

**SCHEME OF TEACHING M. TECH. (NANOSCIENCE AND NANOTECHNOLOGY)**  
**AND EXAMINATION SCHEME 2019-20**

**FIRST SEMESTER**

Course. No	SUBJECT	SCHEDULE FOR TEACHING			THEORY			PRACTICAL			Subject Credits Total	
		L	P	TOTAL	Exam	Sess.	Total	Exam	Sess.	Total		
MNT6101	Foundation of Nanoscience Quantum and Statistical Mechanics	3	-	3	50	25	75	-	-	-	75	<b>3</b>
MNT6102	Basics of Biology and Biotechnology in Nanoscience & Nanotechnology	3	-	3	50	25	75	-	-	-	75	<b>3</b>
MNT6103	Foundation of Nanoscience	3	-	3	50	25	75	-	-	-	75	<b>3</b>
MNT6104	Physical chemistry aspects Synthesis and Characterization of Nanomaterials	4	-	4	50	50	100	-	-	-	100	<b>4</b>
MNT6105	Scientific Computation and Simulation in Nanoscience & Nanotechnology-I	2	-	2	25	25	50	-	-	-	50	<b>2</b>
MNT6106	Laboratory - I	-	6	6	-	-	-	25	25	50	50	<b>2</b>
Total marks =					425;	Total credits =		<b>17</b>				

**SECOND SEMESTER**

Course. No.	SUBJECT	SCHEDULE FOR TEACHING			THEORY			PRACTICAL			Subject TotalCredits		
		L	P	TOTAL	Exam	Sess.	Total	Exam	Sess.	Total			
MNT6201	Chemistry of Nanomaterials and Fabrication	4	_	4	50	50	100	-	-	-	100	<b>4</b>	
MNT6202	Nanobio-technology	4	_	4	50	50	100	-	-	-	100	<b>4</b>	
MNT6203	Physics of Nanomaterials	4	_	4	50	50	100	-	-	-	100	<b>4</b>	
MNT6204	Semiconductor Devices in Nanoscience & Nanotechnology MEMS and NEMS	4	-	4	50	50	100	-	-	-	100	<b>4</b>	
MNT6205	Advanced Nanomaterials and Characterization	4	_	4		50	50	100	-	-	-	100	<b>4</b>
MNT6206	Laboratory-II	--	6	6	-	-	-	25	25	50	50	<b>2</b>	
MNT6207	Scientific Computation & Simulation in Nanoscience & Nanotechnology-II	3	--	3	-	-	-	-	-	25	25	<b>1</b>	

Total marks = 575; Total credits = **23**

**THIRD SEMESTER**

S.NO.	SUBJECT	SCHEDULE FOR TEACHING			THEORY			PRACTICAL			Subject	Credits
		L	P	TOTAL	Exam	Sess.	Total	Exam	Sess.	Total	Total	
MNT7101	Supramolecular and Surface Chemistry of Molecular Devices	4	_	4	50	50	100	-	-	-	100	<b>4</b>
MNT7102	Nanocomposites: Structure Properties & Performance	4	_	4	50	50	100	-	-	-	100	<b>4</b>
MNT7103	Project & Thesis Preliminary	2 <sup>⊕</sup>	8	10	_	_	_	_	150	150	150	<b>5</b>
MNT7104	Laboratory - III	_	6	6	_	_	_	25	25	50	50	<b>2</b>
Total marks = 400; Total credits = 15												

**FOURTH SEMESTER**

MNT7201	Project & Thesis	5 <sup>⊕</sup>	28	33		-	-	-		-	*	<b>19</b>	
MNT7202	Seminar	-				-	-	-	100	-	100	100	<b>1</b>
Total marks = 100; Total credits = 20													

\* No numerical marks are to be assigned to thesis work. It is either “accepted” or “rejected”. Quality of work reported in the thesis can be graded in terms of “Very Good”, “Good” or “Average”.

**Total Marks (all semesters) = 1500**

**Total Credits (all semesters) = 75**

<sup>⊕</sup> In case of project, ‘lecture’ means theoretical work connected with it; e.g., literature survey, preparation of presentation material, etc.

## COURSE CONTENTS

### **MNT 6101 FOUNDATION OF NANOSCIENCE: QUANTUM & STATISTICAL APPROACH**

The question paper for end-semester examination will consist of seven questions of equal marks, viz. 10. The first question will be compulsory and will consist of several short questions/problems covering the entire syllabus. The rest of the questions shall be distributed evenly over the whole syllabus, such that there are at least three questions from each unit. The candidates will attempt five questions in all, selecting at least 02 questions from each section and the compulsory question. The books indicated as text-book(s) are suggestive of the level of coverage. However, any other book may be followed.

#### **Section A**

**Introduction to quantum mechanics:** Failure of classical mechanics, brief discussion of general ideas such as wave particle duality, uncertainty principle, superposition principle, solutions of Schrödinger equation for 1-D and 3-D square wells and potential barriers, H-atom problem, operators, eigen values and eigen vectors, exchange operator and identical particles. Introduction to angular momentum operators, eigen values and eigen vectors of  $L^2$ ,  $L_z$ ,  $J^2$ ,  $J_z$ .

**Approximation methods:** Non degenerate and degenerate perturbation theory and applications and harmonic oscillator; variational method and its application to harmonic oscillator and hydrogen atom.

#### **Section B**

**Theory of ensembles:** The microcanonical ensemble theory and its application to ideal gas; the canonical ensemble and its thermodynamics, Partition function; energy fluctuations; equipartition; harmonic oscillator as canonical ensemble; grand canonical ensemble and significance of statistical quantities.

**Quantum statistics:** Briefly discuss quantum ensemble; statistics of occupation, thermodynamical behavior of ideal Bose gas; Bose-Einstein condensation; discussion of a gas of phonons; thermodynamics of a Fermi gas; free electron gas and Pauli paramagnetism.

#### **Books and Suggested Readings:**

1. **Concepts of Modern Physics** – Arthur Beiser, McGraw-Hill Education.
2. **Quantum Mechanics** – Leonard I. Schiff, TataMcgraw Hill
3. **Quantum Mechanics: Theory and Applications**– S. Lokanathan and A. Ghatak, Macmillan India Limited
4. **Heat and Thermodynamics** by M. W. Zymansky, R. H. Dittman, McGraw-Hill
5. **Statistical Physics** by K. Huang, Wiley
6. **Statistical Physics Part 1: Volume 5 (Course of Theoretical Physics, Volume 5)** L. Landau & I. M. Lifshitz, Butterworth-Heinemann

## MNT 6102 BASICS OF BIOLOGY AND BIOTECHNOLOGY IN NANOSCIENCE AND NANOTECHNOLOGY

The question paper for end-semester examination will consist of seven questions of equal marks, viz. 10. The first question will be compulsory and will consist of several short questions/problems covering the entire syllabus. The rest of the questions shall be distributed evenly over the whole syllabus, such that there are at least three questions from each unit. The candidates will attempt five questions in all, selecting at least 02 questions from each section, and the compulsory question. The books indicated as text-book(s) are suggestive of the level of coverage. However, any other book may be followed.

### Section A

#### Cell structure and physiology:

**Cell structure:** Prokaryotic and eukaryotic cells, plant and animal cells. Cell multiplication-binary fission, mitosis and meiosis, biomolecules- carbohydrates, proteins, lipids, nucleic acids, cellular metabolism, bioenergetics- metabolism of glucose, pyruvate, alcoholic and lactic acid fermentation. Cellular transport- diffusion, osmosis, facilitated diffusion, passive and active transport.

**Enzymology:** Classification, kinetics- Michalis-Menten equation, mechanism of action- acid base catalysis, metal ion catalysis, purification techniques- PAGE, gel-filtration, electrophoresis, ion-exchange chromatography, ligand based chromatography, Industrial applications of enzymes.

**Microbes:** Kingdom Monera, protista, protozoa and fungi- characteristic features of the groups and their importance. Growth curve of microbes in culture, isolation, preservation, DNA replication, genetic recombination.

### Section B

**Immunology:** Cells and organs of immune systems, innate and acquired immunity, antigen and antibodies- types and structure. Primary and secondary immune response. Cell mediated and humoral immunity. Graft rejection- types of grafts, mechanism and causes of graft rejection. Immuno diagnostics techniques - ELISA, RIA. Stem cells – culturing and maintaining, adult and embryonic stem cells and their importance. Cancer: characteristics of cancerous cells, types and causes.

**DNA engineering:** Gene cloning technology restriction enzymes, vectors for cloning DNA – plasmid, bacteriophage and cosmids, PCR, DNA probes, molecular beacon, DNA sequencing, oligonucleotide synthesis, DNA microarray systems- technique and application. Monoclonal antibodies and their importance.

#### Books and Suggested Readings:

1. D. Voet and J. Voet. **Biochemistry 3rd Edition**. John Wiley and Sons Inc, NY 2002.
2. B. R. Glick and J.J. Paternak. **Molecular Biotechnology, Principles and applications of rDNA**. 3rd edition. ASM Press, Washington DC, 2003.
3. Thomas J. Kindt, Richard A Goldsby. **Kuby Immunology (6th Ed)**.

## MNT 6103 FOUNDATION OF NANOSCIENCE: PHYSICAL CHEMISTRY ASPECTS

The question paper for end-semester examination will consist of seven questions of equal marks, viz. 10. The first question will be compulsory and will consist of several short questions/problems covering the entire syllabus. The rest of the questions shall be distributed evenly over the whole syllabus, such that there are at least three questions from each unit. The candidates will attempt five questions in all, selecting at least 02 questions from each section, and the compulsory question. The books indicated as text-book(s) are suggestive of the level of coverage. However, any other book may be followed.

### Section A

**Chemical bond formation:** Electronegativity, recent advances in electronegativity theory, variation of electronegativity, group electronegativity, polarities of bonds and molecules, dipole moments. Percentage of ionic character from dipole moment and electronegativity difference. Valence bond (VB) theory, resonance structures, bond angles and shapes of molecules and ions (containing bond pairs and lone pairs), criterion of bond strength and bond length. Molecular orbital (MO) theory of bonding  $\sigma$ -bonding in homo-nuclear and hetero-nuclear molecules. Comparison of VB and MO theories.

**Molecular geometry:** VSEPR model and hybridization. Various short-range and long range forces and their role in bond formation: Van der Waals interactions, dipole–dipole interactions, ionic interactions, metal bonds, covalent bonds, coordinative bonds, hydrogen bridge bonds and polyvalent bonds. Chemical bonds and surface functionalization and assembly of nanomaterials.

**Crystal structure:** Crystalline and amorphous solids, isotropy and anisotropy, crystal systems, elements of symmetry, space lattice and unit cells, Bravais lattice, Miller indices. Defects in crystals: intrinsic and extrinsic defects, point defects, line and plane defects, vacancies-Schottky and Frankel defects, color centres and other defects in non-stoichiometric crystals. Metals insulators and semiconductors, band theory, band structure of metals, insulators and semiconductors, intrinsic and extrinsic semiconductors, doping semiconductors, p-n junctions, high temperature super conductors.

### Section B

**Surface chemistry:** Adsorption and absorption, adsorption isotherms, Freundlich adsorption isotherm, Langmuir adsorption isotherm, B.E.T. theory of multilayer adsorption, Gibbs adsorption isotherm, wetting behavior of surfaces- concept of contact angle and measurement techniques.

**Thermodynamics of surfaces:** Introduction to thermodynamics-enthalpy and entropy, introduction to the concept of chemical potential, surface energy and surface tension, its consequences in nanomaterials, homogenous and heterogeneous nucleation, introduction to various techniques in surface science-determination of shape and size of nanomaterials.

**Colloids:** Classification of colloids, purification of colloidal solution (dialysis, electro-dialysis, ultrafiltration), , electrical double layer and zeta potential, Instability in colloidal systems-emulsion, gels, nanomaterials, stability of colloidal systems and surface functionalization . Introduction to macromolecules and self-assembly.

#### **Books and Suggested Readings:**

1. **Physical Chemistry** by P. W. Atkins, Oxford Press
2. **Introduction to Modern Colloid Science** by Robert J. Hunter, Oxford University Press.
3. **Thermodynamics and Statistical Mechanics** by A N Tikhonov, Peter Theodore Landsberg
4. **Thermodynamics and Statistical Mechanics** by John M. Seddon, J. D. Gale

### **MNT 6104 SYNTHESIS AND CHARACTERIZATION OF NANOMATERIALS**

The question paper for end-semester examination will consist of seven questions of equal marks, viz. 10. The first question will be compulsory and will consist of several short questions/problems covering the entire syllabus. The rest of the questions shall be distributed evenly over the whole syllabus, such that there are at least three questions from each unit. The candidates will attempt five questions in all, selecting at least 02 questions from each section, and the compulsory question. The books indicated as text-book(s) are suggestive of the level of coverage. However, any other book may be followed

#### **Section A**

**Classification of nanostructures:** Introduction, definition, historical perspective, effects of nanoscience and nanotechnology on various fields. Fundamental basis of classification (metallic and nonmetallic), 0-D (nanoclusters), 1-D (nanowires), 2-D (thin films & multilayers), and 3-D materials. Introduction to size and shape dependent phenomena in nanostructures. Magnetic, electrical and electronic and optical properties of nanomaterials.

**General methods of synthesis:** Metal nanoparticles, metals and inter-metallics, ceramics, nanocomposites, magnetic particles, synthesis of semiconductor nanoparticles, bio-synthesis, and synthesis using porous materials (zeolite hosts) and membranes (anodized alumina membrane). Size distribution – methods for uniform size distribution, superlattice formation.

**Purification methods:** Membrane filtration, selective solvent precipitation, size exclusion chromatography, HPLC, etc.

**Fabrication techniques:** Working principles of chemical vapor deposition, physical vapor deposition, RF sputtering, arc-discharge, laser ablation, thermal evaporation, e-beam techniques,

MBE, MOCVD, self-assembly formation, membrane techniques using anodized alumina. Wet chemical, electrochemical, and chemical bath technique.

**Processing techniques:** Mechanical attrition, high energy ball milling, mechano-chemical pulverization, mechanism of grain size reduction, solution blending, melt mixing, extrusion & molding.

## Section B

**Particle size and structure Determination:** Size determination using dynamic light scattering. X-ray diffraction, Bragg's Law, Structure Factor, Powder diffraction, *Examples of X-Ray diffraction in applications in determination of particle size.*

**Electron Microscopy :** Scanning electron microscope (SEM), working principal, instrumentation and applications, imaging insulating sample with SEM; Transmission electron microscopy (TEM): construction and operation of TEM, electron diffraction, image interpretation, bright field and dark field imaging. Issues with electron optics.

**Optical and electrical:** UV visible, Infrared/Raman, Photoluminescence, Hall Effect, IV and CV.

**Patterning techniques:** Introduction to optical/UV electron beam and X-ray lithography systems and processes, wet etching, dry (plasma /reactive ion) etching, etch resists-dip pen lithography.

**Preparation environments:** Clean rooms - specifications and design, air and water purity, requirements for particular processes, vibration free environments: working practices in clean room environment.

### Books and Suggested Readings

1. **Springer Handbook of Nanotechnology** by Bharat Bhushan
2. **Encyclopedia of Nanotechnology**- Hari Singh Nalwa.
3. **Nanofabrication towards biomedical application: Techniques, tools, Application and impact** – Ed. Challa S., S. R. Kumar, J. H. Carola.
4. **Handbook of Semiconductor Nanostructures and Nanodevices Vol 1-5**- A. A. Balandin, K. L. Wang
5. **Nanotechnology: Importance and Applications** by M.H. Fulekar, IK International 2010.

## MNT 6105 SCIENTIFIC COMPUTATION AND SIMULATION IN NANOSCIENCE & NANOTECHNOLOGY – I

The question paper for end-semester examination will consist of seven questions of equal marks, viz.05. The first question will be compulsory and will consist of several short questions/problems covering the entire syllabus. The rest of the questions shall be distributed evenly over the whole syllabus, such that there are at least three questions from each unit. The candidates will attempt five questions in all, selecting at least 02 questions from each section and the compulsory question. The books indicated as text-book(s) are suggestive of the level of coverage. However, any other book may be followed

## Section A



**Tools:** Practical approach to learning operating systems (DOS, UNIX, Windows) and Graphical packages (Origin)

**Programming:** C++ programming: Character set, variables, constants, Data types and their declarations, relational operators, logical operators, arithmetical operations, built in functions, input output statements, functions, subroutine, Array handling.

**Numerical Methods I :**Matrices, Solution of system of linear equations, direct methods, error analysis, curve fitting, iterative methods; Numerical differentiation and integration methods, quadrature formula, Numerical methods for ordinary equations, stability and convergence.

## Section B

**Numerical methods II:** Interpolation, extrapolation, Numerical solution of partial differential equation, Initial value problems.

**Random numbers:** Monte-carlo integral methods, importance sampling, fast fourier transform.

**Physical simulations:** N body methods and particle simulations, Verlet algorithm, molecular dynamics and monte-carlo methods. Simulation of small system and Ab initio methods.

### Books and Suggested Readings:

1. **Numerical Methods for Scientific and Engineering Computation**, M. K. Jain, S. R. K. Iyengar and R. K. Jain, Wiley Eastern
2. **Handbook of Theoretical and Computational Nanotechnology**, Eds. Michael Rieth and Wolfram Schommers, 2006
3. **Introductory Computational Physics** Andi Klein and Alexander Godunov (Cambridge)

## MNT 6106: LABORATORY I

Each student is required to perform the following open-ended experiments.

1. Hall effect measurement,
2. Four probe conductivity measurement
3. Dielectric constant as a function of temperature
4. Characterization of Solar cell
5. Preparation of 0-D nanoparticles and their characterization by UV-visible, SEM, TEM, XRD, etc. and analysis of results.
6. Visualization and study of protein structures.
7. Enzyme Kinetics

## MNT 6201 CHEMISTRY OF NANOMATERIALS

The question paper for end-semester examination will consist of seven questions of equal marks, viz. 10. The first question will be compulsory and will consist of several short questions/problems covering the entire syllabus. The rest of the questions shall be distributed evenly over the whole syllabus, such that there are at least three questions from each unit. The candidates will attempt five questions in all, selecting at least 02 questions from each section and the compulsory question. The books indicated as text-book(s) are suggestive of the level of coverage. However, any other book may be followed

### Section A

**Photochemistry:** Introduction to photochemistry, quantum yield, mechanism of decay of excited states, quenching, resonance energy transfer.

**Chemical properties:** Origin of chemical reactivity, catalytic activity at nanoscale and specific examples of anomalous catalytic reaction, supported nanoscale catalysts, mass transport.

**Surface engineering:** Surface modification of metal/metal oxide nanoparticles, effect of surface modification of metal/metal oxide nanoparticles. Langmuir Blodgett (LB) films, exchange reactions using self-assembled monolayers, binding of molecules on solid substrate surfaces, molecular nanostructures, strategies of molecular construction. Introduction to supramolecular chemistry: various forces and bond formation, types of supramolecular constructs- host and guests, synthesis and applications.

### Section B

**Reaction mechanisms-** Introduction to kinetics of reactions-unimolecular reactions, polymerization reactions, enzyme reactions. Introduction to reaction dynamics, diffusion and diffusion controlled reactions.

**Electron transfer processes:** Introduction to redox chemistry, electron transfer in homogeneous systems, electron transfer rate law, rate constants-electron tunneling and reorganization. Processes at electrodes-Butler-Volmer equation and voltammetry.

Analytical and environmental chemistry of nanoparticles: chemical and biological nanosensors, controlled pore size materials like zeolites green chemistry, environmental impact of fine particles.

### Books and Suggested Readings

1. **Nanotechnology: Importance and Applications** by M.H. Fulekar, IK International 2010.
2. **Nanochemistry: A Chemical Approach to Nanomaterials** by G. A. Ozin, A.C. Arsenault, and L. Cademartiri, The Royal Society of Chemistry, Cambridge, 2nd Ed., 2009.
3. **Nanostructures & Nanomaterials: Synthesis, Properties, and Applications** by Guozhong Cao, Imperial College Press, London, 2004.
4. **Nanoscale Science and Technology**, edited by R. W. Kelsall, I. W. Hamley, and M. Geoghegan, Wiley, West Sussex, 2005.

5. **Novel Nanocrystalline Alloys and Magnetic Nanomaterials** by Brian Cantor
6. **Nanoscale materials** by Liz Marzan and Kamat.
7. **Polymer nanocomposites**, edited by Yiu-Wing Mai and Zhong-Zhen Yu, First published 2006, Woodhead Publishing Limited and CRC Press LLC, USA.
8. **Carbon Nanotubes: Properties and Applications** by Michael J. O'Connell.
9. **Carbon Nanotechnology** by Liming Dai.
10. **Nanotubes and Nanowires** by C. N. R. Rao and A. Govindaraj, RCS Publishing
11. **CRC Handbook of Thermoelectrics**, Ed. CR Rowe
12. **Microfabrication and Nanomanufacturing** by Mark James Jackson
13. **Chemistry of nanomaterials: Synthesis, properties and applications** by CNR Rao et.al.
14. **Nanoparticles: From theory to applications** by G. Schmidt, Wiley Weinheim 2004
16. **Nanoscale Materials in Chemistry** by Kenneth J. Khabhunde (ed.) Wiley Interscience.
17. **Nanotechnology – An introduction to nanostructure of technique** by Michel Kohler and Wolfgang Frittsche 2004- Wiley VCH

## MNT 6202 NANOBIO TECHNOLOGY

The question paper for end-semester examination will consist of seven questions of equal marks, viz. 10. The first question will be compulsory and will consist of several short questions/problems covering the entire syllabus. The rest of the questions shall be distributed evenly over the whole syllabus, such that there are at least three questions from each unit. The candidates will attempt five questions in all, selecting at least 02 questions from each section and the compulsory question. The books indicated as text-book(s) are suggestive of the level of coverage. However, any other book may be followed

### Section A

**Biophysics and bioengineering:** Bioelectromagnetism-concept and importance, biomechanics-types including sports biomechanics, biotribology and applications, biomaterials-biomineralization, applications and importance of compatibility, biological/circadian rhythms and its phase markers, neurotransport: nerve impulse conduction and conduction across synapse, EEG, ECG and its association with the working of the heart.

**Tissue engineering:** Concept of tissue engineering- cell types, scaffolds and bioreactors, nanopump, molecular motors- types and examples, nanoscale biostructures, self-healing structures.

**Applications:** Lab-on-a-chip, organic molecular based computing - amorphous computing, DNA fingerprinting, bio-imaging, bioassays, nanovectors & drug delivery, nano-diagnostics & therapeutics, DNA molecular therapy, photodynamic therapy, smart materials, biosensors, nanorobotics.

### Section B

**Introduction:** Overview of nanoparticles in biomedical applications, limitations and challenges in using nanoparticles in biomedical fields, biocompatibility/toxicity of nanomaterials

**Bioconjugation:** Introduction to bioconjugation, interaction of biomolecules with nanoparticles, surface functionalization/modification of nanoparticles by ligand exchange or ligand modification; reactions of bioconjugation, types of cross linkers- homofunctional, heterofunctional, zero length; bioconjugation using covalent, non-covalent, biological approaches; examples of bioconjugation with metallic, semiconducting, magnetic nanoparticles and liposomes, modification and conjugation of antibody, enzyme, nucleic acid and oligonucleotide coupling reactions, fluorescent probes and their use in nanotechnology, ligand immobilization on chromatography supports, PEGylation and synthetic polymer modification, characterization of nanobioconjugates using electrophoresis, chromatography and various spectroscopic techniques.

**Bio inspired nanomaterials:** Superhydrophobic materials such as lotus leaf structure, bio-inspired superglues (adhesive nanostructures), ultra hard materials, organic and inorganic natural nanomaterials, natural fibers (spider silk, sponge fibers), nanomaterials derived from cell walls.

### **Books and Suggested Readings**

1. Xiong J. **Essential Bioinformatics**, Cambridge University Press, 2006.
2. M. Ratner, D Ratner. **Nanotechnology, A Gentle introduction to the next big idea.** Pearson Education, 2005. V.A. Shchukin, N.N. Ledentsov, D. Bimerg. Nanostructure.Springer 2007.
3. Greg T. Hermanson, **Bioconjugate Techniques**, Academic Press, 2013
4. Gabor L. Hornyak, **Introduction to Nanoscience**, CRC Press 2008

## **MNT 6203 PHYSICS OF MATERIALS AND NANOMATERIALS**

The question paper for end-semester examination will consist of seven questions of equal marks, viz. 10. The first question will be compulsory and will consist of several short questions/problems covering the entire syllabus. The rest of the questions shall be distributed evenly over the whole syllabus, such that there are at least three questions from each unit. The candidates will attempt five questions in all, selecting at least 02 questions from each section, and the compulsory question. The books indicated as text-book(s) are suggestive of the level of coverage. However, any other book may be followed

### **Section A**

**Resume of structure, binding, lattice dynamics and thermal properties:** Lattice structures, bindings in solids, elastic constants, lattice vibrations, normal modes, density of states, conductivity and band gap, metal to insulator transition, mechanical properties, magnetic and electronic transport properties, thermal expansion.

**Energy band theory:** Review of electrons in a periodic potential, nearly free electron model, tight binding method, bands in pure and doped semiconductors.

**Transport theory:** Electronic transport from classical kinetic theory, calculation of relaxation time in metals and insulators, Hall effect and magnetoresistance.

**Basic ideas of dielectric and magnetic properties of metals:** Polarization mechanisms, Dielectric function from oscillator strength, Clausius-Mosotti relation, piezo, pyro and ferroelectricity, basics of ferromagnetism in materials.

### Section B

**Quantum dots:** Electron confinement, single and interacting quantum dots, self-organized quantum dots, spectroscopy of quantum dots. Lithographic fabrication of III-V and graphene quantum dots. PL, Raman and Optical spectroscopy to characterize quantum dots.

**Electron transport in Nano devices:** Electronic transport in 1,2 and 3 dimensions- Quantum confinement - energy subbands - Effective mass - Drude conduction, ballistic transport, phase coherence length, quantized conductance. Examples of nanoscale Field effect transistors made of nanowires and graphene.

**Advanced nanofabrication methods:** Focused Ion beam lithography working principal, instrumentation and uses in nanostructure, preparation of TEM lamella. Nanoimprint lithography working principal, instrumentation and uses. Scanning near field lithography, Scanning probe based lithography methods: AFM and STM lithography. Dip Pen lithography.

### Books and Suggested Readings

1. **Introduction to Solid State Physics VIIIth Ed.** by C. Kittel
2. **Introduction to Nanotechnology** by Owen and Poole, Wiley
3. **Nano-materials** by A. K. Bandopadhyay, New Age International
4. **Quantum Wells, Wires & Dots: Theoretical & Computational Physics of Semiconductors Nanostureuctures** by Paul Harrison, Wiley International
5. **Nanostructures and Nanomaterials - Synthesis, Properties and Applications** by Cao, Guozhong
6. **Nanoelectronics and Nanosystems** by Karl Goser, Spirnger

### MNT 6204 SEMICONDUCTOR DEVICES IN NANOTECHNOLOGY: MEMS AND NEMS

The question paper for end-semester examination will consist of seven questions of equal marks, viz. 10. The first question will be compulsory and will consist of several short questions/problems covering the entire syllabus. The rest of the questions shall be distributed evenly over the whole syllabus, such that there are at least three questions from each unit. The candidates will attempt five questions in all, selecting at least 02 questions from each section and the compulsory question. The books indicated as text-book(s) are suggestive of the level of coverage. However, any other book may be followed

### Section A

**Introduction:** Review of physics and properties of semiconductor, formation of energy band diagram, intrinsic carrier concentration, donors and acceptors, nondegenerate and degenerate semiconductors, mobility, carrier diffusion, current density, recombination processes, continuity equation.

**Junctions:** p-n junction diode, thermal equilibrium condition, depletion region, depletion capacitance current voltage characteristics and temperature effect, charge storage and transit behavior, junction breakdown.

**Transistors:** Bipolar transistor, fabrication techniques of bipolar transistor, transistor action, static characteristics of bipolar transistor, frequency response and switching of bipolar transistor, heterojunction bipolar transistor.

**Hetero-structures:** Metal semiconductor contacts, basic characteristics, Schottky barrier, ohmic contact, MOS structure, MIS diode, operation and its characteristics, MOSFET scaling and modeling, scaling effects, charge coupled device (CCD). Hetero-junction and hetero structure devices, quantum and nanoelectronics.

## Section B

**MEMS and NEMS:** Introduction, working principle of sensors and micro-actuation, scaling laws, materials for MEMS, active substrate materials, polymers as MEMS and NEMS materials, consideration for microfabrication materials, LIGA process, microsystem packaging, die, device and system level packaging, interfaces in microsystem packaging for different application, signal mapping and transduction, micro system design consideration, process design, mechanical design, mechanical design using Fem, design considerations for optical, fluidic, RF and bio MEMS, overview of CAD tools for MEMS and NEMS design and simulation.

**Photovoltaics:** Introduction to photovoltaics, working principles, theory and device characteristics, calculation of various parameters and terminology used in photovoltaics, efficiency determination, types of solar cells- 1 st, 2nd and 3rd generation solar cells, inorganic and organic solar cells, dye-sensitized solar cells, role of various parameters on efficiency, application of Nanomaterials (quantum dots, plasmonic nanoparticles) in solar cells, and current trend.

### Books and Suggested Readings:

1. **Semiconductor Devices, 2<sup>nd</sup> edition** by S.M. Sze
2. **Introduction to Semiconductor Materials and Devices** by S.M. Tyagi
3. **Nanoelectronics & Nanosystems: From Transistor to Molecular & Quantum Devices** by Karl Goser, Jan Dienstuhl and others.
4. **Nano Engineering in Science & Technology: An introduction to the world of nano design** by Michael Rieth.
5. **Enabling Technology for MEMS and nano devices** -Balles, Brand, Fedder, Hierold.
6. **Optimal Synthesis Methods for MEMS**- G. K. Ananthasuresh
7. **MEMS & MOEMS Technology and Applications**- P. RaiChoudhury
8. **Processing Technologies**- Gandhi

## MNT 6205 ADVANCED NANOMATERIALS AND CHARACTERIZATION

The question paper for end-semester examination will consist of seven questions of equal marks, viz. 10. The first question will be compulsory and will consist of several short questions/problems covering the entire syllabus. The rest of the questions shall be distributed evenly over the whole syllabus, such that there are at least three questions from each unit. The candidates will attempt five questions in all, selecting at least 02 questions from each section and the compulsory question. The books indicated as text-book(s) are suggestive of the level of coverage. However, any other book may be followed.

### Section A

**Introduction to carbon nanotubes:** Introduction to carbon based nanomaterials: CNTs, graphene, fullerenes, etc.

**Structure and properties:** Basis of classifications, defects and their role, density of states, physical and chemical properties of carbon based nanomaterials.

**Preparation:** Various preparation purification methods-growth model and growth mechanism.

**Functionalization:** Functionalization of carbon based nanomaterials using chemical and physical methods.

**Characterizations:** Various characterizations techniques and analysis of carbon based nanomaterials-role of Raman techniques in understanding the purity and functionalization of samples.

**Nanofluidics and microfluidics:** Introduction, significance of nanofluidics and microfluidics, similarities and differences.

**Transport phenomena:** Capillary flows, surface tension and Marangoni flow, Ficks law of diffusion, introduction to various flow processes in microfluidics and nanofluidics.

**Fabrication process and applications:** Various fabrication methods, Applications: chemical reactions in confined fluids, single molecule detection, transport of ions, DNA sequencing and analysis, bio-molecular motors, biomolecule separation and detection, opto-fluidic devices ., Introduction to lab- on -a chip and recent advances in medical diagnostics.

### Section B

**Scanning Probe Microscopy:** Basic principal of tunneling spectroscopy, instrumentation and applications, Constant current and constant height - mode, Atomic Force Microscopy, tip-surface interaction, contact and non-contact modes, different imaging modes of AFM, Force sensor, Deflection detection, working with biological samples.

**X-ray spectroscopies:** X-ray Photoelectron Spectroscopy, Ultraviolet photo electron spectroscopy (UPS), Valance Band spectroscopy, Auger electron spectroscopy (AES), Electron energy analyzers, and X-ray absorption spectroscopy.

**Electron based Surface probes: Electron-matter interaction**, Low energy electron diffraction (LEED), Reflection High energy electron diffraction (RHEED) X- ray photoelectron and Auger electron spectroscopy (XPS, AES)- working principles, instrumentation involved and uses of these techniques in nanoscience.

### **Books and Suggested Readings**

1. **Synthesis, functionalization and surface treatment of nanoparticles** - Marie Isabelle Baraton
2. **Physical properties of Carbon Nanotube** - R Satio
3. **Applied Physics Of Carbon Nanotubes: Fundamentals Of Theory, Optics And Transport Devices**- S. Subramony& S.V. Rotkins
4. **Carbon Nanotubes: Properties and Applications**- Michael J. O'Connell
5. **Nanotubes and Nanowires**- CNR Rao and A Govindaraj, RCS Publishing
6. **Carbon Nanotubes: Multifunctional Materials** – Ed. Prakash R. Somani and M. Umeno, Applied Science Innovations Pvt. Ltd., India
7. **Nanofluidics: Nanoscience and Nanotechnology** by Joshua B Edel and Andrew J deMello (RSC Publishing 2009)
8. **Fundamentals of microfabrication: The science of miniaturization** by Mare J.Madou (CRC Press 2002)
9. **Materials Characterization : Introduction to Microscopic and Spectroscopic Methods**, by Yang Leng, JohnWiley & Sons (2012)



## **MNT 6206: LABORATORY II**

Each student is required to perform the following open-ended experiments.

1. Thin film deposition and crystal structure and surface topography characterization.
2. Synthesis of 1D-nanomaterials by chemical methods and their characterization and analysis.
3. Production of nanoparticles by physical methods and understanding crystal growth.
4. Size determination of microbes/ nanoparticles
5. Sequence analysis of proteins, prediction of protein secondary and tertiary structures, molecular docking.

## **MNT 6207 SCIENTIFIC COMPUTATION AND SIMULATION IN NANOSCIENCE & TECHNOLOGY- II**

Twelve open ended experiments based on Mathematica or C++ and on numerical methods.

### **Books and Suggested Readings:**

1. **Numerical Methods for Scientific and Engineering Computation**, M. K. Jain, S. R. K. Iyengar and R. K. Jain, Wiley Eastern
2. **Handbook of Theoretical and Computational Nanotechnology**, Eds. Michael Rieth and Wolfram Schommers, 2006
3. **Introductory Computational Physics** Andi Klein and Alexander Godunov (Cambridge)
4. **Handbook of Mathematica**
5. **Modelling Molecular Structures** by Allan Hinchliffe (Wiley)

# MNT 7101 SUPRAMOLECULAR AND SURFACE CHEMISTRY OF MOLECULAR DEVICES

The question paper for end-semester examination will consist of seven questions of equal marks, viz. 10. The first question will be compulsory and will consist of several short questions/problems covering the entire syllabus. The rest of the questions shall be distributed evenly over the whole syllabus, such that there are at least three questions from each unit. The candidates will attempt five questions in all, selecting at least 02 questions from each section and the compulsory question. The books indicated as text-book(s) are suggestive of the level of coverage. However, any other book may be followed

## Section A

**Basics of supramolecular chemistry:** Receptors, coordination and the Lock and Key Analogy, binding constants and measurement of binding constants, cooperativity and the chelate effect, preorganisation and complementarity, non-covalent interactions (ion–ion interactions, ion–dipole interactions, dipole–dipole interactions, hydrogen bonding, cation– $\pi$  interactions, anion– $\pi$  interactions,  $\pi$ – $\pi$  Interactions, Van der Waals forces and crystal close packing, closed shell interactions).

**Host – Guest chemistry:** guests in solution, macrocyclic versus acyclic hosts, complexation of cations, anions & neutral molecules (crown ethers template effect). Metal-containing receptors, simultaneous cation and anion receptors, supramolecular catalysis and enzyme mimics.

### **Supramolecular chemistry: structures & design**

Catenanes, rotaxanes, molecular electronic devices, molecular wires, molecular rectifiers, molecular switches, molecular logic, molecular analogues of mechanical machines.

Nanochemistry: Nanoscale photonics, assembly and manipulation on the nanoscale, chemistry with a microscope tip, self-assembly on surfaces, single molecules, atomic-level assembly of materials, grapheme, fullerenes, supramolecular design strategy & nanotechnology, supramolecular polymers, gels and fibers.

## Section B

### **Surface chemistry**

Colloidal State: Determination of size of colloidal particles, types of surfactants: anionic, cationic, gemini, zwitterionic & non-ionic (non-iogenic), theory of surfactants, phase behavior of concentrated surfactant systems, micelle formation- micelle type, micellar growth, micellar solution saturation, structure of liquid crystalline phases, surfactant geometry & packing.

The critical micellization concentration (CMC), factors affecting cmc, effect of chemical structure, temperature, Kraft temperature, emulsions & gels, microemulsion.

### **Books and Suggested Readings**

1. **Surfactants and Polymers in Aqueous Solution** by K. Holmberg, B. Jonsson, B. Kronberg, B. Lindman, Wiley – England 2004.
2. **Dynamics of Surfactant Self-assemblies** by Raoul Zana (Ed.), Taylor & Francis.
3. **Supramolecular Chemistry** by J.W. Steed, J.L. Atwood, Wiley.

## **MNT7102 NANOCOMPOSITES : STRUCTURE, PROPERTIES & APPLICATIONS**

The question paper for end-semester examination will consist of seven questions of equal marks, viz. 10. The first question will be compulsory and will consist of several short questions/problems covering the entire syllabus. The rest of the questions shall be distributed evenly over the whole syllabus, such that there are at least three questions from each unit. The candidates will attempt five questions in all, selecting at least 02 questions from each section and the compulsory question. The books indicated as text-book(s) are suggestive of the level of coverage. However, any other book may be followed

### **Section A**

**Macro-composites and nanocomposites:** Introduction to macro-composites and nanocomposites, structure, significance, and classifications. Synthesis/fabrication methods of nanocomposites. Role of fillers and matrices, reinforcement.

**Processing of nanocomposites:** Various techniques and methods of processing of nanocomposites, processing of bio-nanocomposites, environmental life-cycle assessment.

Nanocomposites made of carbon nanotubes- alignment of CNTs in nanocomposites, fullerenes, and grapheme, their potential applications. Nanocomposites made of metal and metal oxides, magnetic nanoparticles, organic-inorganic nanoparticles, silicates-various types, calcium carbonate, clays-various types.

Bio-nanocomposites: Introduction, types - soft nanocomposites and gels, biopolymers and bio-nanocomposites, fabrication/synthesis, applications. Bio-inspired composites materials and their applications.

**Coatings and thin films:** Nanocomposites in thin films and coating industries, various fabrications methods.

### **Section B**

**Properties of nanocomposites and characterization:** Physical and chemical properties of nanocomposites- photo degradation, corrosion resistance, biodegradability, optical, and wetting behavior, etc. Various testing protocols-elastic modulus, tensile strength, stiffness, impact resistance; swelling behavior, barrier properties and permeability, thermal, electrical and electronic, wear and scratch resistance. Nanocomposites in fire safety- flame retardant materials, fire retardant mechanism and various types. Significance of rheology and rheology control in nanocomposites.

**Specific applications of nanocomposite:** fuels cells, photovoltaics, packaging industry, coating industry, biomedical applications, and applications in optics. Applications of nanocomposites in aerospace industries – role of nano-composites, physical & chemical requirements, various types, industrial fabrication, current trends.

### **Books and suggested readings**

1. **Nanocomposite thin films & coatings: Processing, properties & Performance** by Sam Zhang & Nasar Ali, Imperial College Press (2007).
2. **Advances in Polymer Nanocomposites: Types and Applications** edited by Fengge Gao, Woodhead Publications (WP), UK (2012).
3. **Polymer Nanocomposites** by Yiu-Wing Mai & Zhongzhen Yu, CRC (2006).
4. **Biopolymer Nanocomposites: Processing, Properties, and Applications** edited by Alain Dufresne, Sabu Thomas, Lary A Pothan, Wiley (2013).
5. **Polymer Nanocomposites: Synthesis, Characterization, and Modeling** (Acs Symposium Series) (Hardcover) by Ramanan Krishnamoorti (Editor) and Richard A. Vaia (Editor), An American Chemical Society Publication (2001)
6. **Handbook of Fuel Cells: Advances in Electrocatalysis, Materials, Diagnostics and Durability** by Vielstich, W., et al, ed. Hoboken: John Wiley and Sons (2009).
7. **Fuel Cells: Current Technology Challenges and Future Research Needs (First ed.)** by Noriko Hikosaka Behling, Elsevier Academic Press (2012).
8. **Polymer-Layered Silicate and Silica Nanocomposites** by Y.C. Ke and P. Stroeve, Elsevier Science (2005)
9. [http://www.nsti.org/Nanotech2005/workshops/polymer\\_nanotechnology.html](http://www.nsti.org/Nanotech2005/workshops/polymer_nanotechnology.html)
10. Reference Research Articles/papers from Journals

### **Additional Recommended texts & References**

1. Nanochemistry: A Chemical Approach to Nanomaterials – Royal Society of Chemistry, Cambridge UK 2005.
2. Nanocomposite science and technology – P.M. Ajayan, L.S. Schadler, P.V. Braun, Wiley, New York.
3. Active Metals: Preparation, characterization, applications – A. Furstner, Ed., VCH, New York 1996.
4. Characterization of nanophase materials – Z.L Wang (ed), Wiley-VCH, New York 2000.
5. Nanoparticles: From theory to applications – G. Schmidt, Wiley Weinheim 2004.
6. Nanostructured Silicon – based powders and composites – Andre P Legrand, Christiane Senemaud, Taylor and Francis, London New York 2003.
7. Polymer – clay Nanocomposite – T.J. Pinnayain, G.W. Beall, Wiley, New York 2001.
8. Block Co-polymers in Nanoscience – Massimo Lazzari, Guojun Liu, Sebastien Lecommandoux, Wiley, New York 2007.

## **MNT 7104 LABORATORY III**

**Introduction to Universal Safety Standards:** Hazard classification-flammable, combustible, explosive, bio-hazard, carcinogens, ion and laser radiation, etc. Standard laboratory practices – chemicals classification for storage, safe bulk solvent storage, ventilation requirement, first aid practices.

1. Fabrication of single and few-layer thick 2D-layerd material using liquid exfoliation method.
2. Carbon based nano material production, characterization, and analysis.
3. Experiments to understand the interacting nanomaterials, self-assembly, surface modifications by chemical methods and detection by various techniques.
4. Development of a basic solar cell using available materials.
5. Lab visit for demonstration of SEM, TEM and SPM methods.

### **MNT 7103 and MNT 7201 PROJECT and DISSERTATION**

Each student will be required to work on major project approved by department faculty that will span third and fourth semesters during which periodic progress reports will be monitored. At the end of third semester, project progress will be evaluated by department faculty. At the end of IV semester, the student will submit the thesis based upon his/her project work

### **MNT 7202 SEMINAR**

Each student will be required to *present his/ her project work/ dissertation* in the form of a seminar during the fourth semester.