Bhairab Ganguly College

Department of Physics

SEM-V 2020 [Final Syllabus Distribution]

Core T11 - Quantum Mechanics and Applications

Quantum Mechanics and Applications [TM+RM]	
60 Lectures	**4 Credits**
Basic Formalism	**12 Lectures**
Departure from matter wave description. Quantum mechanics as a new framework to describe the rules of the microscopic world. Postulates of quantum mechanics: State as a vector in a complex vector space, inner product, its properties using Dirac bra-ket notation. Physical observables as Hermitian operators on state space – eigenvalues, eigenvectors and completeness property of the eigenvectors – matrix representation. Measurement statistics. Unitary time-evolution. Demonstration of the rules in 2-level systems. Wave-function as the probability amplitude distribution of a state for the observables with continuous eigenvalues. Position representation and momentum representation of wave-functions and operators. Position, momentum and Hamiltonian operators. Non-commuting observables and incompatible measurement, uncertainty relation. Position-momentum uncertainty principle as an example. Commuting observables and degeneracy; complete set of commuting observables.	
Schrodinger Equation [TM]	**12 Lectures**
Time dependent Schrodinger equation: Time dependent Schrodinger equation and dynamical evolution of a quantum state; Properties of Wave Function. Interpretation of Wave Function Probability and probability current densities in three dimensions; Conditions for physical acceptability of Wave Functions. Normalization and Linear Superposition Principles of the solutions of Schoedinger equation. Wave Function of a Free Particle. Explanation of wave-particle duality in two slit experiment with microscopic particles from the above formalism. Time independent Schrodinger equation-Hamiltonian, stationary states and energy eigenvalues; expansion of an arbitrary wavefunction as a linear combination of energy eigenfunctions; General solution of the time dependent Schrodinger equation in terms of linear combinations of stationary states; Application to spread of Gaussian wave-packet for a free particle in one dimension; wave packets, Fourier transforms and momentum space wave-function; consistency with position-momentum uncertainty principle. Quantum mechanical scattering and tunnelling in one dimension-across a step potential & rectangular potential barrier. Tunnelling effect in the case of alpha decay and in scanning tunnel microscopes (qualitative discussion only).	
Bound states in an arbitrary potential [TM]	**8 Lectures**
Bound states – continuity of wave function, boundary condition and emergence of discrete energy levels. One dimensional infinitely rigid box- energy eigenvalues and eigenfunctions, normalization; generalisation for three dimension and degeneracy of energy levels. Quantum dot as example. Quantum mechanics of simple harmonic oscillator-energy levels and energy eigenfunctions; Hermite polynomials; ground state, zero point energy & uncertainty principle. Raising-lowering operator and their applications.	
Quantum theory of hydrogen-like atoms [RM]	**10 Lectures**
Time independent Schrodinger equation in spherical polar coordinates with spherically symmetric potential; separation of variables for second order partial differential equation; angular momentum operators, commutation relations, ladder operators & quantum numbers; spherical co-ordinate representation of angular momentum operators. Radial wavefunctions for Coulomb potential; shapes of the probability densities for ground & first excited states. Commuting observables and degeneracy of energy levels. Orbital angular momentum quantum numbers l and m; s, p, d,shells-subshells. Applications for Hydrogen atom, He^+ ion, positronium and alikes.	
Applications of Quantization Rules in Atomic Physics [RM]	**18 Lectures**
Absence of exact stationary state solutions for relativistic effects and for multi-electron atoms. Approximate description by semi-classical vector model of atoms. Electron angular momentum quantization rules. Space quantization. Orbital Magnetic Moment and Magnetic Energy, Gyromagnetic Ratio and Bohr magneton. Electron Spin as relativistic quantum effect (qualitative discussion only), Spin Angular Momentum. Spin Magnetic Moment. Stern-Gerlach Experiment. Larmor Precession. Multi-electron atoms. Pauli's Exclusion Principle (statement only). Spectral Notations for atomic States. Aufbau	

principle, *n+l* rule (qualitative discussion only). Periodic table.
Spin orbit interaction. Addition of angular momentum (statement only). Total angular momentum of electron. Total energy level correction due to relativistic effects and spin-orbit interaction (statement only). Fine structure splitting.
Normal and Anomalous Zeeman Effect, Lande *g* factor, Paschen Back effect. Stark Effect (Qualitative Discussion only).
Spin-orbit coupling in atoms – L-S and J-J coupling schemes. Hund's Rule. Term symbols. Spectra of Hydrogen and Alkali Atoms (Na etc.). Mosley's law and its explanation from Bohr theory.

Core P11 – Quantum Mechanics and Applications Lab

Quantum Mechanics and Applications [DB+SS]	
60 class hours	**2 Credits**

General Topics: Detailed discussion on the underlying theory of the following numerical methods including efficiency of the method in each case.

List of Practical

Solve the s-wave Schrodinger equation for the ground state and the first excited state of the hydrogen atom:
Here, m is the reduced mass of the electron. Obtain the energy eigenvalues and plot the corresponding wavefunctions. Remember that the ground state energy of the hydrogen atom is □ □-13.6 eV. Take e = 3.795 $(eVÅ)^{1/2}$, ħc = 1973 (eVÅ) and m = 0.511×10^{6} eV/c^{2}.
Solve the s-wave radial Schrodinger equation for an atom:
where m is the reduced mass of the system (which can be chosen to be the mass of an electron), for the screened coulomb potential
Find the energy (in eV) of the ground state of the atom to an accuracy of three significant digits. Also, plot the corresponding wavefunction. Take e = 3.795 $(eVÅ)^{1/2}$, m = 0.511x106 eV/c2, and a = 3 Å, 5 Å, 7 Å. In these units ħc = 1973 (eVÅ). The ground state energy is expected to be above -12 eV in all three cases.
Solve the s-wave radial Schrodinger equation for a particle of mass m:
For the anharmonic oscillator potential for the ground state energy (in MeV) of particle to an accuracy of three significant digits. Also, plot the corresponding wave function. Choose m = 940 MeV/c^{2}, k = 100 MeV fm^{-2}, b = 0, 10, 30 MeV fm^{-3} In these units, cħ = 197.3 MeV fm. The ground state energy I expected to lie between 90 and 110 MeV for all three cases.
Solve the s-wave radial Schrodinger equation for the vibrations of hydrogen molecule:
Where μ □ □ is the reduced mass of the two-atom system for the Morse potential
Find the lowest vibrational energy (in MeV) of the molecule to an accuracy of
three significant digits. Also plot the corresponding wave function. Take: m = 940x106eV/C^{2}, D = 0.755501 eV, α = 1.44, r_o = 0.131349 Å

Core T12 - Solid State Physics

Solid State Physics [SC+DB]	
60 Lectures	**4 Credits**
Crystal Structure [SC]	**12 Lectures**
Solids: Amorphous and Crystalline Materials. Lattice Translation Vectors. Lattice with a Basis. Unit Cell. Miller Indices. Reciprocal Lattice. Types of Lattices. Brillouin Zones. Diffraction of X-rays by Crystals. Laue's condition and Bragg's Law. Structure Factor.	
Elementary Lattice Dynamics [SC]	**10 Lectures**
Lattice Vibrations and Phonons: Linear Monoatomic and Diatomic Chains. Acoustical and Optical Phonons. Qualitative Description of the Phonon Spectrum in Solids. Dulong and Petit's Law, its limitations. Einstein's theories of specific heat of solids, its limitations.	
Magnetic Properties of Matter [SC]	**8 Lectures**
Dia-, Para-, Ferri- and Ferromagnetic Materials. Classical Langevin Theory of dia– and Paramagnetic Domains. Quantum Mechanical Treatment of Paramagnetism. Curie's law, Weiss's Theory of Ferromagnetism and Ferromagnetic Domains. Discussion of B-H Curve. Hysteresis and Energy Loss.	
Dielectric Properties of Materials [DB]	**8 Lectures**
Polarization. Local Electric Field at an Atom. Depolarization Field. Electric Susceptibility. Polarizability. Clausius Mosotti Equation. Classical Theory of Electric Polarizability. Normal and Anomalous Dispersion. Cauchy and Sellmeir relations. Langevin-Debye equation. Complex Dielectric Constant. Optical Phenomena.	
Ferroelectric Properties of Materials [DB]	**6 Lectures**

Structural phase transition, Classification of crystals, Piezoelectric effect, Pyroelectric effect, Ferroelectric effect, Electrostrictive effect, Curie-Weiss Law, Ferroelectric domains, PE hysteresis loop.

Drude's theory [DB]	**6 Lectures**
Free electron gas in metals, effective mass, drift current, mobility and conductivity, Hall effect in metals. Thermal conductivity. Lorentz number, limitation of Drude's theory	
Elementary band theory [DB]	**6 Lectures**
Kronig Penny model. Band Gap. Conductor, Semiconductor (P and N type) and insulator. Conductivity of Semiconductor, mobility, Hall Effect. Measurement of conductivity (04 probe method) & Hall coefficient.	
Superconductivity [DB]	**4 Lectures**
Experimental Results. Critical Temperature. Critical magnetic field. Meissner effect. Type I and type II Superconductors, London's Equation and Penetration Depth. Isotope effect.	

Core P12 – Solid State Physics Lab

Solid State Physics [SC+SS]	
60 class hours	**2 Credits**
General Topics: Discussion on the operation of the relevant circuits used for the different studies in the following experiments.	
List of Practical	
To determine the Coupling Coefficient of a Piezoelectric crystal. To measure the Dielectric Constant of a dielectric Materials with frequency To study the characteristics of a Ferroelectric Crystal. To draw the BH curve of Fe using Solenoid & determine energy loss from Hysteresis. To measure the resistivity of a semiconductor (Ge) with temperature by reverse bias characteristics of Ge diode (room temperature to 80 oC) and to determine its band gap. To determine the Hall coefficient of a semiconductor sample. To study temperature coefficient of a semiconductor (NTC thermistor) Measurement of susceptibility of paramagnetic solution (Quinck`s Tube Method) To measure the Magnetic susceptibility of Solids. To determine the complex dielectric constant and plasma frequency of metal using Surface Plasmon resonance (SPR) To determine the refractive index of a dielectric layer using SPR	

Department Specific Electives Subjects Syllabus

DSE T3 – Advanced Dynamics

Advanced Dynamics [SS+TS+TM+DB+SC]	
75 Lectures	**6 Credits**
Lagrangian & Hamiltonian Dynamics [SS]	**15 Lectures**
Lagrange's equation for the cases with semi-holonomic constraints. Evaluation of constraint forces in general. Simple problems with both time-dependent and time independent constraints. Idea of canonical transformations. Generating functions. Properties of canonical transformation. Invariance of Poisson bracket. Use of canonical transformations in solving Hamilton's equations; harmonic oscillator problem as test case.	
Rigid Body Mechanics [TS]	**10 Lectures**
Definition of rigid body. General motion as combination of translation and rotation. Rotation of rigid body and the relation between its angular momentum and angular velocity. Moment of inertia and product of inertia. Kinetic energy of rotation. Principal axis transformation and principal moments of inertia, application in simple cases. Euler equations for free top and their solutions describing the motion of symmetric bodies.	
Small Amplitude Oscillations [TM]	**10 Lectures**
Minima of potential energy and points of stable equilibrium, expansion of the potential energy around a minimum, small amplitude oscillations about the minimum, normal modes of oscillations example of N identical masses connected in a linear fashion to (N -1) - identical springs.	
Dynamical Systems [TM 5 DB 20]	**25 Lectures**
Definition of a continuous dynamical system. The idea of phase space, flows and trajectories. Autonomous	

and non-autonomous systems, dimensionality. Linear stability analysis to study the behaviour of an 1-dimensional autonomous system. Illustration of the method using the single particle system described by v=f(x) and comparing it with the exact analytical solution. Extension of the method for simple mechanical systems as 2-dimensional dynamical systems, categorisation of equilibrium/fixed points : illustrations for the free particle, particle under uniform gravity, simple and damped harmonic oscillator (both under-damped and over-damped). Sketching flows and trajectories in phase space; sketching variables as functions of time, relating the equations and pictures to the underlying physical intuition. Study on the behaviour of the quartic oscillator with an attractive or repulsive quadratic term in the potential; idea of bifurcation. Phase space diagram for the general motion of a pendulum and its behaviour. Oscillator with non-linear damping, Van-der-Pol oscillator as the example, behaviour in large dqamping limit, idea of limit cycle. Discrete time dynamical systems, examples. Description by iterative map. Logistic map: Dynamics from time series. Cobweb iteration (using calculator or simple programs only). Fixed points. Parameter dependence- steady, periodic and chaos states. Idea of chaos and Lyapunov exponent.	
Fluid Dynamics [SC]	**15 Lectures**
Basic physics of fluids: The continuum hypothesis- concept of fluid element or fluid parcel; Definition of a fluid- shear stress; Fluid properties- viscosity, thermal conductivity, mass diffusivity, other fluid properties and equation of state; Flow phenomena- flow dimensionality, steady and unsteady flows, uniform & non-uniform flows, viscous & inviscid flows, incompressible & compressible flows, laminar and turbulent flows, rotational and irrotational flows. Euler equation and Navier-Stokes equation, qualitative description of turbulence, Reynolds number.	
Reference Books	
Classical Mechanics, H.Goldstein, C.P. Poole, J.L. Safko, 3rd Edn. 2002, Pearson Education. Mechanics, L. D. Landau and E. M. Lifshitz, 1976, Pergamon. Classical Electrodynamics, J.D. Jackson, 3rd Edn., 1998, Wiley. The Classical Theory of Fields, L.D Landau, E.M Lifshitz, 4th Edn., 2003, Elsevier. Introduction to Electrodynamics, D.J. Griffiths, 2012, Pearson Education. Classical Mechanics, P.S. Joag, N.C. Rana, 1st Edn., McGraw Hall. Classical Mechanics, R. Douglas Gregory, 2015, Cambridge University Press. Classical Mechanics: An introduction, Dieter Strauch, 2009, Springer. Solved Problems in classical Mechanics, O.L. Delange and J. Pierrus, 2010, Oxford Press	

DSE T4 - Nuclear and Particle Physics

Nuclear and Particle Physics [TS+RM+SS]	
75 Lectures	**6 Credits**
General Properties of Nuclei [RM]	**10 Lectures**
Constituents of nucleus and their Intrinsic properties, quantitative facts about mass, radii, charge density (matter density), binding energy, average binding energy and its variation with mass number, main features of binding energy versus mass number curve, N/A plot, angular momentum, parity, magnetic moment, electric moments, nuclear excites states.	
Nuclear Models [TS]	**12 Lectures**
Liquid drop model approach, semi empirical mass formula and significance of its various terms, condition of nuclear stability, two nucleon separation energies, Fermi gas model (degenerate fermion gas, nuclear symmetry potential in Fermi gas), evidence for nuclear shell structure, nuclear magic numbers, basic assumption of shell model, concept of mean field, residual interaction, concept of nuclear force.	
Radioactivity decay [TS]	**10 Lectures**
(a) Alpha decay: basics of α-decay processes, theory of α- emission, Gamow factor, Geiger Nuttall law, α-decay spectroscopy. (b) □-decay: energy kinematics for □-decay, positron emission, electron capture, neutrino hypothesis. (c) Gamma decay: Gamma rays emission & kinematics, internal conversion.	
Nuclear Reactions [SS]	**8 Lectures**
Types of Reactions, Conservation Laws, kinematics of reactions, Q-value, reaction rate, reaction cross section, Concept of compound and direct Reaction, resonance reaction, Coulomb scattering (Rutherford scattering).	
Interaction of Nuclear Radiation with matter [SS]	**8 Lectures**
Energy loss due to ionization (Bethe- Block formula), energy loss of electrons, Cerenkov radiation. Gamma	

ray interaction through matter, photoelectric effect, Compton scattering, pair production, neutron interaction with matter.	
Detector for Nuclear Radiations [SS]	**8 Lectures**
Gas detectors: estimation of electric field, mobility of particle, for ionization chamber and GM Counter. Basic principle of Scintillation Detectors and construction of photo-multiplier tube (PMT). Semiconductor Detectors (Si and Ge) for charge particle and photon detection (concept of charge carrier and mobility), neutron detector.	
Particle Accelerators [RM]	**5 Lectures**
Accelerator facility available in India: Van-de Graaff generator (Tandem accelerator), Linear accelerator, Cyclotron, Synchrotrons.	
Particle physics [TS]	**14 Lectures**
Particle interactions; basic features, types of particles and its families. Symmetries and Conservation Laws: energy and momentum, angular momentum, parity, baryon number, Lepton number, Isospin, Strangeness and charm, concept of quark model, color quantum number and gluons.	

GE T5 - Digital, Analog Circuits and Instrumentation

Digital, Analog Circuits and Instrumentation [SC+SS+TS]	
60 Lectures	**4 Credits**
Digital Circuits [SS]	**15 Lectures**
Difference between Analog and Digital Circuits. Binary Numbers. Decimal to Binary and Binary to Decimal Conversion, AND, OR and NOT Gates (Realization using Diodes and Transistor). NAND and NOR Gates as Universal Gates. XOR and XNOR Gates. De Morgan's Theorems. Boolean Laws. Simplification of Logic Circuit using Boolean Algebra. Fundamental Products. Minterms and Maxterms. Conversion of a Truth Table into an Equivalent Logic Circuit by (1) Sum of Products Method and (2) Karnaugh Map Binary Addition. Binary Subtraction using 2's Complement Method). Half Adders and Full Adders and Subtractors, 4-bit binary Adder-Subtractor.	
Semiconductor Devices and Amplifiers [SC]	**15 Lectures**
Semiconductor Diodes: P and N type semiconductors. Barrier Formation in PN Junction Diode. Qualitative Idea of Current Flow Mechanism in Forward and Reverse Biased Diode. PN junction and its characteristics. Static and Dynamic Resistance. Principle and structure of (1) LEDs, (2) Photodiode, (3) Solar Cell Bipolar Junction transistors: n-p-n and p-n-p Transistors. Characteristics of CB, CE and CC Configurations. Active, Cutoff & Saturation regions Current gains α and β. Relations between α and β. Load Line analysis of Transistors. DC Load line & Q- point. Voltage Divider Bias Circuit for CE Amplifier. H-parameter, Equivalent Circuit. Analysis of single-stage CE amplifier using hybrid Model. Input & output Impedance. Current, Voltage and Power gains. Class A, B & C Amplifiers.	
Operational Amplifiers (Black Box approach) [TS]	**14 Lectures**
Characteristics of an Ideal and Practical Op-Amp (IC 741), Open-loop and closed- loop Gain. CMRR, concept of Virtual ground. Applications of Op-Amps: (1) Inverting and non-inverting Amplifiers, (2) Adder, (3) Subtractor, (4) Differentiator, (5) Integrator, (6) Zero crossing detector. Sinusoidal Oscillators: Barkhausen's Criterion for Self-sustained Oscillations. Determination of Frequency of RC Oscillator	
Instrumentations	**16 Lectures**
Introduction to CRO: Block Diagram of CRO. Applications of CRO: (1) Study of Waveform, (2) Measurement of Voltage, Current, Frequency, and Phase Difference. **TS 6** Power Supply: Half-wave Rectifiers. Centre-tapped and Bridge Full-wave Rectifiers Calculation of Ripple Factor and Rectification Efficiency, Basic idea about capacitor filter, Zener Diode and Voltage Regulation. **SC 7** Timer IC: IC 555 Pin diagram and its application as Astable and Monostable Multivibrator. **TS 3**	

GE P5 – Digital, Analog Circuits and Instruments Lab

Digital, Analog Circuits and Instruments [TS+RM]	
60 class hours	**2 Credits**
List of Practical	

To measure (a) Voltage, and (b) Frequency of a periodic waveform using CRO
To verify and design AND, OR, NOT and XOR gates using NAND gates.
To minimize a given logic circuit.
Half adder, Full adder and 4-bit Binary Adder.
Adder-Subtractor using Full Adder I.C.
To design an astable multivibrator of given specifications using 555 Timer.
To design a monostable multivibrator of given specifications using 555 Timer.
To study IV characteristics of PN diode, Zener and Light emitting diode
To study the characteristics of a Transistor in CE configuration.
To design a CE amplifier of given gain (mid-gain) using voltage divider bias.
To design an inverting amplifier of given gain using Op-amp 741 and study its frequency response.
To design a non-inverting amplifier of given gain using Op-amp 741 and study its Frequency Response.
To study Differential Amplifier of given I/O specification using Op-amp.
To investigate a differentiator made using op-amp.
To design a Wien Bridge Oscillator using an op-amp.

GE T6 - Perspectives of Modern Physics

Perspectives of Modern Physics [TM+RM+SS+DB]	
75 Lectures	**6 Credits**
Relativistic Dynamics [DB]	**8 Lectures**
Brief summary of Lorentz transformation and time dilation, length contraction, velocity addition etc. (no derivation required). Elastic collision between two particles as observed from two inertial frames with relative velocity, idea of relativistic momentum and relativistic mass. Mass-energy equivalence.	
Quantum Theory of Light [DB]	**5 Lectures**
Review on the limitations of classical theory of electromagnetic radiation within a cavity and its solution by Planck's quantum hypothesis (no derivation required). Statement of Planck's law of black body radiation. Photoelectric effect. Einstein's postulate on light as a stream of photons. Compton's scattering and its explanation.	
Bohr's model [RM]	**4 Lectures**
Limitations of Ruherford's model of atomic structure. Bohr's model, its successes and limitations.	
Wave-particle Duality [RM]	**6 Lectures**
De Broglie's hypothesis – wave particle duality. Davisson-Germer experiment. Connection with Einstein's postulate on photons and with Bohr's quantization postulate for stationary orbits. Heisenberg's uncertainty relation as a consequence of wave-particle duality. Demonstration by γ-ray microscope thought experiment. Estimating minimum energy of a confined particle using uncertainty principle.	
Wave-function Description [TM]	**7 Lectures**
Two slit interference experiment with photons, atoms & particles; linear superposition principle of associated wave functions as a consequence; Departure from matter wave interpretation and probabilistic interpretation of wave function; Schroedinger equation for non-relativistic particles; Momentum and Energy operators; stationary states. Properties of wave function. Probability and probability current densities in one dimension.	
Stationary State Problems [DB]	**5 Lectures**
One Dimensional infinitely rigid box, energy eigenvalues and eigenfunctions, normalization; Quantum dot as an example. Quantum mechanical scattering and tunnelling in one dimension - across a step potential and across a rectangular potential barrier (qualitative discussion with statements of end results only).	
Atomic Physics [RM]	**15 Lectures**
Quantization rules energy and orbital angular momentum from Hydrogen and Hydrogen like atoms (no derivation); s, p, d,shells-subshells. Space quantization. Orbital Magnetic Moment and Magnetic Energy of electron, Gyromagnetic Ratio and Bohr magneton. Zeeman effect. Electron Spin as relativistic quantum effect (qualitative discussion only), Spin Angular Momentum. Spin Magnetic Moment. Stern-Gerlach Experiment. Larmor Precession. Spin-orbit interaction. Addition of angular momentum (statement only). Energy correction due to relativistic effect and spin-orbit ineraction (statement only). Fine-structure splitting. Multi-electron atoms. Pauli's Exclusion Principle (statement only). Spectral Notations for atomic States. Aufbau principle, *n+l* rule (qualitative discussion only). Periodic table.	

Nuclear Physics [TM]	15 Lectures
Size and structure of atomic nucleus and its relation with atomic weight; Impossibility of an electron being in the nucleus as a consequence of the uncertainty principle. Nature of nuclear force, NZ graph. Binding energy curve. Radioactivity: stability of the nucleus; Law of radioactive decay; Mean life and half-life; Alpha decay, beta decay, gamma emission – basic characteristics. Fission and fusion- mass deficit, relativity and generation of energy; Fission - nature of fragments and emission of neutrons. Basic principle of a nuclear reactor: slow neutrons interacting with Uranium 235; Fusion and basic principle of thermonuclear reactions	
X-ray and Crystal Structure of Solids [SS]	**10 Lectures**
Generation of X-ray. Mosley’s law, explanation from Bohr’s theory. Amorphous and crystalline solids. Lattice structure of crystalline (no categorisation required). Unit cell and basis vectors of a lattice. Diffraction of X-ray by crystalline solid. Bragg’s law.	