PHYSICS

1. Mathematical Methods of Physics

Dimensional analysis. Vector algebra and vector calculus. Linear algebra, matrices, Cayley-Hamilton Theorem. Eigenvalues and eigenvectors. Special functions (Hermite, Bessel, Laguerre and Legendre functions).

Fourier transforms and integral equations: Integral transforms, Fourier integral. inversion theorem. Convolution theorem. Integral equations: Types of linear integral equations. Neumann series, separable kernels.

Tensor analysis: Algebra of Tensors, Metric tensor. Raising and lowering of indices. Christoffel symbols. Covariant differentiation; grad, divergence, curl and Laplacian in arbitrary curvilinear coordinates.

2. Classical Mechanics

Mechanics of a system of particles: Center of mass. Conservation of linear and angular momentum in the absence of (net) external forces and torques. The energy equation and the total potential energy of a system of particles.

Motion of a particle in a central force field: Binet equation for central orbit, inverse square law force—Kepler's problem. Poisson brackets and canonical transformations. Non-inertial frames and pseudoforces.

Constraints and their classifications, Generalized co-ordinates, virtual displacements, Lagrangian equation of second kind, examples. Generalized momenta, Hamilton's equations, examples; cyclic co-ordinates. Poisson brackets; equations of motion in the Poisson bracket notation.

3. Electromagnetic Theory

Electrostatics: Gauss's law and its applications, Laplace and Poisson equations, boundary value problems. Magnetostatics: Biot-Savart law, Ampere's theorem. Electromagnetic induction. Maxwell's equations in free space and linear isotropic media; boundary conditions on the fields at interfaces. Scalar and vector potentials, gauge invariance. Electromagnetic waves in free space. Dielectrics and conductors. Reflection and refraction, polarization, Fresnel's law, interference, coherence, and diffraction. Dynamics of charged particles in static and uniform electromagnetic fields. Dispersion relations in plasma. Lorentz invariance of Maxwell's equation. Radiation from moving charges and oscillating dipoles; retarded potentials.

Lasers: spontaneous and stimulated emission, Einstein A & B coefficients. Optical pumping, population inversion, rate equation. Modes of resonators and coherence length.

4. Quantum Mechanics

Wave-particle duality. Schrödinger equation (time-dependent and time-independent). Eigenvalue problems (particle in a box, harmonic oscillator, etc.). Tunneling through a barrier. Wave-function in coordinate and momentum representations. Commutators and Heisenberg uncertainty principle. Dirac notation for state vectors. Motion in a central potential: orbital angular momentum, angular momentum algebra, spin, addition of angular momenta; Hydrogen atom. Stern-Gerlach experiment. Time independent perturbation theory and applications. Variational method. Time dependent perturbation theory and Fermi's golden rule, selection rules. Identical particles, Pauli exclusion principle, spin-statistics connection. Spin-orbit coupling, fine structure. Elementary theory of scattering: phase shifts, partial waves, Born approximation. Relativistic quantum mechanics: Klein-Gordon equation and Dirac equation.

5. Thermodynamic and Statistical Physics

Laws of thermodynamics and their consequences. Thermodynamic potentials, Maxwell relations, chemical potential, phase equilibria. Phase space, micro- and macro-states. Micro-canonical, canonical and grand-canonical ensembles and partition functions. Free energy and its connection with thermodynamic quantities. Classical and quantum statistics, distribution functions. Ideal Bose and Fermi gases. Principle of detailed balance. Blackbody radiation and Planck's distribution law. First- and second-order phase transitions. Bose-Einstein condensation. Diffusion equation. Random walk and Brownian motion.

6. Atomic and Molecular Physics

Quantum states of an electron in an atom. Electron spin. Relativistic corrections for energy levels of hydrogen atom, hyperfine structure and isotopic shift, width of spectrum lines, LS & JJ couplings. Zeeman, Paschen-Bach & Stark effects. Electron spin resonance. Nuclear magnetic resonance, chemical shift. Frank-Condon principle. Born-Oppenheimer approximation. Electronic, rotational, vibrational and Raman spectra of diatomic molecules, selection rules. Microwave spectroscopy: The classification of molecules. The rotational spectra of rigid and non-rigid rotators. The microwave oven. Infrared spectroscopy: The Born-Oppenheimer approximation. The diatomic vibrating rotator, example of the CO molecule. The vibrations of polyatomic molecules; skeletal and group frequencies. Experimental technique (FTIR).

7. Special theory of relativity

Lorentz transformations, relativistic kinematics and mass–energy equivalence. Real coordinates in Minkowski space time. Definition of 4-tensors. The Minkowski scalar product. Orthogonality of 4-vectors. Raising and lowering of 4-tensor indices. Time like, null, and space like vectors and world-lines. The light-cone at an event.

The proper-time interval along the world line of a material particle. The instantaneous (inertial) rest-frame of a material particle and the components of 4-velocity, 4-acceleration and the 4-momentum vector in this frame. Statement of Newton’s second law of motion in this frame. Determination of the fourth component of the 4-force along the world line of

the particle. Motion of a particle under the conservative 3-force field and the energy integral. The rest energy and the relativistic kinetic energy of a particle.

8. Nuclear and Particle Physics

Basic nuclear properties: size, shape and charge distribution, spin and parity. Binding energy, semi-empirical mass formula, liquid drop model. Nature of the nuclear force, form of nucleon-nucleon potential, charge-independence and charge-symmetry of nuclear forces. Deuteron problem. Evidence of shell structure, single-particle shell model, its validity and limitations. Rotational spectra. Elementary ideas of alpha, beta and gamma decays and their selection rules. Fission and fusion. Nuclear reactions, reaction mechanism, compound nuclei and direct reactions.

Nuclear reactors: Slowing down of neutrons, logarithmic decrement in energy, condition for controlled chain reactions, Homogeneous spherical reactor, Critical size. Effect of reflectors. Breeder reactor. Gas filled detectors and scintillation detectors.

Classification of fundamental forces. Elementary particles and their quantum numbers (charge, spin, parity, isospin, strangeness, etc.). Gellmann-Nishijima formula. Quark model, baryons and mesons. C, P, and T invariance. Parity non-conservation in weak interaction.

9. Condensed Matter Physics

X-ray crystallography: Crystalline state. Miller indices. External symmetry of crystals; symmetry operations. Two and three dimensional point groups. Lattices; Three-dimensional lattices; crystal systems and Bravais lattices. Screw and glide operations. Space groups; Diffraction of X-rays by crystals: Laue equations. Reciprocal lattice. Bragg equations. Equivalence of Laue and Bragg equations. Diamagnetism and its origin. Paramagnetism. Quantum theory of paramagnetism. Ferromagnetism. Curie-Weiss law. Spontaneous magnetisation and its variation with temperature. Ferromagnetic domains. Antiferromagnetism. Two sub-lattice model. Experimental facts. Type I and type II supercnductors. Phenomenological theory. London equations. Meissner effect. High frequency behaviour. Thermodynamics of superconductors. Entropy and Specific heat in the superconducting state. Intrinsic Semiconductors. Crystal structure and bonding. Expressions for carrier concentrations. Fermi energy, electrical conductivity and energy gap in the case of intrinsic semiconductors. Extrinsic Semiconductors. Variation of Fermi energy with temperature and impurity concentration in the case of impurity semiconductors.

10. Electronics

Operational amplifiers: inverting amplifier, noninverting amplifier, Summing, scaling and averaging amplifiers, voltage to current converter with grounded load, current to voltage converter, integrator, differentiator. Log and antilog amplifiers, Wave form generators, phase shift oscillator, Wein bridge oscillator. mono-stable and astable multivibrators, First and second order Low pass and High pass filters.

Digital electronics: Boolean Laws and Theorems, Families of gates, RS and JK flip-flops, The Master-Slave JK Flip-Flop, D and T flipflops. Decoders-BCD decoders, Encoders.