Blow-up Syllabus

Course Code and Title

BPHYS102/202 Quantum Physics and Applications (CS)

Module - 1 Outline

Quantum Mechanics:

de Broglie Hypothesis, Heisenberg's Uncertainty Principle and its application (Broadneing of Spectral Lines), Principle of Complementarity, Wave Function, Time independent Schrödinger wave equation (Derivation), Physical significance of a wave function and Born Interpretation, Expectation value and its physical significance, Eigen functions and Eigen values, Particle inside one dimensional infinite potential well, Role of higher dimensions (Qualitative), Waveforms and Probabilities, Particle inside a finite potential well and quantum tunneling, Numerical Problems.

Number of Hours - 8

Module - 1 Blow-up

Subtopics	Topics to be covered	Duration
De-Broglie Hypothesis & Matter Waves	Wave-particle duality, de-Broglie wavelength formula ($\lambda = h/p$ Derivation by analogy)	½ Hour
Heisenberg's Uncertainty Principle (HUP)	Mathematical relations $\Delta x \cdot \Delta p \geq \hbar/2$, $\Delta E \cdot \Delta t \geq \hbar/2$, applications to spectral line broadening, Atomic stability.	1 Hour
Complementarity Principle & Wave Function	Bohr's complementarity principle, Probabilistic nature of quantum mechanics and Born interpretation of wave function ψ	½ Hour
Schrödinger Wave Equation	Derivation of the time-independent Schrödinger equation from the classical wave equation in 1D, Extension to 3D(mention).	1 Hour
Eigen values and Eigen functions, Infinite 1D Potential Well	Eigen values and Eigen functions (qualitative), Schrodinger Wave Equation for 1D infinite potential well, Solutions of Schrödinger equation in an infinite well, Quantization of energy levels, normalization of wave function, Waveforms and Probabilities	1 ½ Hour
Higher Dimensions, Expectation Values,	Extension to 2D & 3D(Qualitative), expectation values of position, momentum, energy and physical significance,	½ Hour
Finite Potential Well & Tunneling	Finite square well solutions (only equations and solutions), concept of barrier penetration, quantum tunneling, applications in devices	1 Hour
Numerical Problems	Calculations on de-Broglie wavelength from Energy, uncertainty principle(Energy and time), Energy eigenvalues (Particle in 1D Box)	2 Hour

Module - 2 Outline

Electrical Properties of Metals and Semiconductors:

Failures of classical free electron theory, Mechanisms of electron scattering in solids, Matheissen's rule, Assumptions of Quantum Free Electron Theory, Density of States, Fermi Dirac statistics, Fermi Energy, Variation of Fermi Factor With Temperature and Energy, Fermi Dirac Distribution, Expression for Carrier Concentration in conductors, Success of QFET, Derivation of electron concentration in an intrinsic semiconductor, Expression for electron and hole concentration in extrinsic semiconductor, Fermi level for intrinsic(with derivation) and extrinsic semiconductor (no derivation), Hall effect, Numerical Problems.

Module - 2 Blow-up

Subtopics	Topics to be covered	Duration
Classical Free Electron Theory(CFET) Mobility & Matthiessen’s Rule	A Review (Self Study), Definition of drift velocity and mobility, Electron scattering mechanisms in Solids, Matthiessen’s rule for resistivity.	1 Hour
Failures of Classical Theory	Specific heat of metals, temperature dependence inconsistencies, electron concentration dependence on conductivity (qualitative)	½ Hour
Quantum Free Electron Theory (QFET), Fermi Energy & Fermi Factor,	Assumptions, Density of States (Qualitative, Mention of DOS expression) Fermi-Dirac Statistics, Fermi Energy (Qualitative), Variation of Fermi factor f(E) with energy & temperature, T = 0 K and finite T cases.	1 Hour
Expression for Carrier Concentration, Success of QFET	Derivation of Expression for ‘n’ using N(E) dE=g(E) dE . f(E), Mention of Expression for electrical conductivity as per QFET, Success of QFET (in line with the failures of CFET).	1 ½ Hours
Carrier Concentration and Fermi level in semiconductors	Intrinsic and Extrinsic Semiconductors (Self Study- Flipped Class), Derivation of electron concentration in an intrinsic semiconductor, Expression for electron and hole concentration in extrinsic semiconductor(Mention), Fermi level for intrinsic semiconductor (derivation) and extrinsic semiconductor(No derivation),	2 Hours
Hall Effect	Hall Effect , Explanation, Derivation of Expression for Hall Voltage. Applications	1 Hour
Numerical Problems	Numerical problems on Fermi factor and Hall coefficient	1 Hour

Module - 3 Outline

Superconductivity :

Zero resistance state, Persitent current, Meissner effect, Critical temperature, Critical current (Silsbee Effect) – Derivation of expression of critical current for a cylindrical wire using ampere’s law, Critical field, Formation of Cooper pairs - Mediation of phonons, Two-fluid model, BCS Theory - Phase coherent state, Limitations of BCS theory, Examples of systems with low and high electron-phonon coupling, Type-I and Type-II superconductors, Formation of Vortices, Explanation for upper critical field, Cooper pair Tunneling (Andreev reflection), Josephson junction, Flux quantization, DC and AC SQUID(Qualitative), Numerical Problems.

Number of Hours - 8

Module - 3 Blow-up

Subtopics	Topics to be covered	Duration
Zero Resistance state, Persistent Current & Meissner Effect	Superconducting transition, persistent currents, Meissner effect (qualitative)	1 Hour
Critical temperature, Critical current (Silsbee Effect)-Derivation for a cylindrical wire using ampere's law	Critical temperature, critical current, Silsbee effect, Derivation for a cylindrical wire using ampere's law, critical field	1 Hour
BCS Theory & Cooper Pairs	Concepts of phonon, Electron-phonon interactions, formation of Cooper pairs, energy gap concept	1 Hour
Two-fluid Model, Examples of systems with low and high electron-phonon coupling	Division into normal and superconducting electron fractions, explanation of thermal conductivity, Examples of systems with Low and High electron-Phonon Coupling.	1 Hour
Type I & II Superconductors	M-H characteristics, Type I (complete flux expulsion), Type II (vortex formation, Explanation for Upper Critical field)	½ Hour
Andreev Reflection	Cooper pair tunneling process, retro-reflection at N-S interface	½ Hour
Josephson Junction, flux quantization, DC & AC Josephson Effect	Josephson Junction, flux quantization, DC & AC Josephson effect,	1 Hour
SQUIDs & Numerical Problems	DC and RF SQUIDs (Qualitative), Numerical problems on critical field & critical current.	2 Hour

Module - 4 Outline

Photonics :

Interaction of radiation with matter - Einstein's A and B coefficients and derivatio of expression for energy density, Prerequisites for lasing actions, Types of LASER – Semiconductor diode LASER, Use of attenuators for single photon sources, Optical modulators – Pockel's effect, Kerr effect, Photodetectors : Single Photon Avalanche Diode, Superconducting Nanowire Single Photon Detector, Optical fiber, Derivation of Numerical aperture, V-number, Number of modes, losses in optical fiber, Mach-Zehnder interferometer, Numerical problems.

Number of Hours - 8

Module - 4 Blow-up

Subtopics	Topics to be covered	Duration
Radiation-Matter Interaction	Basic principles (spontaneous & stimulated emission, absorption processes), Einstein A and B coefficients and derivation of expression for energy density.	1 Hour
Lasing Prerequisites	Population inversion, pumping mechanisms, and gain medium requirements (Laser cavity)	½ Hour
Types of laser, Semiconductor Diode Lasers	Types of laser (Solid, Liquid, Gas Lasers) , semiconductor diode laser- Principle, construction and working	1 Hour
Use of attenuators for single photon sources	Single photon Attenuators - Role in quantum communication, intensity control	½ Hour
Optical Modulators-Pockel's effect, Kerr effect	Electro-optic modulators, Pockel's effect, Kerr effect, phase modulation	1 Hour
Photodetectors-single photon avalanche diodes	single-photon avalanche diodes (SPAD) Construction and working, Superconducting Nano-wire Single Photon Detector (SNSPD)	1 Hour
Optical Fibers	Basics of Optical Fibers : Construction and principle (Qualitative), Derivation of numerical aperture, V-number, attenuation & losses	1 ½ Hour
Mach-Zehnder Interferometer & Numericals	Mach-Zehnder Interference principle and working, fiber optics applications, Numerical Problems: LASER on N - Rate emission of photons) & Fiber optics (NA, V-Number and Attenuation)	1 ½ Hour

Module - 5 Outline

Quantum Computing :

Moore's law - limitation of VLSI, Classical vs Quantum Computation, bit, Qubit and its properties, Bloch Sphere, Dirac notation, Brief discussion on types of qubit, Superconducting qubits, Harmonic oscillator (qualitative) – Need for anharmonicity, Charge qubit, Quantum Gates – Pauli Gates, Phase gate (S, T), Hadamard Gate, Two qubit gates – CNOT gate, Predicting the outputs of various combinations of single and two-qubit gates, Numerical Problems.

Number of Hours - 8

Module - 5 Blow-up

Subtopics	Topics to be covered	Duration
Moore's Law & Limitations	Physical limits of miniaturization, motivation for quantum computation	½
Classical vs Quantum Computation	Bits vs Qubits, advantages of quantum computing (parallelism, entanglement)	½
Qubit Properties & Bloch Sphere	Properties of Qubits : Superposition states, entanglement, Measurement(Collapse of states), Quantum Interference. Reversibility. Bloch sphere representation – Diagram and Explanation	1
Dirac Notation and Qubit Types	superconducting qubits, harmonic oscillator model(qualitative), need for anharmonicity, Charge Qubit Dirac notation (|0>, |1>),	1 ½
Operators and Operations (Matrix form)	Unitary and Hermitian operators, inner product, orthogonality, orthonormality	1
Quantum gates-Single-Qubit Gates	Matrix representation of Pauli (X,Y,Z), Phase (S,T), Hadamard gates(Circuit, Matrix, Explanation, Truth Table)	1
Two-Qubit Gates, Entanglement, Bell States	Controlled-NOT gate (Circuit, Matrix, Explanation, Truth Table), Entanglement, Bell states	1
Numerical Problems on Gates	Predictions of circuits with single/two-qubit gates, unitary matrices, matrix operations	1 ½