M.Sc. Physics Curriculum

Semester 1

Course: History of Science

Course contents: Presentation on historical and scientific overview of a discovery/invention on a topic of student's choice.

Course: Electromagnetic Theory

Course contents:

Electrostatics and Magnetostatics: Laplace and Poisson equation; Boundary value problems; method of images; the concept of Green's function and its use in boundary value problems; Ampere's and Biot-Savart law; the concept of a vector potential

Electric Field in Matter: Dielectrics; conductors; dielectric constant; polarization; Gauss's law in dielectrics; bound charge; susceptibility; permittivity.

Magnetic Fields in Matter: diamagnets, paramagnets, and ferromagnets; the effect of magnetic field on atomic orbits; magnetization; magnetic field inside matter; magnetic susceptibility and permeability

Conservation laws in electrodynamics: Poynting's theorem; Newton's third law in Electrodynamics; conservation of momentum

Electromagnetic Waves: The wave equation for the electric and magnetic field; energy and momentum of electromagnetic waves; electromagnetic waves in matter; waveguides

Potential and Fields: Scalar and vector potential; Gauge transformation; The field of moving point charge

Course: Mathematical Physics

Course contents:

Differential equations: Partial differential equation; first-order differential equation; separation of variables; series solution; Green's function approach examples - heat flow, diffusion, etc.

Matrix analysis: Matrices; determinants; orthogonal matrices; Hermitian matrices; unitary matrices; diagonalization of matrices; Cayley-Hamilton theorem; normal matrices; matrix functions

Fourier and Laplace transform, Fourier series; Fourier and Laplace transform, convolution

Tensor analysis: Elementary idea about tensors; covariant and contravariant tensor; Levi-Civita and Christoffel symbols

Special functions: Bessel function of the first kind; modified Bessel function; orthogonality; Neumann function; Legendre functions (generating functions); Hermite function; Chebyshev polynomial

Course: Classical Mechanics

Course contents:

Basics: Constraints, Principle of virtual work, D'Alembert's Principle, and generalized coordinates with examples

Lagrangian and Hamiltonian formulation of mechanics: Lagrange's equation of motion with examples; Hamilton's equation of motion with examples, generalized coordinates, calculus of variation; holonomic and non-holonomic constraints; phase space; conservation theorems and symmetry properties; stability analysis; Noether's theorem

Introduction to Hamiltonian mechanics: Canonical transformation; Poisson brackets; Hamilton-Jacobi theorem; action-angle variable

Oscillations: Linearization; Small oscillations; behaviour of characteristic frequencies; parametric resonance

Special theory of relativity: Lorentz transformation; relativistic kinematics; mass-energy equivalence

Fundamentals of Non-linear dynamics: Phase space; Limit cycles; Hysteresis, Non-linear oscillators

Course: Quantum Mechanics-I

Course Contents:

The formalism of quantum mechanics: Origin of quantum theory and related experiments; wave function in momentum and coordinate space; Schrödinger equation and its interpretation; the uncertainty principle; linear vector space; eigenvalue and eigenvectors; operators; Hermitian operators; observables; commutator; particle-wave duality; symmetries in quantum mechanics; bra-ket notations; time-evolution operator and Heisenberg picture, Pauli's exclusion principle; identical particle and spin-statistics connection.

Time-independent Schrodinger equation: Free particle; infinite square well; harmonic oscillator; raising and lowering operators; finite square well; tunneling through a potential barrier; the delta function potential.

Quantum mechanics in three dimensions: Schrödinger equation in spherical coordinates; the hydrogen atom problem; angular momentum; addition of angular momenta and spin; scattering in central potential.

Perturbation theory: Time-independent perturbation theory and its application; time-dependent perturbation theory and Fermi's golden rule, WKB, and variational approximations.

Course: Introduction to Computer programming and data analysis

Course contents:

Introduction to programming language**:** Bash and C-Shell, Python and Matlab with hands-on training

Git repositories and version control

Statistical Analysis of Data: Random variable; principles of probability and probability distributions; Basic concepts of hypothesis testing; standard error of the mean; confidence interval; curve fitting; exact test of goodness-of-fit; power analysis; Chi-square test of goodness-of-fit; G-test of goodness-of-fit; Chi-square test of independence; G-test of independent; student's t-test for one sample; student's t-test for two sample; paired t-test; Wilcoxon signed-rank test; correlation and linear regression; Spearman's rank correlation; multiple regression; Kalman filter; hands-on python training for these statistical tests

Advanced data analysis tools: Time-series analysis; frequentist, and Bayesian analysis; hidden Markov models

Semester 2

Course: Thermodynamics and Equilibrium Statistical Mechanics

Course contents:

Thermodynamics: Laws of thermodynamics and their consequences; Carnot's engine through PV and TS diagrams; Carnot's engine for finite-time cycle; entropy; entropy and information; thermodynamic potentials; intrinsic and extrinsic thermodynamic variables; Legendre transformations thermodynamic concepts and theories of phase transition and critical points

Introduction to statistical methods: Random walk and its properties; Binomial and Gaussian distribution

Statistical ensembles: The fundamental postulate of equilibrium statistical mechanics; microstates; macrostates; microcanonical; canonical and grand canonical ensemble and their connection their applications; equilibrium fluctuations in canonical and grand canonical ensemble; mixing of ideal gases; Gibbs paradox; Maxwell's demon; ergodic hypothesis and Liouville's theorem

Interacting system: Ising model; X-Y model, and mean field theory

Quantum Statistics: Difference between classical and quantum statistics; ideal quantum gas; Bose-Einstein statistics; Bose-Einstein condensation; Fermi-Dirac statistics; photons and phonons; degenerate Fermi gas.

Introduction to non-ideal gases and viral expansion

Course: Condensed Matter Physics

Course contents:

Basic concepts: Free electron model: Drude and Sommerfield's model of conductivity; heat capacity: Einstein and Debye model.

Lattices and their properties: Crystal lattices, Reciprocal lattice, Equivalence of Bragg and Laue formulations, Ewald construction, Bonding and packing in crystals.

Crystals and their properties: Crystalline, non-crystalline solid and liquid; Bravais lattice; reciprocal lattice; tight binding model; van der Waals solids; dynamics of an electron in periodic potential; Bloch's theorem; nearly free electron model; Kronig- Penny model; lattice vibrations; effective mass.

Superconductivity: Basic phenomenology; Meissner effect; London's equation; BCS model; Type 1 and Type 2 superconductors; flux quantization in superconductors; Josephson effect; concepts of high temperature superconductivity.

Magnetism: Exchange interactions; diamagnetism; paramagnetism, Hund's rule; Pauli para-magnetism; ferromagnetism and anti-ferromagnetism; domains; Curie-Weiss theory.

Course: Quantum Mechanics-II

Course contents:

Dirac Notation: Kets, Bras, and Operators, Base Kets and Matrix Representations, Measurements, Observables, and the Uncertainty Relations, Change of Basis, Position, Momentum, and Translation, Wave Functions in Position and Momentum Space, Time-Evolution and the Schrodinger Equation, Symmetries and Conservation Laws

Angular Momentum: Rotations and Angular-Momentum Commutation Relations, Eigenvalues and Eigenstates of Angular Momentum, Orbital Angular Momentum, Matrix Representation of Angular Momentum, Geometrical Representation of Angular Momentum, Spin Angular Momentum, Rotations and Addition of Angular Momenta, Properties of the Rotation Operator, Representation of the Rotation Operator, Rotation Matrices and the Spherical Harmonics, Addition of Two Angular Momenta: General Formalism, Calculation of the Clebsch–Gordan Coefficients, Coupling of Orbital and Spin Angular Momenta, Addition of More Than Two Angular Momenta

Identical Particles: Many-Particle Systems, Interchange Symmetry, The Pauli Exclusion Principle, The Exclusion Principle and the Periodic Table

Approximation Methods for Stationary States: Time-Independent Perturbation Theory: Nondegenerate Case, Time-Independent Perturbation Theory: The Degenerate Case, Hydrogen-Like Atoms: Fine Structure and the Zeeman Effect, Variational Methods, The Wentzel–Kramers–Brillouin Method

Time-Dependent Perturbation Theory: Time-Dependent Potentials: The Interaction Picture, Hamiltonians with Extreme Time Dependence, Time-Dependent Perturbation Theory, Applications to Interactions with the Classical Radiation Field

Scattering Theory: Scattering as a Time-Dependent Perturbation, The Scattering Amplitude, The Born Approximation, Resonance Scattering

Course: Numerical Methods and Computational Physics

Course contents:

Numerical Methods: Numerical integration and differentiation; Finite difference calculus; ordinary and partial differential equations; boundary value problems; roots of an equation; solution of the simultaneous linear algebraic equation and matrix eigenvalue problems

Introduction to Simulation Methods: Methods of generating random numbers; random walk and its properties; Brownian diffusion; elementary treatment of Monte-Carlo methods and their applications in statistical mechanics (Ising and X-Y model)

Introduction to parallel computing: Basic idea of parallel computing, its concepts and terminology; parallel computer memory architectures; parallel programming models; designing parallel programs with examples

Course: Electronics

Course contents:

BJT and MOSFET Fundamentals and biasing: CE, CB, and CC biasing for BJT; Common source (CS) biasing for MOSFET; Comparison of CE and CS mode operation

Basic BJT Amplifiers: Base-Biased Amplifier, Emitter-Biased Amplifier, Small-Signal Operation, AC Beta, Two Transistor Models, Multistage Amplifiers, CC Amplifier, Output Impedance

Frequency Effects: Frequency Response of an Amplifier, Decibel Power Gain, Decibel Voltage Gain, Impedance Matching, Bode Plots, The Miller Effect, Frequency Analysis of BJT Stages

Differential Amplifiers: The Differential Amplifier, DC and AC Analysis of a Diff Amp, Input Characteristics of an Op Amp, Common-Mode Gain, Integrated Circuits, The Current Mirror, The Loaded Diff Amp

Operational Amplifiers: Introduction to Op Amps, The 741 Op Amp, The Inverting Amplifier, The Noninverting Amplifier, Two Op-Amp Applications

Feedback and Linear Op-Amp: Four Types of Negative Feedback, VCVS Voltage Gain, Bandwidth

Op-Amp Application: Inverting-Amplifier Circuits, Non-Inverting-Amplifier Circuits, Inverter/Non-Inverter Circuits, Differential Amplifiers, Summing Amplifier Circuits

Digital Principles and Logic: The Basic Gates-NOT, OR, AND, Universal Logic Gates-NOR, NAND, AND-OR-Invert Gates, Positive and Negative Logic

Combinational Logic Circuits and Number Systems: Boolean Laws and Theorems, Truth Table to Karnaugh Map, Binary Number System, Binary-to-decimal Conversion, Decimal-to-binary Conversion, Hexadecimal Numbers

Arithmetic Circuits: Binary Addition, Binary Subtraction, Arithmetic Building Blocks, Arithmetic Logic Unit, Binary Multiplication and Division

Clocks and Timing Circuits: Schmitt Trigger, 555 Timer

Flip-Flops: RS FLIP-FLOPs, Gated FLIP-FLOPs, Edge-triggered FLIP-FLOPs, JK Master-slave FLIP-FLOPs

Registers: Shift Register, Applications of Shift Registers

Course: General Physics lab

Course contents:

1. Error analysis
2. Michelson interferometer
3. Hall effect
4. Millikan's oil drop method
5. Principle of EMI using a rigid pendulum
6. Input, output & transfer characteristics of PNP/NPN
7. Particle size of given powder using diffraction method
8. Series and parallel LCR circuit
9. The numerical Aperture of a given single/multimode fiber
10. Dielectric constant measurement
11. Study of magnetic hysteresis
12. Young’s modulus of the given material

Semester 3

Course: Spectroscopy and Analysis

Course contents:

Theory of atoms: Hydrogen atom the quantization of energy, Alkali atom, Energy level diagram, Effective quantum number and quantum defect, Lamb shift, Two electron atom, LS and JJ coupling, X-ray spectra: energy levels, Emission and absorption spectra

Interaction of atoms with electric and magnetic field: Magnetic effects, Processional motion, Spin-orbit interaction, fine structure, Influence of external magnetic field: Zeeman and Paschen-back effects in one and two electron atom, g-factor

Line width and broadening: General factors influencing spectral line widths (collisional, Doppler Heisenberg), transition probability, population of states, Beer-Lambert law

Molecular Physics: Molecular symmetry, irreducible representation Rotational Spectra of diatomic molecule, intensity of spectral lines, Effect of isotope substitutions, non-rigid rotator, Vibrational spectra of diatomic molecules, harmonic and anharmonic Vibrator-rotational spectra, Pure rotational Raman spectra, linear and symmetric top molecules, vibrational Raman spectra, rotational fine structure, selection rule, overtone spectra.

Electronic properties of molecules: Electronic spectra of diatomic molecules: Born-Oppenheimer approximation, Franck-Condon principle, Dissociation energy and dissociation products, rotational fine structures, pre-dissociation of molecules.

Lasers: spontaneous and stimulated emission; Einstein A and B coefficient; optical pumping population inversion; rate equation; modes of resonators and coherence length.

Course: Nuclear and Particle Physics

Course contents:

Charge, mass, constituents, binding energy and separation energy, level scheme, excited states, spin, parity and isospin, nuclear size and form factors, static electromagnetic moments. Two-nucleon system: a) Deuteron: ground and excited states; electric quadrupole and magnetic dipole moments; non-central force and tensor interaction.

Scattering states: n-p and p-p scattering at low energies; effective range and scattering length; singlet and triplet states; ortho- and para-hydrogen, charge independence of nuclear forces. c) Nucleon-nucleon scattering at higher energies d) Polarization in nucleon-nucleon scattering – l.s forces e) Exchange forces and saturation f) General properties of nucleon-nucleon forces

Yukawa potential. Complex–nuclear structure: a) need for nuclear models b) Fermi Gas model c) Static Liquid Drop model d) Shell Model e) Collective Model f) Unified Model. Nuclear Reactions: a) types of reactions and conservation principles b) Compound Nuclear Reactions – Resonances and the Breit Wigner formula c) Direct Reactions, Optical Model, Nuclear Fission – Bohr – Wheeler theory, Electromagnetic Transitions – Multipole transitions and selection rules.

Relativistic kinematics: Mandelstamm variables; collision and decay kinematics; reaction thresholds; phase space, cross-section and decay formulae, Types of interactions and their relative strengths, Discovery of positron, muon, pion, neutrino and other particles, Symmetry, conservation laws and Quantum numbers, Classification of elementary particles, Determination of quantum numbers of different particles, Hadrons – classification by isospin and hypercharge.

Quarks, color, Leptons, and gauge bosons,
Weak Interactions: a) phenomenology, conservation laws, and selection rules b) Fermi theory of beta decay, V-A interaction b) nonconservation of parity c) Neutral Kaon decay – CP violation and regeneration e) Z and W+ and W- bosons.

Course: Department Elective-I

Course: Department Elective-II

Course: Department Elective-III

Course: Physics Lab II

Semester 4

Course: Open Elective

Course: Dissertation / Project