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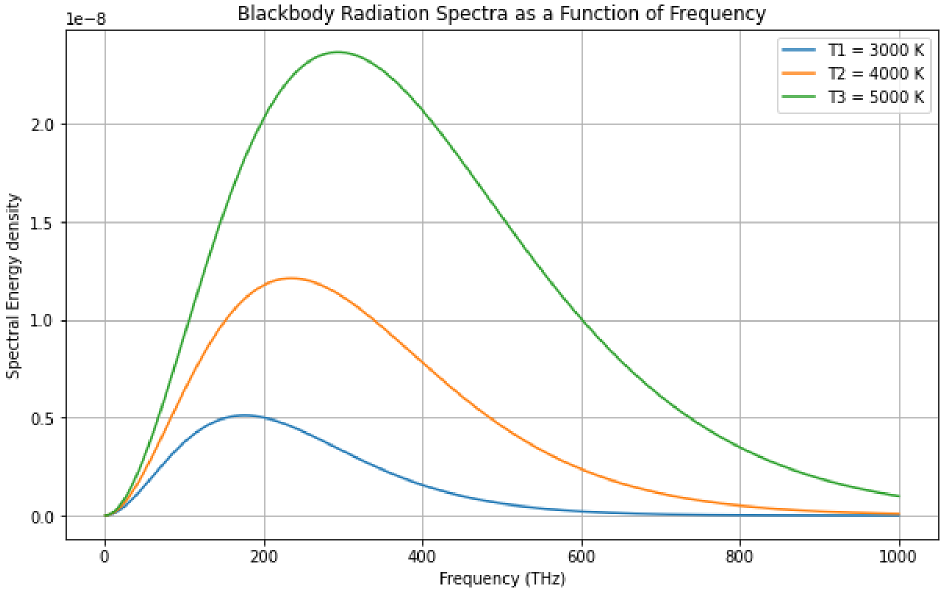
SCHOOL OF ADVANCED SCIENCES
CONTINUOUS ASSESSMENT TEST - II
WINTER SEMESTER 2024-2025

SLOT: E2+TE2

Programme Name & Branch	**B-Tech**
Course Code and Course Name	**BPHY101L and Engineering Physics**
Faculty Name(s)	Tulsi Anna, Anuradha C, Dhanoj Gupta, Laxmi Narayan Tripathi, Samuel P, Vijaya Chamundeeswari S P, Jitendra Kumar Behera, Pankaj Sheoran, Bhaskar Sen Gupta, Arunai Nambiraj N, Anuj Ram Baitha, Anusha P T, Kuraganti Vasu, Amrita Dey, Sridhar S, Sumangala T P, Kanhaiya Lal Pandey, Sangem Rajesh, Shobana M K, Premkumar S, Tarun, Krishna Chandar N, Abhinav Anand, Samir Ranjan Meher
Class Number(s)	**VL2024250505302/5296/5282/5290/5277/5284/5295/5310/5269/5309/5216/5288/5300/5259/5279/5267/5286/5272/5263/5306/5293/5275/5265/5304**
Date of Examination	**20-03-2025**
Exam Duration	**90 minutes** **Maximum Marks: 50**

General instruction(s): Answer All Questions, M - Max mark; CO – Course Outcome; BL – Blooms Taxonomy Level (1 – Remember, 2 – Understand, 3 – Apply, 4 – Analyse, 5 – Evaluate, 6 – Create) CO3- Apply quantum mechanical ideas to subatomic domain.

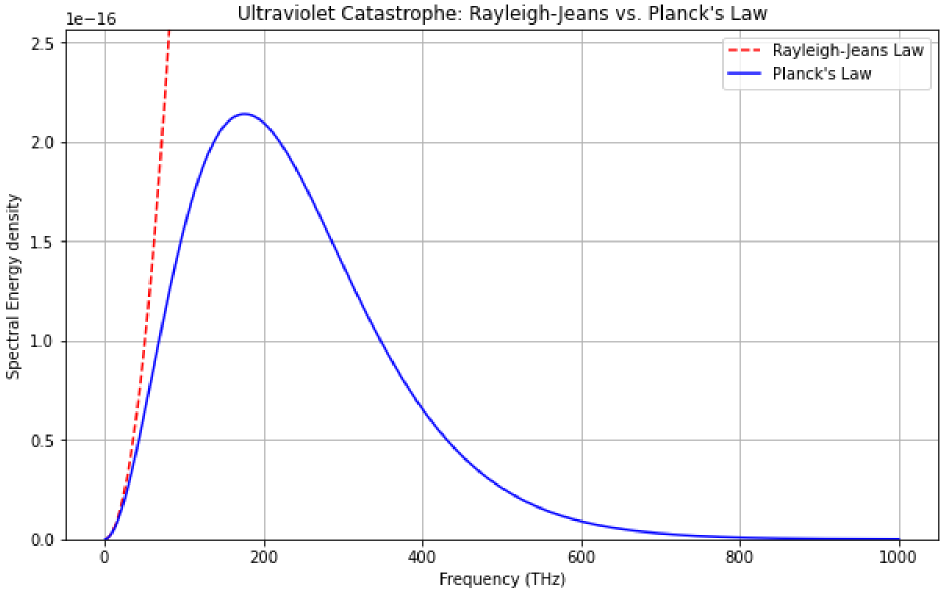
Q. No	Question	M	CO	BL
1.	Draw the blackbody spectra for three different temperatures T_1, T_2, and T_3 ($T_3 > T_2 > T_1$). Discuss the Ultraviolet catastrophe with appropriate diagram and explain how Planck's hypothesis resolved it. Key: 1) To draw the blackbody spectra for three different temperatures T_1, T_2, and T_3 ($T_3 > T_2 > T_1$) as shown below- 2 Marks  2) Discuss the Ultraviolet catastrophe with diagram as shown below- 3 Marks The **ultraviolet catastrophe** refers to a significant problem in classical physics, where the predictions for blackbody radiation at high frequencies (short wavelengths) diverged drastically from experimental results. Here's an overview of the phenomenon:	10	CO3	BL2

What is the Ultraviolet Catastrophe?

1. **Classical Prediction (Rayleigh-Jeans Law)**:
    - Classical physics used the **Rayleigh-Jeans law** to describe the energy emitted by a blackbody as a function of frequency.
    - According to the Rayleigh-Jeans law, the energy radiated increases proportionally to the square of the frequency

$$u(\nu)\ d\nu = \bar{\epsilon}G(\nu)\ d\nu = \frac{8\pi kT}{c^3}\ \nu^2\ d\nu$$

    - This led to the prediction that, as frequency increases, the energy radiated by the blackbody would become infinitely large. This divergence at high frequencies (in the ultraviolet region) was known as the "ultraviolet catastrophe."
2. **Experimental Results**:
    - Experiments showed that blackbody radiation actually peaks at a certain frequency and then decreases for higher frequencies.
    - This stark mismatch between theory and experiment highlighted a significant flaw in classical physics.



3) To Explain how Planck's hypothesis resolved it.- 5 Marks

3. **Resolution (Planck's Quantum Theory)**:
    - **Max Planck** proposed a groundbreaking solution in 1900. He introduced the idea that energy is emitted or absorbed in discrete

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packets (quanta), where the energy of each quantum is proportional to its frequency:

- Using this quantization approach, Planck derived a new formula for blackbody radiation:

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

- This law resolved the divergence at high frequencies and matched experimental data perfectly.

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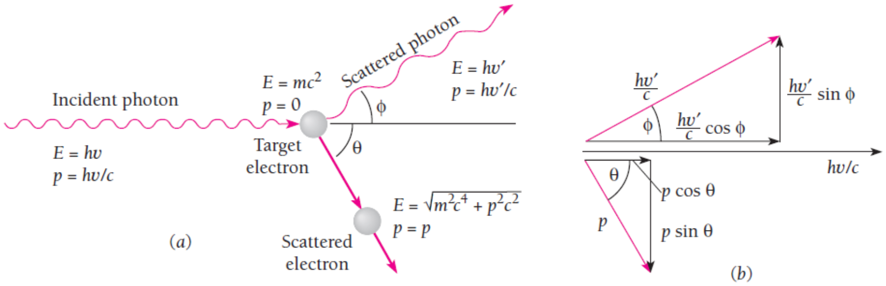
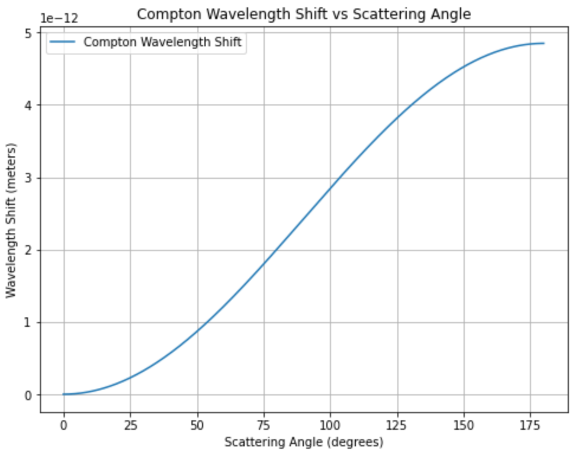
(a) Draw a scattering diagram illustrating a photon scattering off a stationary particle of mass m, clearly labelling all relevant scattering parameters. Plot the Compton wavelength shifts as a function of the photon scattering angle, showing the variation graphically.

Key: 1. To draw a scattering diagram illustrating a photon scattering off a stationary particle of mass m, clearly labelling all relevant scattering parameters. – 5 Marks



2. Plot the Compton wavelength shift as a function of the photon scattering angle, showing the variation graphically.- 5 Marks



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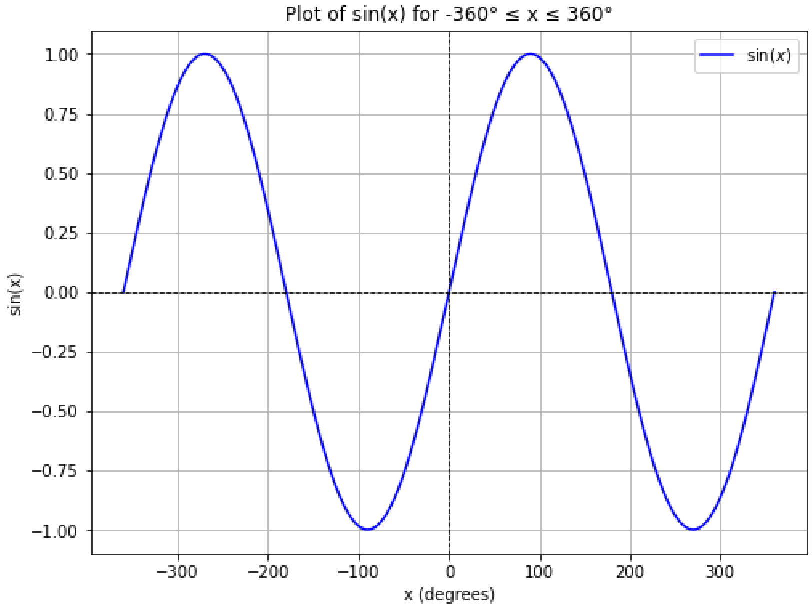
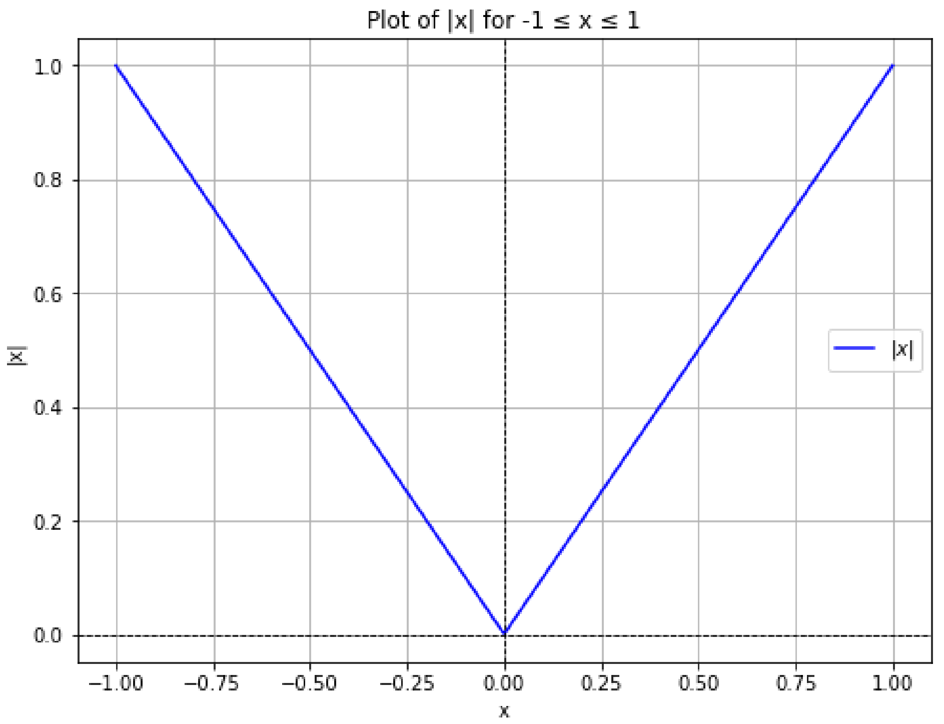
	(b) Analyse whether the functions sin (x) $(-2\pi \leq x \leq 2\pi)$ and $\lvert x \rvert$ $(-1 \leq x \leq 1)$ can be considered well-behaved wave functions. Justify your answer based on the properties of wave functions. Explain the physical significance of the normalization condition for a wave function. Key: The criteria for any function, to be a wave function is that 1 Ψ must be continuous and single-valued everywhere. 2 $\partial\Psi/\partial x$, $\partial\Psi/\partial y$, $\partial\Psi/\partial z$ must be continuous and single-valued everywhere. 3 Ψ must be normalizable, which means that Ψ must go to 0 as $x \to \pm\infty$, $y \to \pm\infty$, $z \to \pm\infty$ in order that $\int \lvert\Psi\rvert^2 \, dV$ over all space be a finite constant. Sin(x) is continuous and single-valued, and differential with respect to x, i.e. cos (x) is also single-valued and continuous. Sin(x) becomes zero at the boundaries i.e. x = -360 degrees, and -360 degrees as shown in the plot below. Hence sin(x) can be considered as a well-behaved wave function.  However, the $\lvert x \rvert$ $(-1 \leq x \leq 1)$, see the graph below, has two slopes at x = 0, i.e. the differential of $\lvert x \rvert$ $(-1 \leq x \leq 1)$ wrt x is multivalued. To consider it to be well-behaved it should be single-valued. Hence $\lvert x \rvert$ $(-1 \leq x \leq 1)$ cannot be considered as a wave function.	5		

	 2- To explain the physical significance of the normalization condition for a wave function. – 1 Mark. The normalization condition confirms that the particle exists **somewhere** in space and guarantees that probabilities derived from the wave function are meaningful and aligned with physical laws.			
3.	(a) Calculate the de-Broglie wavelength of an electron accelerated through a potential difference of 10 kV. Compare the wavelength with that of a proton, if accelerated through the same potential. Key : $\lambda = \frac{h}{\sqrt{2me}} \cdot \frac{1}{\sqrt{V}}$ The de-Broglie wavelength of the electron is approximately **3.88 picometers (pm)**. 2 Marks. For Proton The de-Broglie wavelength of the proton is approximately **2.86 picometers (pm)**. 2 Marks Since the proton is much more massive than an electron, its de-Broglie	5	CO3	BL3

wavelength is smaller under the same accelerating potential - 1 Marks

(b) Determent the constant A for the wave function $\psi(x) = A\, e^{-2ikx}$ for -L<x<L. Also calculate the probability of finding the particle between 0 and L.

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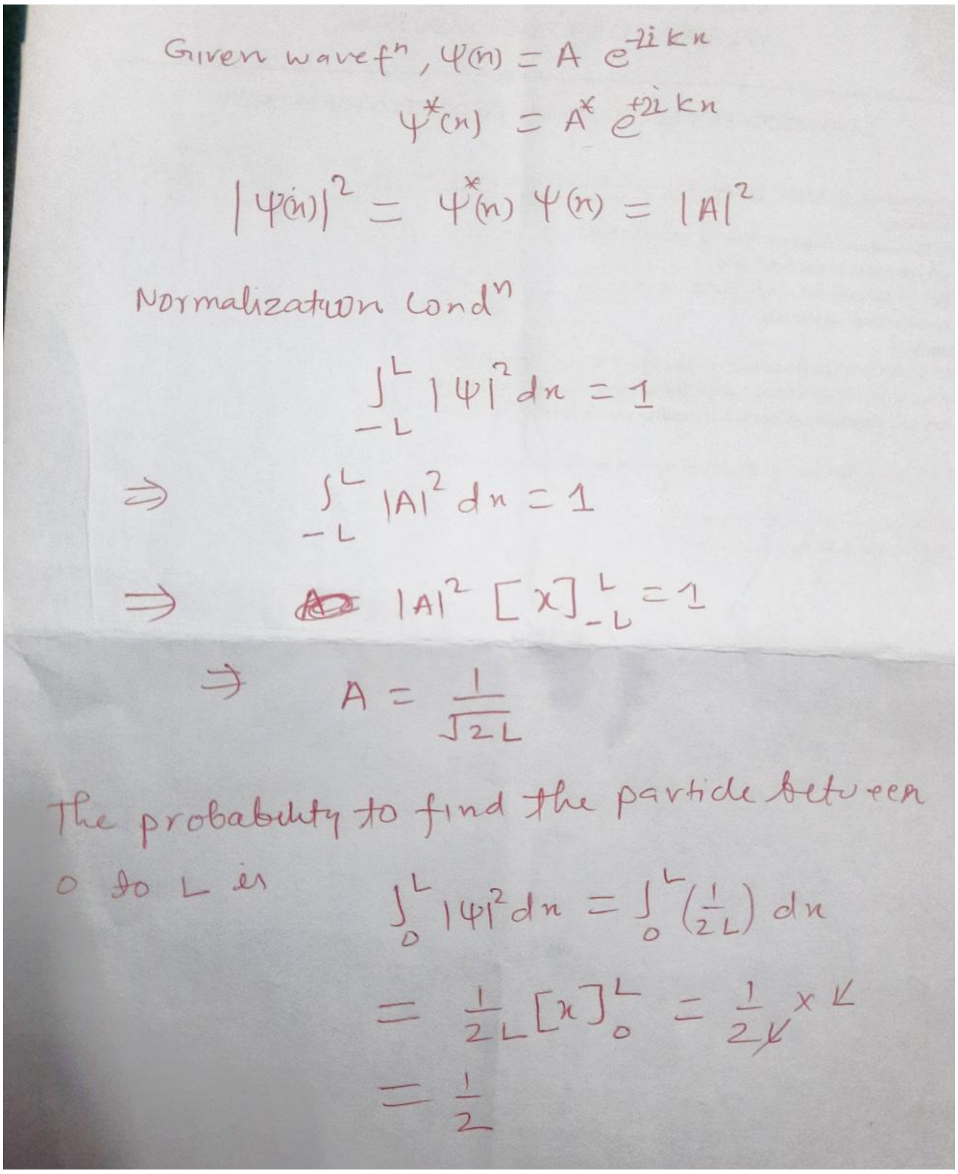
Key:

Calculation of A – 3 Marks
Calculation of probability – 2 Marks



Given wavefⁿ, $\psi(x) = A\, e^{-2ikx}$

$$\psi^*(x) = A^* e^{+2ikx}$$

$$|\psi(x)|^2 = \psi^*(x)\,\psi(x) = |A|^2$$

Normalization condⁿ

$$\int_{-L}^{L} |\psi|^2 dx = 1$$

$$\Rightarrow \int_{-L}^{L} |A|^2 dx = 1$$

$$\Rightarrow |A|^2 [x]_{-L}^{L} = 1$$

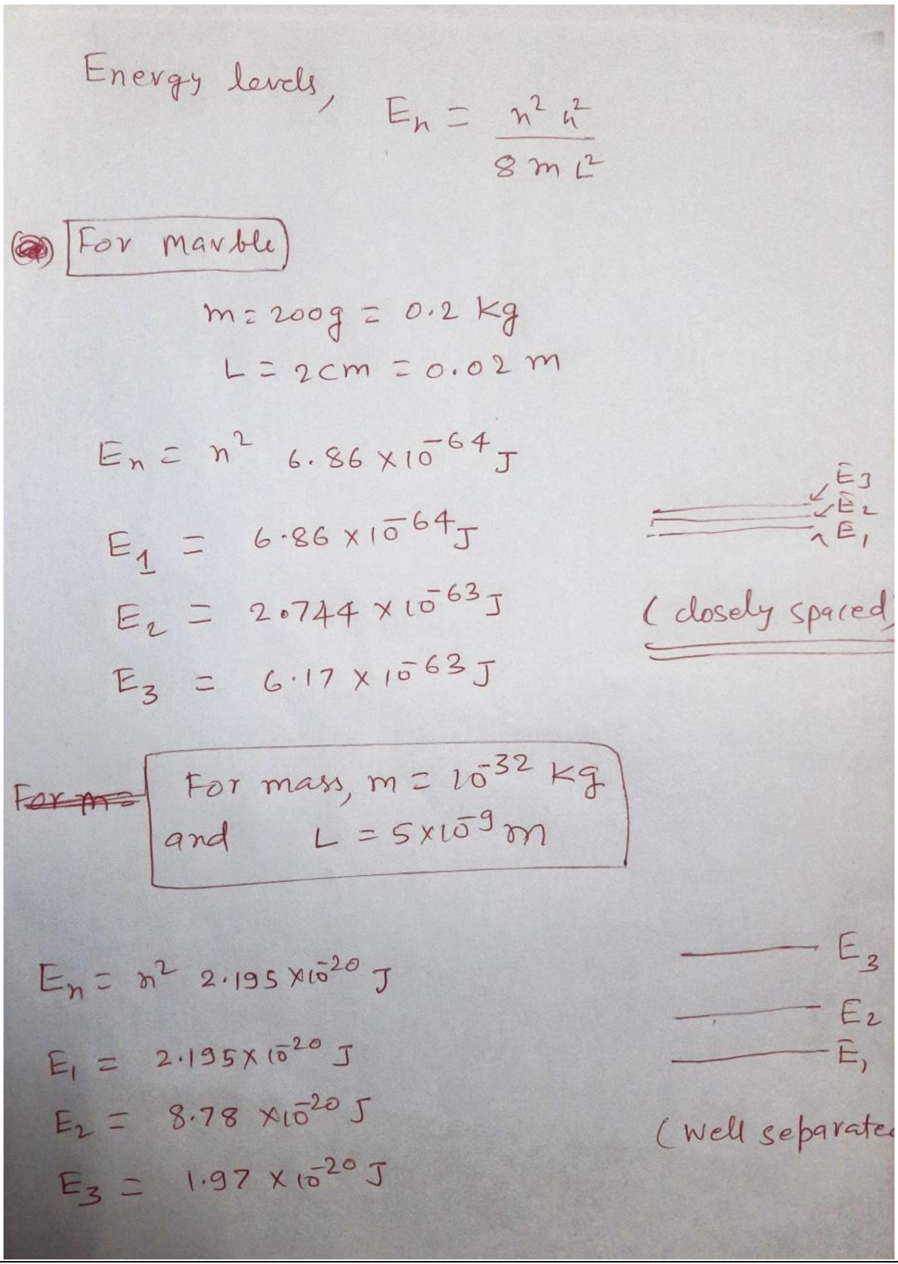
$$\Rightarrow A = \frac{1}{\sqrt{2L}}$$

The probability to find the particle between 0 to L is

$$\int_0^L |\psi|^2 dx = \int_0^L \left(\frac{1}{2L}\right) dx$$

$$= \frac{1}{2L}[x]_0^L = \frac{1}{2\cancel{L}} \times \cancel{L}$$

$$= \frac{1}{2}$$

4.	(a) Calculate the first three energy levels for a 200 gm marble confined in a box of width 2 cm using the particle in a one-dimensional box model. Recalculate the energy levels when the mass is reduced to 10^{-32} kg and the confinement region is reduced to 5 nm. Compare and sketch the energy level spacing for both cases, highlighting the effect of mass and confinement size on quantization. Key: 2 marks for calculating the energy levels of marble, and 2 marks for calculating the energy levels of particles after reducing mass and confinement length. 1 mark for comparing the effects on energy level spacing as shown below.  Energy levels, $E_n = \frac{n^2 h^2}{8 m L^2}$ (a) For marble $m = 200g = 0.2$ kg $L = 2cm = 0.02$ m $E_n = n^2\ 6.86 \times 10^{-64}$ J $E_1 = 6.86 \times 10^{-64}$ J $E_2 = 2.744 \times 10^{-63}$ J $E_3 = 6.17 \times 10^{-63}$ J E_3 E_2 E_1 (closely spaced) ~~For m=~~ For mass, $m = 10^{-32}$ kg and $L = 5 \times 10^{-9}$ m $E_n = n^2\ 2.195 \times 10^{-20}$ J $E_1 = 2.195 \times 10^{-20}$ J $E_2 = 8.78 \times 10^{-20}$ J $E_3 = 1.97 \times 10^{-20}$ J E_3 E_2 E_1 (Well separate	5	CO3	BL3

	The large difference in energy levels highlights the quantum nature of smaller particles, whereas macroscopic objects like marble exhibit practically unobservable and extremely small energy levels, the difference appears to be much smaller and therefore appears continuous.			
	(b) Electrons with energy 4.0 eV are incident on a barrier 10.0 eV high and 0.50 nm wide. Calculate the transmission probability. Key: The transmission probability of a particle (electron) encountering a barrier can be calculated using **quantum tunneling**. For a rectangular potential barrier, the transmission probability T can be estimated using the formula: $T = e^{-2k_2 L}$ here $k_2 = \frac{\sqrt{2m(U-E)}}{\hbar}$ Given U = 10.0 eV, and E = 4.0 eV and L = 0.5 nm, and $\hbar = 1.05 \times 10 - 34\ J.s$, T is calculated ≈ 3.58 ×10^{-6}	5		
5.	(a) Classify the nanomaterials based on quantum confinement with proper diagrams and examples. Key: To classify the nanomaterials based on quantum confinement with proper diagrams and examples. – 5 Marks Nanomaterials can be classified based on **quantum confinement** into three main categories: **quantum wells**, **quantum wires**, and **quantum dots**. These classifications depend on the dimensionality of the confinement, which restricts the motion of charge carriers (electrons and holes) in specific directions. Here's a detailed explanation: **1. Quantum Wells (2D Confinement)** • **Description**: In quantum wells, charge carriers are confined in one dimension (e.g., the z-axis) but are free to move in the other two dimensions (x and y). This creates a two-dimensional system. • **Examples**: o Semiconductor heterostructures like GaAs/AlGaAs. o Thin films used in lasers and LEDs. • **Applications**: o High-efficiency lasers. o Photodetectors.	10	CO3	BL2

- **Diagram**: Imagine a thin slab of material sandwiched between two layers of higher bandgap materials, forming a "well" where carriers are trapped.

2. Quantum Wires (1D Confinement)

- **Description**: In quantum wires, charge carriers are confined in two dimensions but are free to move along one dimension (e.g., the x-axis). This creates a one-dimensional system.
- **Examples**:
    - Nanowires made of materials like silicon or gallium nitride.
    - Carbon nanotubes.
- **Applications**:
    - Transistors in nanoelectronics.
    - Sensors and energy storage devices.
- **Diagram**: Picture a long, narrow wire where carriers can only move along its length.

3. Quantum Dots (0D Confinement)

- **Description**: In quantum dots, charge carriers are confined in all three dimensions, creating a zero-dimensional system. These are often referred to as "artificial atoms" due to their discrete energy levels.
- **Examples**:
    - CdSe quantum dots used in displays.
    - Nanocrystals in solar cells.
- **Applications**:
    - Quantum computing.
    - Bioimaging and drug delivery.
- **Diagram**: Visualize a small spherical particle where carriers are trapped in all directions.

(b) Discuss the role of surface-to-volume ratio and its effects on any two properties of nanomaterials.

Key Discuss the role of surface-to-volume ratio and its effects on any two properties of nanomaterials. – 5 Marks

The **surface-to-volume ratio (S/V ratio)** is a critical factor in determining the properties of nanomaterials. At the nanoscale, the surface area increases dramatically relative to the volume, leading to significant changes in material behavior. Here's a discussion on its role and effects on two key properties:

1. Chemical Reactivity

- **Role of S/V Ratio**: Nanomaterials have a high proportion of their atoms on the surface compared to bulk materials. A higher S/V ratio means more atoms are exposed to the environment, making them chemically active.
- **Effect**:
    - **Enhanced Catalysis**: Nanomaterials like nanoparticles of gold or platinum serve as excellent catalysts due to their increased active sites.
    - **Reactivity Increase**: Higher surface reactivity makes nanomaterials useful in applications such as drug delivery, where they can bind or interact effectively with biological molecules.
- **Example**: Titanium dioxide (TiO_2) nanoparticles are widely used in photocatalysis to decompose pollutants, owing to their high surface area and reactivity under UV light.

2. Mechanical Strength

- **Role of S/V Ratio**: A high S/V ratio alters the mechanical properties of materials, as surface atoms experience different bonding environments compared to those in the bulk. The high surface energy influences the structural behavior.
- **Effect**:
    - **Increased Hardness**: Nanomaterials often exhibit higher hardness and strength due to the dominance of surface atoms. For example, nanoscale metals or ceramics can withstand larger stresses without deformation.
    - **Deformation Resistance**: Grain boundaries in nanocrystalline materials (resulting from high S/V ratio) act as barriers to dislocation movement, improving their strength.
- **Example**: Nanostructured aluminum shows significantly higher strength compared to bulk aluminum, making it suitable for aerospace applications.