M.Sc. DEGREE

IN

MATERIALS SCIENCE AND NANOTECHNOLOGY

CHOICE BASED CREDIT SYSTEM

(Effective from the Academic Year 2015-2016)

DEPARTMENT OF MATERIALS SCIENCE AND NANOTECHNOLOGY

YOGIVEMANA UNIVERSITY,

KADAPA – 516 003, ANDHRA PRADESH, INDIA

APRIL - 2015

COURSE STRUCTURE AND EXAMINATION SCHEME

Semester	Course code	Title of the Course	No. of credits	No. of hours per week	Max. Marks 100	
					Internal Assess-ment	End Exams
SEMESTER I	MSNT 101	Classical and Statistical Mechanics	04	04	25	75
	MSNT 102	Concepts in Materials Science	04	04	25	75
	MSNT 103	Fundamentals of Chemistry	04	04	25	75
	MSNT 104	Mathematics	04	04	25	75
	MSNT 105	Practical - I Physical Chemistry	04	12	25	75
	MSNT 106	Practical-II Inorganic Chemistry	04	12	25	75
SEMESTER II	MSNT 201	Quantum Mechanics	04	04	25	75
	MSNT 202	Properties of Bulk and Nanomaterials - I	04	04	25	75
	MSNT 203	Polymeric Materials and Processing	04	04	25	75
	MSNT 204	Introduction to Nanoscience and Synthesis of Nanomaterials	04	04	25	75
	MSNT 205	Practical - I Polymer Material Lab	04	12	25	75
	MSNT 206	Practical-II Study of Properties of Materials	04	12	25	75
	MSNT 207	***Non-Core: Concepts of Nanomaterials***	***04***	***04***	***25***	***75***
SEMESTER III	MSNT 301	Characterization Techniques	04	04	25	75
	MSNT 302	Semiconductors and Devices	04	04	25	75
	MSNT 303	Alloys and Paints	04	04	25	75
	MSNT 304	Nanocatalysis and its Applications	04	04	25	75
	MSNT 305	Practical - I Nanocatalysis & Materials Synthesis Lab	04	12	25	75
	MSNT 306	Practical- VI Semiconductors Lab	04	12	25	75
	MSNT 307	***Non-Core: Characterization Techniques and Applications of Nanomaterials***	***04***	***04***	***25***	***75***
SEMESTER IV	MSNT 401	Advanced Characterization Techniques	04	04	25	75
	MSNT 402	Properties of Bulk and Nanomaterials – II	04	04	25	75
	MSNT 403	Applications of Nanomaterials and Nanotechnology	04	04	25	75
	MSNT 404	Energy Conversion Technologies	04	04	25	75
	MSNT 405	Project Work – Dissertation	04	12	--	100
	MSNT 406	Project Work – Viva-voce	04	12	--	100
Total for Core Papers			96			
Total for Non-CorePapers			08			
Grand Total			104			

NON CORE COURSES (FOR THE STUDENTS OF OTHER DEPARTMENTS)

COURSE CODE	TITLE
MSNT 207	Concepts of Nanomaterials
MSNT 307	Characterization Techniques and Applications of Nanomaterials

Note: The Department will offer both External Elective Courses depending on the student's strength opted for that course, which will be intimated at the beginning of the semester.

MSNT101: Classical and Statistical Mechanics

Unit-I: Lagrangian Mechanics and Hamiltonian Mechanics 15 h

Newtonian Mechanics of one and many particle systems; Conservation laws ; Constraints and their classification; Principle of virtual work ; D' Alembert's principle; Generalized coordinates; Lagrange's equations of motion; Hamiltonian principle ; Lagrange's equation from Hamilton's principle ; Hamilton's equation of motion ; Some applications of Lagrange's and Hamilton's formulation.

Unit-II : Canonical Transformations and Hamilton – Jacobi Theory 15 h

Canonical transformations ; generating function ; properties: Condition for transformation to be canonical ; Illustration of canonical transformation ; Poisson; brackets ; canonical equations in terms of Poisson – bracket notation ; Lagrangian; brackets and their properties ; The Hamiltonian; Jacobi equation ; one dimensional harmonic oscillator ; action Angle variables ; Kepler problem in action angle variables.

Unit-III: Ensembles & Partition functions 15 h

Foundations of statistical mechanics, specification of states of systems, relation between statistics and thermodynamics, phase space, concept of ensembles, ensemble average, Liouville's theorem.

Canonical, molecular, translational, rotational, vibrational, electronic and nuclear partition function, applications of rotational and vibrational partition functions to solids.

Unit-IV: Maxwell-Boltzman, Bose-Einestein and Fermi-Dirac Statistics 15 h

Maxwell-Boltzman statistics: Distribution of velocities, calculation of mean values, equipartition of energy, Bose-Einestein distribution; Bose-Einestein condensation, thermodynamic properties of an idea Bose-Einestein gas; Ideal Fermi-Dirac Gas, Fermi-Dirac Distribution, degeneracy.

Text Books:

1. Classical Mechanics by N.C. Rana and P.S. Joag (Tata Mc;graw Hill) 1991
2. Classical Mechanics by H. Goldstein (Addi Wesly) 1980
3. Introduction to Classical Mechanics by R. G. Takwale and P.S. Puranic
4. Classical Mechanics by J.C. Upadhyaya, Himalaya Pub.house, Mumbai
5. Introduction to IR & Raman Spectroscopy, N.B. Calthrup, L.N. Daly & S.E. Wiberlay, Academic Press, New York 1964.
6. B.K. Agarwal, Statistical Mechanics, Melvin Einser
7. ESR Gopal, Statistical Mechanics and Properties of Matter
8. F. Reif, Statistical and thermal physics
9. C. Kittel, Elementary Statistical Mechanics

MSNT102: Concepts in Materials Science

Unit-I: Crystal Systems **15 h**

Translational vectors; Lattice and Basis; Unit cell; Bravais lattices; Lattice constants, Crystal planes; Miller indices; Symmetric operations; Point groups; Packing fraction; Simple cubic structures; Body centered cubic structure, Face centered cubic structure; Hexagonal close packed structure; NaCl, CsCl, Diamond and ZnS structures

Unit-II: Imperfections in Crystals **15 h**

Point defects: Impurities; Vacancies - Frenkel and Schottky intrinsic vacancies; Equilibrium concentration of defects; Ionic conductivity in alkali halides; Color centers: Classification-F,F', V centers-Production of color centers

Line defects: Edge and Screw dislocations; Burger vector; Stress field around dislocations; Dislocation energy - Estimation of dislocation densities, Expression for strain energy of dislocation; Role of dislocations in crystal growth;

Plane defects: Stacking faults; Grain boundaries – Low angle grain boundaries

Unit-III: Lattice Vibrations **15 h**

Lattice vibrations: Elastic vibrations of one dimensional homogeneous line; One dimensional line of atoms; Normal modes of vibrations in a finite length of lattice; The linear diatomic lattice; Phonons; Scattering of phonons by neutrons & photons

Unit IV: Band Theory of Solids **15 h**

Motion of electron in periodic potential – Bloch function – Kroning – penny model-formation of energy bands in solids, Concept of effective mass, Brillouin zones- different schemes of representation of E vs K curves, Distinction between metals, insulators and semiconductors.

Text Books:

1. R. L. Singhal, Solid State Physics, Kedarnath Ramnath - Publisher
2. M.A.Wahab, Solid State Physics: Structure and Properties of Materials, Alpha Science International Ltd., (2005)
3. S.O. Pillai, Solid State Physics, Wiley Easter Ltd.(1994)
4. C.Kittle, Introduction to Solid State Physics, Wiley, 7th Edition (1995)
5. Gupta, Kumar, Sharma, Solid State Physics
6. Stephen Elliott and S.R. Elliot, The Physics and Chemistry of Solids, Wiley, 1st Edn (1998)
7. Malik Wahid U. Et. Al, Selected topics in inorganic chemistry, S. Chand & Co., Ltd. (2009)

MSNT 103: Fundamentals of Chemistry

Unit-I: Chemical Kinetics **15 h**

Rate and Order of reaction; Molecularity; First, second and third order reactions; Methods of determining Rate laws; Collision theory of reaction rates; Steric factor, Activated complex theory, Arrhenius Equation, Treatment of unimolecular reactions, Lindemann, Lindemann – Hinshelwood

Unit-II: Electroanalytical techniques **15 h**

Theory of Potentiometry, Calculation of electrode potential at the equivalence, Finding of equilance volume, derivative and linear titration plots, Nernstian response, sources of error in the measurement of potential, Theory of conductometry; Polarography as an analytical tool for qualitative and quantitative analysis, measurement of diffusion current, HMDE, Amperometric and biamperometric titrations, Coulometry at controlled potential and at constant current, cyclic voltametry and Anodic stripping voltametry,

UNIT-III: Coordination Chemistry **15 h**

IUPAC nomenclature; Bonding theories – review of Werner's theory and Sidgwick's concept of coordination, Valence bond theory; Geometries of coordination numbers 4-tetrahedral and square planar and 6-octahedral and its limitations;
Crystal filed theory: Splitting of d-orbitals in octahedral, tetrahedral and square-planar complexes, low spin and high spin complexes; Factors affecting crystal-field splitting energy; Merits and demerits of crystal-field theory; Isomerism in coordination compounds – Structural isomerism and stereo isomerism; Stereochemistry of complexes with 4 and 6 coordination numbers.

Unit-IV: Basic Aspects in Polymers **15 h**

Definition of monomer & polymer; Classification of polymers; Mechanism of polymerization - Addition polymerization (Free radical, ionic and coordination) and Condensation polymerization; Polymerization techniques - Bulk, Solution, Suspension and Emulsion; Molecular weight and its determination by viscometry and end group analysis

Text Books:

1. Physical Chemistry, P. W. Atkins, (ELBS)
2. Principles in Physical Chemistry by Gurudeep Raj
3. A text Book of Physical Chemistry (2nd Ed.), S. Glasstone (Macmilan)
4. Modern Inorganic Chemistry, W. L. Jolly (McGraw-Hill)
5. Coordination Compounds, S. F. A. Kettle (ELBS
6. Text Book of polymer science by Gowarikar, Sreedhar and Viswanathan, Wiley-Eastern Publications. India
7. Introduction to polymers – by R.J.Young, Chapman and Hall, U.K.

MSNT 104: Mathematics

Unit-I: Linear Algebra

Algebra of matrices, inverse, rank, system of linear equations, symmetric, skew-symmetric and orthogonal matrices. Hermitian, skew-Hermitian and unitary matrices.eigenvalues and eigenvectors, diagonalisation of matrices, Cayley-Hamilton Theorem.

Unit-II: Complex variable

Analytic functions, Cauchy-Riemann equations, Application in solving potential problems, Line integral, Cauchy's integral theorem and integral formula (without proof), Taylor's and Laurent' series, Residue theorem (without proof) and its applications.

Unit-III: Calculus

Functions of single variable, limit, continuity and differentiability, Mean value theorems, Indeterminate forms and L'Hospital rule, Maxima and minima, Evaluation of definite and improper integrals, Beta and Gamma functions, Functions of two variables, limit, continuity, partial derivatives, Euler's theorem for homogeneous functions, total derivatives, maxima and minima, Lagrange method of multipliers, double and triple integrals, sequence and series, tests for convergence, power series, Fourier Series, Half range sine and cosine series.

Unit-IV: Probability and Statistics and Numerical Methods:

Probability and Statistics: Definitions of probability and simple theorems, conditional probability, Bayes Theorem, random variables, discrete and continuous distributions, Binomial, Poisson, and normal distributions, correlation and linear regression.

Numerical Methods: Solution of a system of linear equations by Matrix inversion, Gauss-elimination and interation methods; Solution of a algebric and a transcendental equation by Newton-Raphson method; Numerical integration by trapezoidal rule, Simpson's rule and Gaussian quadrature; Numerical solutions of first order differential equation by Euler's method and 1^{st}, 2^{nd} and 3^{rd} order Runge-Kutta method.

Text Books:

1. Numeric analysis by g. Shanker Rao, New Age Internatinal publishers (2^{nd} edition)
2. Introductory methods of numerical analysis by S.S. Sastry, Prentice Hall of India PVt Ltd
3. Higher engineering Mathematics by B.s. Grewal, Khanna Publishers,
4. Advanced Calculus by Murray R. Speical, McGraw Hill Book Company

MSNT 105 Practical – I: Physical Chemistry

1. Determination of rate constant of acid hydrolysis of an ester and investigate the effect of catalyst concentration, reactant concentration and temperature.
2. Conductometry.

   (a) Determination of cell constant

   (b) Verification of Onsager equation

   (c) Determination of dissociation constant of a weak acid

   (d) Titration of a strong acid with a strong base

   (e) Titration of a weak acid with a strong base
3. Potentiometry

   (a) Titration of a strong acid with a strong base

   (b) Titration of a weak acid with a strong base

   (d) Titration of ferrous ammonium sulphate with potassium dichromate.

MSNT 106 Practical – II: Inorganic Chemistry

1. Semi-micro qualitative analysis of a mixture containing four cations of rare elements and insolubles:

   Rare elements: Te, W, Se, Mo, Zr, Ce, Th, V, and U.

   Insolubles: $PbSO_4$, $SrSO_4$, Al_2O_3, Cr_2O_3, Fe_2O_3, SnO_2, TiO_2, ThO_2, WO_3.

2. Quantitative separation and determination of the following pairs of metal ions using complexometric methods

   a) Cu^{2+} and Ni^{2+}

   b) Ca^{2+} and Mg^{2+}

   c) Fe^{3+} and Ti^{3+}

   d) Cu^{2+} and Zn^{2+}

MSNT 201: Quantum Mechanics

Unit-I: Postulates of Quantum Mechanics 15 h

Postulates of quantum mchanics; Eigen values and Eigen functions for finite well and barrier; Simple harmonic oscillator; Schroedinger equation and operator method.

Liner vector space-Ket and Bra notations; Observables as Hermitian operators; Properties of Hermitian operators; Matrix representation of and operator-Unitary transformation

Unit-II Angular Momentum 15 h

Orbital angular momentum – L_x, L_y, L_z, L^2, L_+, L_-operators; Commutation operators, Eigen functions and Eigen values of L^2 and L_z; Spin angular momentum and matrices,; Addition of angular momenta; Clebsch-Gordon coefficients for $J_1=J_2 = ½$.

UNIT-III: Approximate Methods 15 h

Time independent nongenerate perturbation - Anhormonic oscillator; Degenerate; Linear stark effect in H atom; Variation method; He atom and harmonic WKB approximation; Connecting formulae; Application to potential well barrier; Quantization and tunnelling; Time dependent perturbation; Transition - Harmonic perturbation and Fermi Golden rule.

UNIT-IV: Relativistic Quantum Theory 15 h

Klein – Gorden equation; Probability current density; Inadequacy of K. G. equation; Dirac's linear equation-plane wave solution; Negative energy states and spin of electrons.

Reference Books:

1. Arul Das, Quatntum Mechanics
2. S.L. Kakani and H.M. Chandalia, Quantum Mechanics
3. B.S. Rajput and Pragatiprakasan, Advanced quantum Mechanics
4. V.K. Thankappan, Quantum Mechanic, Wiley Eastern Limited
5. P.M. Methews and K. Venkatesan, A Textbook of Quantum Mechanics, Tata McGraw Hill Publishing Company.
6. S. L. Gupta, V. Kumar, H.V. Sharma and R. C. Sharma Jai, Quantum Mechanics, Rakash Nath and Company.
7. P.T. Mathews, An Introduction to Quantum Mechanics, McGraw Hill Publishing Company

MSNT 202: Properties of Bulk and Nanomaterials - I

Unit-I: Dielectric and Ferroelectric Properties **15 h**

Dielectric properties: Dielectric polarization; Dielectric constant and displacement vector; Atomic or molecular polarizability; Clausius Mossotti relation; Types of polarizability - Dipolar polarizability, Frequency dependence of dipolar polarizability; Ionic polarizability; Electronic polarizability

Ferroelectric properties: Classification and properties of ferroelectrics; Ferroelectric domains; Dipole theory of ferroelectricity; Theory of $BaTiO_3$; Dielectric behaviour of $BaTiO_3$ and determination of transition constants; Titanium and oxygen ion displacement theories; Anti-ferroelectricity and piezoelectricity; Effect of particle size on ferroelectrics

Unit-II: Magnetic Properties **15 h**

Classification; Weiss filed theory; Temperature dependence of spontaneous magnetization; Heisenberg model; Exchange; Exchange interaction; Exchange integral; Concept of ferromagnetic domains;

Antiferromagnetism: Molecular field theory of Antiferromagnetism; Ferrimagnetism – Introduction; Structure of ferrites; Curie temperature and susceptibility of ferromagnets; Garnets; Occurrence of super paramagnetism; Effect of nano size particles on domain structures and other magnetic properties

Unit-III: Mechanical Properties **15 h**

Concept of stress and strain; Hook's law; Stress strain behaviour; Anelasticity; Elastic properties of materials -Young's modulus, bulk modulus, shear modulus and Poissson's ratio; Plastic deformation - Yielding and yield strength, tensile strength, ductility, resilience, toughness, true stress and strain and hardness; Creep of soft materials;

Effect of nanodimensions on mechanical properties- Elastic properties, hardness and strength, tensile ductility and strain hardness, creep and super-plastic behaviour, fracture and toughness

Unit-IV: Thermal Properties **15 h**

Specific heat of solids – The classical model, the Einstein model, the Density of states; The Debye's model; Thermal conductivity of solids; Conductivity due to electrons and phonons; Thermal expansion of solids; Thermal properties of nonmaterials

Text Books:

1. R. L. Singhal, Solid State Physics, Kedar Nath Ram Nath & Co.;, India
2. Material science and engineering An introduction by W.D. Callister, Jr, John wiley and Sons
3. Wahab, Solid State Physics
4. Kittle, Introduction to Solid State Physics
5. Gupta, Kumar, Sharma, Solid State Physics
6. S.O.Pillai, Solid-State-Physics
7. Nanostructures and Nanomaterials by Guozhong Cao, Imperial college Press
8. Textbook of Nanoscience and Nanotechnology by B.s. Murthy, P. Shankar, Baldev Raj, B.B. Rath and J. Murday, Universities Press Inida Pvt Ltd.

MSNT 203: Polymeric Materials and Processing

Unit-I: Co-polymerization and Blends **15 h**

Co-polymerization: Chain-growth co-polymerization Mechanism, Simple copolymer equation. Significance of reactivity ratios. Dependency of copolymer composition on monomer feed. Determination of reactivity ratios. Random, alternate, block and graft copolymers

Blends: Importance; Plastic-plastic, rubber- rubber and plastic-rubber blends; Miscibility and compatibility; Methods of determining miscibility/compatibility; Compatabilising agents,

Unit-II: Physical Properties and Polymer Solutions **15 h**

Glass transition temperature: Definition, determination of t_g and factors influencing t_g, relation between t_g and t_m, t_g of blends and copolymers

Crystallinity: Degree of crystallinity and polymer crystallization behaviour

Rheology of polymer materials: Hooke's equation; Newton's equation; Maxwell and Voigt models for visco-elasticity; deformation behaviour of polymer

Polymer solutions: Process of polymer dissolution; Thermodynamics of polymer dissolution; Flory-Huggins theory of polymer solutions

Unit-III: Plastic Additives, Degradation and Stabilization **15 h**

Additives: Type of plastic additives - fillers, plasticizers and softeners, lubricants and flow promoters' anti aging additives, flame retardants, colourants, blowing agents' cross linking agents, photo stabilizers, Nucleating agents; Equipment used for compounding-the fabricator, raw material forms and mixing.

Degradation and Stabilization: Types of degradation – Physical (thermal, photo and mechanical degradation and stabilization) and Chemical degradation (solvolytic, hydraulic, oxidative and bio degradation)

Unit – IV: Polymer Processing **15 h**

Extrusion: Extrusion line; Extruder - screw-single and twin screw; Mixing zones

Injection moulding: Injection unit; Clamping unit - toggle and hydraulic clamping; Basic mould deisgn; Process sequence; Reaction Injection moulding

Blow moulding: Basics of extrusion and injection blow moulding.

Fibre spinning: Spinning process; Spinnerets; Melt, dry and wet spinning

Text Books:

1. Text Book of polymer science by Gowarikar, Sreedhar and Viswanathan, Wiley-Eastern Publications. India
2. Introduction to polymers – by R.J.Young, Chapman and Hall, U.K.
3. Organic polymer chemistry by K.J.saunders, 2nd Ed., Chapmann Hall Publications, U.K.,1988
4. Plastic materials by J. Brydson, 7th ed., Butterworth-Heineman, Elsevier (2005)
5. Polymer processing by D.H. Morton Jones, Chapman and Hall, UK.
6. Polymer Processing and Fundamentals: Tim A Osswald, Hansar publications
7. Polymer mixing Technology: George Mathews,applied science Publishers.
8. Polymer Blends, Paul D.R and Newman S.Academic

MSNT 204: Introduction to Nanoscience and Synthesis of Nanomaterials

Unit 1: Basic Concepts in Nanoscience and Carbon Nanostructures 15 h

Scientific Revolution - Feynman's Vision – Nanoscience – Nanotechnology - Nanomaterials definitions - Classification of Nanomaterials - dimensions, confinement - Surface to volume ratio - Energy at bulk and nano scale - Nature Nanophenomena – Size dependent variation in Physical- Chemical- Catalytic properties - Allotropes of carbon and carbon nanostructures.

UNIT – II: Synthesis of Nanomaterials: Chemical Methods 15 h

Colloidal precipitation - Sol-Gel process - Reduction method - Hydrothermal - Solvothermal - Templated - Combustion route and photochemical method.

UNIT – III: Synthesis of Nanomaterials: Physical and Mechanical Methods 15 h

Arc discharge – Lithography – Chemical Vapor Deposition - High Energy Ball milling – Mechano-chemical reactions - Special Nanostructures - Quantum dots - Magnetic NPs - Nanocomposites- ZnO- TiO_2.

UNIT-IV: Synthesis of Nanomaterials: Biological Methods and applications 15 h

Biological Methods of Synthesis - Use of bacteria, fungi, Actinomycetes, Magnetotactic bacteria for nanoparticle synthesis. Bioremediation- removal of bacteria and microbes – Nanomaterials for antimicrobial coatings- medical implants and paints - Nanocomposites for food storage- medical and defence textiles.

Text books:

1. Nanomaterials, Nanotechnologies and Design - M.F.Ashby, P.J.Ferreira, D.L.Schodek, Elsevier (2009).
2. Text book of Nanoscience and Nanotechnology - B S Murthy, P Shankar, Baldev Raj, B B Rath and James Murday, Universities Press (2012).
3. NANO: The Essentials – T.Pradeep, TATA McGraw Hill (2007).
4. Springer Handbook of Nanotechnology- Ed. by B. Bhushan, Springer-Verlag (2004)
5. Vacuum Technology, A. Roth, North- Holland Pub., 2nd Edition (1982)
6. The Chemistry of Nanomaterials: Synthesis, Properties and Applications, C.N.R. Rao, A. Muller, A. K. Cheetham (Eds), Wiley-VCH Verlag (2004)
7. B.S. Murty and S. Ranganathan, International Materials Reviews (1998) Vol. 43(3), 101

MSNT 205 Practical – III: Polymer Material Lab

1. Estimation of monomer
2. Determination molecular weight of a polymer by viscometer and end group analysis methods
3. To study the effect of solvents on viscosity of polymer using viscometer.
4. Size of the molecule: To determine the intrinsic viscosity, Huggins and Kramer's constants, viscosity average molecular weight and hence root mean square end to end length and expansion coefficient of the given polymer using viscometer
5. Synthesis of polystyrene/PMMA
6. Study the miscibility of the polymer blend using refractometer and viscometry.
7. Degradation studies of poly (vinyl alcohol) by Viscosity method.

MSNT 206 Practical – IV: Study of Properties of Materials

1. Determination of lattice constant of a mono-atomic and di-atomic lattices
2. Creep behaviour
3. Hysteresis behavior of magnetic materials
4. Di-electric behavior of ferroelectric materials
5. Thermal expansion of materials
6. Initial permeability of magnetic materials
7. Determination of specific heat of a graphite with a change in temperature

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MSNT 207 Non-core: Concepts of Nanomaterials

Unit 1: Basic Concepts in Nanoscience and Carbon Nanostructures 15 h

Scientific Revolution - Feynman's Vision – Nanoscience – Nanotechnology - Nanomaterials definitions - Classification of Nanomaterials - dimensions, confinement - Surface to volume ratio - Energy at bulk and nano scale - Nature Nanophenomena – Size dependent variation in Physical- Chemical- Catalytic properties - Allotropes of carbon and carbon nanostructures.

UNIT – II: Synthesis of Nanomaterials: Chemical Methods 15 h

Colloidal precipitation - Sol-Gel process - Reduction method - Hydrothermal - Solvothermal - Templated - Combustion route and photochemical method.

UNIT – III: Synthesis of Nanomaterials: Physical and Mechanical Methods 15 h

Arc discharge – Lithography – Chemical Vapor Deposition - High Energy Ball milling – Mechano-chemical reactions - Special Nanostructures - Quantum dots - Magnetic NPs - Nanocomposites- ZnO- TiO_2.

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Biological Methods of Synthesis - Use of bacteria, fungi, Actinomycetes, Magnetotactic bacteria for nanoparticle synthesis. Bioremediation- removal of bacteria and microbes – Nanomaterials for antimicrobial coatings- medical implants and paints - Nanocomposites for food storage- medical and defence textiles.

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1. Nanomaterials, Nanotechnologies and Design - M.F.Ashby, P.J.Ferreira, D.L.Schodek, Elsevier (2009).
2. Text book of Nanoscience and Nanotechnology - B S Murthy, P Shankar, Baldev Raj, B B Rath and James Murday, Universities Press (2012).
3. NANO: The Essentials – T.Pradeep, TATA McGraw Hill (2007).
4. Springer Handbook of Nanotechnology- Ed. by B. Bhushan, Springer-Verlag (2004)
5. Vacuum Technology, A. Roth, North- Holland Pub., 2nd Edition (1982)
6. The Chemistry of Nanomaterials: Synthesis, Properties and Applications, C.N.R. Rao, A. Muller, A. K. Cheetham (Eds), Wiley-VCH Verlag (2004)
7. B.S. Murty and S. Ranganathan, International Materials Reviews (1998) Vol. 43(3), 101

MSNT 301: Characterization Techniques

Unit-I: UV-Visible and Atomic absorption spectroscopy 15 h

UV-Visible spectroscopy: Introduction, Types of electronic transisitons, Effect of conjugation, Concept of chromophore and Auxochrome, Bathochromic, Hyperchromic and Hypsochromic shifts, Theory, Instrumentation, Double beam spectroscopy; Sources of radiation, Detectors, Monochromators, Applications to organic compounds and Chemical kinetics and disadvantages.

Atomic Absorption spectrophotometer: Theory, Instrumentation, resonance line sources, hollow cathode lamp, chemical and spectral applications with special reference to analysis of trace metals in oils, alloys and toxic metals in drinking water and effluents**.**

Unit-II: IR Spectroscopy 15 h

Vibrational energies of diatomic molecule, Infrared selection rules, Asymmetry of rotation, Hydrogen bonding, Rotational vibration spectra of polyatomic molecules, Interpretation of vibrational spectra, Instrumentation, Fourier transform infrared spectroscopy.

UNIT-III: Raman Spectroscopy 15 h

Classical and quantum theory of Raman effect. Stokes and anti-Stokes Raman lines, Pure rotational Raman spectra, Linear symmetric, top and spherical top molecules, vibrational Raman spectra, Complementary nature of IR and Raman spectra. Structure determination using Raman spectra, Experimental techniques and instrumentation.

UNIT-III: X-ray Diffraction 15 h

Bragg's law, Laue transmission and back reflection methods, Powder Methods: Principle of powder diffraction, Interpretation of powder photographs by analytical and graphical methods, Rotating crystal Methods: Oscillation and rotation methods, Weisenberg and Burger's precession methods, Reciprocal Lattice: Geometrical construction, relation between direct- reciprocal Lattice, Reciprocal of simple cubic, BCC, FCC lattices.

Text Books:

1. M.H.Willard, Instrumental Methods of Analysis, CBS publishers, (1986)
2. G.R. Chatwal and S. Anand, Spectroscopy Atomic and Molecular, Himalaya Pub. House (2004)
3. M. Bersohn and J.C. Baird, An Introduction to Electron Paramagnetic Resonance, Benjamin Inc., London (1967)
4. BK Sharma, Spectroscopy, Goel Publishers House, Meerut (2007)
5. B.D. Cullity, Elements of X-ray Diffraction,
6. L.V. Azarkoff, Elements of X-ray Crystallography,
7. L.V. azarkoff and M.J. Buerger, The Powder Method in X- ray Crystallography
8. Atomic and Molecular spectroscopy-C,L Arora ,S Chand Publishing Company,3rd Edition (2001)
9. Molecular Spectroscopy- Raman Gopalan and Raghavan, Thomson Learning Publishers(2004)

MSNT 302: Semiconductors and Devices

UNIT-I: Basic Aspects of Semiconductors **15 h**

Intrinsic and extrinsic semiconductors, Expression for position of Fermi levels and carrier concentrations, Variation of Fermi levels with temperature, np product, Carrier mobility, Conductivity and their variation with temperature, Direct and indirect band gap semiconductor, Hall effect, Continuity equation, Drift and Diffusion, Einstein relation,

Unit-II: Transport Phenomenon **15 h**

Concept of electrical and thermal resistivity, Different scattering mechanisms, Matheissens rule, Formulation of Boltzmann transport equation, Relaxation time approximation, Distribution function, Expression for thermal and electrical conductivities for metals, Lorenz number.
Somerfield model: its consequences, Electron-Lattice interaction (Quantitative only),

Unit-III: Junctions and Interfaces **15 h**

p-n Junctions: Description of p-n Junction action, Junction in equilibrium, Application of bias- energy band diagrams, The abrupt junction- Calculation of the built-in voltage, Electric field and potential distributions, Expression for Depletion layer capacitance
Static-I-V characteristics of p-n junction diodes: The ideal diode model, Derivation of ideal diode equation, Real diodes- Carrier generation, recombination in the junction depletion region, I-V characteristics of Real Diodes.
Electrical breakdown in p-n junctions: Zener and Avalanche breakdown in p-n junctions, Distinction between the Zeber abd avalanche breakdown, Applications of breakdown diodes.

Unit-IV: Junction Transistors: **15 h**

Bipolar junction transistors: Principle of operation, Ebers Moill Equations- Four regions of operation of a bipolar transistor. Real transistors – carrier recombination in the Emitter- Base junction depletion region- effect of collector bias variation, avalanche multiplication in the collector- base junction and base resistance.
Junction field – effect transistors: JFET principle of operation, Static I-V Characteristics of the idealized model.
MOS transistors and charge- coupled devices: MOS capacitor- Surface field effect- energy band diagrams of an MOS capacitor for different bias conditions. C- V characteristics of the MOS capacitor.
Basic Structures and the operating principle of MOSFET, I-V characteristics of and ideal MOSFET, Charge Coupled Devices (CCD)- Principle of operation.

Text Books:

1. M. S. Tyagi, Introduction to Semiconductor Materials and Devices, John Wiley & Sons, 2004.
2. S. M. Sze, Semiconductor Devices Physics and Technology, 2nd Edition, John Wiley & Sons, 2005.
3. Kannan Kano, Semiconductor Devices, PHI, 2005.
4. Robert F Pierret, Semiconductor Device Fundamentals, Pearson Education, 2006.
5. J. L. Moll, Physics of Semiconductors**,** McGraw-Hill.
6. Ben G. Streetman and Sanjay Banerjee, Solid State Electronic Devices, VI ed, Pearson Ed, 2007.

MSNT303: Alloys and Paints

Unit-I: Alloys **15 h**

Introduction to Alloys; Solid solution - substitutional and interstitial; Hume Rother's rules for primary substitution sold solubility; Intermediate phase – interstitial compounds, defect phase and electro valence compounds;

Shape memory alloys: General Characteristics; Nickel-titanium shape memory alloy, Cu-Zn-Al; Cu-Al-Ni alloy systems; Applications of shape memory alloys

Unit-II: Phase diagrams **15 h**

Introduction; Phase rules; Unary phase diagrams – pure iron phase diagrams; Binary Phase diagrams – Ni-Cu system; Lever rule; Bi-Cd; Fe-C; Pb-Sn system; Uses of Phase diagrams; Limitations of phase diagrams

Unit-III: Fundamentals of Paints **15 h**

Definition; Ingredients of paints –binders, pigments, additives, solvent and plasticizers; Classification of paints by curing mechanism (air dried and baked), solvent (aqueous and non-aqueous), functions of system ingredients (primers, sealers, under coats and finishing/top coats), solid content (high and low) and resin components; Film formers – drying oils and synthetic resins (formulations of alkyd, acrylic and urethane coatings); Methods of film formation; Fundamentals of film formation; Factors affecting coating properties – film thickness (mechanical and optical methods), film density and pigment volume concentration

Unit-IV: Properties and Evaluations of Paints: **15 h**

Optical properties of coatings (basics of color, gloss and hiding power); mechanical properties of coatings [structure-mechanical correlations and measurement and performance (hardness and bending tests)]; Ageing properties (accelerated outdoor and laboratory tests); Adhesion properties of coatings (factors affecting the establishment of adhesion bond, measurement sof surface coating adhesion (Destructive methods film detachment by noremal (direct pull off and topple method), by lateral stress (scratch and peel test) Non-destructive tests; Scratch, mar and wear resistance test; Ani-condensation paint test; Water and chemical resistance of paint films; Tautening test; Fire resistance; Fire retardence to mould; Resistance to yellowing; Bleeding; resistance to mould growth;

References:

1. Physical Metallurgy by Vijendra Singh, Standard Publishing distributors
2. Material Science & Engineering by V. Raghavan, Prentice Hall of India
3. Physical Metallurgy- Principles, Practise by V. Raghavan, Prentice Hall of India
4. Introduction to Paint Chemistry by G.P.A. Turner, Oxford & IBH Publishing Company, India
5. Text Book of polymer science by Gowarikar, Sreedhar and Viswanathan, Wiley-Eastern Publications. India
6. Surface coatings by Swaraj Paul, John Wiley & Sons (1985)
7. Testing of paints by CJA Taylor and S. Mark)

MSNT 304 Nanocatalysis and its Application

Unit I: Fundamentals in Catalysis

Homogeneous and Heterogeneous Catalysis – Characteristics of Catalytic Reactions - Promotors – Catalytic Poisoning – Activation Energy and Catalysis – Intermediate compound formation theory – Adsorption theory – Acid-base Catalysis and its mechanism - Enzyme Catalysis and its mechanism - Requirements for Successful Catalysts - Surface Area determination of non-porous and porous materials using BET method.

Unit II: Synthesis of Nanoporous Catalysts

Microporous materials: Zeolites- Zeotypes – Overall steps in zeolite crystallization- Zeolite synthesis via.- dry gel route- Zeolite Y- determination of surface acidity- shape-selectivity; Mesoporous aluminosilicates: Synthesis of Mesoporous Silica- MCM-41- SBA-15; Mesoporous Carbon - Sulfated Zirconia - Ag/SiO_2 composite nanocatalysts.

Unit III: Nanophotocatalysis and Catalysis of Gold nanocrystals

Introduction to photocatalysis: Principle- Band energy engineering- Degradation of dye - Hydrogen generation- Organic synthesis. Gold catalysts: Uniqueness- particle size- Metal-support interaction; Preparative methods: Co-precipitation – Deposition – Precipitation - Impregnation- Photodeposition- bimetallic catalysts; Properties- Selective oxidation & reduction reactions.

Unit IV: Applications of Nanocatalysts

Environmental protection; Energy processing: Processes involved in crude oil refinery- Gasoline production- Cracking- Fuel cell- Biomass gasification- Biodiesel- Naphtha reforming; Energy conversion & storage; Synthesis of fine chemicals- Hydrogenation/dehydrogenation- Synthetic fuels- Selective oxidation reactions- Polymerization.

References

1. Essentials of Physical Chemistry, Arun Bahl, B.S. Bahl, G.D. Tuli, S.Chand, Revised Edition 2012.
2. Nanoporous Materials: Synthesis and Applications, Edited by Qiang Xu, CRC Press, 2013
3. Catalysis: Principles and Applications, Edited by B. Viswanathan, S. Sivasanker, A.V. Ramaswamy, Narosa Publishing House, 2011
4. Photocatalysis, Edited by Masao Kaneko, Ichiro Okura, Springer, 2003.
5. New and Future Developments in Catalysis, Edited by Steven L. Suib, Elsevier, 2013.
6. Catalysis by Gold, Geoffrey C. Bond, Catherine Louis, David T. Thompson, Imperial College Press, 2006.

MSNT 305 Practical III: Nano Catalysis & Material synthesis Lab

1. Study on Adsorption Properties of porous and non-porous materials
2. Solar Photocatalytic degradation of dyes in aqueous solution
3. Photocatalytic hydrogen generation under solar light irradiations
4. Metal Oxide Semiconductor Band Gap Engineering
5. Nanocomposite preparation by chemical method
6. Hydrothermal Synthesis of Zeolite (Microporous Materials)
7. Synthesis of Mesoporous materials by template assisted method
8. Post-synthesis Modification of catalytic materials by different methods
9. Chemical synthesis of metal (silver/gold) nanoparticles, UV absorption of the colloidal solution; Estimation of size by curve fitting
10. Chemical synthesis of CdS nanoparticles Chemical kinetics, Optical absorption spectra, Band gap estimation from the band edge using UV-VIS spectrophotometer
11. Sol-gel synthesis of nanoparticles and confirmation by UV-Vis Spectra
12. Synthesis of SnO_2 nanoparticles by co-precipitation method
13. Synthesis of SnO_2 nanoparticles by sol-gel method
14. Dye-sensitized solar cells: Fabrication and testing
15. Synthesis of nanostructured materials using solution or solid state methods
16. Synthesis of inorganic nanocomposite materials

MSNT 306 Practical IV: Semiconductors Lab

1. Determination of energy gap of semiconductors
2. Hall effect
3. Field emission transmitter characteristics
4. Bipolar junction transistor
5. MOSFET characteristics
6. Characteristics of zenar-diode
7. Analysis of powder diffraction pattern
8. Lave diffraction pattern
9. Silicon solar cells

MSNT-307 Non-core: Characterization Techniques and Applications of Nanomaterials

Unit 1: X-ray diffraction and UV-Visible spectroscopy 15 h

Bragg's law - Powder Methods: Principle of powder diffraction, Interpretation of powder photographs by analytical and graphical methods, Rotating crystal Methods: Oscillation and rotation methods – Estimation of particle sizes by X-ray diffraction pattern.

Introduction - Types of electronic transitions, Effect of conjugation, Concept of chromophore and Auxochrome, Bathochromic, Hyperchromic and Hypsochromic shifts, Theory, Instrumentation, Double beam spectroscopy; Sources of radiation, Detectors, Monochromators, Applications to organic compounds and Chemical kinetics and disadvantages.

UNIT – II: Electron Microscope and Chromatography Techniques 15 h

Principle, Instrumentation and Applications of Scanning Electron Microscopy (SEM) – Transmission Electron Microscopy (TEM) – Dynamic Light Scattering (DLS) – Gas Chromatograph – High Performance Liquid Chromatograph (HPLC).

UNIT – III: Nanotechnology enabled sensors 15 h

Sensors and Nanotechnology Enabled Sensors - Inorganic Nanotechnology Enabled Sensors – Gas Sensing with Nanostructured Thin Films - Nanotechnology enabled optical sensors - Organic Nanotechnology Enabled Sensors - Proteins in Nanotechnology Enabled Sensors - Nano-sensors based on Nucleotides and DNA.

Unit-IV: Drug Delivery Applications 15 h

Preparation of nanomaterials - Dispersion, Solvent Evaporation, Emulsification, Supercritical fluid technology, polymerization - Drug loading - Drug releases characteristics, surface properties - protein adsorption, characterization methods, surface modification (PEG, PEO coated) – Nanoparticles (Polysorbate) for blood brain barrier.

Text Books:

1. M.H.Willard, Instrumental Methods of Analysis, CBS publishers, (1986)
2. G.R. Chatwal and S. Anand, Spectroscopy Atomic and Molecular, Himalaya Pub. House (2004)
3. B.D. Cullity, Elements of X-ray Diffraction,
4. John J. Bozzola and Lonnie D. Russel, "Electron Microscopy", Jones and Bartlett Publishers Inc., USA, 1999.
5. Sivasankar, Instrumental Methods of Chemical Analysis, Oxford University Press, New Delhi (2012)
6. K.Kalantar-zadeh and B. Fry, Nanotechnology-Enabled Sensors, Springer, USA (2008).
7. Biodegradable Polymeric nanoparticles as drug delivery devices, K.S.Soppimath et al., *Journal of Control Release*, 70 (2001) 1 - 20.

MSNT 401: Advanced Characterization Techniques

Unit-I: Microscopic Techniques **15 h**

Surface topography, Principle, Instrumentation and applications of Electron microscopy, Scanning electron microscopy (SEM), Transmission electron microscopy (TEM), Scanning Probe Microscopy (SPM), Scanning tunnelling electron microscopy (STM), Atomic force microscopy (AFM).

UNIT-II: Thermal Analysis **15 h**

Principles, Instrumentation and applications of Thermogravimetric Analalysis (TGA), Differential Thermal Analysis (DTA), Differential Scanning Calorimetry (DSC), Thermo-mechanical Analysis (TMA); Understanding of curing kinetics and thermal decomposition reaction to ceramics and polymers.

Unit-III: Chromatographic Techniques **15 h**

Chromatographic Parameters - Paper Chromatography (PC), Thin Layer Chromatography (TLC), Column Chromatography (CC), Ion Exchange Chromatography (IEC). High Performance Liquid Chromatography (HPLC): Principle, Instrumentation, pumps, columns, Detectors and Applications of HPLC. Gas Chromatography (GC): Principle, Instrumentation, columns, Detectors and Applications of GC.

UNIT-IV: Chemical and Particle size Analysis Techniques **15 h**

Basic concepts – Energy dispersion Analysis of X-rays (EDAX) – X-ray photoelectron spectroscopy (XPS) – Auger Electron Spectroscopy (AES) – Dynamic Light Scattering (DLS).

Text Books:

1. M.H.Willard, Instrumental Methods of Analysis, CBS publishers, (1986)
2. M. Bersohn and J.C. Baird, An Introduction to Electron Paramagnetic Resonance, Benjamin Inc., London (1967)
3. Sivasankar, Instrumental Methods of Chemical Analysis, Oxford University Press, New Delhi (2012)
4. R. Haynes, Optical Microscopy of Materials, International Textbook Company, Glascow, 1984.
5. John J. Bozzola and Lonnie D. Russel, "Electron Microscopy", Jones and Bartlett Publishers Inc., USA, 1999.
6. H. W. Willard, L. L. Merritt and J. A. Dean, Instrumental Methods of Analysis, (Affiliated East-West)
7. D. A. Skoog and D. M. West (Holt, Rinehart and Wilson) Principles of Instrumental Analysis.
8. Nature (2000) Microscopy Techniques

MSNT 402: Properties of Bulk and Nanomaterials-II

Unit -I: Optical Properties: 15 h

Electromagnetic radiation; Light interaction with solids and Atomic and electron interactions; Optical properties of metal; Optical properties of non metals-refraction, refelction, absorption, transmission, color, opacity and translucency in insulators; Basic concepts of luminescence, photoconductivity, lasers, and optical fibers in communication;
Optical properties of nanomaterials – Surface Plasmon resonance and quantum size effects

Unit-II: Superconductivity 15 h

Concept of zero resistance, Magnetic behaviour, Distinction between a perfect conductor and superconductor, Meissner effect, Isotope effect, Specific heat behaviour, Thermal conductivity, Infrared absorption- Two- fluid model, Expression for entropy difference between normal and superconducting states, First and second order transitions in superconductors, Londons equations, Penetration depth, BCS theory (Qualitative aspects only), Applications of superconductors, High T_c superconductors.

Unit-III Diffusion in Solids 15 h

Fick's laws; Diffusion mechanism; Study state diffusion; Non study state diffusion; Factors that influence diffusion; The Kirkendal effect; Diffusion in alkali halides; Ionic conductivity

Unit-IV Electrical Properties 15 h

Ohm's law; Electrical conductivity; Electronic and ionic conduction; conduction in terms of band and atomic bonding model; electron mobility; electrical resistivity of metals; conduction in ionic materials; Electrical conductivity of semiconductors with temperature; Electrical properties of polymers
Effect of particle size on electrical properties – surface scattering, change of electronic structure, quantum transport, effect of microstructure

Text Books:

1. R. L. Singhal, Solid State Physics, Kedar Nath Ram Nath & Co.;, India
2. Material science and enginerring An introduction by W.D. Callister, Jr, John wiley and Sons
3. Wahab, Solid State Physics
4. Gupta, Kumar, Sharma, Solid State Physics
5. S.O.Pillai, solid-state-physics
6. Nanostructures and Nanomaterials by Guozhong Cao, Imperial college Press
7. Textbook of Nanoscience and Nanotechnology by B.s. Murthy, P. Shankar, Baldev Raj, B.B. Rath and J. Murday, Universities Press Inida Pvt Ltd.

MSNT 403: Applications of Nanomaterials and Nanotechnology

Unit-I: Introduction to MEMS, Photonics and spintronics: 15 h

MEMS: Introduction to MEMS; Materials for MEMS-si based; Processes for micro-machining – dry and wet etching; Substrate bonding; surface micromachining; Oxidation; Applications – pressure sensors.

Photonics: Photons and electrons – similarities and differences, free space propagation, confinement of photons and electrons, Propagation through classically forbidden region; Tunnelling applications; Photonic crystal.

Spintronics: why spin; Metallic magnetic multilayers – interlayer exchange coupling and giant magnetoresistance; Applications – magnetic hard drives

Unit-II: Inorganic Nanotechnology Enabled Sensors 15 h

Introduction - Sensors and Nanotechnology Enabled Sensors; Inorganic Nanotechnology Enabled Sensors – Gas Sensing with Nanostructured Thin Films; Nanotechnology enabled optical sensors; Organic Nanotechnology Enabled Sensors - Proteins in Nanotechnology Enabled Sensors; Nano-sensors based on Nucleotides and DNA.

Unit-III: Environmental Applications: 15 h

Introduction; Nanomaterials for ground water remediation; Nanomaterials for membrane process - principles and membrane fabrication; Nanomaterials as adsorbents; Electrochemical sensors based on nanomaterials for environmental monitoring.

Unit-IV: Drug Delivery Applications 15 h

Introduction; Preparation of nanomaterials - Dispersion, Solvent Evaporation, Emulsification, Supercritical fluid technology, polymerization; Drug loading; Drug releases characteristics, surface properties - protein adsorption, characterization methods, surface modification (PEG, PEO coated) – Nanoparticles (Polysorbate) for blood brain barrier.

Text Books:

1. Nanostructures & Nanomaterials, Guozhong Cao, Imperial College Press (2003)
2. Introduction to Nanoscale Science & Technology, Massimiliano Di Ventra, Stephane Evoy, Randy Heflin, Kluwer Academic Publishers (2004)
3. Nanophotonics by Paras N Prasad, Wiley & sons Publications (2004)
4. Nanoelectronics & Photonics by Anatoli Korkin, Federico Rosei, Spinger publications
5. Biodegradable Polymeric nanoparticles as drug delivery devices, K.S.Soppimath et al., *Journal of Control Release*, 70 (2001) 1 - 20.
6. K.Kalantar-zadeh and B. Fry, Nanotechnology-Enabled Sensors, Springer, USA (2008).
7. Environmental Nanotechnology, Eds. M.R.Wiesner and J.Y.Bottero, McGrawHill (2007)
8. Environmental Applications of Nanomaterials, Eds.G.LFryxell, G.Cao, Imperial College Press (2007).

MSNT 404: Energy Conversion Technologies

Unit – I: Energy from Biomass **15 h**

Biorefinery concept – Definition-Different types of Biorefinery-Challenges and Opportunities; Production of Energy from Biomass – Introduction - Physical upgrading processes – Microbiological Process – Microbiological Ethanol Production – Production of Biodiesel from Plants and Algae – Biogas Production – Thermochemical Processes – Thermal Processing Equipment - Gasification (Fischer-Tropsch Diesel) Chemical Processes – Primary Alcohols – Ethanol from cellulose feedstock.

Unit-II: Batteries **15 h**

Principles of battery operation; Battery components; Types of batteries – Primary and secondary batteries; Lead acid, Nickel-cadmium and Lithium ion batteries

Unit-III: Fuel Cells **15 h**

Fuel Cell principles; Types of fuel cells - Alkaline Electrolyte, Phosphoric acid, Molten Carbonate, solid oxide and direct methanol fuel cells; Principle and operation of Proton Exchange Membrane (PEM) fuel cell - Construction of PEM fuel cell stack, efficiency characteristics of PEM fuel cells; Direct methanol fuel cells

Unit-IV: Solar Cells **15 h**

Importance of solar cells; Principle of operation; Current-voltage characteristics,; Comparison of inorganic and organic solar cells, silicone solar cells - manufacture of polycrystalline and nanocrystalline silicon; Small organic material solar cells; Conjugated polymer solar cells - Concept of heterojunction (dispersed and molecular heterojunctions); Advantages of organic solar cells; Function of dye sensitized solar cells (DSSC);

Reference Books:

1. Introduction to Chemicals from Biomass, James Clark, Fabien Deswarte, John Wiley & Sons (2008)
2. Vielstich, Hand Book of Fuel Cells: Fuel Cell Technology and applications, Wiley CRC Press
3. C.Rayment, S.Sherwin. Introduction to fuel cell technology (2003)
4. D.M.Roundhil, John P.Facker, Optoelectronic properties of inorganic compounds, Plenum press, New York (2009).
5. A brief history of the development of organic and polymeric photovoltoics, H.Spanggaard and F.C. Krebs, Solar Energy Materials & Solar Cells 83 (2004) 125-146.

MSNT 405: Project work - Dissertation

MSNT 406: Project work – Viva-voce