Department of Physics

Section-B: Based on area of specialization (20 Marks)
(5 Descriptive questions of 4 marks each)

1. ATOMIC AND MOLECULAR PHYSICS

Atomic Spectroscopy: LS and JJ coupling schemes. Terms for equivalent and non-equivalent electron atom. Spectra of one and two electron systems. Electron spin, spin orbit interaction, fine structure, relativistic correction and radiation correction (Lamb Shift). Electric dipole selection rules. Intensity rules. Alkali type spectra. Zeeman effect. Paschen-Back effect. Stark effect. Hyperfine structure and isotopic shifts.
Complex Spectra: Vector model for three or more valence electrons. Inverted terms.Compound doublet. Inner-Shell Excitation and Autoionization, Line intensities, Transition probabilities, oscillator strength. Forbidden transitions.

Molecular Spectroscopy: Rotational spectra of diatomic molecules. Vibrational spectra of diatomic molecules. Rotation- Vibration spectra of diatomic molecules. Classification of electronic states. Electronic spectra of diatomic molecules. Franck-Condon principle.
Rotational spectra of linear polyatomic molecules: Coriolis interaction and effect of l-type doubling in linear molecules. Nuclear spin statistical weights and their effect on intensities. Rotational spectra of symmetric (prolate and oblate) molecules.

Vibration-rotation spectra of polyatomic molecules: Parallel and perpendicular bands of linear molecules and symmetric top (prolate and oblate) molecules.

Laser Physics and Laser Spectroscopy: Population inversion. Laser rate equations: The three level and four level systems. Optical resonators: Threshold conditions. Schawlow-Townes condition. Dye lasers. Ar+ laser.
Absorption spectroscopy with lasers. Frequency modulation, photoacaustic and optogalvanic spectroscopy. Optical pumping. Stepwise excitation, spectroscopy of Rydberg states.
Saturation spectroscopy. Two-photon absorption.

Experimental Techniques in Spectroscopy: Fourier transform spectroscopy. Non-linear Raman spectroscopy: Stimulated Raman spectroscopy, coherent anti-stokes Raman scattering, hyper Raman effect. Resonance Raman spectroscopy.
Fluorescence Spectroscopy, Quantum yield, Kasha's Rule, Jablanski diagram , Time- resolved Fluorescence, Determination of excited state life time.

2. CONDENSED MATTER PHYSICS

Lattice translation vectors, Miller indices, symmetry operations and space groups; common crystals; Bonding in solids.
Reciprocal lattice, diffraction and structure factor; Brillouin zones; diffraction of x-rays by crystals, Bragg's law, Bragg formulation, Laue formulation, structure factor of bcc, fcc, diamond and hcp structures.

Lattice vibrations: linear monatomic and diatomic chains, acoustical and optical phonons, adiabatic approximation, normal modes of real crystals, dispersion curve; Dulong and Petit's law, Einstein and Debye theories of specific heat of solids, T^3 law.

Free electron theory: Drude model of electrical and thermal conductivity, Sommerfeld model of free election gas, Boltzmann transport equation, d.c. conductivity, Hall effect; defects and imperfections; colour centres.

Energy bands: failure of free electron model, Bloch's Theorem, Kronig-Penny model, Nearly free electron model, tight binding approximation, Fermi surfaces of metals and semiconductors; Semiconductors: equations of motion of charge carriers in electric and magnetic fields, effective mass, intrinsic and extrinsic conductivity, law of mass action.

Classical theory of magnetoconductivity, a.c. conductivity of metals, magnetoresistance in two-band model; Integral quantized Hall effect (IQHE), Fractional quantum Hall effect (FQHE); Alloys, order-disorder transformation, elementary theory of order, Kondo effect.

Plasmons, plasma oscillations, transverse optical modes in plasma, application to optical phonon modes in ionic crystals, interaction of e.m. waves with optical modes (polaritons), LST relation.

Pyroelectricity and ferroelectricity: polarization catastrophe, soft modes; first and second-order phase transitions, Landau theory of phase transition, antiferroelectricity, piezoelectric crystals, applications.

Magnetism: quantum theory of diamagnetism and paramagnetism, van vleckparamagnetism, Pauli paramagnetism, Neel model of antiferromagnetism and ferrimagnetism; spin waves, magnons in ferromagnets; Bloch $T^{3/2}$ law; magnons in antiferromagnets, temperature dependence of spontaneous magnetization; exchange interaction (two electron system), Heisenberg model (spin Hamiltonian); ferromagnetic domains; Bloch wall.

Superconductivity: Meissner effect, London equations, Type I & type II superconductors, Isotope effect, BCS theory; thermodynamic properties; Ginzburg-Landau theory, flux quantization, Giaever tunneling, ac and dc Josephson effects, supercurrent quantum interference, high temperature superconductors, applications of superconductors.

3. HIGH ENERGY PHYSICS

Basic interactions and their mediationg quanta, classification of particles: Fermions, Bosons and leptons and hadrons, particles and anti particles, idea of resonances, conservation rules in fundamental interactions, determination of spin and parity of pions, strange particles , isospin and its conservation, quarks and their quantum numbers and quark model.

Space reflection and parity, parity of charged pion, parity non-conservation in β-decay, charge conjugation, time reversal, CPT theorem, and symmetry and conservation rules.

Neutrino flavours, mass limits, neutrino detection helicity of neutrino, energy of neutrino for pion decay in flight and decay at rest, difference between ν and $\bar{\nu}$ andν_e and ν_μ and neutrino flavour oscillations.

Introduction to Spin ½ and Spin 3/2 Resonances, Quark model of hadrons, quark flavours, confinement and QCD potential. Isospin and Gell-Mann-Nishijima relation.Baryon decuplet and octet.Colour degree of freedom. Magnetic moments of baryons, Mass relations and splittings. Mesons built of light and heavy quarks.

Weak, electromagnetic and strong decays of particles,, weak decays of strange particles and Cabbibo theory. Decay rates for $\pi^{\pm} \rightarrow \mu^{\pm}\nu_{\mu}(\overline{\nu}_{\mu})$ and $\pi^{\pm} \rightarrow e^{\pm}\nu_{e}(\overline{\nu}_{e})$ processes.

Natural Units, Lorentz transformations for energy and momentum, four-vectors and invariants, Laboratory and Centre-of-momentum systems, calculation of energy, momentum and angle of particles produced in nuclear reactions in Lab. and centre-of-momentum frames and their transformations, two body decay at rest and calculation of threshold energies for particle production. Review of Particle Accelerations and Detectors, Linacs, Synchrotrons and colliding-beam accelerators, principle of Cerenkov counters and calorimeters.

Phenomenology of strange particles and their semileptonic and nonleptonic decays.Cabibbo theory. Neutral kaon decays and CP violation. Flavor oscillation, Discovery of quarks, Charm, bottom and top quarks. Quarkonium and their spectra. Predicted c-cbar and b-bbar states with principal quantum numbers n= 1 & 2 with their properties. The quark-antiquark potential, Lepton-Quark symmetry, Quark mixing, CKM matrix (idea).

4. NONLINEAR DYNAMICS

Linear and nonlinear systems-Qualitative features: Physics of nonlinear systems, conservative versus dissipative systems, dynamical equations and constants of motion, phase space, fixed points, periodic orbits, limit cycles, unstable sets. Linearization and stability analysis, existence and uniqueness theorems, invariant curves and quasiperiodicity, PoincaréBendixson theorem.

Bifurcations and onset of chaos: Bifurcations: Saddle-Node, transcritical, pitchfork, Hopf, period doubling and, intermittency, local and global bifurcations, Poincaré cross-section and iterative maps- logistic and Hénon maps. Chaos, features of chaos; continuous and discrete dynamical systems.
Characterization and control of chaos: Sensitive dependence on initial condition, Lyapunov exponents-examples, Coupled systems, quasiperiodicity and strange nonchaotic attractors, ergodicity.
Oscillations and chaos in chemistry, biology and social sciences: some examples. Control of chaos, synchronization- complete, phase, lag, generalized; multistability and riddling, introduction to pattern formation.

Conservative and Stochastic systems: Phase space of simple pendulum, review of KAM theorem, integrable and nonintegrable systems. Chaos in conservative systems, Hénon-Heiles system and the Standard map.
Stochastic systems, random variables and functions, different moments of random variables; auto and cross correlation, mutual information, stochastic vs chaotic motion,

5. NUCLER PHYSICS

Constituents of nucleus and their intrinsic properties, nuclear mass: measurement of mass using mass spectrograph, defect, binding energy. Idea of nuclear fusion-fission, nuclear angular momentum, nuclear magnetic dipole moment, nuclear quadrupole moment.

Alpha decay; energetics of α-decay, Geizer-Nuttal Law, Gamow theory of α-decay. Beta decay: Neutrino hypothesis, Fermi theory of β-decay, Fermi-Kurie plot, comparative half-life. Selection rules: allowed and forbidden transitions, Idea of electron capture, Gamma decay: energetics of γ-decay, Multipole radiations, selection rules, Idea of Internal Conversions of γ-rays and Coulomb excitation.

Radioactive series decay, types of nuclear reactions, conservation laws, Q-value: threshold energy, Energetics of nuclear reactions, energetics of α, β^+, β^- and electron capture (EC) decay. Standard Q-equation and its solution, nuclear reaction, cross-section, idea of differential cross-section, compound reaction mechanism and its verification – Ghoshal's experiment, Idea of pre-compound emission, direct reactions and their signatures. Liquid drop model; Weizsacker's semi-emperical mass formula and some of its applications.

Energy loss due to ionization (Bethe block formula), range and straggling, Cerenkov radiation, Interaction of Gamma radiation with matter, Photoelectric effect, Compton scattering, Pair production. Detectors for Nuclear radiations: Gas filled detectors, G. M. Counter, Basic principle of Scintillation detectors and construction of Photo multiplier tube (PMT). Principle of Semi-Conductor detectors. Position sensitive gas filled detectors.

The s-wave scattering, Collision matrix, Unitary and symmetry properties of the collsions matrix.The Reciprocity. Definition of the R-matrix.The resonance scattering, Berit-Winger one level formula.

Electromagnetic current and its interaction with nucleons and nuclei.Electron scattering from nucleons and nuclei.Four-momentum transfer and Mott scattering, the nucleon and nuclear form factors and their experimental determination. The nucleon-nucleon potential: Conservation laws and invariance principles, general form of the nucleon-nucleon potential.

The ground state of the deuterons: Ground state of the deuteron and D-state admixture, Magnetic and electric quadrupole moments. Electromagnetics properties of nuclei: Transitions probabilities, electric and magnetic multipole moments

Physical description of heavy ion interaction, nuclear rainbow scattering, exotic and super heavy nuclei.

6. QUANTUM OPTICS

Atom, radiation and quantization of radiation field: Brief history of Quantum optics, Coherence, Nonlinear optics, Second-order nonlinear phenomena, Phase-matching, Quantized states in atoms, Radiative transitions in atoms, Lasers oscillations, Laser modes, Field quantization, Light as a quantum harmonic oscillator.

Photon statistics: Photon counting statistics, Classification of light by photon statistics, Semi-classical and quantum theory of photodetection, Photon antibunching, Hanbury Brown-Twiss experiments, Second order correlation function $g^{(2)}(\tau)$, Experimental demonstration of photon antibunching, Single photon sources, Coherent state and squeezed light, Photon number states.

Light-matter interaction: Resonant light matter interactions, Two-level atom approximation, Density matrix formulation, Optical cavities, Atom-cavity coupling, Weak coupling regime – Spontaneous emission and Purcell effect (spontaneous emission in a single mode cavity), Strong coupling regime – Cavity quantum electrodynamics.

Quantum information processing: Basic principles of quantum cryptography, Quantum key distribution with BB84 protocol and single photon sources, Quantum bits (qubits), Quantum logic gates and applications of quantum computers, Entangled states, Single photon interference, Bell's theorem and Quantum teleportation.

7. UPPER ATMOSPHERIC PHYSICS

Elements of Atmosphere and Physical Meteorology:

Atmospheric composition, laws of thermodynamics of the atmosphere, Adiabatic processes, potential temperature, The Clausius-Claperon equation, radiative transfer and the laws of black body radiation, solar and terrestrial radiation.

Dynamical Meteorology:
The fundamental forces, hydrostatic equation, Lapse rate, Enthalpy equation, Entropy of dry air and entropy change, The circulation theorem, vorticity, potential vorticity and potential vorticity equations.

Numerical Methods in Atmospheric Physics:

The finite difference method, the finite difference equation for sound, gravity and Rossby waves, filtering of gravity and Rossby waves, The equivalent-Barotropic model, essentials of numerical weather analysis and forecasting.

Observational Techniques in Atmospheric Physics:

Conventional observational techniques, conventional measurement of pressure, temperature, humidity, wind, precipitation, visibility.

Modern Observational Techniques: LIDARS, SODARS, RADARS.