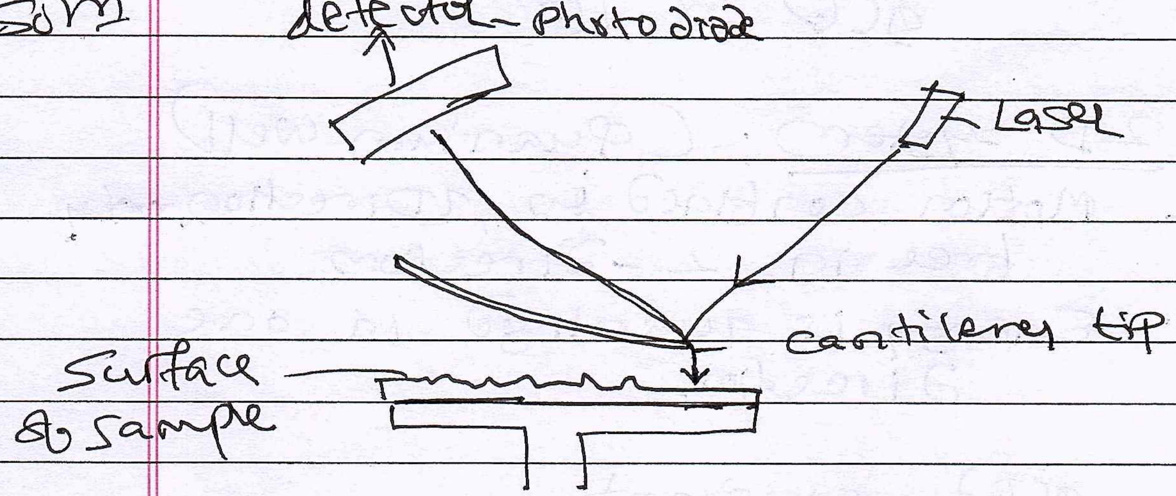
0D system (Quantum dot)

- Motion is confined in all three direction
- Energy levels are fully discrete



Q10(b) Describe the principle, construction & working of an atomic force microscope with neat diagram - (8 m)

Soln



Principle:- AFM works on the principle that when a sharp tip is brought very close to a sample surface, inter-atomic forces act between the tip & the surface.

These forces cause deflection of a cantilever, & the deflection is measured to obtain surface information at 'nm' scale resolution.

Construction:- (1) sharp tip (2) Flexible cantilever (3) Laser source (4) Photodiode detector

Working:- (1) The sharp tip is brought very close to the sample surface (2) Interatomic forces cause the cantilever to bend.
(3) A laser beam reflects from the cantilever onto a photodiode.
(4) Any deflection changes the laser position on the detector
(5) The computer converts deflection data into a 3D surface image

Q.10 (c) A beam of monochromatic x-ray is diffracted by a cubic crystal with glancing angle of 12° for first order. Calculate wavelength of x-rays, if the interplanar spacing of the crystal is 2.82 Å. — 4M

Soln:- using Bragg's law

$$n\lambda = 2d\sin\theta$$

$n = 1$, first order

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

$\theta = 12°$

$$\lambda = 2d\sin\theta$$

$$= 2 \times (2.82 \times 10^{-10}) \times \sin 12$$

$$\lambda = 1.17 \times 10^{-10} \text{ m.}$$

$$\boxed{\lambda = 1.17 \text{ Å}}$$

The solution is prepared by

(Dr. S. M. Gabgali)

24/02/28

(Dr. S. S. Kulkarni) HOD, BSH

(Dean Academic)