# GUJARAT TECHNOLOGICAL UNIVERSITY
**BE- SEMESTER–1 PAPER SOLUTION –SUMMER 2025**

**Subject Name & Code:**
**Physics- BE01000021**

---

**Marks**

**Q.1** **(a)** Transition temperature of mercury of mass number 202 is 4.20 K. Find the transition temperature of isotope of mercury of mass number 204. **03**

**Answer:**
The transition temperature (Tc) of a superconducting element is inversely proportional to the square root of its isotopic mass (M), i.e.,

$$T_c \propto \frac{1}{\sqrt{M}}$$

Let $T_1 = 4.20\,K$ for $M_1 = 202$, and $T_2 = ?$ for $M_2 = 204$

Using the formula:

$$\frac{T_1}{T_2} = \sqrt{\frac{M_2}{M_1}} \Rightarrow T_2 = \frac{T_1}{\sqrt{M_2/M_1}} = \frac{4.20}{\sqrt{204/202}} = \frac{4.20}{\sqrt{1.0099}}$$

$$T_2 \approx \frac{4.20}{1.0049} \approx \boxed{4.18\,K}$$

**(b)** Define: (i) Interference of light, (ii) Diffraction of light, (iii) Fresnel diffraction. Also state Huygens' principle. **04**

**Answer:**

(i) **Interference of Light:**
Interference is the phenomenon of redistribution of light energy due to the superposition of two or more coherent light waves. It results in alternate dark and bright fringes.

(ii) **Diffraction of Light:**
Diffraction is the bending or spreading of light waves when they pass through a narrow aperture or around an obstacle, leading to a pattern of bright and dark fringes.

(iii) **Fresnel Diffraction:**

Fresnel diffraction occurs when the source or screen (or both) is at a finite distance from the diffracting aperture. It considers the curvature of the wavefronts.

(iv)

**Huygens' Principle:**
Each point on a wavefront acts as a source of secondary wavelets. The new wavefront is the tangent to all such secondary wavelets.

**(c)(i)** Define nanomaterials and explain ball milling technique of synthesis of nanomaterials with suitable diagram. **03**

---

**Answer:**
**(i) Definition of Nanomaterials:**
**Nanomaterials** are materials that have at least one dimension in the **nanometer scale (1–100 nm)**. Due to their extremely small size, they exhibit **unique physical, chemical, optical, electrical, and magnetic properties** compared to their bulk counterparts.
Examples include carbon nanotubes, quantum dots, nanowires, etc.

---

✅ **Ball Milling Technique:**
**Ball milling** is a **top-down mechanical method** used to synthesize nanomaterials by breaking down bulk materials into nanoparticles using high-energy collisions.

---

🔧 **Principle:**
In ball milling, **grinding balls** (made of steel or ceramic) inside a rotating chamber repeatedly **collide** with the material, reducing its size through impact and attrition.

---

⚙️ **Construction and Working:**
- A **hollow cylindrical chamber** is filled with grinding balls and the material to be milled.
- The **chamber rotates**, causing the balls to fall onto the material, fracturing it into finer particles.
- Over time, the material reaches **nanoscale size**.

---

📉 **Diagram:**

**Advantages of Ball Milling:**
- Simple and cost-effective
- Suitable for large-scale production
- Produces uniform nanoparticles
- No need for chemical agents

**(c)(ii)** Write any four differences between n-type and p-type semiconductors. **04**

**Answer:**
**(ii) Differences between n-type and p-type Semiconductors:**

| Feature | n-type Semiconductor | p-type Semiconductor |
|---|---|---|
| Doping Element | Pentavalent (e.g., Phosphorus, Arsenic) | Trivalent (e.g., Boron, Gallium) |
| Majority Charge Carriers | Electrons | Holes |
| Minority Charge Carriers | Holes | Electrons |
| Position of Fermi Level | Near conduction band | Near valence band |
| Type of Conductivity | Electron-based conductivity | Hole-based conductivity |

**Q.2** **(a)** What is de-Broglie wave? Write the equation of de-Broglie wavelength and mention the names of each quantity involved in the equation. **03**

**Answer:**

**de-Broglie Wave:**
According to de-Broglie's hypothesis, every moving particle is associated with a wave called a matter wave or de-Broglie wave.
**de-Broglie Wavelength Formula:**

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

Where:
- λ: de-Broglie wavelength (in meters)
- h: Planck's constant ($6.63\times10-34$ J·s)
- m: Mass of the particle (in kg)
- v: Velocity of the particle (in m/s)
- p: Momentum of the particle

This concept links wave and particle nature in quantum mechanics.

**(b)** Find the force required to increase the length of a wire of $10^{-6}$ $m^2$ area of cross-section by 50 % whose Young's modulus is $2\times10^{11}$ N/$m^2$. **04**

**Answer:**

Given:

- Area $A = 10^{-6}\, m^2$
- Strain $= \frac{\Delta L}{L} = 50\% = 0.50$
- Young's modulus $Y = \frac{\text{Stress}}{\text{Strain}} = 2 \times 10^{11}\, N/m^2$

$$\text{Stress} = Y \times \text{Strain} = 2 \times 10^{11} \times 0.50 = 1 \times 10^{11}\, N/\imath$$

$$\text{Force} = \text{Stress} \times \text{Area} = 1 \times 10^{11} \times 10^{-6} = \boxed{1 \times 10^{5}\, I}$$

**(c)** Explain torsional pendulum in brief with suitable diagram and derive the equation of twisting couple per unit twist of a wire. **07**

---

**Answer:**

**Torsional Pendulum:**
A torsional pendulum consists of a disk or any rigid body suspended by a thin wire or rod. When twisted and released, the body oscillates about its axis due to restoring torque produced in the wire.

**Diagram:**
*(Draw a disk suspended by a wire, showing angle of twist θ and torque τ)*

**Let:**

- C = Restoring torque per unit angular displacement (modulus of torsion)
- θ = Angular displacement
- I = Moment of inertia
- τ = Restoring torque

Then,

$$\tau = -C\theta$$

Using Newton's second law for rotation:

$$I\frac{d^2\theta}{dt^2} = -C\theta \Rightarrow \frac{d^2\theta}{dt^2} + \frac{C}{I}\theta = 0$$

This is the differential equation of angular simple harmonic motion.

**Angular frequency:**

$$\omega = \sqrt{\frac{C}{I}}$$

**Time Period:**

$$T = 2\pi\sqrt{\frac{I}{C}}$$

This defines how the system oscillates with angular motion under the restoring couple proportional to the angle of twist.

**OR**

**(c)** Explain: (i) Elastic hysteresis, (ii) Elastic after-effect, and (iii) Elastic fatigue. **07**

---

**Answer:**

(i) **Elastic Hysteresis:**
It is the lag between stress and strain during loading and unloading. When a material is stretched and released, it doesn't retrace the same path on a stress-strain diagram. The enclosed area in the loop represents energy loss (as heat).
**Diagram:**
Draw a stress-strain curve showing loading and unloading paths not overlapping (hysteresis loop).

---

(ii) **Elastic After-Effect:**
It refers to the delay in regaining the original shape after removal of deforming force. In ideal elastic bodies, strain disappears instantly. In real materials, recovery takes time.

---

(iii) **Elastic Fatigue:**
This is the weakening of a material caused by repeated loading and unloading cycles, even if within elastic limits. Eventually, the material may fracture.

**Q.3** **(a)** Define: (i) Transverse waves, (ii) Ultrasonic waves, and (iii) Damped oscillations. **03**

---

**Answer:**

(i) **Transverse Waves:**
Waves in which the particle vibration is perpendicular to the direction of wave propagation, e.g., light waves, waves on a string.

(ii) **Ultrasonic Waves:**
Sound waves with frequencies above 20,000 Hz (20 kHz) which are inaudible to the human ear.

(iii) **Damped Oscillations:**
Oscillations whose amplitude decreases with time due to energy loss (e.g., friction or air resistance) are called damped oscillations.

**(b)** The volume of a room is 1500 $m^3$. The wall area of the room is 250 $m^2$, the floor and the ceiling area is 150 $m^2$ each. The average sound absorption coefficient for the wall, floor and the ceiling are 0.25, 0.06 and 0.80, respectively. Calculate the average absorption coefficient and the reverberation time. **04**

---

**Answer:**

1. **Total surface area:**

$$S = \text{Wall} + \text{Floor} + \text{Ceiling} = 250 + 150 + 150 = 550\, m^2$$

2. **Total absorption:**

$$A = (250 \times 0.25) + (150 \times 0.06) + (150 \times 0.80) = 62.5 + 9 + 120 = 191.5$$

3. **Average Absorption Coefficient:**

$$\bar{\alpha} = \frac{A}{S} = \frac{191.5}{550} \approx \boxed{0.348}$$

4. **Reverberation Time (Sabine's Formula):**

$$T = \frac{0.161 \times V}{A} = \frac{0.161 \times 1500}{191.5} \approx \boxed{1.26\,\text{seconds}}$$

**(c)** Derive the differential equation of simple harmonic motion, also write its general solution and obtain the equation of velocity and acceleration of simple harmonic oscillator. **07**

---

**Answer:**

**Simple Harmonic Motion (SHM):**
Defined as motion in which acceleration is directly proportional to displacement and directed towards the mean position.
Let x= displacement,
a= acceleration
Then,

$$a = -\omega^2 x \Rightarrow \frac{d^2x}{dt^2} = -\omega^2 x$$

This is the differential equation of SHM.
**General Solution:**

$$x(t) = A\cos(\omega t + \phi)$$

Where:
- A: Amplitude
- ω: Angular frequency

- ϕ: Phase constant

**Velocity:**

$$v = \frac{dx}{dt} = -A\omega \sin(\omega t + \phi)$$

**Acceleration:**

$$a = \frac{d^2x}{dt^2} = -A\omega^2 \cos(\omega t + \phi) = -\omega^2 x$$

Thus, SHM is completely described by the displacement, velocity, and acceleration equations.

**OR**

**Q.3** **(a)** Define: (i) Reverberation, (ii) Echo, and (iii) Echelon effect. **03**

**Answer:**

(i) **Reverberation:**
The persistence of sound in a hall due to multiple reflections after the source has stopped. It occurs within a short time (<1 second).

(ii) **Echo:**
A reflected sound heard distinctly after the original sound, generally after 0.1 seconds, when the reflecting surface is more than 17 m away.

(iii) **Echelon Effect:**
In stepped auditoriums or halls, multiple reflections from steps cause successive echoes called the echelon effect. It degrades sound quality.

**(b)** A particle of mass 0.50 kg executes a simple harmonic motion. If it crosses the centre of oscillation with a speed of 10 m/s, find the amplitude of the motion. (force constant k = 50 N/m) **04**

**Answer:**

Given:

- m=0.50 kg
- v max=10 m/s
- k=50 N/m

$$\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{50}{0.5}} = \sqrt{100} = 10\, rad/s$$

At mean position: $v_{max} = A\omega \Rightarrow A = \frac{v_{max}}{\omega} = \frac{10}{10} = \boxed{1\, m}$

**(c)** Explain the construction and working of piezoelectric method of ultrasonic wave production with suitable diagram. **07**

---

**Answer:**
**Principle:**
When certain crystals (e.g., quartz) are subjected to mechanical stress, they produce electric potential (direct piezoelectric effect). The reverse is also true — applying AC voltage causes them to vibrate and produce ultrasonic waves.

---

**Construction:**

- Quartz crystal placed between two metal plates
- Connected to high-frequency oscillator (~1 MHz or more)
- Crystal acts as resonator

**Diagram:**
Draw a block showing quartz crystal between metal plates connected to oscillator and radiating ultrasonic waves.

---

**Working:**

- AC voltage applied → crystal vibrates due to reverse piezoelectric effect.
- At resonance frequency, strong ultrasonic waves are emitted.

---

**Applications:**
Used in SONAR, medical imaging, industrial cleaning, etc.

**Q.4** **(a)** In a Young's double slit experiment, the two slits which are 0.5 mm apart are illuminated by the yellow light of wavelength 589.0 nm. Calculate the distance between two consecutive bright bands in the interference pattern observed on a screen 2 m away from the slits. **03**

---

**Answer:**

**Fringe width (β)** is given by:

$$\beta = \frac{\lambda D}{d}$$

Where:

- $\lambda = 589.0 \times 10^{-9}\, m$
- $D = 2\, m$
- $d = 0.5\, mm = 0.5 \times 10^{-3}\, m$

$$\beta = \frac{589 \times 10^{-9} \times 2}{0.5 \times 10^{-3}} = \frac{1178 \times 10^{-9}}{0.5 \times 10^{-3}} = 2.356 \times 10^{-3}\, m = \boxed{2.36\, mm}$$

**(b)** Write Schrodinger's time independent wave equation and explain its each term. Also write Heisenberg's uncertainty principle in terms of position and momentum. **04**

---

**Answer:**

**Schrödinger's Time-Independent Wave Equation:**

$$-\frac{h^2}{8\pi^2 m}\frac{d^2\psi}{dx^2}+V\psi=E\psi$$

Where:

- h: Planck's constant
- m: Mass of particle
- ψψ: Wave function
- V: Potential energy
- E: Total energy of the particle

This equation describes the quantum behavior of particles. ψ gives the probability amplitude.

**Heisenberg's Uncertainty Principle:**

$$\Delta x\cdot\Delta p\geq\frac{h}{4\pi}$$

Where:

- Δx: Uncertainty in position
- Δp: Uncertainty in momentum

This principle states we cannot simultaneously measure the exact position and momentum of a particle.

**(c)** Explain the formation of Newton's rings with suitable diagram and derive the equation of radius of bright and dark rings produced by the interference of reflected light. **07**

---

**Answer:**

**Concept:**

Newton's rings are circular interference fringes formed by the reflection of monochromatic light between a plano-convex lens and a flat glass plate.

**Diagram:**

(Draw a plano-convex lens placed on a glass plate, showing air film of thickness t, rays interfering, and ring pattern)

---

**Radius of Dark Ring (Destructive Interference):**

Path difference for reflected light:

$$2t=(2n+1)\frac{\lambda}{2}$$

At center (contact point), t=0, dark fringe appears.

For nth dark ring:

$$r_n=\sqrt{n\lambda R}$$

Where:

- rn: Radius of nth dark ring

- λ: Wavelength
- R: Radius of curvature of the lens

---

**Radius of Bright Ring (Constructive Interference):**

$$2t = n\lambda \Rightarrow r_n = \sqrt{(2n-1)\lambda R}$$

---

**Conclusion:**
Newton's rings are due to the interference between light waves reflected from top and bottom surfaces of the air film. Radius depends on ring order, wavelength, and lens curvature.

**OR**

**Q.4 (a)** Calculate de-Broglie wavelength associated with (i) A man of 50 kg mass walking with the speed of 2 m/s, and (ii) An electron moving with the speed of $3\times10^5$ m/s. Based on your answers obtained in above two cases, explain why the wave nature of the man can't be observed. ($h = 6.63\times10^{-34}$ J·s, electron mass = $9.11\times10^{-31}$ kg) **03**

---

**Answer:**

**(i) For man:**

$$\lambda = \frac{h}{mv} = \frac{6.63\times10^{-34}}{50\times2} = \frac{6.63\times10^{-34}}{100} = \boxed{6.63\times10^{-36}\,m}$$

**(ii) For electron:**

$$\lambda = \frac{6.63\times10^{-34}}{9.11\times10^{-31}\times3\times10^5} = \frac{6.63\times10^{-34}}{2.733\times10^{-25}} \approx \boxed{2.43\times10^{-9}\,m}$$

**Conclusion:**
The wavelength of macroscopic objects (like man) is extremely small and undetectable. Hence, wave nature is significant only for microscopic particles (like electrons).

**(b)** Define constructive and destructive interference with their condition in terms of path difference. **04**

---

**Answer:**

**Constructive Interference:**
When two waves meet **in phase**, their amplitudes add, producing bright fringes.
**Condition:**

$$\Delta x = n\lambda, \quad n = 0, 1, 2, \ldots$$

**Destructive Interference:**
When two waves meet **out of phase**, their amplitudes subtract, producing dark fringes.
**Condition:**

$$\Delta x = \left(n + \frac{1}{2}\right)\lambda, \quad n = 0, 1, 2, \dots$$

**(c)** Write a short-note on scanning tunneling microscope. **07**

---

**Answer:**

**Principle:**
STM works on the concept of quantum **tunneling**, where electrons can tunnel between a sharp metal tip and a conducting surface when brought extremely close (a few angstroms apart).

---

**Construction:**
- Sharp metal tip
- Piezoelectric scanner for precise movement
- Feedback system
- Sample mounted on platform

---

**Working:**
- Voltage applied between tip and sample
- Electrons tunnel through vacuum
- Tunneling current varies with tip-surface distance
- Scanning tip records current variations → atomic-resolution image

**Diagram:**
Show tip scanning over atomic surface with current detector.

---

**Applications:**
- Surface imaging at atomic scale
- Studying electron density
- Nanotechnology and material science

**Q.5** **(a)** In He-Ne gas laser, Ne atoms emit laser photons of wavelength 632.8 nm while electrons make transitions from $E_3$ state to $E_2$ state. Find the energy difference between these two states. ($h = 6.63 \times 10^{-34}$ J·s and $c = 3 \times 10^{8}$ m/s) **03**

---

**Answer:**

$$E = \frac{hc}{\lambda}$$

Given:

- $h = 6.63 \times 10^{-34}\, J \cdot s$
- $c = 3 \times 10^{8}\, m/s$
- $\lambda = 632.8 \times 10^{-9}\, m$

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{632.8 \times 10^{-9}} \approx 3.14 \times 10^{-19}\, J$$

$$\boxed{E = 3.14 \times 10^{-19}\, J}$$

**(b)** Write the properties of laser and explain in brief. **04**

**Answer:**

**Properties of Laser:**

1. **Monochromaticity:** Emits single wavelength (pure color).
2. **Coherence:** All waves are in same phase.
3. **Directionality:** Beam is highly directional with negligible divergence.
4. **High Intensity:** Power concentrated in a narrow beam.

**Explanation:**
Laser light is unique compared to ordinary light due to these properties. It is used in surgery, communication, and precision instruments due to its ability to focus and deliver energy accurately.

**(c)** Write the full form of laser and explain (i) Absorption, (ii) Spontaneous emission, and (iii) Stimulated emission with suitable diagrams. **07**

**Answer:**

**LASER:**
**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation

**(i) Absorption:**
When an atom in lower energy state E1 absorbs a photon of energy hν=E2−E1, it jumps to excited state E2.

**(ii) Spontaneous Emission:**
Excited atom returns to lower state E1 by emitting a photon *randomly* without external influence.

**(iii) Stimulated Emission:**

An incident photon causes an excited atom to emit a second photon of *same energy, phase, and direction*. This is the basis of laser operation.

**Diagrams:**
(Draw three energy level diagrams showing each process clearly with E1, E2, photon arrows, and labels)

**OR**

**Q.5** **(a)** A ruby laser emits light of wavelength 694.3 nm. Calculate the frequency and the energy of the laser photons emitted. (h = $6.63\times10^{-34}$ J·s and c = $3\times10^{8}$ m/s) **03**

**Answer:**

$$f = \frac{c}{\lambda} = \frac{3\times10^{8}}{694.3\times10^{-9}} \approx 4.32\times10^{14}\ Hz$$

$$E = hf = 6.63\times10^{-34}\times4.32\times10^{14} \approx \boxed{2.86\times10^{-19}\ J}$$

**(b)** What is population inversion (draw suitable diagram)? Explain why it is necessary for the production of laser? **04**

**Answer:**

**Population Inversion:**
A condition where the number of atoms in the **excited state ($E_2$)** is greater than those in the **ground state ($E_1$)**. This is opposite to normal thermal distribution.
**Diagram:**
Draw a two-level energy diagram showing N2>N1

**Why needed?**
Without population inversion, **stimulated emission** is not dominant. In lasers, photons must trigger more photons (coherent light). This requires more atoms in excited state.

**(c)** Obtain the relation between Einstein's coefficients. **07**

**Answer:**

Let:
- B12: Absorption coefficient
- B21: Stimulated emission coefficient
- A21: Spontaneous emission coefficient

In thermal equilibrium, upward and downward transitions balance:

$$N_1B_{12}\rho(\nu) = N_2B_{21}\rho(\nu) + N_2A_{21}$$

Rewriting:

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

Using Boltzmann distribution:

$$\frac{N_2}{N_1} = e^{-h\nu/kT} \Rightarrow \rho(\nu) = \frac{A_{21}}{B_{21}(e^{h\nu/kT} - 1)}$$

Comparing with Planck's radiation law:

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

Thus, equating coefficients:

$$\boxed{\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}} \quad \text{and} \quad \boxed{B_{12} = B_{21}}$$

These are **Einstein's relations** governing emission and absorption in quantum systems.

******************