Four Year Undergraduate Course in Physics
Semester IV
Paper Name - Quantum mechanics I
Paper Code - PHY040204

Total Lectures: 45, Credits: 4 (Theory: 03, Lab: 01)

(Total Marks 100: Internal 25+External-75)

Course Objectives

- To learn about the inadequacies of classical mechanics, the origin and need of quantum mechanics, historical developments in quantum mechanics.
- Dual nature of radiation & matter, description of matter wave through wave packet.
- Probabilistic nature and wave function, Schrödinger equation, the uncertainty principle, stationary and non-stationary states.
- Applications of Schrödinger equation in different cases like infinite and finite potential well, tunneling effect, linear harmonic oscillator and H-atom.
- Formulation of quantum mechanics in terms of operators.

Course Outcome: On successful completion of the course students will be able to learn physical and mathematical fundamentals of Quantum physics, and various topics in it. These concepts are used in various branches of physics, like condensed matter physics, lasers, quantum statistics, atomic and molecular physics, particle physics, astrophysics and optics etc.

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Theory :

Unit I : Origin of Quantum Theory (Lectures= 3)

Failure of classical theories, Explanation of Black body radiation, Photoelectric effect, Compton effect, different evidences in support of quantum theory, particle nature of radiation, Bohr's correspondence principle.

Unit II: Dynamical Variables as Operators and Uncertainty Principle (Lectures=10)

Dynamical variables as operators, definition of an operator, different types of operators and their properties, position, energy and momentum operator; commutation relations; introduction to Hilbert space, Dirac notation, eigenvalue and eigenfunctions; expectation value of an operator e.g. position, momentum operator etc, orthonormality condition, Ehrenfest's theorem.

Simultaneous measurement and uncertainty principle; general statement of Heisenberg's uncertainty principle(for any two non commutating operators), different uncertainty relations involving canonical pair of variables; particle trajectory and fuzziness, applications of the position momentum uncertainty principle, application of energy time uncertainty principle to virtual particles and range of an interaction.

Unit III : Matter Wave and Wave-Particle Duality (Lectures = 8)
Wave particle duality and de Broglie wavelength, particle as a wave or matter wave, wave description of particles by wave packets; phase and group velocity, wave function, wave amplitude, probability; Experimental verification of matter wave, Davisson and Germer experiment; linearity and superposition principle, two slit experiments with electrons and photons; Uncertainty principle from wave packet description, Gaussian wave packet and its wave function.

Unit IV : Schrödinger Equation and it's applications (Lectures =24)
Time dependent Schrödinger Equation, Time independent Schrödinger Equation; Physical interpretation and properties of wave function, continuity of a wave function, boundary conditions and emergence of discrete and continuous energy levels; probabilities and normalisation in three and one dimension; equation of continuity, current density in both three and one dimension.

Hamiltonian, stationary states and energy eigenvalues; expansion of an arbitrary wave function as a linear combination of energy eigenfunctions; General solution of the time dependent Schrödinger equation in terms of linear combinations of stationary states, discrete and continuous spectrum, wave function of a free particle, spread of Gaussian wave function in one dimension, Fourier transforms and momentum space wave function.

Applications of Time independent Schrödinger Equation in different problems like : (i) particle in a one dimensional infinite potential well (quantum dot as an example) (ii) particle in a one dimensional finite square potential well (iii) barrier penetration problems – potential step and rectangular potential barrier (tunnel effect) (iv) linear harmonic oscillator (v) spherically symmetric potential for hydrogen atom- radial solution, spherical harmonics, angular momentum operator and different quantum numbers, radial distribution function and shapes of the probability densities for ground & first excited states; degeneracy of states : s, p, d states.

Laboratory :

***A minimum of four experiments to be done*.**

1. Measurement of Planck's constant using black body radiation and photo-detector.
2. Photo-electric effect : Photo current versus intensity and wavelength of light; maximum energy of photo-electrons versus frequency of light.
3. To determine work function of material of filament of directly heated vacuum diode.
4. To determine the Planck's constant using LEDs of at least 4 different colours.
5. To determine the wavelength of H_α emission line of hydrogen atom.
6. To determine the ionisation potential of mercury.
7. To determine the absorption lines in the rotational spectrum of iodine vapour.
8. To determine the value of e/m by (a) magnetic focusing or (b) bar magnet.
9. To setup the Millikan oil drop apparatus and determine the charge of an electron.
10. To show the tunnelling effect in tunnel diode using I-V characteristics.
11. To determine the wavelength of laser source using diffraction from single slit.

12. To determine the wavelength of laser source using diffraction from double slits.
13. To determine (1) wavelength and (2) angular spread of He-Ne laser using plane diffraction grating.

Suggested Books

1. N. Zettili, Quantum Mechanics, John Wiley & Sons (2001).
2. J. J. Sakurai and J. Napolitano, Modern Quantum Mechanics, Cambridge Univ. Press, 2020.
3. Y. R.Waghmare, Fundamentals of Quantum Mechanics, Wheeler publishing (2014).
4. P. A. M. Dirac, Principles of Quantum Mechanics, Oxford University Press (1981).
5. B. H. Bransden and C. J. Joachain, Quantum Mechanics, Pearson Education 2nd Ed. (2004).
6. K. Gottfried and T-M Yan, Quantum Mechanics: Fundamentals,2nd Ed., Springer (2003).
7. R. Shankar, Principles of Quantum Mechanics, Springer (India) (2008).
8. D. J. Griffiths, Introduction to Quantum Mechanics, Pearson Education (2005).
9. L. Schiff, Quantum Mechanics, Mcgraw-Hill (1968).
10. A. K. Ghatak and S. Lokanathan, Quantum Mechanics: Theory and Applications, Springer (2002).
11. A. Bieser, Concepts of Modern Physics, McGraw Hill (2002).
12. Arno Bohm, Quantum Mechanics : Foundations and Applications, 3rd Edition, Springer (1993).
13. H. C. Verma, Quantum Mechanics, TBS publications (2019).
14. P. M Mathews and K. Venkatesan, A Text book of Quantum Mechanics, 2nd Edition, McGraw Hill, (2010).