UPSC Combined GeoScientist

STANDARD AND
SYLLABUS

Paper-I in General Studies of Stage-I is common for all streams and its standard will be such as may be expected of a science graduate. Paper-II of Stage-I (Stream specific) and 3 compulsory papers of Stage-II each on Geology, Geophysics, Chemistry and Hydrogeology subjects will be approximately of the M.Sc. degree standard of an Indian University **and** questions will generally be set to test the candidate's grasp of the fundamentals in each subject.

There will be no practical examination in any of the subjects

Syllabus of Combined Geo-Scientist (Preliminary) Examination

Stage-I *(Objective Type)*

Paper-I: General Studies *(Common for all streams)*

- Current events of national and international importance.
- History of India and Indian National Movement.
- Indian and World Geography -Physical, Social, Economic Geography of India and the World.
- Indian Polity and Governance -Constitution, Political System, Panchayati Raj, Public Policy, Rights Issues, etc.
- Economic and Social Development – Sustainable Development, Poverty, Inclusion, Demographics, Social Sector initiatives, etc.
- General issues on Environmental Ecology, Bio-diversity and Climate Change - that do not require subject specialisation
- General Science

Stage-I *(Objective Type)*

Paper-II : Geology/Hydrogeology

1. Physical Geology

Principle of uniformitarianism; origin, differentiation and internal structure of the Earth; origin of atmosphere; earthquakes and volcanoes; continental drift, sea-floor spreading, isostasy, orogeny and plate tectonics; geological action of rivers, wind, glaciers, waves; erosional and depositional landforms; weathering processes and products.

2. Structural Geology

Stress, strain and rheological properties of rocks; planar and linear structures; classification of folds and faults; Mohr's circle and criteria for failure of rocks; ductile and brittle shear in rocks; study of toposheets, V-rules and outcrop patterns; stereographic projections of structural elements.

3. Mineralogy

Elements of symmetry, notations and indices; Bravais lattices; chemical classification of minerals; isomorphism, polymorphism, solid solution and exsolution; silicate structures; physical and optical properties of common rock forming minerals- olivine, garnet, pyroxene, amphibole, mica, feldspar and quartz.

4. Igneous Petrology

Magma types and their evolution; IUGS classification of igneous rocks; forms, structures and textures of igneous rocks; applications of binary and ternary phase diagrams in petrogenesis; magmatic differentiation and assimilation; petrogenesis of granites, basalts, komatiiites and alkaline rocks (carbonatite, kimberlite, lamprophyre and nepheline syenite).

5. Metamorphic Petrology

Limits, types and controls of metamorphism; metamorphic structures- slate, schist and gneiss; metamorphic textures- pre, syn and post tectonic porphyroblasts; concept of metamorphic zone, isograd and facies; geothermal gradients, facies series and plate tectonics.

6. Sedimentology

Origin of sediments; sedimentary textures, grain-size scale; primary sedimentary structures; classification of sandstone and carbonate rocks; siliciclastic depositional environments and sedimentary facies; diagenesis of carbonate sediments.

7. Paleontology

Fossils and processes of fossilization; concept of species and binomial nomenclature; morphology and classification of invertebrates (Trilobites, Brachiopods, Lamellibranchs, Gastropods and Cephalopods); evolution in Equidae and Hominidae; microfossils-Foraminifera, Ostracoda; Gondwana flora.

8. Stratigraphy

Law of superposition; stratigraphic nomenclature- lithostratigraphy, biostratigraphy and chronostratigraphy; Archaean cratonic nucleii of Peninsular India (Dharwar, Singhbhum, and Aravalli cratons); Proterozoic mobile belts (Central Indian Tectonic Zone, Aravalli-Delhi and Eastern Ghats); Purana sedimentary basins (Cuddapah and Vindhyan); Phanerozoic stratigraphy of India- Spiti, Kashmir, Damodar valley, Kutch, Trichinopoly, Siwaliks and Indo-Gangetic alluvium.

9. Economic Geology

Properties of mineral deposits- form, mineral assemblage, texture, rock-ore association and relationship; magmatic, sedimentary, metamorphic, hydrothermal, supergene and weathering-related processes of ore formation; processes of formation of coal, and petroleum; distribution and geological characteristics of major mineral and hydrocarbon deposits of India.

10. Hydrogeology

Groundwater occurrence and aquifer characteristics, porosity, permeability, hydraulic conductivity, transmissivity; Darcy's Law in homogenous and heterogenous media; Bernoulli equation, Reynold's number; composition of groundwater; application of H and O isotopes in groundwater studies; artificial recharge of groundwater.

Stage-I *(Objective Type)*

Paper-II : Geophysics

1. Solid Earth Geophysics:

Introduction to Geophysics and its branches. Solar system: origin, formation and characteristics of planets, Earth: shape and rotation. Gravity and magnetic fields of earth. Geomagnetism, elements of earth's magnetism, Rock and mineral magnetism, Elastic waves, types and their propagation characteristics, internal structure of earth, variation of physical properties in the interior of earth. Plate tectonics, Earthquakes and their causes, focal depth, epicenter, Intensity and Magnitude scales, Energy of earthquakes, Seismicity.

2. Mathematical Methods in Geophysics:

Elements of vector analysis, Vector algebra, Properties of scalars, vectors and tensors, Gradient, Divergence and Curl, Gauss's divergence theorem, Stoke's theorem. Matrices, Eigen values and Eigen vectors and their applications in geophysics. Newton's Law of gravitation, Gravity potential and gravity fields due to bodies of different geometric shapes. Basic Forces of Nature and their strength: Gravitational, Electromagnetic, Strong and Weak forces. Conservation Laws in Physics: Energy, Linear and angular momentum. Rigid body motion and moment of inertia. Basics of special theory of relativity and Lorentz transformation.

Fundamental concepts of inverse theory, Definition of inversion and application to Geophysics. Forward and Inverse problems. Probability theory, Random variables, binomial, Poisson

and normal distributions. Linear algebra, Linear ordinary differential equations of first and second order. Partial differential equations (Laplace, wave and heat equations in two and three dimensions). Elements of numerical techniques: root of functions, interpolation, and extrapolation, integration by trapezoid and Simpson's rule, solution of first order differential equation using Runge-Kutta method, Introduction to finite difference and finite elements methods.

3. Electromagnetism:

Electrostatic and magneto-static fields, Coulomb's law, Electrical permittivity and dielectric constant, Lorentz force and their applications. Ampere's law, Biot and Savart's law, Gauss's Theorem, Poisson's equation. Laplace's equation: solution of Laplace's equation in Cartesian coordinates, use of Laplace's equation in the solutions of geophysical and electrostatic problems. Displacement current, Faraday's law of electromagnetic induction. Maxwell's equations. Boundary conditions. Wave equation, plane electromagnetic waves in free space, dielectric and conducting media, electromagnetic vector and scalar potentials.

4. Geophysical Prospecting:

Elements of geophysical methods: Principles, data reduction and applications of gravity, magnetic, electrical, electromagnetic and well logging methods. Fundamentals of seismic methods: Fermat's Principle, Snell's Law, Energy portioning, Reflection and transmission coefficients, Reflection and Refraction from layered media. Signals and systems, sampling theorem, aliasing effect, Fourier series and periodic waveforms, Fourier transform and its application, Laplace transforms, Convolution, Auto and cross correlations, Power spectrum, Delta function, unit step function.

5. Remote Sensing and Thermodynamics:

Fundamentals of remote sensing, electromagnetic spectrum, energy- frequency-wavelength relationship, Stefan-Boltzmann Law, Wien's Law, electromagnetic energy and its interactions in the atmosphere and with terrain features. Planck's Radiation Law. Laws of thermodynamics and thermodynamic potential.

6. Nuclear Physics and Radiometry:

Basic nuclear properties: size, shape, charge distribution, spin and parity; Binding energy, semi-empirical mass formula; Fission and fusion. Principles of radioactivity, Alpha, beta and gamma decays, Photoelectric and Compton Effect, Pair Production, radioactivity decay law, radioactivity of rocks and minerals, Radiation Detectors: Ionization chamber, G-M counter, Scintillation counter and Gamma ray spectrometer. Matter Waves and wave particle duality, Electron spin, Spectrum of Hydrogen, helium and alkali atoms.

Stage-I *(Objective Type)*

Paper-II : Chemistry

1. Chemical periodicity:

Schrödinger equation for the H-atom. Radial distribution curves for 1s, 2s, 2p, 3s, 3p, 3d orbitals. Electronic configurations of multi-electron atoms.

Periodic table, group trends and periodic trends in physical properties. Classification of elements on the basis of electronic configuration. Modern IUPAC Periodic table. General characteristics of s, p, d and f block elements. Effective nuclear charges, screening effects, atomic radii, ionic radii, covalent radii. Ionization enthalpy, electron gain enthalpy and electronegativity. Group trends and periodic trends in these properties in respect of s-, p- and d-block elements. General trends of variation of electronic configuration, elemental forms, metallic nature, magnetic properties, catenation and catalytic properties, oxidation states, aqueous and redox chemistry in common oxidation states, properties and reactions of important compounds such as hydrides, halides, oxides, oxy-acids, complex chemistry in respect of s-block and p-block elements.

2. Chemical bonding and structure:

Ionic bonding: Size effects, radius ratio rules and their limitations. Packing of ions in crystals, lattice energy, Born-Landé equation and its applications, Born-Haber cycle and its applications. Solvation energy, polarizing power and polarizability, ionic potential, Fajan's rules. Defects in solids.

Covalent bonding: Valence Bond Theory, Molecular Orbital Theory, hybridization. Concept of resonance, resonance energy, resonance structures.

Coordinate bonding: Werner theory of coordination compounds, double salts and complex salts. Ambidentate and polydentate ligands, chelate complexes. IUPAC nomenclature of coordination compounds. Coordination numbers, Geometrical isomerism. Stereoisomerism in square planar and octahedral complexes.

3. Acids and bases:

Chemical and ionic equilibrium. Strengths of acids and bases. Ionization of weak acids and bases in aqueous solutions, application of Ostwald's dilution law, ionization constants, ionic product

of water, pH-scale, effect of temperature on pH, buffer solutions and their pH values, buffer action & buffer capacity; different types of buffers and Henderson's equation.

4. Theoretical basis of quantitative inorganic analysis:

Volumetric Analysis: Equivalent weights, different types of solutions, normal and molar solutions. Primary and secondary standard substances.

General principles of different types of titrations: i) acid-base, ii) redox, iii) complexometric, iv) Precipitation. Types of indicators - i) acid-base, ii) redox iii) metal-ion indicators.

5. Kinetic theory and the gaseous state:

Kinetic theory of gases, average kinetic energy of translation, Boltzmann constant and absolute scale of temperature. Maxwell-Boltzmann distribution of speeds. Calculations of average, root mean square and most probable velocities. Collision diameter; collision number and mean free path; frequency of binary collisions; wall collision and rate of effusion.

6. Chemical thermodynamics and chemical equilibrium:

First law and its applications to chemical problems. Thermodynamic functions. Total differentials and state functions. Free expansion, Joule-Thomson coefficient and inversion temperature. Hess' law.

Applications of Second law of thermodynamics. Gibbs function (G) and Helmholtz function (A), Gibbs-Helmholtz equation, criteria for thermodynamic equilibrium and spontaneity of chemical processes.

7. Solutions of non-electrolytes:

Colligative properties of solutions, Raoult's Law, relative lowering of vapour pressure, osmosis and osmotic pressure; elevation of boiling point and depression of freezing point of solvents. Solubility of gases in liquids and solid solutions.

8. Electrochemistry:

Cell constant, specific conductance and molar conductance. Kohlrausch's law of independent migration of ions, ion conductance and ionic mobility. Equivalent and molar conductance at infinite dilution. Debye-Hückel theory. Application of conductance measurements. Conductometric titrations. Determination of transport number by moving boundary method.

9. Basic organic chemistry:

Delocalized chemical bond, resonance, conjugation, hyperconjugation, hybridisation, orbital pictures of bonding sp^3, sp^2, sp: C-C, C-N and C-O system), bond polarization and bond polarizability. Reactive intermediates: General methods of formation, relative stability and reactivity of carbocations, carbanions and free radicals.

10. Stereochemistry:

Configuration and chirality (simple treatment of elements of symmetry), optical isomerism of compounds containing two to three stereogenic centres, R,S nomenclature, geometrical isomerism in compounds containing two C=C double bonds (E,Z naming), and simple cyclic systems, Newman projection (ethane and substituted ethane).

11. Types of organic reactions:

Aliphatic substitution reactions: S_{N1}, S_{N2} mechanisms, stereochemistry, relative reactivity in aliphatic substitutions. Effect of substrate structure, attacking nucleophile, leaving group and reaction medium and competitive reactions.

Elimination reactions: E_1, E_2, mechanisms, stereochemistry, relative reactivity in aliphatic eliminations. Effect of substrate structure, attacking base, leaving group, reaction medium and competitive reactions, orientation of the double bond, Saytzeff and Hoffman rules.

Addition reactions: Electrophilic, nucleophilic and radical addition reactions at carbon-carbon double bonds.

Electrophilic and nucleophilic aromatic substitution: Electrophilic (halogenation, sulphonation, nitration, Friedal-Crafts alkylation and acylation), nucleophilic (simple S_{NAr}, S_{N1} and aryne reactions).

12. Molecular Rearrangements:

Acid induced rearrangement and Wagner-Meerwein rearrangements. Neighbouring group participation.

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Syllabus of Combined Geo-Scientist (Main) Examination
For the post of Geologist/Scientist 'B'(Hydrogeology)
Stage-II *(Descriptive Type)*
Geology : Paper-I

Section A. Physical geology and remote sensing

Evolution of Earth; Earth's internal structure; earthquakes and volcanoes; principles of geodesy, isostasy; weathering- processes and products; geomorphic landforms formed by action of rivers, wind, glaciers, waves and groundwater; features of ocean floor; continental shelf, slope and rise;

concepts of landscape evolution; major geomorphic features of India- coastal, peninsular and extra peninsular.
Electromagnetic spectrum; electromagnetic bands in remote sensing; spectral signatures of soil, rock, water and vegetation; thermal, near infra-red and microwave remote sensing; digital image processing; LANDSAT, IRS and SPOT- characteristics and use; aerial photos- types, scale, parallax, relief displacement; elements of image interpretation.

Section B. Structural geology
Principles of geological mapping; kinematic and dynamic analysis of deformation; stress-strain relationships for elastic, plastic and viscous materials; measurement of strain in deformed rocks; structural analysis of fold, cleavage, boudin, lineation, joint, and fault; stereographic projection of linear and planar structures; superposed deformation; deformation at microscale- dynamic and static recrystallisation, controls of strain rate and temperature on development of microfabrics; brittle and ductile shear zones; time relationship between crystallisation and deformation, calculation of paleostress.
Section C. Sedimentology
Classification of sedimentary rocks; sedimentary textures-grain size, roundness, sphericity, shape and fabric; quantitative grain size analysis; sediment transport and deposition- fluid and sediment gravity flows, laminar and turbulent flows, Reynold's number, Froude number, grain entrainment, Hjulstrom diagram, bed load and suspension load transport; primary sedimentary structures; penecontemporaneous deformation structure; biogenic structures; principles and application of paleocurrent analysis; composition and significance of different types of sandstone, limestone, banded iron formation, mudstone, conglomerate; carbonate diagenesis and dolomitisation; sedimentary environments and facies-facies models for fluvial, glacial, deltaic, siliciclastic shallow and deep marine environments; carbonate platforms- types and facies models; sedimentation in major tectonic settings; principles of sequence stratigraphy-concepts, and factors controlling base level changes, parasequence, clinoform, systems tract, unconformity and sequence boundary.
Section D. Paleontology
Fossil record and geological time scale; modes of preservation of fossils and concept of taphonomy; body- and ichno-fossils, species concept, organic evolution, Ediacara Fauna; morphology and time range of Graptolites, Trilobites, Brachiopods, Lamellibranchs, Gastropods, Cephalopods, Echinoids and Corals; evolutionary trends in Trilobites, Lamellibranchs, Gastropods and Cephalopods; micropaleontology- methods of preparation of microfossils, morphology of microfossil groups (Foraminifera, Ostracoda), fossil spores, pollen and dinoflagellates; Gondwana plant fossils and their significance; vertebrate life through ages, evolution in Proboscidea, Equidae and Hominidae; applications of paleontological data in stratigraphy, paleoecology, and paleoclimatology; mass extinctions.
Section E. Stratigraphy
Principles of stratigraphy-code of stratigraphic nomenclature of India; lithostratigraphy, biostratigraphy, chronostratigraphy and magnetostratigraphy; principles of stratigraphic correlation; characteristics of Archean granite-greenstone belts; Indian stratigraphy- geological evolution of Archean nucleii (Dharwar, Bastar, Singhbhum, Aravalli and Bundelkhand); Proterozoic mobile belts- Eastern Ghats Mobile Belt, Southern Granulite Terrain, Central Indian Tectonic Zone, Aravalli-Delhi Belt, North Singhbhum Mobile Belt; Proterozoic sedimentary basins (Cuddapah and Vindhyan); Phanerozoic stratigraphy- Paleozoic (Spiti, Kashmir and Kumaon), Mesozoic (Spiti, Kutch, Narmada Valley and Trichinopoly), Gondwana Supergroup, Cenozoic (Assam, Bengal basins, Garhwal-Shimla Himalayas); Siwaliks; boundary problems in Indian stratigraphy.

Stage-II *(Descriptive Type)*
Geology : Paper-II

Section A. Mineralogy
Symmetry, motif, Miller indices; concept of unit cell and Bravais lattices; 32 crystal classes; types of bonding, Pauling's rules and coordination polyhedra; crystal imperfections-defects, twinning and zoning; polymorphism, pseudomorphism, isomorphism and solid solution; physical properties of minerals; polarising microscope and accessory plate; optical properties of minerals- double refraction, polarisation, pleochroism, sign of elongation, interference figure and optic sign; structure, composition, physical and optical properties of major rock-forming minerals- olivine, garnet, aluminosilicates, pyroxene, amphibole, mica, feldspar, clay, silica and spinel group.

Section B. Geochemistry and isotope geology
Chemical composition and characteristics of atmosphere, lithosphere, hydrosphere; geochemical cycles; meteorites-types and composition; Goldschmidt's classification of elements; fractionation of elements in minerals/rocks; Nernst's partition coefficient (compatible and incompatible elements),

Nernst-Berthelot partition coefficient and bulk partition coefficient; Fick's laws of diffusion and activity composition relation (Roult's and Henry's law); application of trace elements in petrogenesis; principles of equilibrium and Rayleigh fractionation; REE patterns, Eh and pH diagrams and mineral stability.

Half-life and decay equation; dating of minerals and rocks with potassium-argon, rubidium-strontium, uranium-lead and samarium-neodymium isotopes; petrogenetic implications of samarium-neodymium and rubidium-strontium systems; stable isotope geochemistry of carbon, oxygen and sulphur and their applications in geology; monazite chemical dating. **Section C. Igneous petrology**

Viscosity, temperature and pressure relationships in magmas; IUGS classification of plutonic and volcanic rocks; nucleation and growth of minerals in magmatic rocks, development of igneous textures; magmatic evolution (differentiation, assimilation, mixing and mingling); types of mantle melting (batch, fractional and dynamic); binary (albite-anorthite, forsterite-silica and diopside-anorthite) and ternary (diopside-forsterite-silica, diopside-forsterite-anorthite and nepheline- kalsilite-silica) phase diagrams and relevance to magmatic crystallization; petrogenesis of granites, basalts, ophiolite suite, komatiites, syenites, boninites, anorthosites and layered complexes, and alkaline rocks (carbonatite, kimberlite, lamproite, lamprophyre); mantle metasomatism, hotspot magmatism and large igneous provinces of India.

Section D. Metamorphic petrology

Limits and physico-chemical controls (pressure, temperature, fluids and bulk rock composition) of metamorphism; concept of zones, facies, isograds and facies series, geothermal gradients and tectonics of orogenic belts; structures, micro-structures and textures of regional and contact metamorphic rocks; representation of metamorphic assemblages (ACF, AKF and AFM diagrams); equilibrium concept in thermodynamics; laws of thermodynamics, enthalpy, entropy, Gibb's free energy, chemical potential, fugacity and activity; tracing the chemical reactions in P-T space, phase rule and mineralogical phase rule in multi-component system; Claussius-Clapeyron equation and slopes of metamorphic reactions; heat flow, diffusion and mass transfer; Fourier's law of heat conduction; geothermobarometry; mass and energy change during fluid-rock interactions; charnockite problem, formation of skarns, progressive and retrogressive metamorphism of pelitic, calcareous and basic rocks; P-T-t path and tectonic setting.

Section E. Geodynamics

Phase transitions and seismic discontinuities in the Earth; seismic waves and relation between V_p, V_s and density; seismic and petrological Moho; rheology of rocks and fluids (Newtonian and non-Newtonian liquids); rock magnetism and its origin; polarity reversals, polar wandering and supercontinent cycles; continental drift, sea floor spreading; gravity and magnetic anomalies of ocean floors and their significance; mantle plumes and their origin; plate tectonics- types of plate boundaries and their inter-relationship; heat flow and heat production of the crust.

Stage-II *(Descriptive Type)*

Geology : Paper-III

Section A. Economic geology

Ore minerals and industrial minerals; physical and optical properties of ore minerals; ore textures and paragenesis; characteristics of mineral deposits- spatial and temporal distribution, rock-ore association; syngenetic and epigenetic deposits, forms of ore bodies, stratiform and strata-bound deposits; ore forming processes- source and migration of ore constituents and ore fluid, mechanism of ore deposition; magmatic and pegmatitic deposits (chromite, Ti-magnetite, diamond, Cu-Ni sulphide, PGE, REE, muscovite, rare metals); hydrothermal deposits (porphyry Cu-Mo, greisen Sn-W, skarn, VMS and SEDEX type sulphide deposits, orogenic gold); sedimentary deposits (Fe, Mn, phosphorite, placer); supergene deposits (Cu, Al, Ni and Fe); metamorphic and metamorphosed deposits (Mn, graphite); fluid inclusions in ore mineral assemblage- physical and chemical properties, microthermometry; stable isotope (S, C, O, H) in ore genesis- geothermometry, source of ore constituents; global tectonics and mineralisation.

Section B. Indian mineral deposits and mineral economics

Distribution of mineral deposits in Indian shield; geological characteristics of important industrial mineral and ore deposits in India- chromite, diamond, muscovite, Cu-Pb-Zn, Sn-W, Au, Fe-Mn, bauxite; minerals used in refractory, fertilizer, ceramic, cement, glass, paint industries; minerals used as abrasive, filler; building stones.

Strategic, critical and essential minerals; India's status in mineral production; co-products and by-products; consumption, substitution and conservation of minerals; National Mineral Policy ; Mineral Concession Rules; marine mineral resources and laws of the sea. **Section C. Mineral exploration**

Stages of exploration; scope, objectives and methods of prospecting, regional exploration and detailed exploration; geological, geochemical and geobotanical methods; litho-, bio-, soil geochemical surveys, mobility and dispersion of elements, geochemical anomalies; ore controls and guides;

pitting, trenching, drilling; sampling, assaying, ore reserve estimation; categorization of ore reserves; geophysical methods- ground and airborne surveys; gravity, magnetic, electrical and seismic methods of mineral exploration.

Section D. Fuel geology and Engineering geology

Coal and its properties; proximate and ultimate analysis; different varieties and ranks of coal; concept of coal maturity, peat, lignite, bituminous and anthracite coal; origin of coal, coalification process; lithotypes, microlithotypes and maceral groups of coal; mineral and organic matter in coal; lignite and coal deposits of India; origin, migration and entrapment of natural hydrocarbons; characteristics of source and reservoir rocks; structural, stratigraphic and mixed traps; geological, geochemical and geophysical methods of hydrocarbon exploration; petroliferous basins of India; geological characteristics and genesis of major types of U deposits and their distribution in India. . Engineering properties of rocks; geological investigations in construction of dams, reservoirs, tunnels, bridges, highways and coastal protection structures; geologic considerations of construction materials.

Section E. Environmental geology and Natural hazards

Stefan-Boltzmann equation and planetary temperature; cause and effects of global climate change; Earth's radiation budget; greenhouse gases and effect; examples of positive and negative feedback mechanisms; biogeochemical cycle of carbon; geological investigations of nuclear waste disposal sites; marginal marine environments- estuaries, mangroves and lagoons; ozone hole depletion, ocean acidification, coral bleaching, Milankovitch cycle, sea level rise, eutrophication and acid rain; environmental impacts of urbanization, mining and hydropower projects; water pollution, water logging and soil erosion; Himalayan glaciers; causes and consequences of earthquakes, volcanoes, tsunami, floods, landslides, coastal erosion, droughts and desertification; application of remote sensing and geographic information systems (GIS) in environmental management.

Stage-II *(Descriptive Type)*

Hydrogeology

Section A. Occurrence and distribution of groundwater

Origin of water on Earth; global water cycle and budget; residence time concept, geologic formations as aquifers; confined and unconfined aquifers; groundwater table mapping and piezometric nests; porosity, void ratio, effective porosity and representative porosity range; primary and secondary porosities; groundwater zonation; specific retention, specific yield; groundwater basins; springs.

Section B. Groundwater movement and well hydraulics

Groundwater flow concepts; Darcy's Law in isotropic and anisotropic media and validity; water flow rates, direction and water volume in aquifers; permeability and hydraulic conductivity and ranges in representative rocks; Bernoulli equation; determination of hydraulic conductivity in field and laboratory; concept of groundwater flow through dispersion and diffusion; transmissivity and aquifer thickness.

Section C. Water wells and groundwater levels

Unidirectional and radial flow to a well (steady and unsteady); well flow near aquifer boundaries; methods for constructing shallow wells, drilling wells, well completion; testing wells, pumping test, slug tests for confined and unconfined aquifers; fluctuations in groundwater levels; stream flow and groundwater flows; groundwater level fluctuations; land subsidence; impact of global climate change on groundwater.

Section D. Groundwater exploration

Surface investigation of groundwater- geologic, remote sensing, electrical resistivity, seismic, gravity and magnetic methods; sub-surface investigation of groundwater- test drilling, resistivity logging, spontaneous potential logging, radiation logging.

Section E. Groundwater quality and management

Groundwater composition, units of expression, mass-balance calculations; rock-water interaction (chemical equilibrium, free energy, redox reactions and cation/anion exchanges), graphic representation of chemical data; groundwater hardness, microorganisms in groundwater; water quality standards; sea-water intrusion; groundwater issues due to urbanization; solid and liquid waste disposal and plume migration models; application of isotopes (H, C, O) in groundwater; concepts of artificial recharge methods; managing groundwater resources; groundwater basin investigations and management practices.

For the post of Geophysicist/Scientist 'B'(Geophysics)

Stage-II *(Descriptive Type)*

Geophysics : Paper-I

PART-A

A1. Solid Earth Geophysics:

Introduction to Geophysics and its branches. Solar system: origin, characteristics of planets, Earth: rotation and figure, Geoid, Spheroid and topography. Plate tectonics and Geodynamic processes, Thermal history and heat flow, Temperature variation in the earth, convection currents. Gravity field of earth and Isostasy. Geomagnetism, elements of earth's magnetism: Internal and External fields and their causes, Paleomagnetism, Polar wandering paths, Continental drift, Seafloor spreading and its geophysical evidences. Elastic Waves, Body Waves and internal structure of earth, variation of physical properties in the interior of earth, Adam-Williamson's Equation.

A2. Earthquake Seismology:

Seismology, earthquakes, focal depth, epicenter, great Indian earthquakes, Intensity and Magnitude scales, Energy of earthquakes, foreshocks, aftershocks, Elastic rebound theory, Types and Nature of faulting, Fault plane solutions, Seismicity and Seismotectonics of India, Frequency-Magnitude relation (b-values). Bulk and rigidity modulus, Lame's Parameter, Seismic waves: types and their propagation characteristics, absorption, attenuation and dispersion. Seismic ray theory for spherically and horizontally stratified earth, basic principles of Seismic Tomography and receiver function analysis, Velocity structure, Vp/Vs studies, Seismic network and arrays, telemetry systems, Principle of electromagnetic seismograph, displacement meters, velocity meters, accelerometers, Broadband Seismometer, WWSSN stations, seismic arrays for detection of nuclear explosions. Earthquake prediction; dilatancy theory, short-, medium- and long- term predictions, Seismic microzonations, Applications for engineering problems.

A3. Mathematical methods in Geophysics:

Elements of vector analysis, Gradient, Divergence and Curl, Gauss's divergence theorem, Stoke's theorem, Gravitational field, Newton's Law of gravitation, Gravitation potential and fields due to bodies of different geometric shapes, Coulomb's law, Electrical permittivity and dielectric constant, Origin of Magnetic field, Ampere's law, Biot and Savart's law, Geomagnetic fields, Magnetic fields due to different type of structures, Solution of Laplace equation in Cartesian, Cylindrical and Spherical Coordinates, Image theory, Electrical fields due to charge, point source, continuous charge distribution and double layers, equipotential and line of force. Current and potential in the earth, basic concept and equations of electromagnetic induction, Maxwell's Equation, near and far fields, Attenuation of EM waves, EM field of a loops of wire on half space and multi-layered media.

A4. Geophysical Inversion:

Fundamental concepts of inverse theory, Definition and its application to Geophysics. Probability, Inversion with discrete and continuous models. Forward problems versus Inverse problems, direct and model based inversions, Formulation of inverse problems, classification of inverse problems, least square solutions and minimum norm solution, concept of norms, Jacobian matrix, Condition number, Stability, non-uniqueness and resolution of inverse problems, concept of '*a priori*' information, constrained linear least squares inversion, review of matrix theory. Models and data spaces, data resolution matrix, model resolution matrix, Eigen values and Eigen vectors, singular value decomposition (SVD), Gauss Newton method, steepest descent (gradient) method, Marquardt-Levenberg method. Probabilistic approach of inverse problems, maximum likelihood and stochastic inverse methods, Random search inversion (Monte-Carlo) Backus-Gilbert method, Bayesian Theorem and Inversion. Global optimization techniques: genetic algorithm and simulated annealing methods.

PART-B:

B1. Mathematical Methods of Physics:

Dimensional analysis; Units and measurement; Vector algebra and vector calculus; Linear algebra, Matrices: Eigenvalues and eigenvectors; Linear ordinary differential equations of first and second order; Special functions (Hermite, Bessel, Laguerre and Legendre); Fourier series, Fourier and Laplace transforms; Elementary probability theory, Random variables, Binomial, Poisson and normal distributions; Green's function; Partial differential equations (Laplace, wave and heat equations in two and three dimensions); Elements of numerical techniques: root of functions, interpolation, and extrapolation, integration by trapezoid and Simpson's rule, solution of first order differential equation using Runge-Kutta method; Tensors; Complex variables and analysis; Analytic functions; Taylor & Laurent series; poles, residues and evaluation of integrals; Beta and Gamma functions. Operators and their properties; Least-squares fitting.

B2. Electrodynamics:

Electrostatics: Gauss' Law and its applications; Laplace and Poisson equations, Boundary value problems; Magnetostatics: Biot-Savart law, Ampere's theorem; Ampere's circuital law; Magnetic vector potential; Faraday's law of electromagnetic induction; Electromagnetic vector and scalar potentials; Uniqueness of electromagnetic potentials and concept of gauge: Lorentz and Coulomb gauges; Lorentz force; Charged particles in uniform and non-uniform electric and magnetic fields; Poynting theorem; Electromagnetic fields from Lienard-Wiechert potential of a moving charge; Bremsstrahlung radiation; Cerenkov radiation; Radiation due to oscillatory electric dipole; Condition

for plasma existence; Occurrence of plasma; Magnetohydrodynamics; Plasma waves; Transformation of electromagnetic potentials; Lorentz condition; Invariance or covariance of Maxwell field equations in terms of 4 vectors; Electromagnetic field tensor; Lorentz transformation of electric and magnetic fields.

B3. Electromagnetic Theory:

Maxwell's equations: its differential and integral forms, physical significance; Displacement current; Boundary conditions; Wave equation, Plane electromagnetic waves in: free space, non-conducting isotropic medium, conducting medium; Scalar and vector potentials; Reflection; refraction of electromagnetic waves; Fresnel's Law; interference; coherence; diffraction and polarization; Lorentz invariance of Maxwell's equations; Transmission lines and waveguides.

B4. Introductory Atmospheric and Space Physics:

The neutral atmosphere; Atmospheric nomenclature; Height profile of atmosphere; Hydrostatic equation; Geopotential height; Expansion and contraction; Fundamental forces in the atmosphere; Apparent forces; Atmospheric composition; Solar radiation interaction with the neutral atmosphere; Climate change; Electromagnetic radiation and propagation of Waves: EM Radiation; Effects of environment; Antennas: basic considerations, types. Propagation of waves: ground wave, sky wave, and space wave propagation; troposcatter communication and extra terrestrial communication; The Ionosphere; Morphology of ionosphere: the D, E and F-regions; Chemistry of the ionosphere Ionospheric parameters E and F region anomalies and irregularities in the ionosphere; Global Positioning Systems (GPS): overview of GPS system, augmentation services GPS system segment; GPS signal characteristics; GPS errors; multi path effects; GPS performance; Satellite navigation system and applications.

Stage-II *(Descriptive Type)*

Geophysics : Paper-II

PART-A

A1. Potential Field (Gravity and Magnetic) Methods:

Geophysical potential fields, Inverse square law, Principles of Gravity and Magnetic methods, Global gravity anomalies, Newtonian and logarithmic potential, Laplace's equations for potential field. Green's Function, Concept of gravity anomaly, Rock densities, factors controlling rock densities, determination of density, Earth's main magnetic field, origin, diurnal and secular variations of the field, Geomagnetic elements, intensity of magnetization and induction, magnetic potential and its relation to field, units of measurement, interrelationship between different components of magnetic fields, Poisson's relation, Magnetic susceptibility, factors controlling susceptibility. Magnetic Mineralogy: Hysteresis, rock magnetism, natural, and remnant magnetization, demagnetization effects. Principles of Gravity and Magnetic instruments, Plan of conducting gravity and magnetic surveys, Gravity and Magnetic data reduction, Gravity bases, International Gravity formula, IGRF corrections. Concept of regional and residual anomalies and various methods of their separation, Edge Enhancement Techniques (Derivatives, Continuation, Analytical Signal, Reduced to Pole and Euler Deconvolution), ambiguity in potential field interpretation, Factors affecting magnetic anomalies, Application of gravity and magnetics in geodynamic, mineral exploration and environmental studies. Qualitative interpretation, Interpretation of gravity and magnetic anomalies due to different geometry shaped bodies and modeling.

A2. Electrical and Electromagnetic methods:

Electrical properties of rocks and minerals, concepts and assumptions of horizontally stratified earth, anisotropy and its effects on electrical fields, geoelectric and geological sections, D.C Resistivity method. Concept of natural electric field, various electrode configurations, Profiling and Sounding (VES). Tpes of Sounding curves, Equivalence and Suppression, Concept of Electrical Resistivity Tomography (ERT). SP Method:, Origin of SP, application of SP surveys. Induced Polarization (IP) Method: Origin of IP, Membrane and Electrode polarization, time and frequency domains of measurement, chargeability, percent frequency effect and metal factor, Application of IP surveys for mineral exploration. Electromagnetic methods, Passive and Active source methods, Diffusion equation, wave equation and damped wave equation used in EM method, boundary conditions, skin depth, depth of investigation and depth of penetration, amplitude and phase relations, real and imaginary components, elliptical polarization, Principles of EM prospecting, various EM methods: Dip angle, Turam, moving source-receiver methods-horizontal loop (Slingram), AFMAG, and VLF.. Principles of Time Domain EM: INPUT method. EM Profiling and sounding, Interpretation of EM anomalies. Principle of EM scale modeling. Magnetotelluric methods: Origin and characteristics of MT fields, Instrumentation, Transverse Electric and Transverse Magnetic Modes, Static Shift. Dimensionality and Directionality analysis. Field Layout and interpretation of MT data and its applications. Principles of Ground Penetrating Radar (GPR).

A3. Seismic Prospecting:

Basic principles of seismic methods, Various factors affecting seismic velocities in rocks, Reflection, refraction and Energy partitioning at an interface, Geometrical spreading, Reflection and refraction of wave phenomena in a layered and dipping media. Seismic absorption and anisotropy, Multi channel seismic (CDP) data acquisition (2D and 3D), sources of energy, Geophones, geometry of arrays, different spread geometry, Instrumentation, digital recording. Different types of multiples, Travel time curves, corrections, Interpretation of data, bright spot, low velocity layer, Data processing, static and dynamic (NMO and DMO) corrections, shot-receiver gather, foldage, multiplexing and demultiplexing. Dix's equation, Velocities: Interval, Average and RMS, Seismic resolution and Fresnel Zone, Velocity analysis and Migration techniques, Seismic Interpretation, Time and Depth Section, Fundamentals of VSP method, High Resolution Seismic Surveys (HRSS).

A4. Borehole Geophysics:

Objectives of well logging, concepts of borehole geophysics, borehole conditions, properties of reservoir rock formations, formation parameters and their relationships-formation factor, porosity, permeability, formation water resistivity, water saturation, irreducible water saturation, hydrocarbon saturation, residual hydrocarbon saturation; Arhcie's and Humble's equations; principles, instrumentations, operational procedures and interpretations of various geophysical logs: SP, resistivity and micro resistivity, gamma ray, neutron, sonic, temperature, caliper and directional logs. Production logging, overlay and cross-plots of well-log data, determination of formation lithology, porosity, permeability and oil-water saturation, sub-surface correlation and mapping, delineation of fractures; application of well-logging in hydrocarbon, groundwater, coal, metallic and non-metallic mineral exploration.

PART-B

B1. Classical Mechanics

Inertial and non-inertial frames, Newton's laws; Pseudo forces; Central force motion; Two-body collisions, Scattering in laboratory and centre-of-mass frames; Rigid body dynamics, Moment of inertia, Variational principle, Lagrangian and Hamiltonian formalisms and equations of motion; Poisson brackets and canonical transformations; Symmetry, Invariance and conservation laws, Cyclic coordinates; Periodic motion, Small oscillations and normal modes; Special theory of relativity, Lorentz transformations, Relativistic kinematics and mass-energy equivalence.

B2. Thermodynamics and Statistical Physics

Laws of thermodynamics and their significance; 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 connection with thermodynamic quantities; First and second order phase transitions; Maxwell-Boltzmann distribution, Quantum statistics, Ideal Fermi and Bose gases; Principle of detailed balance; Blackbody radiation and Planck's distribution law; Bose-Einstein condensation; Random walk and Brownian motion; Diffusion equation.

B3. Atomic and Molecular Physics and Characterization of materials

Quantum states of an electron in an atom; Electron spin; Stern-Gerlach experiment; Spectrum of Hydrogen, Helium and alkali atoms; Relativistic corrections for energy levels of hydrogen; Hyperfine structure and isotopic shift; Width of spectral lines; LS and **JJ** coupling; Zeeman, Paschen Back and Stark effects; Rotational, vibrational, electronic, and Raman spectra of diatomic molecules; Frank-Condon principle; Thermal and optical properties of materials, Study of microstructure using SEM, Study of crystal structure using TEM, Resonance methods: Spin and applied magnetic field, Larmor precession, relaxation times - spin-spin relaxation, Spin-lattice relaxation, Electron spin resonance, g factor, Nuclear Magnetic resonance, line width, Motional narrowing, Hyperfine splitting; Nuclear Gamma Resonance: Principles of Mössbauer Spectroscopy, Line width, Resonance absorption, Isomer Shift, Quadrupole splitting.

B4. Nuclear and Particle Physics

Basic nuclear properties: size, shape, charge distribution, spin and parity; Binding energy, Packing fraction, Semi-empirical mass formula; Liquid drop model; Fission and fusion, Nuclear reactor; Line of stability, Characteristics of the nuclear forces, Nucleon-nucleon potential; Charge-independence and charge-symmetry of nuclear forces; Isospin; Deuteron problem; Evidence of shell structure, Single-particle shell model and, its validity and limitations; Elementary ideas of alpha, beta and gamma decays and their selection rules; Nuclear reactions, reaction mechanisms, compound nuclei and direct reactions; Classification of fundamental forces; Elementary particles (quarks, baryons, mesons, leptons); Spin and parity assignments, strangeness; Gell Mann-Nishijima formula; C, P and T invariance and applications of symmetry arguments to particle reactions, Parity non-conservation in weak interaction; Relativistic kinematics.

Stage-II *(Descriptive Type)*

Geophysics : Paper-III

PART-A

A1. Radiometric and Airborne Geophysics:
Principles of radioactivity, radioactivity decay processes, units, radioactivity of rocks and minerals, Instruments, Ionization chamber, G-M counter, Scintillation counter, Gamma ray spectrometer, Radiometric prospecting for mineral exploration (Direct/Indirect applications), beach placers, titanium, zirconium and rare-earths, radon studies in seismology and environmental applications. Airborne geophysical surveys (gravity, magnetic, electromagnetic and radiometric), planning of surveys, flight path recovery methods. Applications in geological mapping, identification of structural features and altered zones.

A2. Marine Geophysics:
Salinity, temperature and density of sea water. Introduction to Sea-floor features: Physiography, divisions of sea floor, continental shelves, slopes, and abyssal plains, growth and decline of ocean basins, turbidity currents, occurrence of mineral deposits and hydrocarbons in offshore. Geophysical surveys and instrumentation: Gravity, Magnetic and electromagnetic surveys, Sonobuoy surveys, Instrumentation used in ship borne surveys, towing cable and fish, data collection and survey procedures, corrections and interpretation of data. Oceanic magnetic anomalies, Vine-Mathews hypothesis, geomagnetic time scale and dating sea floor, Oceanic heat flow, ocean ridges, basins, marginal basins, rift valleys. Seismic surveys, energy sources, Pinger, Boomer, Sparker, Air gun, Hydrophones and steamer cabling. Data reduction and interpretation. Ocean Bottom Seismic surveys. Bathymetry, echo sounding, bathymetric charts, sea bed mapping. Navigation and Position fixing methods.

A3. Geophysical Signal Processing:
Time Series, Types of signals, sampling theorem, aliasing effect, Fourier series of periodic waveforms, Fourier transform and its properties, Discrete Fourier transform and FFT, Hilbert Transform, Convolution and Deconvolution, Auto and cross correlations, Power spectrum, Delta function, unit step function. Time domain windows, Z transform and properties, Inverse Z transform. Poles and zeroes. Principles of digital filters, types of filters: recursive, non recursive, time invariant, Chebyshev, Butterworth, moving average, amplitude and phase response of filters, low pass, band pass and high pass filters. Processing of Random signals. Improvement of signal to noise ratio, source and geophone arrays as spatial filters. Earth as low pass filter.

A4. Remote Sensing and Geohydrology:
Fundamental concepts of remote sensing, electromagnetic radiation spectrum, Interaction of electromagnetic energy and its interactions in atmosphere and surface of the earth, elements of photographic systems, reflectance and emittance, false color composites, remote sensing platforms, flight planning, geosynchronous and sun synchronous orbits, sensors, resolution, parallax and vertical exaggeration, relief displacement, mosaic, aerial photo interpretation and geological application. Fundamentals of photogrammetry, satellite remote sensing, multi-spectral scanners, thermal scanners, microwave remote sensing, fundamental of image processing and interpretation for geological applications. Types of water bearing formations, porosity, permeability, storage coefficient, specific storage, specific retention, specific yield, Different types of aquifers, vertical distribution of ground water, General flow equation; steady and unsteady flow of ground water in unconfined and confined aquifers.

PART-B

B1. Solid State Physics and Basic Electronics
Crystalline and amorphous structure of matter; Different crystal systems, Space groups; Methods of determination of crystal structure; X-ray diffraction, Scanning and transmission electron microscopes; Band theory of solids, conductors, insulators and semiconductors; Thermal properties of solids, Specific heat: Einstein's and Debye theory; Magnetism: dia, para and ferro; Elements of superconductivity; Meissner effect, Josephson junctions and applications; Elementary ideas about high temperature superconductivity.
Semiconductor devices and circuits: Intrinsic and Extrinsic semiconductors; Devices and structures (p-n junctions, diodes, transistors, FET, JFET and MOSFET, homo and hetero junction transistors, thermistors), Device characteristics, Frequency dependence and applications. Opto-electronic devices (solar cells, photo detectors, LEDs) Operational amplifiers and their applications.

B2. Laser systems
Spontaneous and stimulated emission of radiation. Coherence**,** Light amplification and relation between Einstein A and B coefficients. Rate equations for three and four level systems. Lasers: Ruby, Nd-YAG, CO_2, Dye, Excimer, Semiconductor. Laser cavity modes, Line shape function and full width at half maximum (FWHM) for natural broadening, collision broadening, Doppler broadening; Saturation behavior of broadened transitions, Longitudinal and transverse modes. Mode selection, ABCD matrices and cavity stability criteria for confocal resonators. Quality factor, Expression for intensity for modes oscillating at random and mode-locked in phase. Methods of Q-switching and mode locking. Optical fiber waveguides, Fiber characteristics.

B3. Digital electronics, Radar systems, Satellite communications

Digital techniques and applications: Boolean identities, de Morgan's theorems, Logic gates and truth tables; Simple logic circuits: registers, counters, comparators and similar circuits). A/D and D/A converters. Microprocessor: basics and architecture; Microcontroller basics. Combination and sequential logic circuits, Functional diagram, Timing diagram of read and write cycle, Data transfer techniques: serial and parallel. Fundamentals of digital computers. Radar systems, Signal and data processing, Surveillance radar, Tracking radar, Radar antenna parameters. Fundamentals of satellite systems, Communication and Orbiting satellites, Satellite frequency bands, Satellite orbit and inclinations. Earth station technology.

B4. Quantum Mechanics

Wave-particle duality; Wave functions in coordinate and momentum representations; Commutators and Heisenberg's uncertainty principle; Schrodinger's wave equation (time-dependent and time-independent); Eigenvalue problems: particle in a box, harmonic oscillator, tunneling through a 1-D barrier; Motion in a central potential; Orbital angular momentum; Addition of angular momentum; Hydrogen atom; Matrix representation; Dirac's bra and ket notations; Time-independent perturbation theory and applications; Variational method; WKB approximation; Time dependent perturbation theory and Fermi's Golden Rule; Selection rules; Semi-classical theory of radiation; Elementary theory of scattering, Phase shifts, Partial waves, Born approximation; Identical particles, Pauli's exclusion principle, Spin-statistics connection; Relativistic quantum mechanics: Klein Gordon and Dirac equations.

For the posts of Chemist/Scientist 'B'(Chemical)

Stage-II *(Descriptive Type)*

Chemistry : Paper-I (Inorganic Chemistry)

1. Inorganic solids:

Defects, non-stoichiometric compounds and solid solutions, atom and ion diffusion, solid electrolytes. Synthesis of materials, monoxides of 3d-metals, higher oxides, complex oxides (corundrum, ReO_3, spinel, pervoskites), framework structures (phosphates, aluminophosphates, silicates, zeolites), nitrides and fluorides, chalcogenides, intercalation chemistry, semiconductors, molecular materials.

2. Chemistry of coordination compounds:

Isomerism, reactivity and stability: Determination of configuration of *cis*- and *trans*- isomers by chemical methods. Labile and inert complexes, substitution reactions on square planar complexes, *trans* effect. Stability constants of coordination compounds and their importance in inorganic analysis.

Structure and bonding: Elementary Crystal Field Theory: splitting of d^n configurations in octahedral, square planar and tetrahedral fields, crystal field stabilization energy, pairing energy. Jahn-Teller distortion. Metal-ligand bonding, sigma and pi bonding in octahedral complexes and their effects on the oxidation states of transition metals. Orbital and spin magnetic moments, spin only moments and their correlation with effective magnetic moments, d-d transitions; LS coupling, spectroscopic ground states, selection rules for electronic spectral transitions; spectrochemical series of ligands, charge transfer spectra.

3. Acid base titrations:

Titration curves for strong acid-strong base, weak acid-strong base and weak base-strong acid titrations, polyprotic acids, poly-equivalent bases, determining the equivalence point: theory of acid-base indicators, pH change range of indicator, selection of proper indicator. Principles used in estimation of mixtures of $NaHCO_3$ and Na_2CO_3 (by acidimetry).

4. Gravimetric Analysis:

General principles: Solubility, solubility product and common ion effect, effect of temperature on the solubility; Salt hydrolysis, hydrolysis constant, degree of hydrolysis.

Stoichiometry, calculation of results from gravimetric data. Properties of precipitates. Nucleation and crystal growth, factors influencing completion of precipitation. Co-precipitation and post-precipitation, purification and washing of precipitates. Precipitation from homogeneous solution. A few common gravimetric estimations: chloride as silver chloride, sulphate as barium sulphate, aluminium as oxinate and nickel as dimethyl glyoximate.

5. Redox Titrations:

Standard redox potentials, Nernst equation. Influence of complex formation, precipitation and change of pH on redox potentials, Normal Hydrogen Electrode (NHE). Feasibility of a redox titration, redox potential at the equivalence point, redox indicators. Redox potentials and their applications.

Principles behind Iodometry, permanganometry, dichrometry, difference between iodometry and iodimetry. Principles of estimation of iron, copper, manganese, chromium by redox titration.

6. Complexometric titrations:

Complex formation reactions, stability of complexes, stepwise formation constants, chelating agents. EDTA: acidic properties, complexes with metal ions, equilibrium calculations involving EDTA, conditional formation constants, derivation of EDTA titration curves, effect of other complexing agents, factors affecting the shape of titration curves: indicators for EDTA titrations, titration methods employing EDTA: direct, back and displacement titrations, indirect determinations, titration of mixtures, selectivity, masking and demasking agents. Typical applications of EDTA titrations: hardness of water, magnesium and aluminium in antacids, magnesium, manganese and zinc in a mixture, titrations involving unidentate ligands: titration of chloride with Hg^{2+} and cyanide with Ag^{+}.

7. Organometallic compounds:

18-electron rule and its applications to carbonyls and nature of bonding involved therein. Simple examples of metal-metal bonded compounds and metal clusters. Wilkinson's catalyst.

8. Nuclear chemistry:

Radioactive decay- General characteristics, decay kinetics, parent-daughter decay growth relationships, determination of half-lives. Nuclear stability. Decay theories. Unit of radioactivity. Preparation of artificial radionuclides by bombardment, radiochemical separation techniques. Experimental techniques in the assay of radioisotopes, Geiger-Muller counters. Solid state detectors.

9. Chemistry of d- and f-block elements:

d-block elements: General comparison of 3d, 4d and 5d elements in terms of electronic configuration, elemental forms, metallic nature, atomization energy, oxidation states, redox properties, coordination chemistry, spectral and magnetic properties.

f-block elements: Electronic configuration, ionization enthalpies, oxidation states, variation in atomic and ionic (3+) radii, magnetic and spectral properties of lanthanides, separation of lanthanides (by ion-exchange method).

Stage-II *(Descriptive Type)*

Chemistry : Paper-II (Physical Chemistry)

1. Kinetic theory and the gaseous state:

Real gases, Deviation of gases from ideal behaviour; compressibility factor; van der Waals equation of state and its characteristic features. Existence of critical state. Critical constants in terms of van der Waals constants. Law of corresponding states and significance of second virial coefficient. Boyle temperature.

2. Solids: Nature of solid state. Band theory of solids: Qualitative idea of band theory, conducting, semiconducting and insulating properties.

Law of constancy of angles, concept of unit cell, different crystal systems, Bravais lattices, law of rational indices, Miller indices, symmetry elements in crystals. X-ray diffraction, Bragg's law.

3. Chemical thermodynamics and chemical equilibrium:

Chemical potential in terms of Gibbs energy and other thermodynamic state functions and its variation with temperature and pressure. Gibbs-Duhem equation; fugacity of gases and fugacity coefficient. Thermodynamic conditions for equilibrium, degree of advancement. vant Hoff's reaction isotherm. Equilibrium constant and standard Gibbs energy change. Definitions of K_P, K_C and K_x; vant Hoff's reaction isobar and isochore. Activity and activity coefficients of electrolytes / ions in solution. Debye-Hückel limiting law.

4. Chemical kinetics and catalysis:

Second order reactions. Determination of order of reactions. Parallel and consecutive reactions. Temperature dependence of reaction rate, energy of activation. Collision Theory and Transition State Theory of reaction rates. Enthalpy of activation, entropy of activation, effect of dielectric constant and ionic strength on reaction rate, kinetic isotope effect.

Physisorption and chemisorption, adsorption isotherms, Freundlich and Langmuir adsorption isotherms, BET equation, surface area determination; colloids, electrical double layer and colloid stability, electrokinetic phenomenon. Elementary ideas about soaps and detergents, micelles, emulsions.

5. Electrochemistry:

Types of electrochemical cells, cell reactions, emf and Nernst equation, ΔG, ΔH and ΔS of cell reactions. Cell diagrams and IUPAC conventions. Standard cells. Half-cells / electrodes, types of reversible electrodes. Standard electrode potential and principles of its determination. Concentration cells. Determination of ΔG°, K°, K_{sp} and pH.

Basic principles of pH metric and potentiometric titrations, determination of equivalence point and pK_a values.

6. Quantum chemistry:

Eigenfunctions and eigenvalues. Uncertainty relation, Expectation value. Hermitian operators. Schrödinger time-independent equation: nature of the equation, acceptability conditions imposed on the wave functions and probability interpretation of wave function. Schrödinger equation for particle

in a one-dimensional box and its solution. Comparison with free particle eigenfunctions and eigenvalues. Particle in a 3-D box and concept of degeneracy.

7. Basic principles and applications of spectroscopy:

Electromagnetic radiation, interaction with atoms and molecules and quantization of different forms of energies. Units of frequency, wavelength and wavenumber. Condition of resonance and energy of absorption for various types of spectra; origin of atomic spectra, spectrum of hydrogen atom.

Rotational spectroscopy of diatomic molecules: Rigid rotor model, selection rules, spectrum, characteristic features of spectral lines. Determination of bond length, effect of isotopic substitution.

Vibrational spectroscopy of diatomic molecules: Simple Harmonic Oscillator model, selection rules and vibration spectra. Molecular vibrations, factors influencing vibrational frequencies. Overtones, anharmonicity, normal mode analysis of polyatomic molecules.

Raman Effect: Characteristic features and conditions of Raman activity with suitable illustrations. Rotational and vibrational Raman spectra.

8. Photochemistry:

Franck-Condon principle and vibrational structure of electronic spectra. Bond dissociation and principle of determination of dissociation energy. Decay of excited states by radiative and non-radiative paths. Fluorescence and phosphorescence, Jablonski diagram. Laws of photochemistry: Grotthus-Draper law, Stark-Einstein law of photochemical equivalence; quantum yield and its measurement for a photochemical process, actinometry. Photostationary state. Photosensitized reactions. Kinetics of HI decomposition, H_2-Br_2 reaction, dimerisation of anthracene.

Stage-II *(Descriptive Type)*

Chemistry : Paper-III (Analytical and Organic)

PART-A (Analytical Chemistry)

A1. Errors in quantitative analysis:

Accuracy and precision, sensitivity, specific standard deviation in analysis, classification of errors and their minimization, significant figures, criteria for rejection of data, Q-test, t-test, and F-test, control chart, sampling methods, sampling errors, standard reference materials, statistical data treatment.

A2. Separation Methods:

Chromatographic analysis: Basic principles of chromatography (partition, adsorption and ion exchange), column chromatography, plate concept, plate height (HETP), normal phase and reversed phase concept, thin layer chromatography, frontal analysis, principles of High Performance Liquid Chromatography (HPLC) and Gas Liquid Chromatography (GLC), and Ion-exchange chromatography.

Solvent extraction: Classification, principle and efficiency of the technique, mechanism of extraction, extraction by solvation and chelation, qualitative and quantitative aspects of solvent extraction, extraction of metal ions from aqueous solutions.

A3. Spectroscopic methods of analysis:

Lambert-Beer's Law and its limitations.

UV-Visible Spectroscopy: Basic principles of UV-Vis spectrophotometer, Instrumentation consisting of source, monochromator, grating and detector, spectrophotometric determinations (estimation of metal ions from aqueous solutions, determination of composition of metal complexes using Job's method of continuous variation and mole ratio method).

Infra-red Spectrometry: Basic principles of instrumentation (choice of source, monochromator and detector) for single and double beam instruments, sampling techniques.

Flame atomic absorption and emission spectrometry: Basic principles of instrumentation (choice of source, monochromator, detector, choice of flame and burner design), techniques of atomization and sample introduction, method of background correction, sources of chemical interferences and methods of removal, techniques for the quantitative estimation of trace level metal ions. Basic principles and theory of AAS. Three different modes of AAS - Flame-AAS, VG-AAS, and GF-AAS. Single beam and double beam AAS. Function of Hollow Cathode Lamp (HCL) and Electrode Discharge Lamp (EDL). Different types of detectors used in AAS. Qualitative and quantitative analysis.

A4. Thermal methods of analysis:

Theory of thermogravimetry (TG), basic principle of instrumentation, techniques for quantitative analysis of Ca and Mg compounds.

A5. X-ray methods of Analysis:

Introduction, theory of X-ray generation, X-ray spectroscopy, X-ray diffraction and X-ray fluorescence methods, instrumentation and applications. Qualitative and quantitative measurements. Powder diffraction method.

A6. Inductively coupled plasma spectroscopy:

Theory and principles, plasma generation, utility of peristaltic pump, sampler–skimmer systems, ion lens, quadrupole mass analyzer, dynode / solid state detector, different types of interferences-

spectroscopic and non-spectroscopic interferences, isobaric and molecular interferences, applications.

A7. Analysis of geological materials:

Analysis of minerals and ores- estimation of (i) $CaCO_3$, $MgCO_3$ in dolomite (ii) Fe_2O_3, Al_2O_3, and TiO_2 in bauxite (iii) MnO and MnO_2 in pyrolusite. Analysis of metals and alloys: (i) Cu and Zn in brass (ii) Cu, Zn, Fe, Mn, Al and Ni in bronze (iii) Cr, Mn, Ni, and P in steel (iv) Pb, Sb, Sn in 'type metal'.

Introduction to petroleum: constituents and petroleum fractionation. Analysis of petroleum products: specific gravity, viscosity, Doctor test, aniline point, colour determination, cloud point, pour point. Determination of water, neutralization value (acid and base numbers), ash content, Determination of lead in petroleum.

Types of coal and coke, composition, preparation of sample for proximate and ultimate analysis, calorific value by bomb calorimetry.

PART B (Organic chemistry)

B1. Unstable, uncharged intermediates:

Structure and reactivity of carbenes and nitrenes and their rearrangements (Reimer-Tiemann, Hoffman, Curtius, Lossen, and Schimdt,).

B2. Addition reactions:

Addition to C-C multiple bonds: Mechanism of addition involving electrophiles, nucleophiles and free radicals (polymerization reactions of alkenes and substituted alkenes), Ziegler-Natta catalyst for polymerization, polyurethane, and conducting polymers; addition to conjugated systems (Diels-Alder reaction), orientation and reactivity (on simple *cis*- and *trans*- alkenes).

Addition to carbon-heteroatom multiple bonds: Addition to C=O double bond, structure and reactivity, hydration, addition of ROH, RSH, CN-, bisulphite, amine derivatives, hydride ions.

B3: Reactions at the carbonyl group:

Cannizzaro, Aldol, Perkin, Claisen ester, benzoin, benzil-benzilic acid rearrangement, Mannich, Dieckmann, Michael, Strobe, Darzen, Wittig, Doebner, Knoevenagel, Reformatsky reactions.

B4. Oxidation and Reduction:

Reduction of C=C, Meerwein-Pondorf reaction, Wolff-Kishner and Birch reduction.

Oxidation of C=C, hydration, hydroxylation, hydroboration, ozonolysis, epoxidation, Sharpless epoxidation.

B5. Electrocyclic Reactions:

Molecular orbital symmetry, frontier orbitals of ethylene, 1,3-butadiene, 1,3,5-hexatriene, allyl system, FMO approach, pericyclic reactions, Woodward-Hoffman correlation diagram method and perturbation molecular orbital (PMO) approach for the explanation of pericyclic reactions under thermal and photochemical conditions. Simple cases of Norrish type-I and type-II reactions. Conrotatory and disrotatory motions of (4n) and (4n+2) polyenes with emphasis on [2+2] and [4+2] cycloadditions, sigmatropic rearrangements- shift of H and carbon moieties, Claisen, Cope, Sommerlet-Hauser rearrangement.

B6. Spectroscopic methods of analysis:

Infrared spectroscopy: Characteristic frequencies of organic molecules and interpretation of spectra. Modes of molecular vibrations, characteristic stretching frequencies of O-H, N-H, C-H, C-D, C=C, C=N, C=O functions; factors affecting stretching frequencies.

Ultraviolet spectroscopy: Chromophores, auxochromes. Electronic transitions ($\sigma-\sigma^*$, $n-\sigma^*$, $\pi-\pi^*$ and $n-\pi^*$), relative positions of λ_{max} considering conjugative effect, steric effect, solvent effect, red shift (bathochromic shift), blue shift (hypsochromic shift), hyperchromic effect, hypochromic effect (typical examples). Woodward rules. Applications of UV spectroscopy to conjugated dienes, trienes, unsaturated carbonyl compounds and aromatic compounds.

Nuclear Magnetic Resonance Spectrometry: (Proton and Carbon-13 NMR) Nuclear spin, NMR active nuclei, principle of proton magnetic resonance, equivalent and non-equivalent protons. Measurement of spectra, the chemical shift, shielding / deshielding of protons, upfield and downfield shifts, intensity of NMR signals and integration factors affecting the chemical shifts: spin-spin coupling to ^{13}C ^{1}H-^{1}H first order coupling: some simple ^{1}H-^{1}H splitting patterns: the magnitude of ^{1}H-^{1}H coupling constants, diamagnetic anisotropy.

Mass spectrometry: Basic Principles, the mass spectrometer, isotope abundances; the molecular ion, metastable ions. McLafferty rearrangement.