GUJARAT TECHNOLOGICAL UNIVERSITY
BE- SEMESTER–1 PAPER SOLUTION – WINTER 2024

Subject Name & Code:
Physics- BE01000021

Marks

Q.1 **(a)** Define: (1) Stress (2) Strain and (3) Young's modulus. **03**

Answer:

1. **Stress:**
   Stress is the **internal restoring force per unit area** that develops in a body when it is deformed under an external force.

$$\text{Stress} = \frac{\text{Force (F)}}{\text{Area (A)}} \quad \left[\text{Unit: N/m}^2 \text{ or Pascal (Pa)}\right]$$

2. **Strain:**
   Strain is the **ratio of change in dimension to the original dimension** when a body is deformed. It is a **dimensionless quantity**.

$$\text{Strain} = \frac{\text{Change in length } (\Delta\text{L})}{\text{Original length (L)}}$$

3. **Young's Modulus (Y):**
   It is the ratio of **longitudinal stress** to the corresponding **longitudinal strain**, within the elastic limit.

$$Y = \frac{\text{Stress}}{\text{Strain}} = \frac{FL}{A\Delta L} \quad \left[\text{Unit: N/m}^2\right]$$

(b) The critical temperature for a metal with isotopic mass 199.5 is 4.185 K. Calculate the isotopic mass if the critical temperature falls to 4.133 K. **04**

Answer:

Given:

- $T_1 = 4.185\,K,\ M_1 = 199.5$
- $T_2 = 4.133\,K,\ M_2 = ?$

Relation between critical temperature and isotopic mass:

$$T_c \propto \frac{1}{\sqrt{M}} \Rightarrow \frac{T_1}{T_2} = \sqrt{\frac{M_2}{M_1}}$$

Squaring both sides:

$$\left(\frac{T_1}{T_2}\right)^2 = \frac{M_2}{M_1} \Rightarrow M_2 = M_1\left(\frac{T_1}{T_2}\right)^2$$

Substitute values:

$$M_2 = 199.5\left(\frac{4.185}{4.133}\right)^2 = 199.5 \times (1.01258)^2 = 199.5 \times 1.0253 = \boxed{204.55}$$

(c) What is Cantilever? Obtain the expression for depression at free end of thin beam clamped horizontally at one end and loaded at other end. **07**

Answer:

Cantilever and Expression for Depression

A **cantilever** is a beam fixed at one end and free at the other.

When a load WWW is applied at the **free end**, it produces a **bending** in the beam. The **depression (deflection)** at the free end depends on material properties and geometry.

Assumptions:

- Beam is uniform and of length L
- Young's Modulus: Y
- Moment of Inertia: I
- Load at free end: W

Derivation:

Let us consider a small element of length dx at a distance x from the fixed end.

The **bending moment** at point xxx is:

M(x)=−W(L−x)

Using the bending equation:

$$\frac{1}{R} = \frac{M}{YI}$$

But,

$$\frac{1}{R} \approx \frac{d^2y}{dx^2} \Rightarrow \frac{d^2y}{dx^2} = -\frac{W(L-x)}{YI}$$

Integrate:

$$\frac{dy}{dx} = -\frac{W}{YI}\int (L-x)dx = -\frac{W}{YI}\left[Lx - \frac{x^2}{2}\right] + C_1$$

Apply boundary condition:

At $x = 0$, $\frac{dy}{dx} = 0$

$$0 = -\frac{W}{YI}[0] + C_1 \Rightarrow C_1 = 0$$

Now integrate again:

$$y = -\frac{W}{YI}\int \left[Lx - \frac{x^2}{2}\right] dx = -\frac{W}{YI}\left[\frac{Lx^2}{2} - \frac{x^3}{6}\right] + C_2$$

Apply boundary condition:

At x=0x = 0x=0, y=0⇒C2=0

So the equation of deflection:

$$y(x) = -\frac{W}{YI}\left[\frac{Lx^2}{2} - \frac{x^3}{6}\right]$$

At the free end, $x = L$, so:

$$y = -\frac{W}{YI}\left[\frac{L\cdot L^2}{2} - \frac{L^3}{6}\right] = -\frac{W}{YI}\left(\frac{L^3}{2} - \frac{L^3}{6}\right) = -\frac{WL^3}{3YI}$$

Final Answer:

$$\boxed{y = \frac{WL^3}{3YI}} \quad \text{(Depression at the free end)}$$

Q.2 **(a)** Define:(1) Reverberation (2) Nano-materials (3) Absorption co-efficient **03**

Answer:

1. **Reverberation:**
   Reverberation is the persistence of sound in a closed space after the source has stopped, due to multiple reflections from surfaces like walls, ceilings, etc. It is measured in seconds.
2. **Nano-materials:**
   Materials having at least one dimension in the nanometer range (1 to 100 nm) are called nano-materials. They exhibit unique physical and chemical properties due to their high surface area to volume ratio.
3. **Absorption Coefficient (α):**
   It is the fraction of sound energy absorbed by a surface compared to the incident energy. It ranges from 0 (total reflection) to 1 (total absorption).

(b) The volume of a hall is 475 m^3. The area of wall is 200 m^2, area of floor and ceiling each is 100 m^2. If the absorption co-efficient of wall, ceiling and floor are 0.025, 0.02 and 0.55, respectively. Calculate the reverberation time for the hall. **04**

Answer:

Given:

- Volume of hall V=475 m^3
- Surface areas:
  - Walls Aw=200 m^2,
  - Floor Af=100 m^2
  - Ceiling Ac=100 m^2
- Absorption coefficients:
  - Wall αw=0.025,
  - Floor αf=0.55,
  - Ceiling αc=0.02

Reverberation time formula (Sabine's formula):

$$T = \frac{0.161 \times V}{A} \quad \text{where } A = \sum(\alpha_i \cdot A_i)$$

Calculation:

$$A = (0.025 \times 200) + (0.55 \times 100) + (0.02 \times 100) = 5 + 55 + 2 = 62\,m^2$$

$$T = \frac{0.161 \times 475}{62} = \frac{76.475}{62} = \boxed{1.233\,\text{seconds}}$$

(c) Describe production of ultrasonic waves by Piezo-electric method. Give its advantages and limitations. **07**

Answer:

Production of Ultrasonic Waves by Piezoelectric Method
Principle:
When mechanical stress is applied to certain crystals (like quartz), they produce an electric voltage. Conversely, applying an electric field causes mechanical deformation. This is called the **piezoelectric effect**.
Construction:

- Quartz crystal is cut in a specific direction and placed between two metal plates.

- These plates are connected to a high-frequency oscillator.

Working:

- An alternating voltage is applied to the plates.
- The crystal vibrates mechanically at the frequency of the applied voltage.
- If the frequency matches the **natural frequency** of the crystal, resonance occurs.
- This generates **ultrasonic waves** (typically > 20 kHz).

Advantages:

- High efficiency and output.
- Frequency remains stable.
- Compact and simple construction.

Limitations:

- Crystals are fragile.
- Output power is limited.
- Not suitable for low-frequency generation.

OR

(c) What is simple harmonic motion? Obtain equation for kinetic energy and potential energy of simple harmonic oscillator. Show that at any time the sum of kinetic energy and potential energy remains constant. **07**

Answer:

Simple Harmonic Motion (SHM)
Definition:
A body performs SHM when it moves to and fro about a mean position under a restoring force proportional to displacement and directed toward the mean position.

$$F = -kx \quad \Rightarrow \quad a = -\omega^2 x$$

Kinetic Energy (K.E):
Let displacement at time t be:

$$x = A\sin\omega t \quad \Rightarrow \quad v = \frac{dx}{dt} = A\omega\cos\omega t$$

$$K.E = \frac{1}{2}mv^2 = \frac{1}{2}mA^2\omega^2\cos^2\omega t$$

Potential Energy (P.E):

$$P.E = \frac{1}{2}kx^2 = \frac{1}{2}m\omega^2x^2 = \frac{1}{2}m\omega^2A^2\sin^2\omega t$$

Total Energy (E):

$$E = K.E + P.E = \frac{1}{2}mA^2\omega^2\cos^2\omega t + \frac{1}{2}mA^2\omega^2\sin^2\omega t$$

$$E = \frac{1}{2}mA^2\omega^2(\cos^2\omega t + \sin^2\omega t) = \frac{1}{2}mA^2\omega^2$$

Thus, **total energy remains constant** throughout the motion.

Q.3 (a) An ultrasonic source of 0.09 MHz sends down a Pulse towards the seabed which returns after 0.55 sec. The velocity of sound in water is 1800 m/s. Calculate the depth of the sea and wavelength of pulse. **03**

Answer:

Given:

- Frequency f=0.09 MHz=90,000 Hz
- Time t=0.55 sec
- Speed of sound in water v=1800 m/s

Depth Calculation:
Sound travels **to the seabed and back**, so:

$$\text{Total distance} = v \times t = 1800 \times 0.55 = 990\,\text{m} \Rightarrow \text{Depth} = \frac{990}{2} = \boxed{495\,\text{m}}$$

Wavelength (λ):

$$\lambda = \frac{v}{f} = \frac{1800}{90000} = \boxed{0.02\,\text{m} = 2\,\text{cm}}$$

(b) Differentiate: Spontaneous and Stimulated emission. **04**

Answer:

Spontaneous Emission	Stimulated Emission
Occurs without external influence.	Occurs due to interaction with an external photon.
Emits photons in **random direction**.	Emits photons in **same direction** as incoming one.
Photons may have different phase and energy.	Emitted photons are **coherent** and of same energy.
Basis of natural light (e.g., sunlight).	Basis of **LASER** operation.

(c) What are Einstein's coefficients? Give relation between them and discuss the result. **07**

Answer:

Einstein's Coefficients & Relations
Einstein introduced three coefficients to describe the interaction between matter and radiation:

1. **B12:** Probability per unit time for **absorption** of radiation.
2. **B21:** Probability per unit time for **stimulated emission**.
3. **A21:** Probability per unit time for **spontaneous emission**.

Let:

- N1: Number of atoms in lower energy state E1
- N2: Number of atoms in higher energy state E2
- ρ(ν): Radiation energy density at frequency ν

Transition rates:

- Absorption:

$$R_{abs} = B_{12} N_1 \rho(\nu)$$

- Stimulated Emission:

$$R_{stim} = B_{21} N_2 \rho(\nu)$$

- Spontaneous Emission:

$$R_{spont} = A_{21} N_2$$

At thermal equilibrium:

$$B_{12}N_1\rho(\nu) = A_{21}N_2 + B_{21}N_2\rho(\nu)$$

Solve for $\rho(\nu)$:

$$\rho(\nu) = \frac{A_{21}}{B_{12} \cdot \frac{N_1}{N_2} - B_{21}}$$

Using Boltzmann distribution:

$$\frac{N_2}{N_1} = e^{-h\nu/kT}$$

Substitute and simplify using Planck's law:

$$\rho(\nu) = \frac{8\pi h\nu^3}{c^3} \cdot \frac{1}{e^{h\nu/kT} - 1}$$

Einstein's Relations:

By comparing with Planck's law, we get:

1. A21=B21
2. B12=B211

Result:

- Spontaneous emission dominates at **high frequency** or **low temperature**.
- Stimulated emission is important for **LASERs**.
- These coefficients form the theoretical basis for laser physics.

OR

Q.3 **(a)** Define:(1) Meta stable state (2) Population inversion (3) Pumping **03**

Answer:

Define:

1. **Meta-stable State:**
   A state in which an atom stays longer than in normal excited states. It enables **population inversion** and is essential for laser action.
2. **Population Inversion:**
   A condition where the number of atoms in the excited state exceeds that in the ground state. It is a **non-equilibrium** condition necessary for **stimulated emission**.
3. **Pumping:**
   The process of supplying energy to atoms to achieve population inversion. Methods include **optical pumping**, **electrical discharge**, etc.

(b) Write a short note on Scanning Tunneling Microscope (STM). **04**

Answer:

Short Note: Scanning Tunneling Microscope (STM)

- Invented by **Binnig and Rohrer** in 1981.
- STM is based on the **quantum tunneling effect**.

Working:

- A **sharp metallic tip** is brought extremely close (~1 nm) to the surface of a conducting sample.
- A **bias voltage** is applied, allowing electrons to tunnel through the gap.
- **Tunneling current** depends on the distance between tip and surface.
- As the tip scans, current variations are recorded to generate **atomic-scale images**.

Applications:

- Imaging atoms and surfaces.
- Study of surface defects.
- Nanotechnology research.

(c) What is full form of LASER? Write the characteristics and applications of LASER. **07**

Answer:

Full Form of LASER:
Light **A**mplification by **S**timulated **E**mission of **R**adiation.

Characteristics of LASER:
1. **Monochromatic** – single wavelength.
2. **Coherent** – same phase and direction.
3. **Highly Directional** – beam spreads very little.
4. **High Intensity** – very concentrated power.

Applications of LASER:
- **Medical:** Eye surgery, skin treatment.
- **Industrial:** Cutting, welding, drilling.
- **Communication:** Fiber optics.
- **Military:** Rangefinding, missile guidance.
- **Scientific Research:** Holography, spectroscopy.

Q.4 **(a)** State any three differences between interference and diffraction. **03**

Answer:

Interference	Diffraction
Occurs due to superposition of two or more waves.	Occurs when a wave bends around an obstacle or slit.
Requires **two sources** of waves.	Can occur with a **single slit or edge**.
Fringe width is **uniform**.	Fringe width is **not uniform**.
Example: Young's double slit experiment.	Example: Single slit diffraction.

(b) Calculate the minimum number of lines in a grating which will just resolve the lines of wavelength 5890 Å and 5896 Å in the second order. **04**

Answer:

Given:
- Wavelengths: $\lambda_1 = 5890\ \text{Å}, \lambda_2 = 5896\ \text{Å}$
- Order $n = 2$

Formula:

$$R = \frac{\lambda}{\Delta\lambda} = nN \quad \Rightarrow \quad N = \frac{\lambda}{n\Delta\lambda}$$

$$\lambda = 5890\ \text{Å}, \Delta\lambda = 5896 - 5890 = 6\ \text{Å}$$

$$N = \frac{5890}{2 \times 6} = \frac{5890}{12} = \boxed{491 \text{ lines}}$$

Thus, minimum number of lines required is **491**.

(c) Derive the time independent Schrödinger's wave equation. **07**

Answer:

Derivation of Time-Independent Schrödinger Wave Equation
Start with classical total energy:

$$E = K.E + P.E = \frac{p^2}{2m} + V \quad \text{where } p = \text{momentum}, V = \text{potential energy}$$

From quantum theory:

$$\hat{p} = -i\hbar\frac{d}{dx}, \quad \hat{E} = i\hbar\frac{d}{dt}$$

Wave function (1D form):

$$\psi(x,t) = \psi(x)e^{-iEt/\hbar}$$

Apply kinetic energy operator to the wave function:

$$\hat{T} = \frac{\hat{p}^2}{2m} = -\frac{\hbar^2}{2m}\frac{d^2}{dx^2}$$

So, total energy becomes:

$$E\psi = -\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} + V(x)\psi$$

✅ **Time-Independent Schrödinger Equation:**

$$\boxed{-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} + V(x)\psi = E\psi}$$

This equation governs the quantum behavior of particles in a potential field V(x).

OR

Q.4 (a) An unknown weight is attached to the lower end of wire of length 4 m, radius 0.7 mm, extends it by 0.8 mm. If Y= 2×10^{11} N/m^2. Find the unknown weight. **03**

Answer:

Elasticity Problem – Unknown Weight
Given:

- Length $L = 4\,m$
- Radius $r = 0.7\,\text{mm} = 0.7 \times 10^{-3}\,m$
- Extension $\Delta L = 0.8\,\text{mm} = 0.8 \times 10^{-3}\,m$
- Young's Modulus $Y = 2 \times 10^{11}\,N/m^2$

Formula:

$$Y = \frac{FL}{A\Delta L} \Rightarrow F = \frac{YA\Delta L}{L} \quad \text{where } A = \pi r^2$$

$$A = \pi(0.7 \times 10^{-3})^2 = \pi \times 0.49 \times 10^{-6} = 1.54 \times 10^{-6}\,m^2$$

$$F = \frac{2 \times 10^{11} \times 1.54 \times 10^{-6} \times 0.8 \times 10^{-3}}{4} = 61.6\,\text{N}$$

$$\boxed{F \approx 61.6\,\text{N}} \quad (\text{Unknown weight})$$

(b) Write a short note on black body radiation. **04**

Answer:

Short Note on Black Body Radiation
A **black body** is an ideal object that absorbs **all** incident radiation and emits maximum possible thermal radiation.
Characteristics:

- Emission depends only on temperature.
- Radiation spectrum is continuous.
- No reflection – perfect absorber.

Explanation:

- Experimental results showed classical theory failed to explain high-frequency behavior (UV catastrophe).
- **Planck's law** resolved this by assuming energy is quantized:

$$E=nh\nu$$

This laid the foundation for **quantum mechanics**.

(c) Explain Heisenberg's uncertainty principle and derive it. **07**

Answer:

Heisenberg's Uncertainty Principle
Statement:
It is impossible to determine simultaneously the exact position and momentum of a particle.

$$\boxed{\Delta x \cdot \Delta p \geq \frac{\hbar}{2}} \quad \text{or} \quad \boxed{\Delta E \cdot \Delta t \geq \frac{\hbar}{2}}$$

Derivation (Using wave packet concept):

- A wave packet formed by superposition has a range of momenta Δp
- Narrower the packet in space (small Δx), the broader the spread in momentum.

Using Fourier analysis:

$$\Delta x \cdot \Delta k \geq \frac{1}{2} \quad \text{and since } p = \hbar k \Rightarrow \Delta p = \hbar \Delta k$$

$$\Rightarrow \Delta x \cdot \Delta p \geq \frac{\hbar}{2}$$

Conclusion:

- A fundamental limit of measurement in quantum mechanics.
- Not due to instrument error, but the **wave nature of particles**.

Q.5 **(a)** Define: (1) Critical Temperature (2) Critical Magnetic field (3) Critical Current density. **03**

Answer:

Define:

1. **Critical Temperature (Tc):**
   The maximum temperature below which a material exhibits **superconductivity** (zero electrical resistance).
   Example: For mercury, T_c=4.2 K
2. **Critical Magnetic Field (Bc):**
   The maximum magnetic field that a superconducting material can withstand without losing its superconductivity.
3. **Critical Current Density (Jc):**
   The maximum current per unit cross-sectional area a superconductor can carry without losing its superconducting state.

(b) Write the applications of nano materials. **04**

Answer:

Applications of Nano Materials:

1. **Electronics:**
   Used in transistors, sensors, and quantum dots for miniaturized circuits.
2. **Medical Field:**
   Nano-materials like silver nanoparticles are used for targeted drug delivery, diagnostics, and antimicrobial coatings.
3. **Energy Sector:**
   Used in **solar cells**, **hydrogen storage**, and **battery electrodes** for better efficiency.
4. **Environment:**
   Nanoparticles are used in water purification, air filters, and removal of pollutants.
5. **Mechanical Applications:**
   Nano-composites are used in lightweight, high-strength materials for aerospace and automotive parts.

(c) Describe the principle, construction and working of Michelson interferometer. **07**

Answer:

Michelson Interferometer

Principle:

Based on **interference** of light. It splits a single light beam into two parts, reflects them back, and recombines to form interference fringes.

Construction:

- **Beam Splitter (semi-silvered mirror):** Divides the incoming beam into two.
- **Mirror M1 and M2:** Reflect beams back.
- **Compensating Plate:** Ensures equal optical paths.
- **Observation Screen / Telescope:** Displays interference fringes.

Working:

- Light from source is split at 45° by beam splitter.
- Part of beam reflects to mirror **M1**, other part transmits to mirror **M2**.
- Both beams return and recombine at the beam splitter, producing **interference fringes** depending on **path difference**.

Applications:

- Measurement of **wavelength of light**.
- Determination of **refractive index** of gases.
- Used in detection of small displacements and in **LIGO** (gravitational wave observatory).

OR

Q.5 **(a)** State and explain principle of superposition of waves. **03**

Answer:

Principle of Superposition of Waves:

When two or more waves overlap in space, the resultant displacement at any point is the **algebraic sum** of the displacements due to each wave.

$$y=y1+y2$$

Conditions:

- Waves must be **coherent** (constant phase difference).
- Superposition leads to **interference** patterns.

(b) What is interference? Differentiate Constructive and destructive interference. **04**

Answer:

Interference:
The phenomenon in which two or more waves superpose to form a resultant wave of greater or lower amplitude.

Constructive Interference	**Destructive Interference**
Occurs when waves are **in phase**.	Occurs when waves are **out of phase** by π\piπ.
Amplitudes **add up**, resulting in bright fringes.	Amplitudes **cancel**, resulting in dark fringes.
Path difference: $n\lambda$	Path difference: $(2n+1)\lambda/2$

(c) Explain working of the p-n junction diode and state its applications. **07**

Answer:

Construction:
A **p-n junction** diode is made by joining **p-type** and **n-type** semiconductors.

- **p-side:** Majority carriers are holes.
- **n-side:** Majority carriers are electrons.

Working:

1. **Unbiased Condition:**
    - A depletion layer forms at the junction due to diffusion of charges.
    - No current flows.
2. **Forward Bias (p connected to +ve):**
    - Depletion layer narrows.
    - Current flows due to movement of majority carriers.
3. **Reverse Bias (p connected to -ve):**
    - Depletion layer widens.
    - Very small leakage current flows due to minority carriers.

Applications:

- **Rectifiers:** Convert AC to DC.
- **Clipping and Clamping circuits.**
- **Voltage regulators** and **LEDs**.

****