Course number: MSE201
Course title: Thermodynamics and Phase Equilibria
Credits: (11) 3-1-0

TOPICS		No. of lectures
1. Introduction	Introduction, Thermodynamics terminology	1
2. First law	First law of thermodynamics and its applications	2
3. Second Law	Second law of thermodynamics and its consequences, Combined statement of first and second laws	5
4. Statistical Interpretations	Statistical interpretation of entropy, entropy and disorder	1
5. Thermodynamic functions	Auxiliary functions: Helmholtz free energy, Gibbs free energy, Chemical potential, Maxwell's relations, Gibbs-Helmholtz equations.	2
6. Third law	Third law of thermodynamics	1
7. Phase equilibria in single component system	Phase equilibria in one-component systems: variation of Gibbs free energy with temperature and pressure, Clausius-Clapeyron equation, P-T diagram	1
8. Solutions	Thermodynamics of solutions: Raoult's and Henry's Law, activity of a component, Regular solutions, Gibbs-Duhem equation and its application, non-ideal solutions, Sievert's Law, activity and alternative standard states, dilute solutions and interaction parameters.	6
9. Reaction Equilibria	Equilibrium constant, Reaction equilibria for (a) homogeneous reactions consisting of gas mixtures, (b) heterogeneous reactions consisting of condensed phases and gas mixtures, Ellingham Diagram.	6
10. Phase rules	Phase rules and its applications, Lever Rule	1
11. Electrochemical cells	Thermodynamics of electrochemical cells: Relation between chemical and electrical driving forces, Nernst equation, Concentration and formation cells, thermodynamics of aqueous solutions.	3
12. Free energy composition diagram	Fundamentals of Free energy-composition diagram for binary systems. Examples of common binary Free energy-composition diagrams: Eutectic, Eutectoid, Peritectic etc.	6
13. Phase diagrams	Study of some common phase diagrams, such as Fe-C, Cu-Zn, Al-Cu, FeO-SiO2 and evolution of equilibrium microstructure on cooling.	5
Total Lectures		*40*

Suggested Text books:

1. Thermodynamics of Solids: Richard A. Swalin
2. Introduction to Thermodynamics of Materials: David R. Gaskell
3. Physical Chemistry of Metals: L.Darken and R.W.Gury
4. Problems in Metallurgical Thermodynamics and Kinetics: G. S. Upadhyaya and R. K. Dube
5. Phase Equilibria in Materials: S.P.Gupta
6. Phase Transformation: Porter and Easterling.

Course number: MSE202
Course title: Rate Processes
Credits: (11) 3-1-0

TOPICS		No. of Lectures
1 Introduction to Fluid flow	Newton's Law of Viscosity and mechanisms of momentum transfer; Newtonian & non-Newtonian fluids; Laminar and turbulent flows	1
	Newton's second law of motion ; Navier Stokes equation; typical boundary conditions in fluid flow problems; Dimensional analysis of equation of change	2
	Engineering Bernoulli's equation and application	2
	Compressible flow in conduits; Mixing and agitation	3
2. Introduction to heat transfer	Heat conduction: Phenomenological description , thermal conductivity and dependence on composition and temperature; generalized heat conduction equation and boundary conditions . Solution of steady and 1D unsteady state solution for slab , semi infinite geometry; Heat flow through composite layers	2
	Convective heat transfer (laminar and Turbulent); Heat transfer coefficient ; Free and forced convention ; important heat transfer correlations	1
	Radiative heat transfer : Radiation rate law, Black and grey bodies, Kirchoff's identity	0.5
	Heat exchange between surfaces : radiation view factors; heat exchange between grey surfaces ; concept of surface and space resistances	1
	Selective examples from Met processes including: Thermal insulation in materials processing reactors, Melting , Quenching and Radiative losses at high temperature from furnaces and other reactors.	3.5
3. Introduction to mass transfer	Molecular diffusion : Phenomenological description, mass diffusivity and its analogy with momentum and thermal diffusivity, temperature dependence of diffusion coefficient Diffusion in solids : generalized diffusion equation , the steady and transient, 1D solutions; Uphill diffusion; Kirkendal's effect	3
	Convective mass transfer; The concept of mass transfer coefficient, mass transfer correlations and dimensionless groups in free and forced mass transfer; mass transfer in laminar and	1

	turbulent flow	
	Interface mass transfer: mass transfer between two fluids ; film and interface renewal theories	1
	Selective examples from Met processes including : carburizing, Dissolution, doping and gas permeation	3
4. Mass transfer with Chemical reaction	Interfacial chemical reaction preceded by adsorption; ideal adsorption isotherms; Phenomenological description of Chemical reaction controlled phenomena and mixed controlled phenomena.	3
5. Introduction to Heterogeneous Reaction Kinetics	General characteristics of heterogeneous chemical reaction ; Activation energy and temperature dependence; rate limiting steps: mass transfer controlled and chemical reaction controlled processes; Study of over all resistance to mass transfer ; Boundary layer mass transfer controlled, chemical reaction controlled and mixed controlled phenomena)	3
6. Simultaneous Heat and Mass Transfer with Chemical reactions	Elucidation through Gas carburizing process; Discussion on solidification phenomena (formation of gas bubbles during solidification), post combustion in steelmaking	4
7. Introduction to Electrochemical Kinetics	Basic principles : concept of polarization; activation over potential; Butler-Volmer and Tafel's equation; concentration over potential, limiting current concept an application	3
	Applications of electrochemical kinetics to corrosion and passivation	3
Total Lectures		*40*

Suggested text books:

1. Engineering in Process Metallurgy: R. Guthrie, Oxford Scientific Publications
2. Transport Phenomena in Metallurgy: GH Geiger and DR Poirier; TMS publication
3. Kinetic and metallurgical processes: Fathi Habashi
4. Mass transport in solids and fluids: DS Wilkinson, Cambridge solid state science series.

Course number: MSE203
Course title: Structure and Characterization of Materials
Credits: (09) 3-0-0

TOPICS		No. of Lectures
1. Introduction	• Bond types- structural descriptors of bonded materials.	1
2. Crystalline State	• Crystallography of 2D: Translational symmetry, reflection and glide symmetry • Rotational symmetry: Proper rotation axes • Quasicrystals: aperiodic tiling patterns; Icosahedral structures • Plane point groups: combination of reflections and rotations • Five distinct plane lattices and 17 plane groups, International convention for plane groups • Crystallography of 3D: Inversion, rotoinversion, rotoreflection, screw axis. • Stereographic projection fundamentals • Basis for the 32 crystallographic point groups • International notations and conventions for representation of point groups • Space lattices: Bravais lattices and crystal system • Space groups: Derivation and international table for crystallography • Important crystal structures like Rocksalt, fluorite, zinc blende, antifluorite, perovskite etc to be discussed	12
3. Non-crystalline state	• Generic descriptors: short-range order, glass transition, pair-distribution Function , Hard sphere model • Liquid crystalline state - Structural classes, Concept of isotropic and anisotropic liquid crystals,	4
4. Microstructures	• Structural hierarchies: Nano-, micro-, meso-, macro-structures Discussion with illustrative examples • Deformation structures. • Transformation microstructures: solidification, solid-solid, composite structures • Fundamentals of stereology and application to microstructural analysis	5

5. X-ray Diffraction	• The laue equations and Bragg's law • Reciprocal space, Ewald sphere construction • X-diffraction methods: Powder diffraction, single crystal laue diffraction, rotating single crystal method, Thin film analysis • Scherrer formula and grain size determination • Diffraction analysis: Atomic scattering factors, scattering by the unit cell, Structure factor, diffraction intensities.	7
6.**Electron diffraction**	• Wave properties of electron, electron-matter interactions • Ring patterns, spot patterns, Laue zones	2
7.**Optical microscopy**	• Fundamentals of Imaging: magnification, resolution, depth of field and depth of focus • Image contrast – special microscopy techniques	2
8.**Scanning electron microscope**	• Fundamentals principles of SEM • SE and BSE imaging modes, X-ray mapping • Fractography and failure analysis	3
9.**Transmission electron microscope**	• Resolution limitation and lens aberrations • The origin of contrast: mass-thickness contrast, diffraction contrast and crystal defect analysis • BF, DF, Weak beam DF images • Phase contrast and lattice imaging	4
10.**Surface analysis technique**	• RBS, STM, AFM etc.	2
	Total lectures	*42*

Suggested text books and reference material:

1. Elements of X-ray diffraction, B.D. Cullity and S.R. Stocks, Addison-Weiley Publishing Co.
2. Introduction to solids, L.V. Azaroff, McGraw-Hill Book Company
3. Elementary Crystallography by M.J. Buerger
4. The structure of materials, S.M. Allen and E. L. Thomas, John Wiley and Sons, 1998
5. Crystals and Crystal structures, R.J.D. Tilley, John Wiley and Sons, 2006
6. Fundamentals of Materials Science-the microstructure-property relationship using metals as model systems, E.J. Mittemeijer, Springer, 2010
7. Microstructural Characterization of Materials – D. Brandon and W.D. Kaplan, John Wiley and Sons, 2008

Course number: MSE204
Course title: Introduction to Biomaterials
Credits: (06) 2-0-0

<table>
<tr><th colspan="2">TOPICS</th><th>No. of Lectures</th></tr>
<tr><td rowspan="2">1. Introduction to Biomaterials</td><td>Introduction to materials at the interface with biological sciences</td><td>2</td></tr>
<tr><td>Social, Environmental & Ethical Issue</td><td>1</td></tr>
<tr><td rowspan="2">2. Classification of biomaterials</td><td>a) <u>Response Based</u>: Bioinert/ Bioactive/ Bioresorbable
b) <u>Material Based</u>: Bioceramic/ Biopolymer/ Biometallic
c) <u>Application Based</u>: Structural (Bone replacement materials, dental biomaterials, cardiovascular biomaterials, total hip and knee replacement), Non-structural (drug-delivery/ sensing/ surface modification)</td><td>3</td></tr>
<tr><td>Concept of biocompatibility:
- Definition
- Immune response
- Testing (in vitro/ in vivo)</td><td>3</td></tr>
<tr><td rowspan="3">3. Structure-Property correlation</td><td>- Biomimetics
- Introduction to structure and properties of proteins, biological cells and tissues</td><td>2</td></tr>
<tr><td>Biological phenomenon on material surfaces
- Protein adsorption isotherms
- Kinetics of cell-material interaction
- Bacterial adhesion and kinetics of biofilm formation</td><td>4</td></tr>
<tr><td>Principles of various surface Characterization techniques: Atomic force microscopy, fluorescence microscopy, tensiometer (contact angle measurement), quartz crystal microbalance</td><td>2</td></tr>
<tr><td>4. Processing and properties of biocompatible materials</td><td>- Quantification of structure-property correlation
- Bioglass/ Glass-ceramics
- Macroporous scaffolds
- Biodegradable polymers
- Biocomposites</td><td>6</td></tr>
</table>

	- Thin films and coatings	
7.Surface engineering & case-studies	Surface Engineering - Micro-contact printing - Layer-by-layer assembly/ Functionalization Case Study - Self-assembly: Thermodynamics and kinetics aspects - Drug-delivery/ Bio-responsive surfaces - Articulating joints - Dental restorative applications - Cardiovascular patches/ heart valves	4
	Total Lectures	*27*

Suggested text books:

- Biomaterials Science: An introduction to Materials in Medicine, Edited by Ratner, Hoffman, Schoen and Lemons, Second Edition: Elsevier Academic Press, 2004.
- Biological Performance of Materials: Fundamentals of Biocompatibility, Janathan Black, Marcel Dekker, Inc., New York and Basel, 1981.

Reference material:

- Biomaterials: Principles and Applications Joon B. Park (Editor), Joseph D. Bronzino (Editor) CRC Press
- Materials Characterization Techniques; Sam Zhang, Lin Li, Ashok Kumar; CRC press, (2008)
- Advanced Biomaterials: Fundamentals, Processing and Applications; Ed. B. Basu, D. Katti and Ashok Kumar; John Wiley & Sons, Inc., USA (http://www.wiley.com/WileyCDA/WileyTitle/productCd-0470193409.html)
- Biomaterials Science and Biocompatability, Fredrick H. Silver and David L. Christiansen, Piscataway, Springer, New Jersey.
- Advanced Structural Ceramics: B. Basu and K. Balani, John Wiley & Sons, Inc., USA, 2011.

Course number: MSE 300
Course title: Professional and Technical Communication
Credits: (02) 0-0-2-2

Importance of professional communication, effective communication, channels of communication: written, oral and appearance. Reading skills: inculcating values/character. Writing skills: expression, clarity, and crispness. Reading and writing on a daily basis. Plagiarism. Technical writing (paper, thesis, report, letters, etc) and its components. Presentation skills: oral, report writing, group discussions, time management.

<u>MSE 300 Professional and Technical Communication:</u>

- Importance of professional/technical communication:
- Domains: Thesis/Report writing, Paper writing, Business letters, job letters, résumé, etc.
- Plagiarism: Importance, what is it and how to keep a check
- Projects/Assignments: Oral talks, Group discussions, Preparing report, Presentation skills, and time management (on selecting contents, highlighting novelty, using visual aids and providing illustrations)

Course number: MSE 301
Course title: Phase Transformations
Credits: (06) 2-0-0

Sl. No.	Topics	No. of Lectures
1. Introduction	Introduction and classification of phase transformations.	1
2. Gibbs free energy change calculations	Calculation of ΔG_v for various transformations (polymorphic & solidification, precipitation, massive, eutectic & eutectoid)	2
3. Interfaces	Nature of inter-phase interfaces and their energies.	2
4. Nucleation	Theory of nucleation, Homogeneous and heterogeneous nucleation (surfaces, grain boundaries, edges and corners, dislocations).	4
5. Growth	Theory of thermally activated growth, interface controlled growth (polymorphic and massive), diffusion controlled growth (one and three dimensional), coupled growth (eutectoid and discontinuous precipitation).	4
6. Transformation kinetics	Theory of Transformation Kinetics, Johnson-Mehl and Avrami Models. Isothermal Transformation diagrams.	2
7. Precipitation	Precipitation and precipitation hardening (Al-Cu), Oswald ripening.	2
8. Recrystallisation and grain growth	Recrystallisation and grain growth.	2
9. Martensitic Transformation	Martensitic transformations.	2
10. Isothermal and continuous cooling transformations	Isothermal and continuous cooling transformation diagrams for steels and basis of heat treatment.	2
11. Spinodal decomposition	Spinodal decomposition.	1

12. Solidification	Solidification: pure metals and alloys, constitutional super-cooling, denderitic growth, eutectic solidification	4
Total lectures		*28*

Suggested text books:

1.Phase Transformations in Materials by R. C. Sharma, CBS Publishers, New Delhi

2. Solid State Transformations by V. Raghavan, Prentice-Hall of India, New Delhi

Course number: MSE302
Course title: Mechanical Behaviour of Materials
Credits: (09) 3-0-0

TOPICS		No. of Lectures
1. Elasticity	Elastic constants and atomistic origin	1
	State of stress in 2D/3D: Mohr circle, transformation of stress, stress tensor	3
	Strain Tensor, Elastic Stress-strain relations	1
	Isotropic versus Non-Isotropic Materials	1
	Non-Liner Elasticity (eg., polymers) and Viscoelasticity	1
2. Plasticity	Yield Criteria: Von Mises, and Tresca	1
	Tensile Stress-Strain Curve	1
	Single Crystal Slip	1
	Theoretical shear strength: Dislocations & Twins	1
3. Dislocations	Types, Burgers Vectors, Slip Systems	2
	Dislocation Motion: jogs, kinks, cross-slip, climb, Peierls Stress	2
	Stress Field of dislocation (derivation)	1
	Forces on dislocations, dislocation multiplication	1
	Interaction of Dislocations with other dislocations, Point defects, Grain boundaries, Mechanism of Work-Hardening	4
	Dislocation dissociation, Stacking faults, Twins (deformation twins), sessile dislocations	2
4. Applications	Strengthening Mechanisms : - yield point phenomena, strain aging, solid solution strengthening, strengthening from fine particles, grain size strengthening, work hardening, heat treatment	3
	Fracture and Fatigue - Fracture Mechanisms in Metals and ceramics - Linear Elastic Fracture Mechanics, Griffith's criteria, fracture toughness - Environmentally Assisted Fracture (e.g., SCC, Hydrogen Embrittlement) - Fatigue Mechanisms, Fatigue Testing, S/N Curve - Fatigue Crack Propagation (LEFM)	 1 2 2 1
	Creep : - Creep Mechanisms: *Diffusion Creep,*	 1

	Dislocation Creep - Correlation between properties and performance: *parametric models* - Deformation Mechanism Maps	1 1
	Case Studies : - Examples from elasticity, plasticity, fracture, fatigue and creep life prediction	1 4
Total Lectures		*40*

Suggested text books:

1. Mechanical Behaviour of Materials, M.A. Meyers and K.K. Chawla
2. Introduction to Dislocations, Hull and Bacon

Reference Material:

3. Mechanical Metallurgy, G.E. Dieter
4. Mechanical Behavior of Materials, Courtney
5. Theory of Elasticity, Timoshenko
6. An Introduction to Mechanics of Solids, S.H. Crandall and N.C. Dahl
7. Deformation and Fracture Mechanics, R.W. Hertzberg
8. Mechanical Testing, Metals Handbook
9. Recrystallization and Related Annealing Phenomena, F.J. Humphreys

Course number: MSE303
Course title: Electronic and Magnetic Properties of Materials
Credits: (09) 3-0-0

TOPICS		No. of Lectures
1.**Introduction to electronic structure**	Review of quantum mechanics: Electron as waves and particles; Wave-function; Electron as a plane-wave, Operators; Schrodinger Equation, Wave-vector (k); Energy of free-electron as a function of wave-vector k (ε - k diagram, a parabola), k-space; Density-of states [g(ε)]; Fermi-sphere, -energy, -surface, -temperature, and –velocity Electrons in a solid following Fermi-Dirac distribution; DC conductivity in metals	3 2
2. **Electronic structure in crystalline materials**	Lattice; Bravais-Lattice; Wigner-Seitz cell; k-space: Reciprocal space; Reciprocal lattice and it's connection to its direct-lattice, Brillouin zone; Von-Lau condition of Bragg diffraction and boundaries of Brillouin-zone being the Bragg-Planes Electrons in a periodic-potential; Bloch Theorem, Kronig-Penny model; Origin of energy bands and band-gap; Free electron band diagram, Extended-, Periodic and reduced-zone representation for ε - k diagram; Allowed number of states in a band	2 3
3. **Electron Dynamics**	Group-velocity, electron dynamics from ε-k diagram and the concept of effective-mass and concept of holes; Conductivity in relation to band structure; Band structure of metals and semiconductors, and insulators; Band-overlap: why some metals show positive charge carriers in Hall-effect	2
4.**Semiconductors**	Band diagrams, direct and indirect bandgap, applications of semiconductors ; Effective-mass of electron in conduction-band and that of hole in valence-band **Intrinsic semiconductors**: Fermi-level; Density-of-states near the edges of conduction and valence-band; Fermi-dirac statistics approximated by Maxwell-boltzman; Intrinsic charge-carrier concentration, Law-of mass-action; Direct vs Indirect Semiconductors, **Extrinsic-semiconductor**: hydrogen-model for rough estimate of the donor and acceptor energy level, n- and p-type semiconductors; Population of impurity levels in thermal-equilibrium, charge-carrier concentration in n- and p- type semiconductors; Fermi-level, Degenerate and non-degenerate	1 2 2

	semiconductors, determination of dopant levels and mobility measurements Semiconductor Devices: p-n junction and solar cells; Bandgap engineering: Solid-state LEDs, Lasers and IR detectors	3
5. **Ionic conductors**	Ionic conduction – review of defect equilibrium and diffusion mechanisms; Theory of ionic conduction, conduction in glasses; Effect of stoichiometric and extrinsic defects on conduction, Applications in sensors and fuel cells	2 2
6. **Dielectric materials**	Dielectric constants and polarization, linear dielectric materials, capacitors; Polarization mechanisms; Non-linear dielectrics, pyro-, piezo-, and ferro-electric properties, hysterisis and ferroelectric domains; Applications in sensors, actuators and memory devices	4
7. **Magnetic materials**	Orbital and spin - permanent magnetic moment of atoms, diamagnetism, paramagnetism, and Pauli-paramagnetism, Ferro, anti-ferro and ferri magnetism, Fe, Co and Ni and alloy additions, ferrites, magnetic hysteresis, exchange energy, magnetocrystalline energy, magnetorestriction; Highly correlated systems Applications: Spintronics and memory devices Superconductors, Multiferroic materials	2 6 2
8. **Optical materials**	Light interaction with materials-transparency, translucency and opacity, refraction and refractive index, reflection, absorption and transmission ; LC materials Application: LCD Displays	4
Total Lectures		*42*

Suggested Books and reference material:

1. Electronic Properties of Materials: An Introduction for Engineers, Rolf E. Hummel, Springer Verlag, 1985
2. Physical Properties of Semiconductors, Charles M. Wolfe, Nick Holonyak and Gregory E. Stillman, Prentice Hall, 1989
3. Solid State Physics, Neil W. Ashcroft and N. David Mermin, Sauders College, Philadelphia, USA, 1976
4. Advanced Theory of Semiconductor Devices, Karl Hess, Prentice Hall, 1988
5. Advanced Semiconductor Fundamentals, Robert F. Pierret as part of Modular Series on Solid State Devices Vol. 6, Addison Wesley, 1989
6. Introduction to Solid State Physics, Charles Kittel, John Wiley & Sons 1991
7. Electrical Properties of Materials, L. Solymar and D. Walsh, Oxford University press, 1998.
8. Physics of Solids, C. A. Wert and R.M. Thomson, McGraw-Hill Book Company, 1970 or later
9. "Physics of Semiconductor Devices" by J-P Colinge and C. A. Colinge, Kluwer Academic Pub. 2002
10. "Electronic Properties of Materials" by R. E. Hummel, Springer, 2011

Course number: MSE304
Course title: Principles of Metals Extraction and Refining
Credits: (06) 2-0-0

TOPICS		No. of Lectures
1. Thermodynamics and Kinetics in metals extraction and refining	Reaction equilibria; Heat effect of chemical reactions; oxide and sulphide Ellingham diagram; Chemical potential; activity – composition relationships; solution; ideal and non ideal solution. Interaction parameters; Sievert's law and solubility of gases in metals, Chemical kinetics, Virtual maximum rate; rate limiting steps; relative importance of mass transfer and chemical kinetics in extractive metallurgy	4
2. Principles of Mineral Beneficiation	Laws of communition; Crushing and grinding, Principles of heavy media separation; Principles of froth floatation, magnetic and electrostatic separation techniques with application in metal extraction circuitry	4
3. Principles of Pyro-metallurgy	Pyro, hydro and elctro- metallurgical techniques; The sources of energy in metal extraction; Principles of major pyro metallurgical processes such as Drying, Calcinations, Roasting, smelting (including flash smelting), smelting of sulphides and predominance area diagram; Their relevance to Iron, copper , lead, zinc extraction; Oxidizing refining and steelmaking; Energy and material recovery ; slag and recycling issues	6
4. Principles of Electrometallurgy :	Faraday's law; Electrolysis ;current density and efficiency; Electrolyte resistance and its role; factors affecting electrolytic resistance; impurity interference; cathodic deposits; Their relevance to Aluminium and magnesium extraction ; specific energy consumption in aluminum electrolytic cell (Hall-Heroult cell)	5
5. Principles of Hydrometallurgy	Dissolution and Leaching; Solvent extraction, Treatment of leached solution , Precipitation, cementation; Their relevance to Bayer's Process, Gold and Silver extraction; Amalgamation	4
6. General issues related to metal extraction	Choice of a specific route; grades of ore; specific energy consumption , waste recycling and treatment ; Environmental impact	1
	Classification of dissolved impurities in metals; Common Impurities in metals and their origin; The effect of impurities on	3

7. Refining of Metals	properties of metals with some specific examples Principles of Fire-refining, electrolytic refining, zone refining and electroslag refining, removal of gases from metals	
Total lectures		*27*

Suggested text books:

1. DR Gaskel: An Introduction to Metallurgical Thermodynamics, McMillan Publishing Co., 1992
2. Barry Willis: Mineral Processing Technology, Elsevier
3. T.A.Engh: Principles of metal refining, Oxford Scientific Publications;1992
4. JJ More: Chemical Metallurgy, Butterworth, 1990
5. Terkel Rosenqvist: Principles of Extractive Metallurgy, 2nd Edition, Tapiar Academic Press

Course number: MSE305
Course title: Materials Processing
Credits: (06) 2-0-0

TOPICS		No. of Lectures
1. Solidification Processing	Introduction; Mold, Feeder and Riser Design in Casting	1
	Fluidity Considerations	1
	Semi-Solid Processing (*solidification processing of metal-ceramic or dispersed systems; thixotropic behaviour; rheocasting; spray-casting)*	2
	Continuous Casting of Steels	1
	Casting Defects	1
	Case Studies	1
2. Mechanical Working	Workability of Materials	1
	Forging *(open die and closed die forging; forging load calculation)*	1
	Rolling *(classification of different rolling mills and their applications; roll bite condition; rolling load calculation)*	2
	Extrusion *(direct and indirect extrusion; load-displacement relationship; extrusion load; hydrostatic extrusion)*	1
	Sheet Metal Forming *(deep drawing; forming-limit diagram)*	1
	Defects in Mechanically Worked Materials	1
3. Metal and Ceramic Powder Processing	Powder Production and Characterization	2
	Powder Compaction *(pressing operation and press selection; stress distribution during compaction; guidelines for part geometry)*; Cold-Isostatic Pressing	1
	Solid-State Sintering *(phenomenological aspect of sintering; Kuczynksi's equation; Herring's scaling law; microstructural evolution)*; Grain Size – Density and Grain Size – Pore Size Relationship during Sintering; Liquid Phase Sintering *(stages of liquid phase sintering; supersolidus sintering)*; Pressure-Assisted Sintering *(hot-pressing and hot-isostatic pressing)*	3 1
	Select Case Studies	
4. Thin-Film and Coating Techniques	Introduction to Vacuum Technology • Why a high vacuum is required • Operational principles of various mechanical pumps as well as limitations • Operation of high vacuum pumps such as oil diffusion pumps • Principles of UHV pumps such as ion and	2

	getter pumps • How can one create non-equilibrium structures via thin film processing i.e. kinetic effects • Role of cleanliness in devices and processing	
	Physical Vapour Deposition Processes: Thermal and e-beam evaporation, Molecular beam epitaxy, sputtering and laser ablation	2
	Chemical deposition: Chemical vapour deposition, atomic layer deposition and solution processing, Role of heat treatments	1
	Plasma Spray Coating	1
	Case Studies	1
Total lectures		*28*

Suggested text books:

1. R.W. Heine, C.R. Loper, and P.C. Rosenthal, Principles of Metal Casting, 2nd ed., 1967.
2. A. Upadhyaya, G.S. Upadhyaya: Powder Metallurgy -Science, Technology and Materials (2011)
3. Donald Leonard Smith "Thin-film deposition: principles and practice", McGraw Hill
4. J.N. Harris, Mechanical Working of Metals- Theory & Practice, Pergamon Press, Exeter, UK, 1983.

Reference Material:

1. M.C. Flemmings, Solidification Processing.
2. R.M. German, Powder Metallurgy Science, 2nd ed (2008)
3. B. Basu, K. Balani: Advanced Structural Ceramics, J. Wiley & Sons, Inc. (2011).
4. G.E. Dieter, Mechanical Metallurgy, McGraw Hill, Inc., London, UK, 1992.
5. W.F. Hosford and R.M. Caddell, Metal Forming- Mechanics & Metallurgy, Prentice Hall, Englewood-Cliffs, NJ, USA, 1983.
6. Milton Ohring “The Materials Science of Thin Films", Academic Press 1992
7. Donald A. Neamen, "Semiconductor Physics and Devices", 3rd edition, McGraw Hill, 2007.
8. S. M. Sze, "Physics of Semiconductor Devices" John Wiley and Sons
9. S.A. Campbell, “The Science and Engineering of Microelectronic Fabrication”

Course number: MSE311
Course title: Physical Metallurgy Laboratory
Credits: (3) 0-0-3

Suggested list of experiments

No.	Title of the experiment
1	Metallographic specimen preparation
2	Optical microscopy of illustrative Ferrous samples
3	Optical microscopy of Non-Ferrous samples
4	Optical microscopy of Ceramic samples: Colour metallography and phase contrast microscopy of non-metallic materials
5	Quantitative metallography and image analysis
6	X-ray powder diffraction in materials analysis
7	Study of nucleation and growth in eutectoid steel
8	Carburization of Steel and Hardenability of steel
9	Recovery and Recrystallisation
10	Thermal analysis using DSC to study phase transformations
11	Bubble raft experiments
12	Stereographic projections

Course number: MSE 312
Course title: Functional Materials Laboratory
Credits: (03) 0-0-3

Suggested list of experiments

No.	Title of the experiment
1	Ionic conductivity • Conductivity measurement as a function of temperature for different samples
2	Dielectric and ferroelectric/piezoelectric materials • Measurement of dielectric constant • Hysteresis loop
3	Optical behavior of Liquid Crystals • Measure response to applied field • Measure the transmittance • Measure threshold voltage
4	Fabrication of organic light emitting diodes • Partial fabrication of organic polymer light emitting diodes • Characterization of an OLED
5	Magnetic materials • Magnetoresistance • M-H curves
6	Semiconductor characterization • Semiconductors resistivity • Hall measurement • Bandgap measurement
7&8	Solar cell fabrication and characterization • Fabrication of organic photovoltaic cells (PV) cells • Characterization of solar cells
9	Processing of biomaterials • Fabricate biomaterials using (i) compression molding (for entire component), and (ii) electrostatic spraying (for coatings)
10	Tribology of bio-coatings • Tribology of two samples: (i) polymer with modifier (ii) polymer without modifier for comparison purpose. • Comparison with metallic substrates (demo).
11	Biomimetics/ Surface modification

	• Effect of surface energy on wetting of surfaces • Samples prepared by the students → measuring the contact angle. • Role of surface roughness/ chemistry on affecting the wettability of surface.
12	Effect of surface modification on Bacteria/ Cell growth • Effect of surface modification/functionalization characterized by comparing cell growth/proliferation on treated versus pristine surfaces. • One or more of the following will be performed by students to learn cell response: (i) Role of surface chemistry (hydrophobic/ hydrophilic and hydrophobic/ hydrophilic + modifier) (ii) Role of surface roughness

Course number: MSE 313
Course title: Mechanical Behaviour Laboratory
Credits: (3) 0-0-3

Suggested list of experiments (any seven experiments from the list of 9)

No.	Title of experiment
1.	Determination of tensile properties of different classes of materials
2.	Principles of Hardness Testing: comparison of different hardness measurement techniques
3.	Impact Testing of Materials: Charpy Impact Test
4.	Creep Testing of Materials
5.	Fatigue Testing
6.	Strain Ageing and Yield Point Phenomenon
7.	Observation of dislocations by using the etch pitting technique
8.	Effect of Work-Hardening on Tensile Properties of Metals.
9.	Plastic Anisotropy
10	Project

Some possible project areas:

1. Determination of DBTT for different crystal structures (e.g., low C steel, Al)
2. Superplastic deformation of materials
3. Environmentally Assisted Cracking of Materials, e.g., Hydrogen Embrittlement.
4. Failure Analysis of real life problems using various testing and characterization techniques.
5. To study the effect of solid-solution strengthening on mechanical properties in metal systems, e.g., brass with increasing amount of Zn
6. To study precipitation hardening in metal systems, e.g., Duralumin
7. Effect of heat treatment on microstructure and mechanical properties of steels.
8. Investigation of the Hall Petch relationship in polycrystals, e.g., 304 stainless steel
9. Effect of heat treatment on the mechanical properties of work-hardened materials
10. Fracture strength of brittle materials
11. Viscoelastic behaviour of polymers

Course number: MSE 314
Course title: Process Engineering Laboratory
Credits: (3) 0-0-3

Suggested list of experiments

<table>
<tr><th>No.</th><th>Title of Experiment</th></tr>
<tr><td>1</td><td>Measurement techniques
Calibration and measurement of liquid flow rate using orifice meter and rotameter.
Temperature measurements using thermocouple and pyrometer.</td></tr>
<tr><td>2</td><td>Laminar fluid flow
Viscosity measurement of liquids using torsional flow apparatus.
Validation of fully-developed velocity profile in Poiseuille flow using flow rate measurement.</td></tr>
<tr><td>3</td><td>Macroscopic energy balance (Bernoulli's equation)
Filling of overhead tanks from a reservoir through a piping system consisting of valves, expansion/contraction joints, and bends.</td></tr>
<tr><td>4</td><td>Steady and unsteady conduction heat transfer
Steady state conduction heat transfer in single and composite solids using spatial temperature measurements.
Solidification time in sand moulds</td></tr>
<tr><td>5</td><td>Convective heat transfer
Determining natural heat transfer coefficients for heat transfer through a fin with the help of spatial temperature measurements.</td></tr>
<tr><td>6</td><td>Radiation heat transfer
Comparison of calculated and measured radiation heat flux from an electrical source inside a chamber with a thin conductive metal strip placed at the mouth of the chamber.
Radiation flux will be calculated by measuring the steady state temperature of the metal strip.
Temperature of the heat source to be measured by an optical pyrometer.</td></tr>
<tr><td>7</td><td>Mass transfer
Measurement of mass transfer coefficient under natural and forced convection, and visualization of boundary layer dynamics.</td></tr>
</table>

8	Thermodynamics • Dissociation of limestone. • Determining heat of reaction with a bomb calorimeter.
9	Kinetics • Reduction of oxides ○ Determining rate controlling step using the shrinking core model.
10	Mineral processing • Particle size analysis. • Demonstration of froth flotation, magnetic and electrostatic separators.
11	Hydrometallurgy I • Pressure leaching in an autoclave and precipitation.
12	Hydrometallurgy II • Solvent extraction of copper using a mixer-settler.
13	Process metallurgy I • Flow visualization in an air-agitated tank. • Measurement of mixing times in an air/impeller-agitated tank.
14	Process metallurgy II • Flow visualization, particle dynamics and pressure drop measurements in a fluidized bed reactor.
15	Electrochemistry • Measurement of standard and non-standard reduction potential. • Validation of Faradays law for deposition of copper. • Overpotential measurements for determining constants in Tafel’s equation.

Course number: MSE 315
Course Title: Manufacturing Process Laboratory
Credits: (3) 0-0-3

Suggested list of experiments

No.	Title of the Experiment
1	Deformation Behavior of Metals during Rolling and study of the associated microstructural changes
2	Fluidity Measurement during Casting
3	Permanent mold casting and casting defect evaluation
4	Effect of MMAW and MIG Welding on the Microstructure and HAZ in Steels
5	TIG and OAW Welding of Aluminium Alloys
6	To Study Various Characteristics of Metal Powders and Evaluate the effect of particle size and shape on the green density, apparent density and green strength of cold-compacted powders
7	Conventional and Microwave Sintering of Particulate Compacts
8	PM Design of Engineering Components (CD-Based Design Expt)
9	Structural Nano-Materials through ECAP
10	Spray Forming of Alloys and MMCs
11	Micro-Extrusion of Alloys
12	Injection molding of thermoplastic polymers (e.g. PE, PP)
13	3-Dimensional Printing (3DP) of designed structures
14	Thin film deposition using evaporation technique