XE Engineering Sciences

XE2: Materials Science

Section XE2.1: Classification and Structure of Materials

Classification of Materials: Metals, ceramics, polymers and composites.

Fundamentals of crystallography: Definitions of crystal, lattice and motif: Crystal=Lattice+Motif. Distinction between atoms and lattice points; Symmetry operations: Translations (required symmetry of crystals/lattices); Symmetry based definitions of 7 crystal systems; Unit cells: primitive and non-primitive cells; Fourteen Bravais lattices and their classification into crystal systems; Miller and Miller-Bravais indices of crystallographic planes and directions.

Close-packed crystal structures of elements: Cubic close-packed (CCP), Hexagonal close-packed (HCP) and body-centred cubic (BCC) structures; Stacking sequence of planes; Tetrahedral and octahedral voids.

Crystalline and other ordered structures of carbon: Diamond and Graphite in terms of lattice and motif; Graphene and fullerene; Carbon nanotubes.

Crystalline structure of compounds: NaCl, CsCl, ZnS (Zinc blend and Wurtzite), Perovskite, Spinels; Pauling's rule for structure of ionic compounds.

Structure of amorphous materials: Crystalline and glassy silica; Fused silica and soda-lime glass.
Solid solutions: Interstitial and substitutional; Hume-Rothery rules.

Structure of polymers: Monomers and polymers. Addition and condensation polymers. Bonding in polymers. C-C chain. Degree of polymerization. Chain configuration vs. chain conformations. Atactic, isotactic and syndiotactic configurations. Crystalline, semi-crystalline and amorphous polymers. Copolymers: alternating, block and random. Examples of common polymers: Polyethylene (PE), Polypropylene (PP), Polyvinylchloride (PVC), Polyetraflouroethylene (PTFE), Polystyrene (PS). Crosslinking. Natural and vulcanised rubber.

Defects in Crystalline Materials:
Zero-dimensional or point defects: Vacancies, interstitials, substitutional atoms, Frenkel and Schottky defects; Equilibrium concentration of point defects.

One-dimensional or line defects: Dislocations: edge, screw and mixed. Burgers vector and Burgers circuit; Burgers vectors of stable dislocations in simple cubic, body-centred cubic and face-centred cubic lattices; Dislocations meeting at a node; Line energy of a dislocation. Dislocation motion: glide and climb.

Two-dimensional or surface defects: Free surfaces, Grain boundaries, twin boundaries, stacking faults, phase boundary; Surface energy of a free surface in terms of a simple bond breaking model.

Section XE2.2: Thermodynamics, Kinetics and Phase Transformations

Extensive and intensive thermodynamic properties, laws of thermodynamics, phase equilibria, phase rule, phase diagrams - unary pressure-temperature diagrams, binary temperature-composition diagrams, construction of temperature composition diagrams from free energies, common tangent construction in free energy-composition diagrams, invariant reactions.

Reaction kinetics, rate constants, order of reactions, Arrhenius law, Fick's laws, Steady state and non-steady state solutions of diffusion equations, diffusion distance and diffusion time, applications of solutions of diffusion equations, atomistic mechanisms of diffusion, fast diffusion paths.

Solidification of pure metals and alloys, homogeneous and heterogeneous nucleation, nucleation rate, growth, partitioning during binary solidification; diffusional solid-state phase transformations (precipitation and eutectoid), overall transformation kinetics (TTT and CCT), martensitic/displacive transformation; glass transition.

Section XE2.3:	Properties and Applications of Materials

Mechanical properties: elastic and plastic deformation; atomic bonding and elasticity; shear strength of perfect crystals; plastic deformation by slip and dislocation motion; Strengthening mechanisms: strain hardening, solid solution hardening, precipitation hardening, grain size refinement; Grifith theory of fracture; fatigue: cyclic loading, S-N curve, crack initiation and propagation; Creep in crystalline materials: stages and mechanisms of creep; Composites: particle and fibre reinforced composites; elastic modulus (rule of mixtures).

Electronic Properties: Drude model and classical description of electrical conductivity, Drawbacks of classical theory, Quantum mechanical description including concept of Fermi energy, Fermi surface and density of states. Band Theory to explain insulators, conductors, and semiconductors via allowed and forbidden energy bands, Effective mass concept, Intrinsic and extrinsic semiconductors, temperature dependence of conductivity, Carrier concentration and mobility, drift vs. diffusion current, Hall Effect for a simple metal or semiconductor. Dielectric behavior, piezo- and ferro-electric behavior.

Magnetic Properties: Origin of magnetism in materials, types of Magnetism: Diamagnetism, Paramagnetism, Ferromagnetism, Ferrimagnetism and Antiferromagnetism, Magnetic Domains & Hysteresis, Hard and soft magnetic materials.

Thermal Properties: Specific heat, Classical Dulong–Petit Law, Wiedemann-Franz Law, Thermal conductivity of metals and insulators (role of electrons and phonons), Einstein and Debye model, heat conduction, thermal diffusivity, thermal expansion, and thermoelectricity.

Optical Properties: Refractive index, absorption and transmission of electromagnetic radiation.

Section XE2.4:	Characterization and Measurements of Properties

X-ray diffraction: Bragg's Law, structure factor, indexing of cubic diffraction patterns; spectroscopic techniques: UV-Vis, IR and Raman; band-gap measurement; Microscopy (optical, scanning and transmission electron microscopy): wavelength range, resolution, depth of field; Composition analysis using energy dispersive spectroscopy.

Tensile test: engineering and true stress-strain curves, parameters, such as, yield stress, ultimate tensile stress, elongation, area under the curve; Hardness: Brinell, Rockwell and Vickers.

Electrical conductivity, carrier mobility and concentrations.
Thermal analysis techniques: thermogravimetry and calorimetry.

Section XE2.5:	Processing of Materials

Heat Treatment of steels: TTT and CCT diagram: coarse and fine pearlite, martensite and bainite; Annealing, normalizing, quenching, tempering.

Heat treatment of aluminium alloys: Precipitation hardening: Solutionising, quenching and ageing. Hardness vs. aging time and its dependence on aging temperature.

Silicon processing: production of metallurgical and semiconductor grade, zone refining, single crystal growth, silicon oxidation, doping, photolithographic process

Preparation of powders; sintering.

Section XE2.6:	Degradation of Materials

Electrochemical basis of corrosion of metals: standard electrode potential, galvanic series, Nernst equation, polarization and passivation; forms of corrosion; corrosion prevention

Polymer degradation: swelling and dissolution; bond rupture: radiation, chemical and thermal effects; weathering.