UM-DAE Centre for Excellence in Basic Sciences

Syllabus for 5-years integrated M. Sc. Degree

(Implemented from Academic year 2018-2019)

(Humanities syllabus was modified in December 2021)

- ***Mathematics Syllabus revised in 2016 and approved by the Academic Board***
- ***Chemistry, Physics and Biology Syllabi revised in 2018 and approved the Academic Board in its 18th Meeting held on 27th March 2018.***
- ***Humanities syllabus was modified in December 2021 and was approved by the Academic Board in its meeting No 25 held on 14th December 2021.***

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(Abbreviation: B = Biology; BL = Biology Laboratory; BPr = Biology Project; C = Chemistry; CL = Chemistry Laboratory; CPr = Chemistry Project; GL = General Laboratory; H = Humanities and Social Sciences; M = Mathematics; MPr = Mathematics Project; P = Physics; PL = Physics Laboratory: PPr = Physics Project)

NOTE: This syllabus will be implemented from the batch admitted to CEBS from 2018-2019 Academic Year, while students admitted during Academic Years 2014-2015; 2015-2016; 2016-2017 and 2017-2018 will follow the syllabus provided at the time of their admission.

Code No	Syllabus
B-101	**Biology-I (Introductory Biology)** 1. **Life:** History and origin of life, Concepts of biological evolution, Darwinism, Lamarckism, Hardy-Weinberg equilibrium, natural selection, speciation. 2. **Classification of living things:** Classification and domains of life, Prokaryotes and Eukaryotes, Taxonomy of plants, animals and microorganisms. 3. **Ecology and Ecosystem:** Concept of ecology and ecosystem, ecological succession, ecosystem dynamics, flow of ecology and matter, biogeochemical cycling, ecosystem changes, biotic and biotic factors and stresses, food web, adaptation of individual organism to the environment through genetic changes. 4. **Cell Biology**: Discovery of cell, cell theory, classification of cell types, cell membrane, cell-cell interactions, energy and metabolism, respiration, photosynthesis, sexual reproduction. 5. Cell Division and System Development: cell cycle, mitosis, meiosis, mechanism of development (stem cells), formation of tissues. **References** 1. Biology with mastering Biology (8th Edition) by Neil A. Campbell and Jane B. Reece (Hardcover - Dec. 7, 2007). 2. Biology: Concepts and Connections with my biology" (6th Edition) by Neil A. Campbell, Jane B. Reece, Martha R. Taylor, and Eric J. Simon (Hardcover - Feb. 28, 2008). 3. On the Origin of Species by Charles Darwin (Kindle Edition - Mar. 3, 2008) - Kindle Book. 4. Essential Cell Biology by Bruce Alberts, Dennis Bray, Karen Hopkin, and Alexander D Johnson (Hardcover - Mar. 27, 2009). 5. Molecular and Cell Biology for Dummies by René Fester Kratz (Paperback - June 2, 2009). 6. Darwin's Black Box: The Biochemical Challenge to Evolution by Michael J. Behe (Paperback - Mar. 7, 2006). 7. Biology: A Self-Teaching Guide, 2nd edition by Steven D. Garber (Paperback - Aug. 15, 2002).
B-201	**Biology-II (Introduction to Macromolecules)** 1. Cell – Overview: Cellular organization, Bio-membranes, Nucleus, Cytoplasmic organelles, Bacteriophages. 2. Nucleic Acids, Genomes and Proteomics: Building blocks- nucleotides, DNA structure, RNA structure and function, chromatin structure, genome code, genes, repetitive DNA sequences. 3. Gene Transcription: Overview of gene expression, overview of transcription, gene's regulatory elements, transcription mechanisms in prokaryotes and eukaryotes (a comparison). 4. Protein Structure and Function: Building blocks- amino acids, peptides, secondary structure, three-dimensional structure, membrane proteins, miscellaneous proteins, enzymes. 5. Cell Signalling: Overview, signalling via hydrophobic molecules, signalling via ion channels, signalling via G-protein coupled receptors, signalling via cell surface enzymes, intracellular signalling. 6. Biotechnology: DNA cloning, Uses of recombinant DNA technology, Polymerase chain reaction (PCR), Production of recombinant proteins and SDS-PAGE. **References** 1. Molecular Biology of the Cell by Bruce Alberts, Alexander Johnson, Julian Lewis, and Martin Raff. 2. Molecular Biology of the Gene (6th Edition) by James D. Watson, Tania A. Baker, Stephen P. Bell, and Alexander Gann.

	3. Molecular Biology of the Cell, Fifth Edition: The Problems Book by John Wilson and Tim Hunt (Paperback - Nov 28, 2007). 4. Genes IX (Lewin, Genes XI) by Benjamin Lewin (Hardcover - Mar 5, 2007).
B-301	**Biochemistry-I** 1. General biochemistry concepts: Concept of pH, dissociation and ionization of acids and bases, pKa, buffers and buffering mechanism, Henderson Hasselbalch equation, dissociation of amino acids and determination of pKa. Basic thermodynamics 2. Protein structure and functions: Chemical and physical properties of amino acids, primary, secondary, tertiary structure and quaternary structures of protein, Classification of proteins: globular and fibrous, Protein folding and modification. 3. Enzymes and enzyme activity: Enzymes Mechanism, Classification, Enzyme kinetics, enzyme regulation and inhibition 4. Structure and Functions of Carbohydrates: Classification of Carbohydrates, monosaccharides, di-, oligo- and Polysaccharides, cellulose, lignin, cell wall, Sugar derivatives, Glycosidic Bonds, Lectins, Selectins 5. Structure and Functions of Lipid: Sources in human body; General properties; Classifications: fatty acid, fats, essential oils, oils, waxes, cholesterol, phospholipids, glycolipid, glycocalyx, antigen, isoprene, Vitamins and Hormones; Membranes: fluid mosaic model, properties of membrane: diffusion and osmosis, ion channel, proton pump, electron transport, ion gradient, antiporter, symporter, quinine, riboflavin 6. Structure and Functions of Nucleic acid: Nucleic acid structure: DNA and RNA, Nucleotides: building blocks of nucleic acids: structure, nomenclature and function; types of RNA: mRNA, tRNA and rRNA, Chemistry of nucleic acids: Nucleic acid melting, non-enzymatic transformations, methylation. **References** 1. Lehninger Principles of Biochemistry, Fourth Edition by David L. Nelson & Michael M. Cox. 2. Stryer L (1995) Biochemistry, 4th edition, W. H. Freeman & company, New York. 3. Energy and Entropy equilibrium to stationary states, Starzak, Michael E. 2010, XI, 303 p. 4. Fundamentals of General Organic and Biological Chemistry (Study Guide) by John McMurry (Paperback - Jan. 1999).
B-302	**Cell Biology-I** 1. Visualization of cells History of cellular imaging; Principles and applications of immunofluorescence microscopy, transmission electron microscopy, phase-contrast microscopy, confocal microscopy; Visualization of living cells. 2. Cellular organelles and their functions Mitochondria: Structure of mitochondria, Electron transport complexes and energy production, ATP synthase, Mitochondrial DNA. Chloroplast: Structure of chloroplast, protein complexes and photosynthetic electron transport chain, chloroplast DNA. Structure and functions of the ribosomes, endoplasmic reticulum, Golgi bodies, lysosomes, and nucleus 3. Protein sorting, vesicular traffic inside the cells, protein targeting & degradation The compartmentalization of cells; The transport of molecules between the nucleus and the cytosol; The transport of proteins into mitochondria and chloroplasts. The molecular mechanisms of membrane transport; Transport from the ER through the Golgi apparatus; Transport from the trans-Golgi network to lysosomes; Transport into the cell from the plasma membrane: Endocytosis; Transport from the trans-Golgi network to the cell exterior: Exocytosis 4. The plasma membrane: Structure

	The cell membrane and its structure: Models of the bio-membrane: Charles Overton's "Lipid Membrane" model. Lipid monolayer model of Irving Langmuir, Lipid bilayer model by Gorter and Grendel, Protein-containing lipid bilayer model of Davison and Danielly, David Robertson's direct observation of the membrane, Fluid Mosaic model of Singer and Nicholson. Constituents and fluidity of plasma membrane: structure, classification and functions of membrane lipids. Types and functions of membrane proteins. Use of FRET and FRAP in studying the membrane. 5. **Transport across cell membrane:** Principles and types of membrane transport: Simple diffusion, facilitated diffusion and active transport. Carrier proteins and active membrane transport. Voltage-gated, ligand-gated and mechano-sensitive channels. 6. **The cytoskeleton:** General features of the cytoskeletal proteins. *Microtubules*; Assembly dynamics of microtubules; the structure of tubulin. Dynamic instability and treadmilling of microtubules. Functions of microtubules. Roles of microtubules in cell division and intracellular transport. Microtubule-associated proteins. *Actin*: Structure and functions of actin, treadmilling of actin filaments, regulation of actin assembly, mechanisms of actin-assisted cell motility. *Intermediate filaments*: Structure and functions of intermediate filaments. Assembly of intermediate filaments. Examples of intermediate filaments: Keratin, vimentin, desmin. 7. **Molecular Motors:** Classification of motor proteins; structure and mechanisms of movement of kinesins and dyneins. Myosin motor proteins. 8. **Cilia and Flagella:** Structure of cilia, major functions of cilia and mechanism of ciliary movement. Flagella: structural organization and mechanism of movements. Eukaryotic *vs* prokaryotic flagella. **References** 1. Molecular Biology of the Cell (Sixth Edition) by Bruce Alberts, Alexander D. Johnson, Julian Lewis, David Morgan, Martin Raff, Keith Roberts, Peter Walter. 2. Cell Biology (Third Edition) by Thomas D. Pollard MD and William C. Earnshaw
B-401	**Biochemistry-II** 1. Fundamentals of metabolism, Nature of anabolic and catabolic pathways 2. Concept of free energy, standard free energy, redox reactions and standard reduction potential, Substrate level phosphorylation 3. Metabolism of carbohydrates 4. Glycolysis and regulation, Feeder pathways of glycolysis, cori cycle, oxygen debt, Pasteur effect, Fates of pyruvate 5. TCA, regulation., Amphibolic nature, Glyoxylate pathway, Malate Aspartate shuttle 6. Pentose phosphate pathway 7. Oxidative phosphorylation and Electron transport chain, mitochondrial structure, inhibitors of ETC 8. Chemiosmotic theory and competing theories, Structure of FoF1 ATPase 9. Photophosphorylation, Photosynthesis, Structure of chloroplasts, Antennae Pigments, Light Harvesting complex, Photochemical reaction center 10. Cyclic and Non-cyclic photophosphorylation 11. Green and Purple bacteria and plant photosynthesis, Light and Dark reactions, C4 and C3 pathways 12. Gluconeogensis, futile cycle, Glycogen synthesis and degradation 13. Fatty acid catabolism, carnitine mediated transfer, beta oxidation, beta oxidation of odd number fatty acids, beta oxidation of mono and poly-unsaturated fatty acids, Absorption and transport of fats.

	References 1. Lehninger Principles of Biochemistry, Fourth Edition by David L. Nelson & Michael M. Cox. 2. Stryer L (1995) Biochemistry, 4th edition, W. H. Freeman & company, New York. 3. Energy and Entropy equilibrium to stationary states, Starzak, Michael E. 2010, XI, 303 p. 4. Fundamentals of General Organic and Biological Chemistry (Study Guide) by John McMurry (Paperback - Jan. 1999).
B-402	**Molecular Biology** 1. Molecular biology an overview: Concept and definition of the gene, complexity of the eukaryotic gene. Structural organization of the DNA in the nuclear material- General properties of histones, nucleosomes and solenoid structure, RNAs and their structure & function. 2. DNA synthesis: The enzymes of DNA replication in prokaryotes and eukaryotes, mechanism of replication in bacteria and viruses, reverse transcriptase, salient features of eukaryotic nuclear and mitochondrial DNA replication. 3. RNA synthesis: The enzymes of transcription in prokaryotes and eukaryotes, mechanism of transcription in bacteria, heteronuclear RNA, post transcriptional processing of RNA, role of ribozymes. 4. Protein synthesis: Concept of the genetic code, structure of t-RNA and t-RNA, enzymes of translation in prokaryotes and eukaryotes, mechanism of protein synthesis, post translational processing of proteins. 5. Gene expression and its characterization: Regulation of gene expression in prokaryotes and eukaryotes, structure and mechanism of different operons, Gene regulation during development, Gene function and phenotype loss of function & gain of function, Gene interaction, suppressors & enhancers redundancy & epistasis. 6. Mutations and their consequences: Definition of mutation, mutagenesis & mutant selection, Alleles, Complementation, Recombination, recombination mapping and mechanism of recombination, Repair of DNA, Transposons and retroposons, Genomic & evolution of diversity. **References** 1. Stryer L (1995) Biochemistry, 4th edition, W. H. Freeman & company, New York. 2. Watson J. D., Hopkins, N. H., Roberts, J. W., Steitz, J. A. and Weiner, A. M. (1988) Molecular biology of the gene, 4th edition, The Benjamin/Cummings publishing companies, inc, California. 3. Benjamin Lewin (1999) Genes VII, oxford University Press, Oxford. 4. Weaver R. F. (1999) Molecular biology, WCB McGraw-Hill companies, Inc, New York. 5. Brown T A (1995) Essential molecular biology, vol. I, A practical approach, IRL press, Oxford. 6. Molecular Themes in DNA Replication, by Cox Lynne S (Ed.) 2009 443 p. 7. Cantor, C. R., and Schimmel, P. R. Biophysical Chemistry. San Francisco: 8. W.H. Freeman and Company, 1980. 3 Volumes.
B-403	**Biostatistics** 1. Meaning and scope of Bio – Statistics 2. Basic Concepts: Parameters, statistics, sample, census, Random variable (Discrete and Continuous) 3. Collection of Data, sources and methods 4. Sampling Methods: Simple random sampling, stratified random sampling, systematic sampling 5. Graphs and Diagrams 6. Measures of Central Tendency: Mean, Median & Mode 7. Measures of Dispersion: Variance / Standard Deviation and co – efficient of variance, Standard Error, confidence limits for mean and proportion 8. Co – relation, regression and multiple regression 9. Probability: Basic concepts, Binomial and Normal distribution

	10. Test of Hypothesis: Null Hypothesis, Alternate Hypothesis 11. Test Statistics, Type I & Type II errors, level of significance and critical region 12. Z – Test, t – test, chi-squared test ($\chi 2$) and F – test 13. One way and two-way classification of ANOVA 14. Designs of Experiments: Basic concepts, completely randomized block design, randomized block design, Latin square design 15. Non – Parametric Tests: Sign Test, Run – Test, Wilcoxon test **References** 1. Statistics: A Guide to the Use of Statistical Methods in the Physical Sciences, R.J. Barlow, John Wiley 1989 2. The Statistical Analysis of Experimental Data, John Mandel, Dover Publications 1984 3. Data Reduction and Error Analysis for the Physical Sciences, 3rd Edition, Philip Bevington and Keith Robinson, McGraw Hill 2003
B-501	**Genetics** 1. Overview and Introduction of Genetics: Central Dogma, Genotype and Phenotype, Eukaryotic and Prokaryotic Genes, Forward and Reverse Genetics 2. Mendelian Inheritance: Law of Dominance, Law of Segregation, Law of Independent Assortment, Deviation from Mendelism: Incomplete dominance, Co-dominance, Multiple alleles, Epistasis Polygeneic Inheritance, Cytoplasmic Inheritance 3. Linkage and Recombination 4. Sex Linkage and Sex-Linked Inheritance 5. Pedigree Analysis 6. Bacterial Genetics: Transformation, Conjugation, Transduction (Lambda Phage) 7. Human Genetics and Model Organisms: Drosophila, Yeast, Maize, Mouse 8. Immunogenetics (Generation of Antibody Diversity – VDJ Recombination) 9. Genomes and Genomics: Nature of genomics, Sequence map of a genome, Creating Sequence maps 10. Molecular basis of: Spontaneous Mutations, Induced Mutations and their role in evolution; Environmental mutagenesis and toxicity testing (Ames Test). 11. The law of DNA constancy and C-value paradox. 12. Population genetics (Hardy-Weinberg Law) **References** 1. Principles of Genetics, by Eldon J. Gardner (Author), D. Peter Snustad (Editor), Michael J. Simmons (Editor) 2. Genetics: From genes to genomes, by: Leland Hartwell, Leroy Hood, Michael Goldberg, Ann Reynolds, Lee Silver, Ruth Veres. Publisher: McGraw-Hill Science/Engineering/Math, published: 2006-10-09. 3. Introduction to genetic analysis: by: Anthony J. F. Griffiths. Publisher: W.H. Freeman & Company, published: 2010-01-30. 4. Intuitive Biostatistics: A Nonmathematical Guide to Statistical Thinking. by: Harvey Motulsky, publisher: Oxford University Press, USA, published: 2010-01-20. 5. Principles of Biostatistics (with CD-ROM) by: Marcello Pagano, Publisher: Duxbury Press, published: 2000-03-09. 6. Genetics for Dummies by T. R. Robinson (Paperback - Sept. 2, 2005).
B-502	**Cell Biology-II** 1. Cell Cycle and Cell Division: An overview of the cell cycle; Components of the cell-cycle control system, Intracellular control of cell-cycle events. Mechanisms and regulations of cell division, Cyclins and CDKs, Phases of the cell cycle, Key events in G1 Phase, S-Phase, G2 Phase and Mitosis. Cell cycle checkpoints: The START point, G2-M checkpoint, and spindle assembly checkpoint. Molecular mechanism of cytokinesis

	2. Cell Division and Cancer: Characteristic features of cancer cells. Compromised cell cycle checkpoints, mutations leading to uncontrolled cell division. Roles of Retinoblastoma protein, p 53, and APC in cancer induction and progression. Monoclonal and polyclonal expansion of cancer. Deregulation of cell cycle machinery by viruses. Epithelial to mesenchymal transformation and metastasis. 3. Cell Death: Overview of cell death: Apoptosis: Molecular mechanisms of apoptosis; Key proteins involved in apoptosis: Pro- and anti-apoptotic proteins. Apoptosis and cancer. Extrinsic and intrinsic mechanisms of apoptosis induction. Other forms of cell death: General features of necrosis: Causes and factors involved in necrotic cell death. Molecular mechanism and general features of anoikis. 4. Cell Junctions, Cell Adhesion, and the Extracellular Matrix: Overview of cell junctions, Cell-cell adhesion and the extracellular matrix, Extracellular Matrix Receptors on Animal Cells. Integrins, Selectins, and other proteins involved in intercellular contacts 5. Cell Signalling: Overview of cell signalling; Components involved in signalling, Types of signalling, Three major classes of signalling receptors: Ion channel-linked, G protein-coupled (GPRs), and enzyme-linked receptors: Tyrosine-Kinase Receptors, other enzyme-linked receptors. Second Messengers: cAMP, cGMP, IP3 and DAG, Ca+2, PIP3. Signalling Cascades 6. Cell Signalling and Cancer: Deregulation of cell signalling in cancer. Oncogenes and cell signalling; involvement of tyrosine kinase receptors, and calcium signalling in cancer. Involvement of other signalling mechanisms in cancer **References** 1. Molecular Biology of the Cell (Sixth Edition) by Bruce Alberts, Alexander D. Johnson, Julian Lewis, David Morgan, Martin Raff, Keith Roberts, Peter Walter. 2. Cell Biology (Third Edition) by Thomas D. Pollard MD and William C. Earnshaw 3. The Cell: A Molecular Approach (7th Edition) by Geoffrey M. Cooper, Robert E. Hausman
B-503	**Biodiversity** 1. Principles of taxonomy: Concept of species and hierarchical taxa, Biological nomenclature, Taxonomical structure, Outline classification of animals, important criteria used for classification in each taxon, Classification of animals 2. Levels of Structural organizations: Larval forms and their evolutionary significance, Unicellular, colonial, and multicellular forms, Levels of organization of tissues, organs, and systems, Comparative anatomy 3. Classical and quantitative methods in taxonomy: Biosystematics, Interrelationship among major invertebrate phyla and minor invertebrate phyla; Evolutionary relationship among taxa, Natural History of Indian subcontinent: Major habitat types, Geographical origin and migration of species, Common Indian mammals and birds, Seasonality and Phenology of Indian subcontinent 4. Concepts and characteristics of biodiversity: The concepts of biodiversity, Comparison of historical and current rate of species extinction, how genetic diversity may change between generations and within population of species, Complexity and functions of ecosystems; predictable and non-predictable features of ecosystem, Importance of preserving biodiversity, Genetic diversity **References** 1. Biology: The Unity and Diversity of Life by Cecie Starr, Ralph Taggart, Christine Evers, and Lisa Starr (Hardcover – Aug 5, 2008). 2. Plant Conservation and Biodiversity. Series: Topics in Biodiversity and Conservation, Vol. 6 Hawksworth, David L.; Bull, Alan T. (Eds.) Reprinted from Biodiversity and Conservation, 16:6, 2007, VIII, 424 p. 3. Plant Biodiversity & Taxonomy by M P Singh. 4. Biodiversity, E.O. Wilson, Editor. Frances M. Peter, Associate Editor. National Academy Press, Washington, D.C. 1988.

	5. Biology of Plants by Peter H. Raven, Ray F. Evert, and Susan E. Eichhorn (Hardcover - Dec. 17, 2004).
B-601	**Immunology – I** 1. Overview of the Immune system: Historical perspective and ethics, types of immunity, innate, acquired, passive and active, self vs nonself discrimination, Adaptive immune response, Autoimmunity 2. Cells and organs of the immune system: T cell receptors, T cell receptor genes & gene rearrangements, T cell maturation, activation & differentiation, B cell generation, activation & development, the role for microbiota 3. Antigens and Antibodies: Immunoglobulins- structure and function, Immunoglobulin Genes-Organization and rearrangement, Antibody diversity, Antigen antibody reactions, MHC (antigens and genes), Antigen processing & presentation 4. Immune response: Self Non-self-discrimination (mechanism), Clonal selection theory & idiotypic network hypothesis, Cytokines, the complement system, Cell mediated effector response, Leukocyte migration and inflammation, Hypersensitive reactions, Immune regulation, Immune response to infectious organisms, Vaccines, Immunodeficiency diseases (AIDS) 5. Immuno-technology: Monoclonal Abs and their applications, diagnostic techniques, CD markers and flow cytometry **References** 1. Essential Immunology – Roitt 2. Immunology by Janice Kuby
B-602	**Animal Physiology** 1. Cellular physiology and tissue-level organization: Overview of cellular physiology, Gibbs-Donnan equilibrium, interstitial fluid, kinetics of membrane transport. Classification of tissues based on their structure, cell types, and functions. 2. The Digestive System: Overview of the digestive system. Anatomy of the alimentary canal. Accessory glands: Structure, functions and locations of salivary glands, liver, gallbladder, and pancreas, and their functions in digestion. Cephalic and gastric phases of digestion. Hormonal and neuronal control of digestion. Digestion of proteins, fats, carbohydrates and nucleic acids. Mechanisms of absorption of nutrients. Waste elimination 3. The Excretory System: Anatomy of the Excretory system. Structure of kidney, the anatomy of the nephron. Kidney functions, regulation of salt-water balance, blood pressure, and pH. Renin-angiotensin mechanism. Structure of ureters, gallbladder, and urethra. Voluntary and involuntary control of micturition 4. The Muscular System: Overview of the muscular system. Skeletal muscles, cardiac muscles, and smooth muscles: their structural features and functions. Mechanisms of contraction of skeletal muscles, cardiac muscles, and smooth muscles. Isometric and isotonic contractions; Ultrastructure of muscles, tetani, twitch, and fatigue 5. The Respiratory System: Basic organization, physical properties of gaseous exchange, Modes of oxygen transport and cellular delivery, Oxygen dissociation curve, Bohr and Haldane effect, Biochemical features of gaseous exchange, nervous system control of respiration 6. The Circulatory System: The basic structural feature of the heart, electrical conduction through the heart (basic ECG), Cardiac output and venous return. Hemodynamics of blood flow, circulation through the arterial and venous system, microcirculation, lymphatics, local, and nervous system control of circulation. 7. The Nervous System: Basic anatomy and classification and cell types, electrical conduction and action potential generation and propagation, synapse classification

	and conduction, signal transduction in the visual, auditory, vestibular and olfactory system. Somatosensation. 8. The Endocrine System: Overview of the endocrine system, endocrine glands: Structure, location, and functions; hypothalamus, pituitary gland, pineal gland, thyroid and parathyroid glands, adrenal glands, pancreas, testes, and ovaries. Long-term and short-term stress responses. Homeostasis: Mechanisms of homeostasis. Positive and negative feedbacks. 9. The Reproductive System: Structure and functions of testes and ovaries. Spermatogenesis and spermiogenesis, acrosome reaction, oogenesis and the ovarian cycle, accessory reproductive glands, and their functions. Hormonal control of reproduction; Hypothalamic-pituitary-gonadal axis; physiology of fertilization and prevention of polyspermy. **References** 1. Animal Physiology: Adaptation and Environment by Knut Schmidt-Nielsen 2. Guyton and Hall Textbook of Medical Physiology, 13th Edition by John E. Hall
B-603	**Plant Physiology** 1. Plant tissues, cells, nucleus, protein sorting: Plant tissue systems: Dermal, Ground, and Vascular, Structure of Nuclear pore (NP), Nuclear import and export, SNAREs, Rabs, and Coat Proteins, Specialized Vacuoles in Plant Cells, Actin-Binding proteins, Kinesins 2. Cell Walls: Structure, Biogenesis, and Expansion: Role in Carbon Flow through ecosystems, Chemistry of cell wall polysaccharides, Molecular model for the synthesis of cellulose and other wall polysaccharides, matrix components of the cell wall, The mechanical properties of cell walls: Studies with Nitella, Wall degradation and plant defence, Biologically Active oligosaccharins 3. Water and Plant Cells: Calculating capillary rise and half-times of diffusion, Water potential, components of water potential, Can negative turgor pressures exist in living cells?, Measurement of ψw, ψs and ψp, Wilting and plasmolysis, Hydraulic conductivity 4. Translocation in the Phloem: Phloem tissue - sieve elements and companion cells, Materials translocated in phloem, Sources and Sinks, Sampling Phloem Sap, Sugar Transport Rates in the Phloem, Short-distance transport and Long-distance transport, Phloem Loading and Phloem Unloading, Mechanism of phloem translocation: Pressure flow mechanism, Allocation in source leaves: The balance between starch and sucrose synthesis, Partitioning: The role of sucrose-metabolizing enzymes in sinks, Mechanisms linking sink demand and photosynthetic rate in starch storers, Proteins and RNAs: Signal molecules in the phloem 5. Respiration and Lipid Metabolism: Q-Cycle, Inhibitors of electron transport chain, Multiple energy conservation bypasses in oxidative phosphorylation of plant mitochondria, FoF1-ATP Synthases: The world′s smallest rotary motors, type II NAD(P)H dehydrogenases and alternative oxidase, Does Respiration Reduce Crop Yields?, Utilization of Oil Reserves in Cotyledons 6. Gibberellins: Regulators of Plant Height and Seed Germination: Structures of important Gibberellins (GAs) and their precursors, derivatives, Detection and measurement of (GAs), Gibberellin biosynthesis – MVA, MEP pathways, terpenoid biosynthesis pathway, Inhibitors of GA biosynthesis, Free and bound Gas, Physiological effects of Gas, Commercial uses of Gas, GA signal transduction, DELLA Proteins as Integrators of Multiple Signals 7. Cytokinins: Regulators of Cell Division: Discovery of cytokinins - cultured cells can acquire the ability to synthesize cytokinins, The Ti Plasmid and plant genetic engineering, Naturally occurring and synthetic cytokinins, Detection and identification of cytokinins – bioassays, Free and bound cytokinins Physiological

	effects of cytokinins, Commercial uses of cytokinins, Cytokinin receptors and signal transduction 8. Ethylene: The Gaseous Hormone: Discovery of ethylene as a plant growth regulating hormone, Ethylene measurement by Gas Chromatography, Ethylene biosynthesis and Yang's cycle, Inhibitors of ethylene biosynthesis, Ethylene oxidation, Physiological effects of ethylene, Commercial uses of ethylene, Ethylene receptors and signal transduction 9. Auxin: The Growth Hormone: Auxin discovery and definition, Structures of naturally occurring and synthetic auxins, Identification and the measurement of auxins – auxin bioassays, Auxin biosynthesis – tryptophan dependant and independent pathways – IPA, TAM, IAN, IAM etc., Conjugated and bound auxins, Degradation of auxins, Distribution of auxins in cell, Auxin transport – Chemiosmotic model explaining auxin transport, Physiological effects – auxin induced cell elongation – Current model for IAA-induced H+ extrusion, Developmental effects of auxins, Auxin induced genes – early response genes and late response genes, Auxin responsive domains, A model for regulation of transcriptional activation of early response genes by auxin 10. Abscisic Acid: A Seed Maturation and Stress-Response Hormone: ABA May Be an Ancient Stress Signal, Lunularic Acid in Liverworts, The bioassay of ABA, Yellow Cameleon: A Noninvasive Tool for Measuring Intracellular Calcium, Phosphatidic Acid May Stimulate Sphingosine-1-Phosphate Production, Extracellular and intracellular ABA Receptors and signal transduction, Physiological effects of ABA, role in plant pathogen responses, Desiccation tolerance, Seed dormancy, types and the roles of environmental factors, ABA-Induced senescence and ethylene 11. Responses and Adaptations to Abiotic Stress: Water deficit and response of plants to water stress, water-deficit-regulated ABA signalling and stomatal closure, High temperature and plant responses, Heat shock proteins (HSPs) and their functions in plants, Chilling and freezing injury, Plant responses to salinity stress 12. Solute Transport: Membrane potential and distribution of ions across the membrane, The Goldman Equation, Patch Clamp Studies in Plant Cells, Chemiosmosis in action, Multiple Transporter Systems, ABC transporters in plants 13. Water Balance of Plants: Irrigation, physical properties of soils, Leaf transpiration and water vapor gradients, Calculating velocities of water movement in the xylem and in living cells 14. Photosynthesis: The Light Reactions: Principles of Spectrophotometry, Quantum Yield, The Distribution of Chlorophylls and Other Photosynthetic Pigments, Antagonistic Effects of Light on Cytochrome Oxidation, Structures of Two Bacterial Reaction Centers, Midpoint Potentials and Redox Reactions, Oxygen Evolution, Photosystem I, ATP Synthase, Mode of Action of Some Herbicides, Chlorophyll Biosynthesis 15. Photosynthesis: The Carbon Reactions: Inorganic Carbon-Concentrating Mechanisms: CO2 and HCO3 – Pumps, How the Calvin–Benson Cycle Was Elucidated, Rubisco: A Model Enzyme for Studying Structure and Function, Energy Demands for Photosynthesis in Land Plants, Rubisco Activase, Thioredoxins, Operation of the C2 Oxidative Photosynthetic Carbon Cycle, Carbon Dioxide: Some Important Physicochemical Properties, Three Variations of C4 Metabolism, Single-Cell C4 Photosynthesis, Photorespiration in CAM plants, Glossary of Carbohydrate Biochemistry, Starch Architecture, Fructans, Chloroplast Phosphate Translocator 16. Photosynthesis: Physiological and Ecological Considerations: Working with Light, Heat Dissipation from Leaves: The Bowen Ratio, The Geographic Distributions of C3 and C4 Plants, Calculating Important Parameters in Leaf Gas

	Exchange, Prehistoric Changes in Atmospheric CO2, Projected Future Increases in Atmospheric CO2, Using Carbon Isotopes to Detect Adulteration in Foods, Reconstruction of the Expansion of C4 Taxa 17. Phytochrome and Light Control of Plant Development: Phytochrome and High-Irradiance Responses, The Origins of Phytochrome as a Bacterial Two-Component Receptor, Profiling Gene Expression in Plants, Two-Hybrid Screens and Co-immunoprecipitation, Phytochrome Effects on Ion Fluxes. **References** 1. Plant Physiology by Hans Mohr, Peter Schopfer, Springer 1995, 629 pages 2. Taiz & Zeiger (2006) Plant Physiology.4th Edition. Sinauer 3. Hopkins WG (1998 or 2004 ed). Introduction to Plant Physiology. 2nd or 3rd Ed. Wiley. Used previously for course. This is a good introductory text, but it is not a substitute for Taiz. 4. Stern KR (1997) Introductory Plant Biology. 7th Ed. Wm C Brown Publishers 5. Fosket (1994) Plant Growth and Development: A molecular approach. Acad. Press. More details on how plants grow and develop. 6. Buchanan R., Gruissem W. and Jones R. (eds) 2000. Biochemistry and Molecular Biology of Plants. An excellent new text by leading plant biologists in the world. The book provides a contemporary view of molecular biology, cell biology and plant physiology. Valuable reference for teaching and research. 7. Chrispeels MJ and DE Sadava (2002) Plants, Genes and Crop Biotechnology.2nd Ed. Jones and Bartlett. Understanding plant biology and the potential of agricultural biotechnology. Highly recommended.
B-604	**Microbiology** 1. General Microbiology a) Prokaryotic Structure & Function b) Microbial Nutrition, c) Microbial Growth, d) Control of Microbes, e) Gram Negative Bacteria, Gram Positive Bacteria, & Archaea 2. Fundamentals of General Microbiology – a) Isolation of a broad range of non-pathogenic bacteria from natural sources, b) Selective and Enrichment techniques, c) Microscopic, biochemical, and molecular identification. d) Growth Energetics (Genetics, physiology, quantitation) 3. Microbes and Society. Microbe-related topics include: Disease, bioterrorism, Food, Biotechnology, and Ecology. (Focuses on activities of bacteria, viruses, and other microorganisms, and their influence on humans.) 4. Prokaryotic Diversity - Structure, biochemical properties, and genetics of the major groups of prokaryotes. 5. Microbial Ecology a) Microbial Interactions b) Microbial ecology; food, industrial and medical microbiology c) Aquatic Ecology d) Terrestrial Ecology e) Metagenomics 6. Medical Bacteriology – (Medically important bacterial pathogens in terms of the clinical, therapeutic, and epidemiological aspects of diseases caused by them, molecular mechanisms of pathogenesis and their identification in the clinical laboratory, procedures for isolation and identification of pathogenic bacteria, testing their susceptibility to antibiotics. Bacterial Pathogenesis: Introduction, Genetic tools used for bacterial pathogenesis study; Bacterial cell-cell communications and biofilm formation, Bacterial genomics, lateral transfer, phage, Vertebrate microbial communities in health and disease, Strategies for bacterial adhesion and invasion)

	a) Skin Infection b) Respiratory Tract Infections c) Urinary Tract Infections d) Gastro-Intestinal Tract Infections 7. Medical Mycology and Parasitology - Consideration of medically important fungi and parasites, with emphasis on their biology in relation to disease and its laboratory diagnosis. 8. Aquatic Microbiology - Basic principles of aquatic microbiology and aquatic microbial ecology: role and identity of aquatic microorganisms; introduction to modern methodologies for research. Laboratory work with local freshwater and marine samples for those enrolled in the five-credit section. 9. Evolution of Prokaryotic Diversity - Evolution, diversity, and genomics of prokaryotic microorganisms, Enrichment, isolation, and molecular phylogenetic characterization of selected prokaryotic organisms. 10. Methanogenesis genetics and biochemistry of selected bacteria. 11. Molecular Mechanisms of Bacterial Pathogenesis Mechanisms of bacterial pathogenesis explored at the molecular, genetic, and cellular levels through selected models as presented in the current scientific literature. Molecular and Medical Microbiology recent advances in molecular biology of microbial pathogenesis or the current research of the participants is presented and discussed critically. 12. Signal transduction in bacteria (Quorum Sensing in Gram positive & Gram-Negative Bacteria) 13. Protozoan infections: Introduction to protozoa, a survey of the major protozoan infections of humans including a brief description of the parasite life cycles and a brief discussion of the clinical diseases seen during these infections. 14. Biology and pathogenesis of Plasmodium. Life cycle Plasmodium parasites and pathology of human malaria, biochemical and cell biological similarities and differences with other apicomplexa (Babesia, Cryptosporidium, Toxoplasma, etc.), and implications for therapeutic development. Biology and pathogenesis of Toxoplasma, Leishmania, Trypanosoma. **References** 1. Brock's Biology of Microorganisms (Hardcover) by Thomas D. Brock 2. Medical Microbiology: with STUDENT CONSULT Access (Paperback) by Patrick R. Murray 3. The Great Influenza: The Story of the Deadliest Pandemic in History (Paperback) by John M. Barry 4. Benson's Microbiological Applications: Laboratory Manual in General Microbiology (Spiral-bound) by Alfred E. Brown 5. Textbook of Microbiology, Ananthanarayan and Paniker Orient Blackswan, 2005 - Medical microbiology - 665 pages
B-701	**Biotechnology – I** 1. Basic principles of genetic engineering: a) Methods of creating recombinant DNA molecule, splicing, properties of restriction endonucleases and their mode of action b) Cloning vectors (lambda phage plasmid, M-13 phage, cosmid, shuttle vectors, yeast and viral vectors, expression vectors), construction of DNA library, Subtraction cDNA cloning, genomic vs cDNA library - Expression libraries and vectors for protein synthesis, protein purification, protein solubilization, protein export, RNA probes, BACs, PACs and cosmid vectors, Yeast vectors and YACs c) Chemical synthesis of gene and engineering artificial life

	2. Selection/screening: Analysis of genomic DNA by Southern hybridization, Northern and Western blotting techniques, Restriction mapping: Restriction fragment length polymorphism (RFLP). 3. DNA sequencing and analyses techniques: plus, and minus, dideoxynucleoside, Maxam and Gilbert, deep sequencing and next gen sequencing, microarray technology and hybridizations. 4. DNA manipulation techniques: a) Preparation of radiolabelled and synthetic probes, Amplification of DNA by polymerase chain reaction (PCR), Site directed mutagenesis, Gene transfer methods for animals and plants; Agrobacterium mediated gene transfer, electroporation and particle gun b) Transgenic plants [Agrobacterium mediated transformation, Ti plamid, Transgenic tobacco expressing luciferase gene, Bt Cotton, Herbicide-resistant plants, Plant viruses as vectors (e.g., CaMV virus)] c) Application of genetic engineering in medicine and agriculture, vaccine production. 5. Cell and tissue culture in plants and animals: Primary culture; Cell line; Cell clones; Callus cultures; Somaclonal variation; Micropropagation; Somatic embryogenesis; Haploidy; Protoplast fusion and somatic hybridization; Cybrides; Gene transfer methods in plants and in animals; Transgenic biology; Allopheny; Artificial seeds; Hybridoma technology. **References** 1. Principles of Gene Manipulation and Genomics, 7th Edition, Sandy B. Primrose and Richard Twyman Blackwell Publishing, 2006 2. Gene Cloning and DNA Analysis: An Introduction, Brown T. A, Wiley-Blackwell, 2010, Genes IX Benjamin Lewin Oxford Publishers 3. Bernard Glick, Jack Pasternak and Cheryl Patten, Molecular Biotechnology- principles and applications of Recombinant DNA, 4th 4. Principles of gene manipulation by S.B. Primrose and Twyman, 7 5. Molecular Biology of the Gene by Watson fifth edition Pearson Education India, 2004
B-702	**Immunology – II** 1. Host-Pathogen relationship –Equilibrium 2. Diseases caused by Viruses and the immune response to them- HIV and AIDS-immune responses 3. Bacterial diseases – and the immune response to bacteria-tuberculosis and leprosy 4. Vaccines- mechanisms, types of vaccines 5. Parasites – protozoan parasites, parasitic worms and the immune response to them- malaria, leishmaniasis, worm infestations 6. Autoimmune diseases- generalized- SLE, Rheumatoid arthritis; localized- multiple sclerosis 7. Diseases due to immune cross reactivity- Rh incompatibility, transfusion, transplantation 8. Inherited immune diseases 9. Cancer immunology **References** 1. Immunobiology, 5th edition, 2. The Immune System in Health and Disease, by Charles A. Janeway, Jr, Paul Travers, Mark Walport, and Mark J Shlomchik 3. Immunology by Janice Kuby

B-703	**Developmental Biology** 1. Basic concepts of molecular regulation of development: Transcription factors in differential gene expression; morphogens and axis formation; autocrine and paracrine regulation. How cell proliferation, apoptosis, and fate specification determine developmental processes. 2. Fertilization: Structure of oocytes and spermatocytes. The process of fertilization. 3. Comparative study of early embryonic development: (Caenorhabditis elegans, amphibians, birds, and mammals) a) Cleavage formation b) Gastrulation c) Axis formation: Signalling cascades and molecular understanding of anteroposterior, mediolateral, and dorsoventral axes development. 4. Organogenesis in vertebrates: Germ layer formation. Regulation of formation of the somite's, heart, kidney, blood vessels, and limb. Changes in circulation pattern between fetus and newborn. 5. Metamorphosis and regeneration process: Hormonal control of metamorphosis in amphibians and insects; wing imaginal disc formation in drosophila. Regeneration in planaria and that of vertebrate limb. 6. Stem cells: Concepts of totipotent, pluripotent, and multipotent cells. Factors regulating "stemness" of a cell. Embryonic vs. adult stem cells. Sources of stem cells in vertebrates and their applications. 7. Developmental disorders and aging: Regulatory role of genetic and environmental factors. Role of carcinogens and teratogens. 8. Development processes in plants: How are the mechanisms different from that of animal development? Gametogenesis, pollination, and fertilization processes in angiosperms. Hormonal regulation of seed dormancy and the process of germination. Root and shoot development mechanisms. Reproductive phase: photoperiod sensitivity and molecular regulation of flowering process. 9. Epigenetic and environmental control of development: Sexual dimorphism, sex determination, X inactivation. Environ-elicited phenotypic changes. Defense mechanism-related changes.
B-704	**Imaging Technology in Biological Research** 1. Basic properties of light: a) dual nature – principle with equation, photoelectric effect and simple problems associated with it b) Wave nature: properties, numericals associated with it c) EM waves six properties: definitions, examples, phenomenon, relevance to microscopy d) Absorption of light e) Diffraction: mechanism, single slit, double slit f) Interference: principle, mechanism, significance to the current topic g) Airy disc: concept, factors determining h) Interaction of light with matter: scattering, dispersion, absorption, chromatic spectrum 2. Lens: basic lenses, image formation, object placement, focal length 3. Light sources 4. Basic concepts/features of microscope: a) Parts, units of measurement, how to control light intensity, aperture, objective lens measurements, diaphragm roles etc. b) field of view: definition, problem c) magnification: definition, problem 5. Light microscopy: adv, disadv

	6. Bright field: principle, adv, disadv, sample prep, data interpretation 7. Dark field: principle, significance, adv, diasdv, sample prep 8. Phase contrast: how to establish contrast, what is contrast, phase rings, ray diagrams associated with phase contrast microscope, adv, disadv, sample prep, Optical path distance etc. 9. DIC microscopy: principle, ray diagrams, adv, diasdv, significance 10. Fluorescence microscopy: a) Phenomenon, fluorophore compounds – structure, modes of action; GFP, EGFP, mcherry, engineering of proteins to yield fluorophore proteins: YFPs, etc. b) phosphorescence, autofluorescence, photobleaching, phototoxicity (mechanisms of all) c) Fluorescence microscope: epi-fluorescence working principle, Immunocytochemistry: principle, methods, choices of fixatives and their modes of action, how to use immune-stained slides for image acquisition, data analyses etc. d) Confocal microscope: principle, ray diagrams, spinning disc, light sources, uses of lasers, how to set up a confocal microscope?, rastor scanning, pinhole, z-sections, 3D image, advantages and disadvantages e) Total internal fluorescence microscope: principle, use f) SRFM, nanoscopy, Fluorescence speckle microscope 11. Atomic force microscope: principle, use 12. Electron microscope: principle, types, tour to TIFR 13. Laser dissection microscopy, Optical tweezers, Traction force microscope: principle, use 14. Numericals/Data analysis using ImageJ on: Images are provided and students are taught how to process the images using ImageJ. a) counting particles b) measuring intensity of signals/vesicle trafficking, etc c) co-localisation index using Pearson's coefficient d) migration assay: wound healing assay 15. Experiment designs: learning how to design experiments using microscopy as a tool, followed by data acquisition, conditions, image analysis etc. a) New techniques/topics/pathways are always updated in both the courses as and when required. b) Resources are mostly slides, handouts of books, papers, research articles and class notes that are provided to students from time to time. **References** 1. Light microscopy: Keller, Goldman (handout) 2. Light microscopy: Murphy (this book I had requested earlier to have in the library) --> I give the pdf to students of this book 3. Fluorescence microscopy: Goldman Spector (Live cell imaging, this book I had requested earlier to have in the library) 4. Cold spring harbour: physics of light, microscopy basics 5. Recent Research Papers
B-801	**Virology** 1. Principles of Universal Biosafety Occupational health and safety, Biological risk groups, Levels of biosafety, Biosafety cabinets—types and classes, Personal Protective Equipment, Sterilization, disinfection, sanitization and cleaning 2. History of Virology 3. Taxonomy of Viruses, Binomial classification, LHT classification, ICTV/Baltimore classification 4. Cultivation of Viruses, Animal viruses (in vitro, in vivo, in ovo), Plant viruses, Bacteriophages

	5. Diagnosis of Viruses, Collection of appropriate samples, Platforms of detection (Microscopic, Serological/immunological, molecular) 6. Viral Architecture, Organization of virus structure, Helical symmetry, Icosahedral symmetry, Binary symmetry, Viral envelope 7. Transmission of Viruses, Horizontal transmission (Air, Food and water, body fluids, sexual and mechanical), Vertical transmission, Zoonoses 8. Viral Epidemiology, Concept of sporadic, endemic, epidemic and pandemic, Evolution and adaptation (Change of virulence & transmission dynamics, Crossing inter-specific barrier) 9. Viral Pathogenesis, Sub-clinical and acute infections, Persistent and latent infections, Transforming infections, Abortive infections and null infections, Cytopathology 10. Viral Immunology, Intrinsic mechanisms (RNAi, CRISPER, APOBEC3, IFITM, tetherin, cGAS), Innate mechanisms (IFN, Complements, RLR, TLR), Adaptive mechanisms (CMI, Humoral immunity) 11. Viral Vaccines, History and important milestones in vaccine development, Types (Live, Killed/ inactivated, VLPs, peptide vaccines, DNA vaccines, genetically engineered using other viral vectors), Immunization Programme, India 12. Antiviral Agents, Targets of antiviral agents, Current strategies (Antivirals against HSV, HIV, HBV, HCV), Experimental strategies 13. Viral Hepatitis (HBV, HCV), Genome, Entry and Replication, Pathophysiology, Natural immunity, Diagnosis, Therapy & Management 14. Viral Encephalitis Concept of AES, myelitis, encephalomyelitis, encephalopathy, meningoencephalitis, ADEM, Encephalitic viruses, Pathogenesis, Diagnosis and differential diagnosis 15. Viral Infections of Respiratory Systems, Viruses affecting respiratory systems, Special Emphasis on Influenza (Genome, Entry and Replication, Pathophysiology, Natural immunity, Diagnosis), Therapy and Management 16. Retroviral Infections—HIV/AIDS Genome, Entry and Replication, Pathophysiology, Natural immunity, Diagnosis, Therapy and Management 17. Emerging and Re-Emerging, Viral Infections Concept of emerging diseases, re-emerging diseases, Factors contributing to emergence, Recent emerging and re-emerging infections, India, Strategic goals for combating EIDs **References** 1. Introduction to Modern Virology - N. J. Dimmock. A. J. Easton. K. N. Leppard, Seventh Edition Publisher Wiley- Blackwell 2. Principles of Molecular Virology A. Cann, Sixth Edition Publisher: Academic Press 3. Principles of Virology S. Jane Flint. Lynn W. Enquist. Vincent R. Racaniello. Glenn F. Rall. Anna Marie Skalka, Fourth Edition (2 Vol Set) Publisher: American Society for Microbiology 4. Fields Virology D. Knipe, P. Howley, Sixth Edition (2 Vol Set) Publisher: Lippincott Williams & Wilkins
B-802	**Neurobiology** 1. The glial system Generation of Astrocytes, Oligodendrocytes, and Schwan cells. Function of glia in normal brain and in neuroprotection. 2. Chemical composition of the brain Metabolism (utilization and uptake of glucose and amino acids). Blood-Brain barrier. 3. Neurotransmitters Synthesis, storage, release, uptake, degradation and action of neurotransmitters, Acetyl choline, GABA, Serotonin, Dopamine, Glutamate, Nitrous oxide, etc. Receptors: different subtypes (cholinergic, dopaminergic, adrenergic, and glutamatergic), mechanism of action, Agonists and Antagonists – their mode of

	action and effects. Exocytosis of neurotransmitter – Role of synapsis, synaptogamins, SNAP, SNARE and other proteins in docking, exocytosis and recycling of vesicles. 4. Sleep and Learning and memory Mechanism of short-term memory and Long-term memory (long-term potentiation). Role of sleep in memory consolidation. Electroencephalogram. Role of second messenger pathways in learning and memory process. Role of synaptic plasticity. 5. Sensory organs: a) Vision: Biochemistry of vision: Rod and cone cells, mechanism and regulation of vision, colour vision, visual field, visual acuity. Visual pathway and topographic mapping. b) Audition: functional anatomy of the middle and inner ear. Amplification of sound. Functional anatomy and mechanism of detection of specific sound frequency in the inner ear. Mechanism of action of the mechanosensory receptors in the inner ear. c) Chemical senses d) Olfaction: The olfactory pathway, mechanism and the combinatorial code of detecting a smell. e) Taste: Mechanism of taste perception. f) Touch/pain: The touch/pain/temperature pathway (ascending and descending). Higher order integration in the brain. 6. Pathologies of the nervous system: Molecular basis of Parkinson's disease, Alzheimer's disease, Schizophrenia, Myasthenia gravis and Multiple sclerosis, stress and antidepressants. **References** 1. Neurochemistry by Ferdinand Hucho, VCH Publication, 1986. 2. Basic Neurochemistry by M. P. Spiegel. 3. Cell Biology of the Axon, Series: Results and Problems in Cell Differentiation, Vol. 48. Koenig, Edward (Ed.) 2009, 350 p. 4. Principles of neural Sciences. Eric Kendel, J. H. Schwartz, T. Jessel. 5th 5. Textbook of medical physiology. A Guyton and J Hall
B-803	**Bioinformatics** 1. Overview of Bioinformatics General overview of Bioinformatics 2. Bioinformatics resources Nature of biological data, Major Bioinformatics resources, Biological databases: Nucleic acid databases (Genbank, EMBL, DDBJ), protein sequence (PIR-PSD, Swiss Prot TrEMBL/GenPept). Primary and derived databases. Querying in the databases. Entrez/SRS query engines. 3. Sequence Analysis/Alignment techniques Sequence comparison and alignment concepts. Pair wise sequence alignment: local and global alignment, consensus sequence (sequence logo), frequency matrices (PAM, BLOSUM), log odds score, penalty, introduction to graphical, dynamic programming and heuristic methods, database similarity searches-BLAST/FASTA algorithms, Multiple sequence alignment: clustering, dendogram/tree construction, molecular phylogeny. Consensus, patterns, motifs, blocks. 4. Genomics and Functional Analysis Methodologies for high throughput analysis including NGS, application of bioinformatics in genomics. Comparative genomics. 5. Structural Bioinformatics Introduction to the protein structural databases (PDB, CATH, SCOP etc.), Instrumentation: structural/functional genomics initiatives, evolution of structural

	motifs and molecular evolution (convergent/divergent evolution), structure prediction methods with particular focus on homology/comparative modelling, structural validation approaches, protein structures in biotechnology (drug design/Docking). **References** 1. Biostatistics: A foundation for Analysis in the Health Sciences 7/E Wayne W. Daniel, Wiley Series in Probability and Statistics. 2. Introductory Statistics. Fifth Edition (2004) Prem S. Mann. John Wiley and Sons (ASIA) Pvt. Ltd. 3. Basic Statistics-A primer for Biomedical Sciences- (Olive Jean Dunn). 4. Biostatistics-An introductory text - (Auram Gold Stein). 5. Statistics: An Introductory Analysis (Taro Yamane) Harper and Row Publisher 1964,67,73 6. Computational Biochemistry, By: C. Stan Tsai, A John Wiley & Sons, Inc., publication.
B-804	**Biotechnology-II** **1. Industrial Biotechnology** a) Bioprocess Technology [basics of bioreactor kinetics and mathematical equations regarding bioreactors, scale-up and aeration of bioreactors in detail, Kinetics of microbial growth, substrate utilization and product formation: Batch, Fed- Batch and continuous processes, scale up concepts with respect to fermenter design and product formation, Gas exchange and mass transfer: O2 transfer, critical oxygen concentration, determining the oxygen uptake rate, Solid state fermentation. Common examples: Biopolymers: Xanthan, melanin, adhesive proteins, rubber, poly hydroxyl alkaloids b) Downstream Processing - Flocculation and floatation, Filtration, Centrifugation, Cell disruption, Liquid extraction, Precipitation, Adsorption, Dialysis, Reverse osmosis, Chromatography, Crystallization and drying, Biodegradation of xenobiotic compounds c) Remediation and Biotechnology - Priority pollutants and their health effects, Microbial basis of biodegradation, Bioremediation (phyto and metal), Environmental and industrial pollution control, Biopesticides, Microbial plastics, Solid waste management **2. Medical Biotechnology** a) Small Biological Molecules: - ascorbic acid, indigo, amino acids, lycopene, succinic acid production, Antibiotics, Tissue Engineering - Growth Factors and morphogens: signals for tissue engineering and whole organ development, extracellular Matrix: structure, function and applications to tissue engineering, Cell adhesion and migration, Inflammatory and Immune responses to tissue engineered devices b) Biomaterials - Polymeric scaffolds, Calcium Phosphate Ceramics for bone tissue engineering, Bio mimetic materials, Nanocomposite scaffolds **3. Nanotechnology (Norine)** a) Introduction to nanotechnology and nano-biotechnology, Nanomaterials and their uses. b) Nanoparticles derived from biological molecules, Synthesis of nanoparticles: strategies, biological methods, general properties and characterization methods c) Applications of nanotechnology: Nano-sensors, Carbon nanotubes and their applications in biology d) Environmental and safety issues with nanoparticles. 4. Principles of plant breeding: Important conventional methods of breeding self and cross pollinated and vegetatively propagated crops; Non-conventional methods; Polyploidy: Genetic variability; Plant diseases and defensive mechanisms. 5. Ethics of GM crops and animal cloning 6. Model organisms - S. cerevisiae, Dictyostelium, Caenorhabditis elegans, Arabidopsis, Zebra Fish, Mouse and Drosophila.

	References 1. Principles of Gene Manipulation and Genomics, 7th Edition, Sandy B. Primrose and Richard Twyman Blackwell Publishing, 2006 2. Gene Cloning and DNA Analysis: An Introduction, Brown T. A, Wiley-Blackwell, 2010 3. Genes IX Benjamin Lewin Oxford Publishers 4. Bernard Glick, Jack Pasternak and Cheryl Patten, Molecular Biotechnology- principles and applications of Recombinant DNA, 4th 5. Principles of gene manipulation by S.B. Primrose and Twyman, 7 6. Molecular Biology of the Gene by Watson fifth edition Pearson Education India, 2004
BL-101	**Biology Laboratory-I** 1. Introduction to Biology laboratory 2. Introduction to Research Laboratory: Different kinds of microbial plates, liquid growth media for microbes, Laminar air flow system, stem cells laboratory, Centrifuges, Spectrophotometer, Sonicator, PCR and Real-time PCR, Gel Documentation system, *Chlamydomonas* and *Drosophila* incubation systems, Stereo-microscope and various Incubators 3. Introduction to Light Microscopy 4. Gram Staining: To differentiate bacteria cells by Gram staining. 5. Micrometry: Measuring size of a microscopic specimen. 6. Staining and Observing human cheek cells: To carry out staining of epithelial cells from the mouth using methylene blue stains. 7. Staining human blood cells: To observe human blood cell types by differential staining. 8. Haemocytometer 9. Dye exclusion method of differentiating dead v/s live cells: To use a vital stain to distinguish dead and live yeast cells. 10. Concept of pH & Buffers: Hydrogen ion concentration in solutions, Inorganic ion concentration in solutions, Inorganic Buffers and Biological fluids, Henderson-Hesselbach equation 11. Media Preparation: Preparing and inoculating solid and liquid nutrient media for culturing microorganisms, pouring nutrient agar plates and streaking bacterial culture on solid media, inoculating nutrient broth with bacterial culture, Preparing nutrient media 12. Taxonomy 13. Methods of Classification: Dichotomous key, Hierarchical Classification, Phylogenetic Classification 14. Phototaxis 15. Growth Curve: Generating a bacterial growth curve under various pH and environmental conditions (steady and shaking), Calculations of Growth rate constant (μ), Calculation of generation time 16. Plant anatomy: Relationship between plant anatomy and habita **Biology Remedial course (Saturdays, 4:30 pm, PF AG 14)** 1. Cell-Unit of life: Animal and Plant cell structures, Differences between Animal and Plant cell, Biomolecules [1st unit chapter 3, 4 and 3rd unit chapter 8 of NCERT book Class-XI] 2. Cell: Structure and function: Cell cycle and Cell division. [3rd unit chapter 9, 10 of NCERT book Class-XI] 3. Human anatomy and physiology Class 1- 1) Breathing and exchange of gases 3) Body fluids and Circulation. [5th unit chapter 17, 18 of NCERT Book Class-XI] Class 2- 1) Digestion and Absorption 2) Excretory products and their elimination 2) Muscular system. [5th unit chapter 16, 19, 20 of NCERT Book Class-XI]

	Class 3- 1) Neural control and Coordination 2) Chemical coordination and Integration 3) Reproduction [5th unit chapter 21, 22 of NCERT Book Class-XI] 4. Plant anatomy: Morphology of Flowering plant, Anatomy of Flowering plant, Structural organization in animals. [2nd unit chapter 5, 6, 7 of NCERT Book Class-XI] 5. Physiology of Plants: Transport in Plant, Photosynthesis in Higher Plants, Respiration in Plants, Sexual Reproduction in Flowering plants. [4t^h unit chapter 11, 13, 14 of NCERT book Class-XI and 6th unit chapter- 2 of NCERT book Class-XII] 6. Genetics and Evolution: Principles of Inheritance and Variation, Molecular basis of Inheritance, Evolution. Plant, Animal and Microorganism- classification. [7th unit chapter 5, 6, 7 of NCERT book Class-XII] 7. Ecology: Organisms and Populations, Ecosystem, Biodiversity and Conservation. [10th unit chapter 13, 14, 15 of NCERT book Class-XII]
BL-201	**Biology Laboratory-II** 1. Observing instruments to be used in Semester-II, their use and maintenance: (a) micro-pipettes, (b) tissue homogenizer, (c) electrophoresis apparatus, (d) centrifuges, (e) ultraviolet and visible (UV-Vis) absorption spectrophotometer 2. Centrifugation of the cell contents at varying speeds such that the subcellular fractions separate out based on their density differences 3. Nucleic acid extraction - from plant & animal tissue using ethanol precipitation 4. Agarose gel electrophoresis 5. Analysis of DNA under various conditions – pH and Temperature 6. Carbohydrate extraction & estimation - extraction of sugars from grapes & estimation of the same by DNSA method 7. Protein extraction & estimation determination of total protein content in microorganisms by Folin-Ciocalteu method 8. Protein extraction & separation using polyacrylamide gel electrophoresis (PAGE) 9. Photosynthesis - floating leaf disc experiment under various conditions (light, dark & light - dark) 10. Separation of biomolecules using: a) Adsorption chromatography b) Partitioning of indicators in various solvent systems. c) Separation of a mixture of solutes by partitioning d) Separation of leaf pigments by paper chromatography e) Separation of flower pigments by paper chromatography 11. Reverse phase thin layer chromatography (RPTLC) - Separation of photosynthetic pigments
BL-301	**Biology Laboratory** **1. Cell Structure** a) Capsule Staining b) Cell wall staining c) Lipid Granule staining d) Endospore Staining e) Metachromatic Granule staining 2. ABO Blood Grouping and Barr Body Identification 3. Meiosis 4. Effect of Colchicine on Mitosis in Onion Root Tips 5. MTT Assay 6. Deflagellation and Regeneration 7. Polytene Chromosome Staining (Drosophila and Blood Worms) 8. Isolation of Mitochondria 9. Isolation of lysosome

	10. Membranes: Osmosis-Osmotic fragility test & Osmosis in leaves 11. Lipid Solubility of Membrane 12. Cell Motility 13. Paramoecium Morphology 14. Biochemical Calculations 15. Carbohydrate Identification using Dichotomous Key 16. Carbohydrate Estimation using Anthrone Method 17. Amino Acid Titration 18. Isolation of Starch from Potato 19. Enzyme Kinetics a) Km and Vmax b) Optimum pH and Temperature c) Inhibitor Profile 20. Testing the α-Amylase Inhibitor of the Common Bean 21. Photosynthesis: Isolation of chloroplast and Hill Reaction 22. Identification of unknown protein solution and Sugar Crystal Formation 23. Urine Analysis: Normal and Abnormal Constituents of Urine
BL-401	**Biology Laboratory** 1. General Laboratory procedures 2. Pouring plates and streaking techniques 3. Introduction to Bioinformatics 4. Primer Designing 5. Extraction and isolation of Genomic DNA using Kit and Ethanol precipitation 6. Detection of the Nucleic acids using Agarose gel electrophoresis 7. Polymerase Chain Reaction (PCR) and Detection of PCR product 8. PCR product purification 9. Blunting and Ligation 10. Preparation of Competent cells and Transformation 11. Plasmid isolation and re-digestion 12. Detection of the RE digested product 13. Overexpression and detection by PAGE 14. Biochemistry of Saliva 15. Acid and Gas formation (Fermentation) 16. Diauxic Growth Curve 17. Glycogen: Isolation of glycogen, Preparation of calibration curve for glucose determination, Acid hydrolysis of glycogen, Acid hydrolysis of glycogen, Enzymic hydrolysis of glycogen and paper chromatography. 18. Lipid Peroxidation: Quantitative determination of malonic dialdehyde in liver tissue and Catalase activity in the blood 19. Metabolism of amino acid transferases: SGOT and SGPT 20. Estimation Part I: a) Glucose by GOD/POD b) Triglycerides c) Cholesterol by Zak and Zaltsky method d) Calcium by Clark and Collip method/Trinder method e) Iron by Dipyridyl method f) Copper by Dithiocarbamate method. g) Phosphorous by Fiske-Subbaraow method. 21. Estimation II: a) Creatinine by Jaffe's method b) Blood Urea Nitrogen (BUN) by Diacetyl monoxime method c) Uric acid by Caraway method d) Haemoglobin by Drabkin method e) Differential proteins (A/G ratio) by Reinhgart Biuret method.

	22. Estimation III: a) Total Alkalinity of Water Effluent b) COD of Wastewater c) Total Hardness of Well Water 23. Enzymes: Extraction, Partial Purification of the following enzymes and determination of their Km values a) GPT from Germinating Moong Seeds b) Alkaline Phosphatase from Germinating Moong Seeds
BL-501	**Biology Laboratory** 1. *Drosophila* Genetics a) Introduction to Drosophila melanogaster b) Identification of mutants c) Set up of Monohybrid Cross d) Set up of Dihybrid Cross e) Lethal Mutation f) Dissection of Drosophila ovaries and immunostaining g) Check lethality stage 2. Bacterial Genetics a) Transformation b) Conjugation c) Transduction - Phage Titration d) Alpha Complementation 3. Animal Tissue Culture a) Passaging of HeLa Cells b) Wound healing 4. Cell Biology a) DNA Laddering & Cell Death Assay b) Subcellular Fractionation c) Karyotyping 5. Field Trips
BL-601	**Biology Laboratory** **1. Microbiology** a) Antibiotic Sensitivity by Ditch plate technique b) Antibacterial activity of dyes (Gradient Plate techniques) c) Effect of UV-B radiations on growth of microorganisms d) Milk quality analysis by MBRT & RRT and Phosphatase test for milk e) Study of Fungal morphology (Bright field microscopy) f) Study of Actinomycetes (Slide culture techniques) g) Winograd sky column set up & Colony Characterisation **2. Immunology** a) Antibody detection - Indirect Elisa Method b) Antigen detection - Direct Elisa Method c) Ouchterlony- Double diffusion (Antibody Titration) d) Ouchterlony Double Diffusion (Antigen-Antibody Pattern) e) Single Radial Immunodiffusion - Mancini technique f) Immunoelectrophoresis g) Rocket Electrophoresis h) WBC & RBC count i) Serum Protein Electrophoresis

	3. Plant Physiology a) M.S. Media Preparation, Callus formation and sub culturing b) Leaf Pigment Extraction & separation using column chromatography & Analysis by spectrophotometry c) Antagonistic action of Gibberellic acid and abscisic acid on germination using Zea mays seeds
BL-701	**Biology Laboratory** 1. Developmental Biology a) Collection, handling and staging of Zebra fish Embryos b) Effect of temperature & pH on Zebra fish embryonic development c) Effect of Lithium chloride, ethanol and nicotine on Zebra fish embryonic development d) Fin amputation to study regeneration. e) Stain connective tissues (bone & cartilage) of Zebrafish larvae f) Preparation of growth media - Nematode Growth Medium (NGM) agar, S Liquid medium & bacterial food source g) Culturing Caenorhabditis elegans (C. elegans) & Staging h) Effect of Lithium chloride, ethanol and nicotine on C. elegans development i) Study of chick embryo development j) Study of Hydra development 2. Immunology a) Venereal Disease Research Laboratory (VDRL) test b) Widal Test 3. Biotechnology a) Restriction fragment length polymorphism (RFLP) b) Random Amplification of Polymorphic DNA (RAPD) c) Colony PCR d) Southern Blotting e) RNA extraction, cDNA preparation, qPCR f) Protein Purification 4. Electron Microscopy
BL-801	**Biology Laboratory** **1. Neurobiology** a) Anatomy using Virtual Anatomy Software b) Chicken Brain Anatomy c) Goat Brain – Mulligan Staining d) Protein Content & Estimation of Acetylcholinesterase Activity e) Biochemical Estimation of Na+ / K+ - ATPase from brain f) Estimation of Nitric Oxide g) Display of Invertebrate Nervous System – Cockroach h) Display of Invertebrate Nervous System – Earthworm i) Strops Test j) C. elegans behavioural assay – Chemotaxis k) Biopic: EEG, ECG, EOG, EMG l) Olfactory behaviour of Drosophila larvae m) Drosophila - Brain Dissection and mounting of Imaginal Discs

	n) Silver Staining of Neuronal Cells o) Cog lab: Memory Span & Attention Blink **2. Plant & Industrial Biotechnology** a) Agrobacterium-mediated genetic transformation of tobacco leaf discs b) Evaluation of Soil Fertility Parameters c) Protoplast Isolation d) Isolation of Cellulose Degrading Bacteria from Soil Sample e) Isolation and characterization of Azotobacter from rhizosphere f) Isolation and Characterization of Rhizobium strain from the roots of Trigonellafoenumgraecum g) In vitro evaluation of antifungal activity of plant extracts h) Qualitative Test for Plant Metabolites i) Lipid Accumulation j) Lactic Acid Fermenter k) Penicillin Production l) Glutamic Acid Production
BPr-701	To be assigned by the Supervisor
BPr-901	To be assigned by the Supervisor
C-101	**Chemistry-I (Structure & Bonding)** **Part-1: Building Blocks: Atoms & Molecules (20 + 10 = 30 Hrs)** **Atoms:** *Hydrogen atom:* Line spectra, Old quantum theory: Bohr's theory and beyond. *Many-electron atoms:* Electronic configuration, energy level sequence, Pauli exclusion principle, Hund's rule, concept of screening of charge. *Properties of atoms:* Size of atoms and ions, ionization energy, electron affinity, concept of electronegativity, its scales and applications, variable valency, oxidation states, position in the periodic table and periodic variation of properties. **Molecules:** Concept of chemical bond between atoms: Types of bonds: Ionic, covalent, and coordinate bond. *The quantum chemical picture:* Concept of atomic orbitals, Concept of hybridization. *Molecular geometry:* Bond length, bond angle & dihedral angle, d-orbital participation in molecular bonding, sigma and pi bonding. Shapes of the molecules: Valence shell electron pair repulsion (VSEPR) theory, effect of lone pair and electronegativity, isoelectronic principle, examples. *Theory of bonding:* Valence bond theory and molecular orbital theory. Molecular orbitals (MO) as linear combination of atomic orbitals (LCAO), MO treatment for di- and tri-atomic molecules and molecules involving delocalized pi-electron bonding. Basic concepts of resonance, conjugation, aromaticity, and hyperconjugation. **Bulk phase**: *Physical properties and molecular structures:* Polarizability and dipole moment, melting and boiling points, solubility and acid-base properties, Intermolecular forces (dipole-dipole interaction), Hydrogen bonding and van der Waals forces. **Spectroscopy:** *Interaction of molecular systems with light*: Introduction to spectroscopy of different types. **Part-2: Chemical Reactivity and Mechanism (10 + 5 = 15 h)** **Stability and Reactivity:** Polarization and polarizability effects, delocalization of electrons, resonance, hyperconjugation. Aromaticity: Criteria for aromaticity, Hückel

	theory, Benzenoid and non-benzenoid compounds, anti-aromaticity, homo-aromaticity. Acidity and basicity: Different concepts, hard and soft acid base. Hydrogen bonding and its effect on properties of molecular systems and chemical reactions. **Reactive intermediates**: Structure, generation, stability, and general reactions of carbocation, cation radicals, carbene, electrophile and nucleophile, ambident electrophile and nucleophile, Solvents and solvent effect. **Mechanism:** Guidelines for depicting mechanism. Thermodynamics and kinetic control of chemical reactions. **References** 1. J.D. Lee, Concise Inorganic Chemistry, 4th Edition, ELBS, 1991. 2. P.W. Atkins, Physical Chemistry, 7th Edition, Oxford University Press, 2006. 3. G.M. Barrow, Physical Chemistry, 5th Edition, Tata McGraw-Hill, New Delhi, 1992. 4. R.T. Morrison and R.N. Boyd, Organic Chemistry, 7th Ed, Prentice Hall of India, 2010 5. G.W. Castellan, Physical Chemistry, 3rd Ed. Addison-Wesley / Narosa Pub. House, 1993.
C-201	**CHEMISTRY- II (Chemical Thermodynamics)** **Revisit to Thermodynamics & Kinetic theory:** Basic concepts, laws of thermodynamics, concepts of heat & energy, temperature, internal energy, work, state function, reversible & irreversible processes, isothermal & adiabatic processes, Carnot cycle, gas laws, van der Waals equation, Kinetic theory of gases, Maxwell Boltzmann velocity distribution. **Thermochemistry:** Enthalpy, heat of fusion & vaporisation, enthalpy of a chemical reaction (heat of combustion, solution, & neutralization), enthalpy of formation, standard reaction enthalpy, Hess's law, Kirchhoff's law, bond energy, dissociation energy. **Entropy:** Formulation of Second law (different statements), entropy change in a phase transition & other process, entropy and Gibbs energy of mixing, Trouton's Rule, calculation of absolute (Third law) entropy, entropy change in a chemical reaction. **Free energy functions:** Criteria for spontaneity and equilibrium of closed systems, variation of Gibbs free energy with pressure and temperature, Gibbs Helmholtz equation, the concept of chemical potential, partial molar quantity, Gibbs Duhem equation. **Phase equilibrium:** Simple systems: Solid – liquid, liquid – vapour, vapour – solid transitions, phase diagrams: water, carbon dioxide, sulphur, phase equilibrium condition, Gibbs phase rule, Clapeyron & Clausius – Clapeyron equation. **Ideal Solutions:** Chemical potential of a solute in a binary ideal solution, Raoult's Law, colligative properties: vapour pressure lowering, freezing point depression, boiling point elevation, osmotic pressure, van't Hoff equation. **Chemical equilibrium:** Gibbs free energy change of a reaction, standard reaction Gibbs free energy, condition for chemical equilibrium, equilibrium constant, reactions involving gases and pure substances, effect of temperature, pressure on the equilibrium, Le Chatelier principle and applications. **Electrochemical systems:** Chemical potential of a charged species, electrochemical cell (galvanic and electrolytic). half-cell potential (electrode potential), relation with free energy, Nernst equation. **Molecular thermodynamics**: Concept of ensembles, partition function, evaluation of partition function for vibrational, rotational, electronic energies, evaluation of free energy, entropy and equilibrium constants from partition functions. **References** 1. P.W. Atkins, Physical Chemistry, 7th Ed, Oxford University Press, 2006. 2. G.W. Castellan, Physical Chemistry, 3rd Ed. Wesley/Narosa Publishing House, 1993.

	3. G.N. Lewis and M. Randall, Thermodynamics, (Revised by K.S. Pitzer and L. Brewer), International Students Edition, McGraw Hill, 1961. 4. K.G. Denbigh, The principles of Chemical Equilibrium: With Applications in Chemistry and Chemical Engineering, 4th Ed., Cambridge University Press, 1981
C-301	**Mathematics for Chemists and Biologists** **Series:** Taylor series and its applications **Differential equations:** Review of first order ordinary differential equations (ODE), Linear ODEs with constant coefficients, Linear ODEs with variable coefficients: solutions by series expansion methods, introduction to partial differential equations, Laplace's equation, separation of variables. **Special functions/orthogonal polynomials:** Legendre differential equation and Legendre polynomials, important properties of Legendre polynomials, Hermite polynomials, Laguerre polynomials, and applications. **Integral Transforms:** Fourier series and Fourier transform, Laplace transform and applications, convolution and applications. **Vectors and Matrices: Vector calculus:** Concept of gradient, divergence and curl, determinant and inversion of a matrix, Eigen value problems, Secular determinants, Characteristics polynomials, Eigen values of real symmetric matrices; Eigen values and Eigen functions, important properties and examples. **Basics of complex variables:** Complex numbers, Analytic functions, Cauchy Riemann equations, Cauchy's integral formula, Residue theorem and simple applications. Concept of contour integration and its application. **References** 1. M.R. Spiegel, Schaum's Outline of Advanced Mathematics for Engineers and Scientists, McGraw-Hill, 2009. 2. E. Kreyszig, Advanced Engineering Mathematics, 10th Ed., John Wiley & Sons, 2010.
C-302	**Organic Chemistry –I** **Part-1: Chemistry of Aliphatic compounds** **Systematic naming of organic compounds:** acyclic, alicyclic, polycyclic, aromatic, spiro compounds. **Sources of organic compounds:** Coal, natural gas, petroleum, C_1 compounds. **Alkanes as cycloalkanes:** As fuel (calorific value, isomerization of alkenes to better fuel, octane number, improvements in hydrocarbon fuels, environmental effect) mechanism of halogenation of alkanes, strains in cycloalkane/cycloalkene **Alkenes and cycloalkenes:** Preparation: cracking of petroleum, Elimination reaction E1 and E2, Saytzeff and Hoffman elimination, Reactivity of C=C bond, electrophilic and radical reaction and selectivity therein, epoxidation and reactions of epoxides, hydroboration, oxidation; polymerization: Mechanism, important monomers, structures of poly-olefins and properties, conjugate addition: 1,2- and 1,4- addition, Diels Alder reaction Kinetic and thermodynamic control, Cumulene, catalytic hydrogenation of alkenes. **Alkynes:** Nature of C=bond, Methods of preparation, Electrophilic addition, acidity, metal acetylides and their reactions, reductions. **Alkyl halides:** Nucleophilic substitution reaction, SN1, SN2, SNcA, SN'reactions, metalation reaction and utility of organometallics.

	Alcohols and thiols: Acidity, H-Bonding, polyhydric alcohols, preparation and properties of thiols. **Ethers and thioethers:** Methods of preparation, reactions, applications. **Aliphatic and aromatic Aldehydes and ketones:** Methods of preparations, carbonylation, Tetrahedral mechanism of nucleophilic addition, aldol and related reactions; Cannizzaro's reaction, Reductions, Oximes and their reactions, Baeyer Villiger and Wittig reaction, conjugate addition, acetals and ketals, α-halogenation, reductive amination. **Aliphatic and aromatic carboxylic acids and their derivatives:** Mono- and poly-carboxylic acids, acidity, salt formation. Preparations and reactions of esters, amides, imides, anhydrides. Hoffmann rearrangement, oils, fats and waxes **Aliphatic and aromatic amines:** Nitroalkanes and nitroaromatics, Methods of preparation of ammines, Basicity, Alkylation, Reaction with aldehydes and ketones, Chemistry of aromatic diazonium salts. **Aliphatic and aromatic sulfonic acids:** Methods of preparation, acidity and applications. **Part-2: Aromatic electrophilic substitution reaction** **General mechanism:** Energy profile diagram, effect of substituents on the rate and orientations in substituted arenes-charge distribution method and stability of intermediate methods, Hammonds postulate. **Aromatic nucleophilic substitution reaction:** General addition-elimination reaction with energy profile diagram, benzyne mechanism. Hydrolysis and amination of haloarenes, metalation of haloarenes. **Friedel Crafts and related reactions:** Mechanism and synthetic applications of Friedel Craft alkylation and acylation, Formylation reaction. **References** 1. I. L. Finar, Organic Chemistry, Vol. 1 & 2, Pearson., 2012, 2. R.T. Morrison and R. N. Boyd, Organic Chemistry, Prentice Hall of India, 2010. 3. L.G. Wade, Organic Chemistry, Pearson Education, 2012. 4. G. Solomons and C. Fryhle, Organic Chemistry, 10th Ed., John Wiley & Sons (Asia) Pte Ltd., 2009. 5. P. Bruce. Organic chemistry; 8th Ed., Pearson, 2016.
C-303	**Inorganic Chemistry-I** **Hydrogen:** Preparation of hydrogen, Isotopes, ortho and para hydrogen, hydrides. *Rare gases:* Occurrence and recovery of the elements, physical and chemical properties, Clathrate compounds, chemistry of Xenon and xenon fluoride complexes. **Chemistry of s-block elements:** a) alkali and alkaline earth metals: Extraction, general physical properties, flame colours and spectra, Reaction with water, air and nitrogen, oxides, hydroxides, peroxides and superoxide, sulfides, oxy salts, halides and hydrides, organic and organometallic compounds. b) *Group IIB elements:* Zn, Cd, Hg **Chemistry of p-block elements:** i) Group IIIA elements: Boron, aluminium, gallium, indium and thallium ii) Group IVA elements: carbon, silicon, germanium, tin and lead – physical properties, allotropes of carbon, graphite compounds, carbides, carbonates, carbon cycle, silicates, organosilicons, hydrides, halides and cyanides, cluster compounds. iii) Group VA elements: Nitrogen, phosphorous, Arsenic, antimony and bismuth – general properties, hydrides, azides, oxides and oxy-acids, sulphides and organometallics, fertilizers.

	iv) Group VIA elements: oxygen, sulphur, selenium, tellurium and polonium – general properties, structure and allotropy of the elements, chemistry of ozone, oxides, oxy-acids, oxo-halides, hydrides and halides, organo- derivatives. e) Group VIIA elements: Fluorine, chlorine, bromine, iodine and Astatine- general properties, oxidizing power, hydrogen halides, ionic and molecular halides, bridging halides, halogen oxides, oxoacids, interhalogen compounds, poly-halides, pseudo-halogens and pseudo-halides. **References** 1. J.E. Huheey, 'Inorganic Chemistry - Principles of Structure and Reactivity', 4th Ed. Dorling Kindersley Pvt. Ltd., 2008. 2. D.F. Shriver, P.W. Atkins and C.H. Langford, 'Inorganic Chemistry', Oxford University Press, 1991. 3. F.A. Cotton and G. Wilkinson, 'Basic Inorganic Chemistry', Wiley Easter, 1978. 4. J.D. Lee, 'Concise Inorganic Chemistry', 5th Ed. Wiley-Blackwell, 1999.
C-401	**Spectroscopy-I** **Introduction:** Failures of Classical mechanics, wave-particle duality of matter and the de Broglie equation, quantization of energy levels, Heisenberg Uncertainty principle and natural broadening of energy levels, light absorption and electric dipole - dipole interaction, transition probability and the basis of selection rules for transition between energy levels, absorption coefficient and transition moment integral, Lambert – Beer's law, mechanism of broadening and the width of spectral lines. **Rotational or Microwave Spectroscopy:** Rotation of molecules and moment of inertia, classification of molecules, rotational spectra of diatomic molecules as rigid and non-rigid rotator, Effect of isotopic substitution and isotopic abundance, non-rigid rotator and rotational spectra. Rotational spectra of polyatomic molecules – linear, symmetric top (prolate and oblate) and asymmetric top. Techniques and instrumentation. **Infrared or vibrational spectroscopy:** One dimensional harmonic oscillator, shape of vibrational wave functions and energy levels. Anharmonic oscillator - Oscillation frequency and anhrmonicity constant, Fundamental, overtone and hot vibrational bands. Diatomic vibrating rotator, vibration-rotation spectra of CO and rotational constant from the maxima of P and R branch lines. Breakdown of B-O approximation – interaction of rotations and vibrations. Vibrations of polyatomic molecules – Fundamental vibrations and their symmetry, parallel and perpendicular vibrations. Identifying the organic molecules from IR spectra, Techniques and instrumentation, FTIR spectroscopy. **Raman Spectroscopy:** Classical and quantum theories of Raman effect, Raleigh scattering, Stokes and Antistokes Raman lines, molecular polarizability and polarizability ellipsoid. Pure rotational Raman spectra of linear, spherical top and asymmetric top molecules. Change of polarizability ellipsoid with vibration and Raman activity of vibrations, rotational fine structure. Polarized Raman spectrum. Influence of nuclear spin on the intensities of rotational lines. Structure determination from Raman and infrared spectroscopy as complementary techniques, Techniques and Instrumentation. **Electronic spectroscopy of atoms and molecules:** Electronic orbital (i) and spin (s) angular momenta, l-s coupling and total angular momenta (j). Fine structure of hydrogen atom spectrum, Spectrum of Li and other H-like atoms, Na-D lines. Spectrum of He and the alkaline earth atoms. Atomic energy levels of atoms in the ground and excited states with equivalent and non-equivalent electrons and term symbols. Zeeman effect and determination of L, S and J values. Vibrational coarse structure of electronic spectrum of diatomic molecules, Franck–Condon Principle and intensities of vibrionic lines. Dissociation of diatomic molecules, determination of dissociation energy,

	Berge-Sponer extrapolation method. Rotational fine structure of electronic and vibration transitions and pre-dissociation. MO diagram of hydrogen and other diatomic molecules and their electronic properties. MO diagram of formaldehyde molecule and n-π* and π - π* transitions. Techniques and instrumentation. Molecular photoelectron spectroscopy. **Nuclear Magnetic Resonance (NMR) Spectroscopy:** Introduction to Nuclear Magnetic Resonance (NMR) spectroscopy. 1H and 13C NMR, number of signals, integration, chemical shift, splitting of signals. Principles and instrumentation of NMR spectroscopy. Nuclear spin and nuclear magnetism. Energies of nuclear spin states in a magnetic field. Boltzmann population of nuclear spin states and the origin of NMR signals. Applications: Interpretation of simple 1H NMR spectra. Information from: chemical shifts and delta values, peak areas and integration, splitting patterns and spin-spin coupling constants. (n+1) rule and Pascal's triangle, Nuclear Overhauser enhancement, J values, T1 relaxation, sensitivity, analysis of NMR spectra. **References** 1. G.M. Barrow, Introduction to Molecular spectroscopy, McGraw-Hill, 1962 2. C. N. Banwell and E. M. McCash, Fundamentals of Molecular spectroscopy, Tata McGraw Hill Pub. Co., New Delhi, 2017. 3. J. D. Graybeal, Molecular Spectroscopy, McGraw Hill International Book Co. N.Y., 1988. 4. Peter F. Bernath, Spectra of atoms and molecules, 3rd Ed., Oxford University Press, 2016. 5. J. Michael Hollas, Modern Spectroscopy, 4th Ed. Wiley, 2004 6.. Andrew E. Derome, Editor, Modern NMR Techniques for Chemistry Research, Pergamon press, 1997.
C-402	**Physical Chemistry-I (Chemical Kinetics and States of Matter)** **Part 1: Chemical Kinetics** **Basic Concepts:** Review of order and molecularity of a reaction, first, second and third order reactions, pseudo-unimolecular and autocatalytic reactions, effect of temperature on reaction rate, Arrhenius equation and concept of activation energy and transition state. **Complex Reactions:** Parallel and consecutive first order reactions, competitive, consecutive second order reactions, reversible reactions, complex mechanisms involving equilibria. **Reactions in Solutions***:* Theory of reaction rates, diffusion limited reactions, effect of ionic strength on reactions between ions, linear free energy relationships, relaxation methods for fast reactions. **Catalysis:** Homogeneous catalysis, acid base catalysis, Bronsted catalysis law, general and specific catalysis, heterogeneous catalysis: adsorption on surfaces, different isotherms for gas adsorption, negative catalysis and inhibition, surface reactions, effect of temperature and nature of surface, industrial catalysis. Oscillating chemical reactions. **Transition state Theory**: Collision theory, transition state theory, derivation of expression of rate constant. **Part 2: States of matter** **Gaseous State:** Ideal gases and gas laws, kinetic theory of gases, Maxwell's law of distribution of molecular velocities, heat capacity of gases, equipartition of energy, collision frequency and mean free path. Transport properties: viscosity, thermal conductivity and diffusivity of gases. **Real gases*:*** Deviations of behaviour of real gases from ideal gas laws, collision diameter, equation of state, van der Waals equation, reduced equation of state, Dieterici

	equation, Berthelot's equation, equation of Kammerling-Onnes, Virial Theorem and equation of state, compressibility factors, continuity of state and critical phenomena, derivation of critical constants for van der Waals equation of state. **Liquid State:** Intermolecular forces – dipole-dipole London forces, hydrogen bonding. vapour pressure and its measurement, Clausius Clapeyron equation, boiling point. Surface tension: angle of contact, wetting phenomena, capillary rise, measurement, temperature dependence, parachor. Viscosity: definition, measurement, temperature dependence, molecular weight from viscosity. Refractive index: molar refraction and chemical constitution, optical activity and specific rotation. Ideal solutions and colligative properties. **Soft mater and colloids***:* Concept of soft matter, examples, colloidal system: preparation, classification, optical and electrical properties, effect of electrolytes, zeta potential, electrophoresis, electro-osmosis. Origin of charge and the mechanism of flocculation, stability and kinetic properties of sols. Brownian motion, Tyndall effect, determination of Avogadro's number. Macromolecules: viscosity and molecular weight of polymers, osmotic pressure. **Solid State**: Introduction to solids, crystalline and amorphous solids, glass transition **References** 1. P. L. Houston, Chemical Kinetics and reaction dynamics., Dover Publ., 2001. 2. K. J. Laidler, Chemical Kinetics, 3rd ed. Harper and Row, 1987. 3. P. W. Atkins, Physical Chemistry, 7th Ed., Oxford University Press, 2006. 4. G. M. Barrow, Physical Chemistry, 5th Edition, Tata McGraw-Hill, New Delhi, 1992.
C-403	**Quantum Chemistry-I** **Foundations of quantum mechanics:** Review of old quantum theory, wave particle duality, concept of matter wave, concept of wavefunction, Schrodinger equation for time-dependent and time-independent potentials, postulates of quantum mechanics, concept of operators, eigenfunctions and eigenvalues, wave function for a free particle, physical interpretation of the wave function, expectation value of a dynamical quantity, wave packets and the uncertainty principle, Ehrenfest theorem. **Solution of Schrodinger's equation for exactly solvable systems:** *One-dimensional problems:* Constant potential: particle in one-, two- and three-dimensional boxes, particle in a rectangular well, electron in a ring, rectangular potential barrier penetration, concept of tunnelling, WKB approximation, variable potential: one-dimensional harmonic oscillator. **Three-dimensional problems:** Angular momentum, rigid rotator, particle in a sphere, hydrogen-like atoms, atomic orbitals and their shapes. **Approximate methods in quantum chemistry:** Basics of variational principle and time-independent perturbation theory. **Many electron systems:** Orbital approximation, helium atom, variational and perturbation theory treatment of helium atom. Aufbau principle, Pauli exclusion principle, Slater determinant form of the wave function. **Atoms to molecules:** Hydrogen molecule ion and hydrogen molecule, basics of molecular orbital and valence bond methods. Simple diatomic molecules. **References** 1. I.N. Levine, Quantum Chemistry, 5th Ed., Prentice Hall, India, 2012.

	2. P.W. Atkins, R. Friedman, *Molecular Quantum Mechanics, 4th Ed., Oxford University Press, 2005.* 3. A.K. Chandra, Introductory Quantum Chemistry, 4th Ed., Tata McGraw-Hill Publishing, 2001.
C-404	**Organic Chemistry – II** **Part I: Stereochemistry** **Stereochemistry of Organic compounds:** Chirality, stereogenic elements, elements of symmetry, Stereochemistry of compounds with two or more chiral centres. Stereochemistry of 3,4,5, 6 membered ring compounds; mono and di substituted cyclohexanes; strains in cycloalkanes, fused ring compounds – decalins. Stereochemistry of N, S, Si, P, As compounds. Stereochemistry of allenes, spiranes, biphenyls, ansa compounds, paracyclophanes, alkylidene cycloalkanes Racemates: types, resolution of racemates. Conformations and conformational analysis, trans annular effects **Topocity and prostereoisomerism:** Homotopic ligands and faces, enantiotropic ligands and faces, diastereotopic ligands and faces. **Stereoselective synthesis:** Additions, elimination, dihydroxylation, addition to carbonyl group Felkin-Anh model. **Chiral synthesis:** Different approaches. Chiral reagents and Chiral auxiliaries. Diastereoselective synthesis of alkenes, stereoselective alkylation of enolates. Asymmetric reactions: aldol reaction, Michael reaction, Sharpless epoxidation, dihydroxylation, oxidations and reductions aminohydroxylation; Jakobson epoxidation, Hydrogenation, Diels-Alder reaction. Chiral borane reagents. Asymmetric catalysis-Grubb's catalyst, Wilkinson's catalyst. Cram and Felkin models **Part II: Organic Synthesis** **Functional groups:** Their reactivity profile, interconversions and protection. **Ylides and Enamines:** Ylides of P and S. Synthesis and reactivity, Wittig reaction and its modification. **Reduction***:* Catalytic hydrogenation. Dissolving metal reductions. Hydride transfer reagents. Complex hydrides including nucleophilic, electrophilic and radical reducing agents. Organo boranes. MVP reduction. **Oxidation:** Cr, Os, Ti, Fe and Mn reagents, per acids and peroxides, oxidation by ozone and oxygen, Swern oxidation. Bayer Viliger oxidation **Selected organic reagents:** TMSC/I, TBTH, DCC, DDQ, TCQ, CAN, NBS, DIBAL, PTC, Crown ethers, SmI_2, SeO_2 Corey- Chaykowsky reagent, DABCO, Gilman's reagent, Lawesson reagent, Simmon Smith reagent. **Selected name reactions:** Hoffmann-Loffler-Fritag reaction, Sharp reaction, Paterson reaction, Heck reaction, McMurry coupling reaction, Suzuki reaction, Birch reduction, Woodward-Prevost reaction, Mukaiyama esterification, Mitsunobu reaction. Finkelstein reaction, Buchwald-Hartwig amination, McMurry coupling, Baylis-Hilman reaction, Corey-Fuchs reaction, Ritter reaction, Tsuji-Trost allylic alkylation. **Rearrangements:** Favorskii reaction, Curtius Lossen, Benzil-Benzilic acid rearrangement, Steven, Shapiro, Tiffenev-Demyanov, Benzidine rearrangement, Baker-Venkatraman rearrangement, Ireland-Claisen rearrangement, Wittig rearrangements. **Disconnection approach and retrosynthetic analysis:** Planning of multistep synthesis. Concepts of synthons, retrones and synthetic equivalents. Generation of structural complexity using tandem and cascade processes. **References** 1. I. L. Finar, Organic Chemistry, Vol. 1 & 2, Pearson., 2012. 2. R. T. Morrison and R. N. Boyd, Organic Chemistry, 7th Ed, Prentice Hall of India, 2010 3. Emest Eliel, Stereochemistry of Carbon Compounds, Tata-McGraw Hill Edition, 2001. 4. P.S. Kalsi, Stereochemistry Conformation and Mechanism, New Age International, 2005.

5. F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part A and B, Springer International Edition, 2007.
6. J. Clayden, N. Greeves, S. Warren, Organic Chemistry, Oxford Edition, 2014.
7. V. K. Ahluwalia, R.K. Parasher, Organic Reaction Mechanisms, Narosa Publishing House, 2011.

C-501 Analytical Chemistry

Error analysis: Methods of sampling and associated errors, Classification of errors, Propagation of errors, treatment of errors, Normal distribution, Tests of Significance and Confidence Limits.

Separation techniques: Solvent Extraction Technique: Conventional, Liquid Membranes – Bulk, Supported and Emulsified, Solid Phase Extraction (SPE). Ion Exchange: Conventional, Membranes. Chromatography: Gas chromatography (GC), High Performance Liquid Chromatography (HPLC), Ion chromatography (IC).

Mass Spectrometry: Mass Analysers – Magnetic, Quadrupole, Time of Flight (TOF), Features – Resolution, Dispersion, Abundance, Sensitivity, Detectors, Ion Sources – Thermal Ionisation (TI), Electron Impact, ICP, GD, Laser Ablation (LA-ICP), Secondary Ionisation (SI), Matrix Assisted Laser Desorption and Ionisation (MALDI), IC-MS, HPLC-MS, GC-MS.

Thermal Methods: Thermogravimetric Analysis (TGA), Derivative Thermogravimetric Analysis (DTG), Differential Thermal Analysis (DTA), Differential Scanning Calorimetry (DSC), Evolved Gas Analysis (EGA).

Electrochemical Methods: Introduction, Potentiometry, Ion Selective Electrodes (ISE), Voltammetry & Polarography, Cyclic, Pulse and Stripping Voltammetry, Coulometry and Amperometry, AC Electrochemical Techniques, Scanning Electrochemical Microscopy.

Detectors: Photomultiplier Tube (PMT), Charge Coupled Device (CCD), Charge Injection Device (CID), Spectrometers – Czerny Turner, Echelle, Sample Introduction Devices – Flame, Electrothermal, Laser Ablation, Direct Sample Insertion Devices, Interferences, detection limits, sensitivity.

Conductance of solutions and electrochemistry: Faraday's laws of electrolysis, Electrolytic conduction- Arrhenius theory of electrolytic dissociation, strong and weak electrolytes. Migration of ions – transference numbers, Determination of transference number using Hittrof's rule and moving boundary method. Conductance of solutions – electrolytic conductance, determination of conductance, equivalent conductance and concentration, Kohlrausch's law of independent migration of ions, ionic mobilities, temperature dependence. Hydration of ions, the interionic attraction theory. Applications of conductance measurements – degree of dissociation of weak electrolytes, dissociation constants of weak acids, degree of dissociation of water, basicity of organic acids, determination of solubilities of sparingly soluble salts, conductometric titrations, activities of electrolytic solutions, ionic strength. The Debye-Hückel theory of dilute ionic solutions.

References

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	5. J. A. C. Broekaert, Analytical Atomic Spectrometry with flames and Plasmas, Wiley-VCH, 2002. 6. S.K. Aggarwal and H.C. Jain, Editors, Introduction to Mass Spectrometry.
C-502	**Quantum Chemistry-II** **Revisit to one-electron atoms:** Review of hydrogenic atoms, energy levels, orbitals, their shapes, electronic transitions, Stark and Zeeman effect. **Approximate methods in quantum chemistry***:* Review of Variational principle and time-independent perturbation theory. Time-dependent perturbation theory: Application to interaction of radiation with matter, derivation of spectroscopic selection rules. **Many electron systems***:* Orbital approximation, Slater determinant; Hartree and Hartree-Fock self-consistent field theory; Concept of electron correlation and post Hartree Fock methods. **Angular momentum of many-particle systems:** Spin orbit interaction; LS and JJ coupling. Spectroscopic term symbols for atoms and diatomic molecules. **Molecular Electronic Structure:** Born-Oppenheimer approximation, Molecular orbital and valence bond theories. Concept of LCAO approximation and introduction to *ab-initio* molecular orbital calculations for molecules. Application to homonuclear and heteronuclear diatomic molecules. Electronic structure and Chemical bonding, Directed valence and concept of hybridization in simple polyatomic molecules. Group theory-based symmetry adapted LCAO approach. **Semiempirical methods:** Huckel theory for conjugated systems, Parisar Parr Pople approximation and several approximate semiempirical methods of electronic structure calculations. **Miscellaneous topics:** Concept of basis sets and Slater and Gaussian type orbitals, virial theorem and Hellmann Feynman theorem, introduction to density functional methods, Molecules to solids and bonds to bands for extended systems. **References** 1. I. N. Levine, Quantum Chemistry, 6th Ed., Prentice Hall, India, 2012. 2. *P*. W. Atkins, R. Friedman, Molecular Quantum Mechanics, 4th Ed., Oxford University Press, 2005. 3. A. K. Chandra, Introductory Quantum Chemistry, 4th Ed., Tata McGraw-Hill Publishing, 2001. 4. A. Szabo and N.S. Ostlund, Modern Quantum Chemistry, Dover, 1996 5. F. L. Pilar, Elementary Quantum Chemistry, McGraw Hill, 1968.
C-503	**Inorganic Chemistry-II** **Coordination compounds:** Werner's theory, effective atomic number, coordination number, shapes of d-orbitals and bonding in transition metal complexes, stability of complexes, the chelates and macrocyclic effects, types of classification of ligands, second sphere of coordination, □-complexes, □-acid ligands, multiple bonds from ligands to metals. **Crystal Field theory:** Crystal field splitting and elementary treatment of the electronic spectra, Jahn-Teller distortion of octahedral complexes, square planar complexes, tetrahedral complexes, magnetic properties of 3*d* compounds.

	Molecular Orbital theory*:* Nomenclature of coordination compounds, d-orbital splitting in various fields - Spectroscopic states - Tanabe-Sugano and Orgel diagrams - Derivation of Ligand field parameters (Dq. B) from electronic spectra - Magnetic moments - Orbital contribution, spin-orbit coupling and covalency - Molecular orbitals and energy level diagrams for common symmetries. **Bonding involving-donor ligands**: Back-bonding - f-orbital splitting - Spectral and magnetic properties of f-block elements. **Reaction mechanisms***:* Substitution reactions - Dissociative and associative interchange - trans-effect, Linear free energy relations. Rearrangements - Berry pseudo rotation, Electron transfer reactions. Photo-dissociation, substitution and redox reactions, Fluxional molecules. **References** 1. F. A. Cotton, G. Wilkinson, C. A. Murillo and M. Bochmann, Advanced Inorganic Chemistry, 6th Ed., Wiley Eastern, John Wiley, 1999. 2. J. E. Huheey, E. Keiter and R. Keiter, Inorganic Chemistry, 4th Ed., Harper Collins College Publisher, 1993. 3. D. Banerjea, Inorganic Chemistry Principles, Books Syndicate Pvt. Ltd., 2000. 4. N. N. Greenwood and E. A. Earnshaw, Chemistry of Elements, Pergamon Press, 1989.
C-504	**Spectroscopy-II** **Electronic Spin Resonance (ESR) Spectroscopy:** The Zeeman effect; Magnetic moment of an electron due its spin and orbital angular momenta; Magnetic moment in a magnetic field; magnetic resonance spectroscopy; Resonance condition; Field-swept vs frequency-swept ESR spectra; Observation of hyperfine lines in several molecular systems and the existence of electron-nuclear hyperfine interaction. EPR spectra of benzosemiquinone anion radical, methyl radical; Pascal triangle for several equivalent spin-½ nuclei; Hyperfine lines due to nuclear spin $I = 1$ and $I > ½$; Linewidths and intensities of various hyperfine lines; ESR spectrum of singlet oxygen molecule; splitting due to coupling of orbital angular momentum with rotational angular momentum. **Determination of structures of molecules using Spectroscopic Techniques:** Use in Determining Molecular Structures from uv-vis, IR and NMR Spectra, Use in Investigating Reaction Mechanisms, Use in Protein Structure Determination. ^{13}C NMR spectra and sensitivity issues. Interpretation of NMR spectra using examples of organic compounds. **References** 1. L. D. Field, S. Sternhell and J. R. Kalman. Organic Structures from Spectra, 5th Ed., John Wiley and Sons, 2013 2. R. M. Silverstein, F. X. Webster, Spectrometric Identification of Organic Compounds, 6th Ed., Wiley, 2006. 3. P.S. Kalsi, Spectroscopy of organic compounds, 6th Ed., New Age International, 2006. 4. J. E. Wertz and J. R. Bolton, Electron spin resonance: Elementary theory and practical applications, McGraw-Hill, New York, 1972. 5. C. P. Poole, Jr., Electron Spin Resonance: A Comprehensive Treatise on Experimental Techniques, 2nd Ed., John Wiley and Sons, New York, 1983.
C-601	**Biophysical Chemistry** **The Chemistry of Life: An introduction***:* Physical properties of water: Structure, water as solvent, The hydrophobic effect, osmosis and diffusion. Introduction to Biomolecules:

	Nucleic Acid, Protein - Polymer Description of Macromolecular Structure, Intermolecular and Intramolecular forces, Non-Covalent Interaction. **General principles of Biophysical chemistry I:** Hydrodynamic properties: Diffusion and sedimentation, determination of molecular weight from sedimentation and diffusion; Introduction of Ultra Centrifugation, Dynamic Light Scattering and Electrophoresis. Spectroscopic properties of proteins and nucleic acid: UV/Vis, Intrinsic fluorescence, Circular dichroism, Introduction to single molecule spectroscopy **General principles of Biophysical chemistry II:** The concept and application of Chemical and Physical equilibria in Biological system, Double Strand formation in nucleic acid, Ligand-protein binding, Protein denaturation and stability, Introduction of DSC and ITC. **Molecular self-assembly and Molecular medicine:** Protein folding kinetics and Biophysical methods, Misfolding and aggregation; Physical basis of conformation diseases, Therapeutic approaches to protein misfolding diseases**.** **Introduction to structural biology:** Introduction to basic principles of protein X-ray crystallography, protein NMR, Small Angle X-ray scattering (SAXS), and Electron microscopy (EM). **References** 1. Tinoco, Sauer, Wang, and Puglisi, Physical Chemistry: Principles and Applications in the Biological Sciences, Prentice Hall, Inc., 2003. 2. Peter Atkins and Julio de Paula, Physical Chemistry for the Life Sciences, 3. Dobson CM. General review papers: Principles of protein folding, misfolding and aggregation. Semin Cell Dev Biol. 2004 Feb;15(1):3-16.
C-602	**Group Theory and Applications (Symmetry in Chemistry)** **Group Theory: Machinery** **Introduction:** Symmetry in everyday life and chemistry **Symmetry Operations***:* Qualitative concept to quantitative definition, Symmetry Elements and operations (Identity, rotation, reflection, inversion, rotation-reflection), their algebra, role of symmetry in determining dipole moment and optical activity of molecules. **Basics of Group theory:** Definition of a group, concept of subgroup, group multiplication table, concept of classes, symmetry operations forming a group, concept and classification of Point groups, Schoenflies notation, determination of point groups for molecules. **The matrix machinery:** Matrix representation of symmetry operations, similarity transformations, concepts of equivalent, non-equivalent, reducible and irreducible representations, The Great Orthogonality theorem: Original form recast in terms of the traces of the representative matrices, Character Tables: their construction and content. **Group Theory: Applications** **The Approach**: Choice of basis set, forming characters of the reducible representations, decomposing into irreducible representations, concept of direct product representation, Projection Operators. **Application to spectroscopy & quantum chemistry:** Prediction **of v**anishing of matrix elements for transition to excited states, Symmetry Adapted Linear Combinations for the

	LCAO approach to the construction of molecular orbitals, vanishing of matrix elements and simplifications thereby, Application to coordination chemistry, crystal field splitting and the resulting spectral properties. **References** 1. F.A. Cotton, Chemical Applications of Group Theory, 3rd Ed., John Wiley, 2003 2. D.M Bishop, Group Theory and Chemistry, Dover Publication, 1993. 3. C.N. Banwell and E.M. McCash, Fundamentals of Molecular spectroscopy, Tata McGraw Hill, 1995.
C-603	**Inorganic Chemistry-III** **Chemistry of *d*-block elements** **General introduction to transition elements***:* Electronic structure, Metallic character, variable oxidation state, complexes, magnetic and catalytic properties. **Elements of the first transition series:** Occurrence, separation, extraction and chemistry of the scandium group (IIIB), titanium Group (IVB) , vanadium group (VB), chromium group (VIB), Manganese group (VIIB), Iron group (VIIIB(8)), Nickel group (VIII(9)) and Copper group (VIIIB(10)). **Chemistry of the elements of the second and third transition elements***:* **Ha**fnium group (Group IVB), Niobium and Tantalum (Group VB), Molybdenum and Tungsten (Group VIB); Technetium and Rhenium (Group VIIB), The Platinum group Metals, Ruthenium and Osmium (Group VIII(8)); Rhodium and Iridium (Group VIII(9)), Palladium and Platinum (Group VIII(10), Silver and gold Group (1B(11)). **Chemistry of f-block elements*:*** The lanthanide and actinide elements. **Reference** 1. F. Albert Cotton and G. Wilkinson, Advanced Inorganic Chemistry, John Wiley & Sons, 1988.
C-604	**Organic Chemistry-III** **Chemistry of Natural Products:** **Terpenoids:** Occurrence, isolation, classification, structure, chemistry and biogenesis of some important mono; sesqui-, di-, and tri-terpenes. **Steroids***:* Occurrence, isolation, structure, classification, biological role. Important structural and stereochemical features of cholesterol, ergosterols, bile acids, steroidal hormones. Synthesis of 16-DPA from cholesterol, synthesis of commercially important steroids from 16-DPA, synthesis of Taxol. Sterols and bile acids, estrogens, androgens, gestogens and adrenocortical hormones. **Alkaloids:** Occurrence, characteristic reactions, general methods of degradation, structure and chemistry of some well-known alkaloids. **Natural Pigments:** Occurrence, isolation, anthocyanines, flavones, flavanones, isoflavones, xanthones, quinones, carotenoids, chlorophyll and haemin. **Insect pheromones***:* Prostaglandins- Classification and biological importance, Plant growth regulators **Antibiotics***:* Classification. B-lactam antibiotics. Penicillins and cephalosporins. en-dyne-antibiotic. **Chemistry of heterocyclic compounds**

	Nomenclature: Nomenclature of heterocyclic compounds- Trivial, Hantzch-Widman, Replacement. Nomenclature of mono and polycyclic compounds. Polarity, tautomerism, aromaticity, electrophilic substitution. **Reactivity,** *preparation and reactions of the following:* **Small rings:** Aziridines, thiirane, azetidine, oxetane, thietanes **Five membered:** Diazoles, oxazoles and thiazoles. **Six membered:** Diazines, triazenes, pyranes and pyrones **Seven membered:** Diazepines **Fused ring:** Benzofurans, benzopyrones, benzodiazepines, indole, quinolines and isoquinolines, purines **References** 1. I. L. Finar, Organic Chemistry, Vol. 1 & 2, Pearson., 2012. 2. R. K. Bansal, Heterocyclic Chemistry, New Age International Publisher, 2014. 3. J. A. Joule, K. Mills and G. F. Smith, Heterocyclic Chemistry, 3rd Ed., Springer, 1995. 4. L. A. Paquette, Principles of Modern Heterocyclic Chemistry, W.B. Benjamin, Inc., 1978. 5. R. T. Morrison and R. N. Boyd, Organic Chemistry, 7th Ed, Prentice Hall of India, 2010.
C-605	**Nuclear Chemistry** **Nuclear Stability***:* Concept of nucleus and properties, nuclear mass and binding energy, elemental abundance, radioactive decay laws and equilibria**.** Nuclear Models: Liquid drop model, Shell model, Fermi gas model, collective model, optical model, concept of spin, parity electric and magnetic moments, isomerism. **Modes of Decay***:* □ decay, □ decay, electron captures, □ de-excitation, internal conversion, artificial radioactivity. **Nuclear reactions***:* Energetics, cross-section, centre of mass system, angular momentum, compound nucleus, statistical model, nuclear fission and fusion, nuclear reactors, Heavy ion induced reactions, Accelerators. **Applications of radioactivity***:* Probing by isotopes, preparation of radioisotopes**, Szilard**-Chamers' reaction, Concept of tracers, chemical yield, radiochemical purity, Application of radiotracers in Chemical Sciences, uses of nuclear radiations, radioisotopes as a source of electricity. **Elements of Radiation Chemistry***:* Interaction of radiation with matter, radiation dosimetry, radiolysis of water and some aqueous solutions, other radiolytic events. **Nuclear Methods***:* Activation Analysis – Neutron Activation Analysis (NAA), Charged Particle Activation Analysis (CPAA)**,** X-ray fluorescence (XRF) spectrometry**,** Ion Beam Analysis– Backscattering Spectrometry (BS), Particle Induced □-ray Emission (PIGE), Nuclear Reaction Analysis (NRA), Elastic Recoil Detection Analysis (ERDA), Particle Induced X-ray Emission (PIXE). **Mossbauer spectroscopy:** Introduction and applications **References** 1. G. Friedlander, J. Kennedy, Nuclear and Radiochemistry –J. M. Miller and J. W. Macias, 1981. 2. R.D. Evans, Atomic Nucleus, 1955. 3. S. Glasstone, Source book of Atomic Energy, 1969. 4. G.T. Seaborg, Manmade elements, 1963. 5. H. J. Arnikar, Essentials of Nuclear Chemistry, 1982. 6. C. Keller, The Chemistry of Trans-uranium Elements, 1971.

7. J. C. Bailar, H. J. Emelius, R. S. Nyholm and A. F. Trotman-Dickenson; *Comprehensive Inorganic Chemistry,* Vol. 5, Pergamon Press, Oxford, 1973.

C-701 Photochemistry

Part 1: Basic Principles of photochemistry

Photophysical processes: Properties of the excited states*:* Einstein theory of induced absorption and emission processes, laws of photochemistry, Lambert – Beer's law, absorption coefficient and transition moment integral, Jablonski diagram, De-excitation processes of the excited molecules (radiative and non-radiative processes, radiative lifetime, delayed emission, nonradiative relaxation, excimer and exciplex formation, heavy atom effect, etc.). Kinetics of excited state processes and quantum yields of different processes. Acid-base properties, redox potential, geometry, dipole moment, dynamic properties of the excited states.

Photoinduced chemical processes*:* Photo-dissociation, photo-ionization, intramolecular charge and proton transfer processes, intermolecular electron and proton transfer reactions, conformational relaxations, intra and intermolecular energy transfer processes and other important photochemical reactions. Kinetics and mechanism of photochemical reactions.

Applications of photochemistry*:* Photosynthesis, vision, solar energy conversion, atmospheric photochemistry, single molecule spectroscopy, Photon-up-conversion process, absorption properties of nanoparticles and nanoaggregates.

Techniques and Studies on ultrafast processes*:* Nanosecond laser flash photolysis, Single photon counting technique, picosecond and femtosecond Pump- probe transient absorption and fluorescence up conversion techniques. Singlet and triplet state properties, solvation dynamics and studies on other excited state properties.

Part 2: Organic Photochemistry

Distinctive features of photochemical reactions, methods of preparative photochemistry, Photochemistry of alkenes, alkynes and related compounds – geometrical isomerism, electrocyclic processes, sigmatropic shifts, di-□ methane reactions, addition, cycloaddition and oxidative reactions. Photochemistry of aromatic compounds – bond cleavage and hydrogen abstraction reactions, cycloaddition reactions, rearrangements of cyclo-hexenones and cyclo-hexadienones, thiocarbonyl compounds. Photochemistry of other organic compounds – imines, imminium salts, nitriles and nitro compounds, azo and diazo compounds, diazonium salts, sulphur and halogenated compounds, photohalogenation and photonitrosation reactions. Photooxidation of alkanes.

Part 3: Inorganic Photochemistry

Introduction, Photophysical processes, electronic absorption spectra and characteristics of the electronically excited states of inorganic compounds. Photo-electro-chemistry of excited state redox reactions: Photosensitization. Photochemical reactions: substitution, decomposition and fragmentation, rearrangement, and redox reactions. Selective inorganic photochemistry using laser beams. Inorganic photochemistry in biological processes and their model studies. Ligand field photochemistry of d_n complexes, photochemistry of carbonyl compounds, energy conversion (solar) and photodecomposition of water.

References

1. K. K.Rohatagi-Mukherjee, Fundamentals of Photochemistry, Wiley Eastern, 1978.
2. M. S.Wrighton, Inorganic and Organometallic photochemistry, ACS Pub.,1978.
3. V. Balzani and V. Carasiti, Photochemistry of Co-ordination compounds, Academic Press,1970.
4. J. D. Coyle, Introduction to Organic Photochemistry.

C-702	**Molecular Thermodynamics** **Introduction:** Review of Basics of Thermodynamics and scope of Statistical Mechanics as a route for bridging the microscopic and macroscopic description. Concept of probability distribution, correlation functions and their application in determining the structure and dynamics in chemistry. **Ensembles and Averages**: Concept of ensembles and averages: micro-canonical; canonical and grand canonical ensembles. Interconnection and equivalence of ensembles. **Partition Functions**: Concept of partition function, evaluation of thermodynamic quantities from partition functions for ideal gas, classical systems as well as simple quantum systems, evaluation of equilibrium constants of chemical reactions in terms of partition functions. **Theory of Simple liquids**: Application of classical statistical mechanics to simple liquids, radial distribution function, integral equation theories and density functional theories for equilibrium systems. Brief introduction to computer simulation methods such as Monte Carlo and molecular dynamics simulation. **Miscellaneous topics**: Concept of time-correlation functions and their applications, Linear response theory, Jarzynski equality, phase transitions, thermodynamics of small systems: nano-thermodynamics, Basic concepts of nonequilibrium thermodynamics and applications of chemical significance, relaxation processes, diffusion process. Illustration with simple examples. **References** 1. D.A. Mcquarrie, Molecular Thermodynamics, Viva Books, 2010 2. D.A. Mcquarrie, Statistical Mechanics, Viva Books, 2011. 3. H.B. Callen, Thermodynamics and an Introduction to Thermostatics, 2nd Ed., John Wiley, 1985. 4. R K Pathria and Paul D. Beale, Statistical Mechanics, 3rd Ed., Elsevier, 2011. 5. M.P. Allen and D.J.Tildesley, Computer Simulation in Liquids, Oxford University Press, 1987.
C-703	**Organometallics and Bioinorganic Chemistry** **Part 1: Organometallics of main group and transition elements** **Overview**: 18-electron rule, square planar complex. Carbonyl ligand – bonding, binary carbonyl complexes, oxygen-bonded carbonyls, other ligands similar to CO, IR spectrum, main group parallels with binary carbonyl. Pi-ligands – linear and cyclic pi systems, NMR spectra of organometallic complexes. Comparative survey of structure and bonding of metal alkyls and aryls, complexes with □ acids, CO and related ligands, complexes with olefins, acetylenes and related unsaturated molecules, catalytic properties of mononuclear compounds, stereochemical non-rigidity in organometallic compounds, boranes, carboranes and metallocarboranes, bimetallic and cluster complexes, structure and applications in catalysis, applications of organometallic compounds in organic synthesis, enantioselective synthesis via organometallic compounds, importance of organometallic compounds in certain biological systems. Other important ligands – complexes containing M – C, M= C, M ≡ C bonds, hydride and dihydrogen complexes, phosphines and related ligands. **Organometallic reactions** occurring in metal – ligand substitution, oxidative, addition, reductive, elimination. Organometallic reactions involving modification of ligands – insertion and deinsertion, nucleophilic addition to ligands, nucleophilic abstraction, electrophilic reactions. Homogeneous catalysis and heterogeneous catalysis – use of

	transition metal complexes, hydroformylation reaction, Walker-Smidt synthesis of acetaldehyde, hydrogenation, Monsanto acetic acid process. Transition metal carbine complexes – structure, preparation and chemistry, metathesis and polymerization reactions. Applications of organometallics to organic synthesis and other applications. Metal cluster compounds - metal-metal bond, carbonyl and non-carbonyl clusters, structure and bonding low dimensional solids, clusters in catalysis. **Part 2: Bio-inorganic chemistry** Biochemistry of iron - its storage, transport and function, copper and zinc proteins, biological activation of oxygen, bioinorganic chemistry of alkali and alkaline earth metal cations, photosynthesis, nitrogen fixation, toxicity of metals. Chemical makeup and essential inorganic elements of organisms. Chemistry aspects of metal complexes. Spectral, biochemical and biological methods used in bioinorganic chemistry. Bioinorganic chemistry of Na^+, K^+, Mg^{2+} and Ca^{2+}. Role of metal ions in biology. Proteins and enzymes of V, Mn, Fe, Co, Ni, Cu, Zn and Mo. Structural and functional models. Transport and storage of metal ions. Carcinogenicity of chromium. Selenium in biology. **References** 1. 'The organometallic chemistry of the transition metals', sixth edition, R. H. Crabtree, John Wiley & Sons, 2014. 2. 'Basic Organometallic chemistry: Concepts, synthesis and applications', second Edition, B. D. Gupta and A. J. Alias, University Press (India) Pvt. Ltd. 2013. 3. 'Organometallic chemistry: A Unified Approach', R. C. Mehrotra and A. Singh, Wiley Interscience, 1991. 4. F. A. Cotton, G. Wilkinson, C.A. Murillo and M. Bochmann, Advanced Inorganic Chemistry, 6th Edn., Wiley, 1999. 5. N. N. Greenwood and A. Earnshaw, Chemistry of the Elements, Ist Ed., Pergamon, 1985. 6. S. J. Lippard & J. M. Berg, Principles of bioinorganic chemistry, University Science Books, Mill Valley, 1994.
C-704	**Physical Organic Chemistry** **Pericyclic reactions:** Cycloadditions, Orbital correlation diagram, Frontier Molecular Orbital, Comments on forbidden and allowed reactions, Photochemical pericyclic reactions, D-A cycloadditions, regio- and stereo-selectivity, endo-effect, [2+2] cycloaddition, ketene cycloaddition, 1,3-dipolar cycloaddition, ene-reaction, retrocycloaddition, electrocyclic reactions, to regioselectivity, sigmatropic rearrangements, Claisen and Cope rearrangements, Cheletropic reactions. Linear free energy relationship and Hammett and Taft plots **Catalysis:** Catalytic mechanism, homogenous, heterogenous catalysis, acid base catalysis. **Acidity Basicity:** Aqueous and non-aqueous solution, Hammett acidity function, super acid and super bases **Solvatochromism** **Methods of determining reaction mechanism** **References** 1. E. V. Anslyn and D. A. Dougherty, *Modern Organic Chemistry*, University Science, 2005. 2. I. Fleming, *Molecular Orbitals and Organic Chemical Reactions*, John Wiley, 2009. 3. J. Clayden, S. Warren, N. Greeves, P. Wothers, *Organic Chemistry*, 1st Ed., Oxford University Press, 2000 4. F. J. Carey and R. J. Sundburg, *Advanced Organic Chemistry, Part A and Part B*, 5th Ed., Springer, 2007 5. J. March, *Advanced Organic Chemistry*, 3rd edition, McGraw Hill, 1991.

C-801	**Materials Chemistry** **Introduction to Hard and Soft Matter** **Basic Aspects of the Solid State (Hard Matter)**: Types of solids, crystalline and amorphous structures. **Solid State Crystalline Structure***:* Primitive lattice vectors - reciprocal lattice - crystal systems and desymmetrization schemes. Bravais lattices; closed packed structures, octahedral and tetrahedral holes, crystallographic point groups and space groups - organic and in organic crystal structure motifs - polytypes and polymorphs. perovskites and related structures, normal and inverse spinels. **Defects and Non-stoichiometry***:* Intrinsic and extrinsic defects - point, line and plane defects; vacancies, Schottky defects, Frenkel defects - Charge compensation in defective solids - non-stoichiometry, thermodynamic aspects and structural aspects. **Thermal and electrical Properties***:* Specific heat of solids, thermal conductivity, Free electron theory, electrical conductivity, Hall effect - band theory, band gap, metals and semiconductors -intrinsic and extrinsic semiconductors, hopping semiconductors - semi-conductor/metal transition - p-n junctions – super conduction, Meissner effects, type I and II superconductors, isotope effect, basic concepts of BCS theory, manifestations of the energy gap, Josephson devices. **Ionic Conductors***:* Types of ionic conductors - Mechanism of ionic conduction; interstitial jumps (Frenkel), vacancy mechanism, diffusion - superionic conductors, phase transitions and mechanism of conduction in superionic conductors - examples and applications of ionic conductors. **High Tc Materials***:* Defect perovskites - high Tc superconductivity in cuprates – preparation and characterization of 1-2-3 and 2-1-4 materials - normal state properties, anisotropy, temperature dependence of electrical resistance, optical phonon modes – superconducting state, heat capacity, coherence length, elastic constants, positron lifetimes, microwave absorption - pairing and multigap structure in high Tc materials - applications of high Tc materials. **Magnetic Properties***:* Classification of magnetic materials - Langevin diamagnetism - Quantum theory of paramagnetism - cooperative phenomena - magnetic domains and hysteresis - magnetism and dimensionality. **Optical Properties***:* Optical reflectance - excitons - Raman scattering in crystals - photoconduction - color centers - lasers - photovoltaic effect. **Synthesis of Materials***:* Phase diagrams - preparation of pure materials, mass transport, nucleation and crystal growth - preparative techniques, zone refining, chemical transport, etc. **Multiphase materials***:* Ferrous alloys, Fe-C phase transformations in ferrous alloys, stainless steels - non-ferrous alloys - properties of ferrous and non-ferrous alloys and their applications. **Nanocrystalline phase:** - preparation procedures – special properties - applications Thin Films, Langmuir-Blodgett Films: Preparation techniques, evaporation/sputtering, chemical processes, MOCVD, sol-gel etc. - LB film growth techniques - photolithography - properties and applications of thin films, LB films. **Soft Matter: Liquids Crystals***:* Mesomorphic behavior - thermotropic and lyotropic phases – description of ordering in liquid crystals, the director field and order parameters - nematic and semectic mesophases, smectic -nematic transition and clearing

	temperature - homeotropic, planar and twisted nematics - chiral nematics - smectic A and smectic C phases - cholesteric-nematic transition - optical properties of liquid crystals - effect of external field. **Materials for Solid State Devices:** Rectifiers, transistors, capacitors - IV-V compounds - low-dimensional quantum structures, optical properties. Organic materials: Organic Solids, Fullerenes, Conducting organics – organic superconductors - magnetism in organic materials, Fullerenes - doped fullerenes as superconductors **Nonlinear Optical Materials:** Nonlinear optical effects, second and third order – molecular hyperpolarisability and second order electric susceptibility - materials for second and third harmonic generation. **References** 1. H. V. Keer, Principles of the Solid State, Wiley Eastern, 1993. 2. N. W. Ashcroft, N. W. Mermin, Solid State Physics, Saunders College, Philadelphia, 1976. 3. W. D. Callister, Material Science and Engineering. An Introduction, Wiley, NY, 1985. 4. C. Kittel, Introduction to solid state physics, John Wiley & Sons, New York, 1968. 5. A. R. West, Solid State Chemistry and its Applications, John Wiley & Sons, NY, 2005. 6. N. N. Greenwood, Ionic crystals, Lattice defects and non-stoichiometry, Butterworths, London 1970
C-802	**Macro- and Supra-molecular Chemistry** **Part-I: Polymer Chemistry** **Polymerization reactions, mechanism and kinetics:** Cationic, anionic and radical polymerization. Template, emulsion and electrochemical polymerization, Condensation, ring opening, step growth and radiation polymerization reactions. Coordination complex polymerization, naturally occurring polymers, Biological polymers, inorganic polymers. Polymerization of cyclic organic compounds. Copolymerization and multicomponent polymerization, **Thermodynamics and kinetics**: Polymerization and depolymerization equilibria - Kinetics of condensation (Step-Growth), Free radical and ionic polymerizations. **Physical Characterization**: Fabrication and Testing, Relationship between structure and properties - Thermal, flame and chemical resistance - Additives - Electroactive polymers - Biomedical applications. Molecular wieght (Mn, Mw) determination - Morphology -Glass transitions and crystallinity - Conformational analysis. Dynamics of dilute polymer solutions and effect of increasing concentration, NMR and neutron scattering studies. **Reactions and degradation of polymers**: Biodegradable polymers. Thermal and oxidative degradation, catalysis by macromolecules, computer applications. **Part-II: Supramolecular Chemistry** **Introduction** to Supramolecular Chemistry. **Molecular and Chiral Recognition**: Self-Organization, Self-Assembly and Preorganization, molecular and chiral recognition, self-Assembly and self-organization, role of preorganization in the synthesis of topological molecules, template reactions, one-pot' reactions. **Covalent self-assembly based on preorganization**: Inclusion complexes, host-guest chemistry, early development of host-guest chemistry. Pedersen's works on crown

	ethers, nomenclature, the structure of inclusion complexes, dynamic character of inclusion complexes, the complexes involving induced fit and without it, endo-hedral fullerene, hemicarcerand and soft rebek's tennis ball-like hosts. **Mesoscopic Structures**: An Intermediate Stage Between Molecules (Micro Scale) on the One Hand and Biological Cells (Macro Scale) on the Other: introduction, medium sized molecular aggregates. **Understanding and Mimicking Nature**: Introduction, the role of self-organization and self-association in the living nature, modelling processes in living organisms. **Nanotechnology and Other Industrial Applications of Supramolecular Systems**: Introduction to link between chemistry and solid-state physics- crystal engineering, obtaining crystals with desired properties, nanotechnology and other industrial applications, supramolecular catalysis. **Most Interesting Macrocyclic Ligands:** Hosts for Inclusion Complexes, Crown ethers and coronands, cryptates and cryptands, calixarenes, hemispherands, and spherands, carcerands, hemicarcerands and novel `molecular flasks' enabling preparation and stabilization of short-lived species, cyclodextrins, and their Complexes, endohedral fullerene complexes, nanotubes and other fullerene-based supramolecular systems, dendrimers, cyclophanes and steroids forming inclusion complexes, anion binding receptors and receptors with multiple binding Sites. **Other Exciting Supramolecular Systems**: Making Use of the preorganization phenomenon, topological molecules, multiple hydrogen-bonded Systems, organic zeolite, metal directed self-assembly of complex, supramolecular architecture, chains, racks, ladders, grids, macrocycles, cages, nanotubes and self-Intertwining strands (helicates). **The Prospects of Future Development of Supramolecular Chemistry**. **References** 1. H. R. Allcock, F. W. Lampe and J. Mark, Contemporary Polymer Chemistry, Prentice Hall, Inc., 1990. 2. M. P. Stevens, Polymer Chemistry: An Introduction, 2nd Ed, Oxford University Press, 1990. 3. F. W. Billmeyer, Jr., Textbook of Polymer Science (3rd Edition) Wiley-Inter Science, 1984. 4. A. Ravve, Principles of Polymer Chemistry. 5. F. Vogtle, Supramolecular Chemistry, John Wiley, 1991. 7. G. R. Desiraju, Crystal Engineering. The Design of Organic Solids, Elsevier, 1989. 8. Helena Dodziuk, Introduction to Supramolecular Chemistry, Kluwer Academic Press, 2002.
C-803	**Computational Chemistry** **Introduction:** Introducing the different length scales inherent for investigation of chemical problems, theoretical techniques inherent at different length scales and tools of computational chemistry, role of computational chemistry in the broad perspective of describing chemical systems and phenomena. A brief review of quantum chemistry, statistical mechanics, and chemical reactivity theories. **Microscopic length scales:** Revisit and a brief review of quantum chemistry-based techniques for electronic structure calculations of molecular systems, semi-empirical approximations, ab initio methods, density functional theory, coupled cluster approaches, basis sets; Application of these computational methods for prediction of structural and electronic properties of molecules by using standard programs. A brief outline of molecular mechanics and its use for conformational analysis, FMOs in organic

	chemistry, crystal and ligand field calculations, computation of potential energy surfaces, etc. **Atomistic and continuum length scales:** Outline of Monte Carlo and Molecular dynamics simulation, Implementation of these methods, using standard or own developed software, for equilibrium and dynamical properties of simple liquids. Calculation of radial distribution function, time correlation functions, transport coefficients and other thermodynamic properties. **Miscellaneous topics:** Calculation of chemical reactivity parameters, numerical solution of diffusion equation **References** 1. C. J. Cramer, Essentials of Computational Chemistry: Theories and Models, John Wiley & Sons, 2002. 2. David Young, Computational Chemistry: A practical Guide for applying Techniques to Real World Problems, Wiley Interscience, 2001. 3. A. R. Leach, Molecular Modelling: Principles and Applications, Pearson Education, 2001. 4. E. G. Lewars, Computational Chemistry, 2nd Ed., Springer, 2011. 5. J. B. Foresman, A. Frisch, Exploring Chemistry with Electronic Structure Methods. Gaussian Inc., 1996. 6. M. P. Allen and D. J. Tildesley, Computer Simulations of Liquids, Oxford, 1987.
C-804	**Lasers and its Applications (Elective Course)** **Fundamental Principles of lasers***:* Key elements for a laser oscillator, Optical amplification – Einstein's theory of light absorption and emission, Stimulated emission and light amplification, population inversion, three level and four level lasers and rate equations, total loss in the cavity and threshold population inversion. Resonator cavity and quality factor. Resonator configurations. Pumping processes and pumping efficiency. Laser modes, gain threshold, axial and longitudinal modes, TEM_{00} mode, Mode configurations and resonant frequencies. Selection of single longitudinal mode. Properties of laser beams. **Different kinds of lasers***:* (a) gas lasers: excitation mechanisms, He-Ne laser, Argon ion laser, Cu-vapor laser, nitrogen laser, excimer laser CO_2 laser, Chemical laser. (b) Liquid state laser: Dye laser. (c) Solid state laser: Doped insulator lasers- Nd:YAG, Nd:Glass, Ti: Sapphire and Ruby lasers, semiconductor laser. (d) Other lasers: Free electron laser. **Pulsed lasers***:* (a) Q-switching: Principle, rotating mirror, electro-optic Q-switch – half wave and quarter wave configurations, Passive or saturable absorber. (b) Mode-locking: Principle, Differences in the output of non-mode-locked and mode-locked lasers, Time – bandwidth product, condition for obtaining ultrashort pulses, peak power. Methods of mode-locking: Active mode-locking – Accousto-optic method, passive saturable absorber – CPM dye laser and Kerr lens mode-locking – Ti:Sapphire laser. Chirped pulse amplification, Frequency conversion techniques. **Applications of tuneable lasers in absorption and fluorescence spectroscopy:** Advantages of lasers in spectroscopy. High sensitivity methods of absorption spectroscopy – cavity ring down spectroscopy, Laser induced fluorescence, Fluorescence excitation spectroscopy, Photoacoustic spectroscopy, Optothermal spectroscopy, Ionization spectroscopy. Nonlinear optical spectroscopy: Basic concepts, Second order non-linear spectroscopies – surface harmonic generation. Third order non-linear optical spectroscopies – optical kerr effect. CARS spectroscopy, Z-scan method.

	References 1. J. Wilson and F. B. Hawkes, Optoelectronics, 2. A. Ghatak and Thyagarajan, Optical Electronics, 3. W. Demtroder, Laser Spectroscopy – Basic concepts and Instrumentation, 4. William T. Silfvast, Laser Fundamental,
C-805	**NMR in Chemistry (Elective Course)** **Advanced techniques in NMR spectroscopy** Nuclear magnetic resonance (NMR) phenomenon and the experimental aspects, Chemical shift, indirect spin-spin coupling, direct spin-spin coupling, Relaxation times, nuclear Overhauser effect, polarization transfer, Two-dimensional NMR, correlation spectroscopy (COSY), Nuclear Overhauser effect spectroscopy (NOESY). Hetero-nuclear correlation spectroscopy (HETCOR), Inverse experiments, hetero-nuclear multiple quantum spectroscopy (HMQC), NMR in higher dimensions, NMR of oriented molecules, Structure and dynamics of bio-molecules, NMR in the solid state, Magnetic resonance imaging. **Reference** 1. Andrew E. Derome, Editor, Modern NMR Techniques for Chemistry Research, Pergamon press, 1997.
CL-101	**Chemistry Laboratory** **Objectives of the Experiments**: To familiarise the students with chemistry laboratory and basic experiments involving simple chemical reactions and physical processes. Details of Safety requirement and practice in laboratory will be emphasised. **Topics to be covered**: Calibrations of pipette, burette, standard flasks etc., acid base titrations, recrystallization, thin layer chromatography, identification of organic functional groups, complexometric titrations based on EDTA complexation with metal ions, Synthesis of benzoic acid, diazotization etc. **References** 1. Vogel's Textbook of Quantitative Chemical Analysis (5th Edition; Longman) 2. Vogel's Qualitative Inorganic Analysis (7th Edition) 3. Various relevant articles in Journal of Chemical Education, American Chemical Society
CL-201	**Chemistry Laboratory** **Objectives of the Experiments:** To familiarise the students with various analytical procedures and use of a few equipments. **Topics to be covered:** Use of colorimeter for quantitative estimation, determination of equilibrium constant of complexation reactions, use of conductometry, and pH meter for determination of concentration of acids and bases, their dissociation constants, and critical micelle concentration of surfactants and identification of functional groups/ inorganic ions. **References** 1. Vogel's Textbook of Quantitative Chemical Analysis, 5th Edition 2. Vogel's Qualitative Inorganic Analysis, 7th Edition, 3. Various relevant articles in Journal of Chemical Education, American Chemical Society

CL-301	**Chemistry Laboratory** **Inorganic Chemistry** 1. Determine the percentage of purity of the given sample of boric acid 2. To estimate the chloride ions from given sample of saline by Mohr's method 3. Synthesis of aluminium acetylacetonate, $Al(acac)_3$ and its further use in complex formation with 8-hydroxy quinoline 4. Preparation of Alum from aluminium and determination of aluminium and sulfate in the prepared Alum 5. Synthesis of Ni and Co-DMG complexes **Physical chemistry** 1. Enzyme kinetics: Determination of Km and Vmax 2. Determination of protein concentration by Bradford method 3. Spectroscopic determination of concentration and purity of DNA and proteins (urea denaturation method) 4. An SDS-PAGE examination of protein quaternary structure 5. To determine the freezing point of two solutions and compare the effect of solute type and concentration for each solution. 6. Molecular weight determination by boiling-point elevation of a urea solution 7. Solar irradiations of bilirubin: An experiment in photochemical oxidation
CL-401	**Chemistry Laboratory** **Organic Chemistry** 1. Acetylation of primary amine: preparation of acetanilide 2. Radical coupling reaction: Preparation of 1,1-bisnaphthol 3. Benzil-benzillic rearrangement 4. Use of diazonium salt: 4-nitro aniline to 1-iodo 4-nitrobenzene 5. Electrophilic aromatic substitution reaction: Nitration of Phenol 6. Co-enzyme catalysed Benzoin condensation: Thiamine hydrochloride catalysed synthesis of benzoin 7. Reduction of organic Compound: Borohydride reduction of ketone 8. Green Phorochemical reaction: photoreduction of benzophenone 9. Pinacole Pinacolone rearrangement 10. Synthesis of Local Anaesthetic: Benzocaine **Physical Chemistry** 1. To determine the energy of activation of acid catalysed hydrolysis reaction of methyl acetate. 2. To determine the order of reaction between $K_2S_2O_8$ and KI 3. Determination of the rate and order of reaction using clock reaction 4. Catalyst effect on the rate of reaction using clock reaction 5. To determine the rate constant & the order of reaction with respect to crystal violet (with respect to variable concentration of crystal violet). 6. Learn chemical structure drawing tool: ChemDraw and Molden
CL-501	**Chemistry Laboratory** **Analytical Chemistry** 1. Estimation of Ascorbic acid by differential pulse polarography

	2. Cyclic voltammetry of $K_3Fe(CN)_6$ + $K_4Fe(CN)_6$ 3. Estimation of copper by Normal pulse polarography and differential pulse polarography 4. Cyclic voltammetry of redox system 5. Electrochemical deposition of metals 6. Estimation of silver by differential pulse polarography 7. Making an alloy (solder) 8. Thermal decomposition of calcium carbonate 9. Microscale reactions of positive ions with sodium hydroxides 10. Making of a photographic print. **Organic Chemistry** 1. Preparation of 2,5-dimethyl-1-phenylpyrrole 2. Preparation of 1,2,3,4-tetmhydrocarbozole 3. Preparation of benzimidazole 4. Preparation of benzofurazan-l-oxide 5. Preparation of ethyl 2-oxo-2H-1-benzopyran-3-carboxylate 6. Preparation of 4-methyl-2(1H)-quinoline 7. Preparation of pyrimidone
CL-601	**Chemistry Laboratory** **Bio-Physical Chemistry** 1. Determination of fluorescence quenching rate constant (kq) using Stern-Volmer plot: Elucidation of mechanism of collisional and static quenching 2. Characterization of intermediate states of protein using fluorescence spectroscopy 3. Determination of association constant (Ka) and binding capacity (n) of drug-protein interaction using difference spectroscopy. 4. Determination of Tm of protein unfolding 5. Determination of protein aggregation kinetics parameters, kapp, Vmax, Vi, amplitude and lag time 6. To estimate the melting temperature of DNA by spectroscopic methods. 7. Protein labelling with fluorescent dye FITC 8. Crystallization of commercial HEW-Lysozyme and draw the phase diagram to identify the nucleation zone for the protein 9. Determination of Helix –coil transitions in polypeptides: Conformational changes in poly-γ-benzyl-l-glutamate (PBG) in mixed solvent of dichloro acetic acid (DCA) and ethylene dichloride using polarimeter 10. Conformational characterization of proteins and nucleic acids using circular dichroism spectropolarimeter. 11. Secondary structure prediction of proteins from CD data using different structure prediction software 12. Quantitative determination of DNA-ligand binding using fluorescence 13. Assessment of the purification of a protein by ion exchange and GFC 14. Evaluation of the Hill coefficient from Scatchard and Klotz plots 15. Determination of equilibrium constant (K) and vant Hoff's enthalpy (ΔHVH) N-acetylglycosamine (NAG) and lysozyme interaction using fluorescence spectrophotometer 16. Determination of melting temperature (Tm), calorimetric enthalpy (ΔHcal), vant Hoff's enthalpy (ΔHVH) and heat capacity (ΔCp) of lysozyme unfolding using Differential scanning calorimeter 17. Determination of binding constant (Ka), enthalpy (ΔH), entropy (ΔS) and reaction stoichiometry of drug-serum albumin association

	18. Thermodynamics characterization of intermediate states of protein using isothermal titration calorimetry
CL-701	**Chemistry Laboratory** **Physical Chemistry** 1. Use of three-dimensional excitation and emission matrix fluorescence spectroscopy for predicting the dissolved organic compound in drinking and waste water 2. Determination of pKa of protein using denaturation method 3. Determination of the Octanol/Water Partition Coefficients for Organic Pollutants of Varying Hydrophobic/Hydrophilic Character 4. Nuclear Chemistry: Experiment-1 5. Nuclear Chemistry: Experiment-2 **Organic Chemistry** 1. Experiment on solvent extraction 2. Isolation of caffeine from tea/coffee 3. Isolation of lycopene from tomato 4. Synthesis of heterobiaryl compound and synthesis of drug (dentrolene) 5. An operationally simple aqueous Suzuki-Miyaura cross-coupling reaction 6. Preparation and use of Wilkinson's catalyst
CL-801	**Chemistry Laboratory** 1. Determination of critical micellar concentration (cmc) of surfactant using pyrene fluorescence 2. Determination of enthalpy (ΔmicH), entropy (ΔmicS) and Gibbs free energy change (ΔmicG) of micellization using isothermal titration calorimetry. 3. Determination of partitioning parameters of different drugs in HTAB micelles using isothermal titration calorimetry 4. Powder XRD 5. Powder XRF 6. Study of excimer formation using pyrene 7. Thermodynamics of DNA Duplex Formation 8. Study of microenvironment Trp and Tyr in native protein by Synchronous fluorescence 9. Study the change in dynamic of protein upon ligand binding by REES 10. Quantification of chemical mixtures using 1D NMR. 11. Analysis of small organic molecules using 1D and 2D-NMR spectra 12. Pymol; VMD; CCP4img
CPr-701	To be assigned by the Supervisor
CPr-801	To be assigned by the Supervisor
CPr-901	To be assigned by the Supervisor
CPr-1001	To be assigned by the Supervisor

G-501	**Environmental Science** **Introduction to Environmental Science. Natural Environments:** Ecosystems and ecology, biodiversity. Socio-cultural environments: demography, population density, human organizations. Land use and its planning. Global climate change and effects on environment. Carbon cycle from human activity, calculation of carbon budgets. Water harvesting, storage and treatment. Natural calamities, hazards, and effects of human activity: Chemical and other technological hazards. Various case studies of natural calamities and human-induced disasters. Causes, effects, forecasting, preparedness, planning measures, technological solutions, social interventions. Concept of sustainability, individual and social, and local and global actions for a sustainable future. Introduction to energy Sources - evolution of energy sources with time. Power production, per capita consumption in the world, and relation to development index. **Energy scenario in India:** Various issues related to consumption and demands - energy crisis issues in India. Renewable and non-renewable energy sources - technology and commercialization of energy sources, local (decentralized) versus centralized energy production, constraints and opportunities of renewable energy (hydrocarbon and coal-based energy sources). Energy conservation – calculation of energy requirements for typical and home and industrial applications. Alternative to fossil fuels - solar, wind, tidal, geothermal. Bio-based fuels. Hydrogen as a fuel. Energy transport and storages, comparison of energy sources - passage from source to delivery (source, production, transport, delivery) - efficiencies, losses and wastes. Nuclear energy: Power production: Components of a reactor and its working, types of reactors and comparison. India's three stage nuclear program. Nuclear fuel cycle. Thorium based reactors. Regulations on nuclear energy. **References** 1. Energy in Perspective, J. B. Marion, University of Maryland, Academic Press, (1974) 2. Energy and Environment, Robert A. Ristinen and Jack J. Kraushaar, 2nd Edn., John Wiley and Sons, Inc. (2006). 3. Renewable Energy, Boyle Godfrey, Oxford University Press (2004) 4. Environment, Problems and Solutions, D.K. Asthana and Meera Asthana, S.Chand and Co.(2006) 5.Text Book on Environmental Chemistry, Balaram Pani, I.K.International Publishing House(2007).
GL-101	**Computer Basics** **History of Computers:** A brief outline of the history of computing machines and processes. The first modern mechanical computers. The generation of electronic computers. General understanding of the computer architecture of the different generations. The different classes of computers.

	Current Trends in Computation Industry: General introduction of the current computer hardware and software. The basic building blocks of a modern hardware, viz. 1) processing unit, 2) graphical processing unit, 3) memory and storage, 4) input and output devices and their ports. The basic building blocks of software, viz. 1) the concept of Operating System and their different types, 2) the file system for different operating systems, 3) concept of programs and scripts. Trends in current computing industry: viz. parallel processing, virtualization, cloud computing, etc. Binary Logic and Logic Gates Introduction to binary arithmetic. Introduction to logic gates and logic operations. **Introduction to Linux Operating System:** The structure of the OS. The file system. Introduction to the shell (BASH) and the GUI. Introduction to Office applications (word processor, spreadsheet, etc.). Basic commands of the shell. Some aspects of system administration. Usage of plotting software to plot graphs, viz. GNUPLOT. **Introduction to Programming:** Fortran (using the GNU Fortran compiler "GFORTRAN" for Linux kernel). The concept of compiling and running a program. The structure of a computer program. The concept and purpose of syntax. Use of editors in writing a program and the use of a command line / shell in compiling and running a program. The Novice's Programming Techniques in Fortran: The data types. Reading and writing of data (input and output). Basic arithmetic operations. Formatting of input and output. Conditional statements. **The Beginner's Programming Techniques in Fortran:** Complex conditional statements. Different types of loops. Applications of conditional branching and loops for scientific, statistical and other applications. **The Intermediate Programming Techniques in Fortran:** Concept of arrays. Application of one-dimensional arrays in manipulation of data. Sorting of data and its application. Two dimensional arrays. Matrix manipulation. Application in vector analysis. **The Advanced Programming Techniques in Fortran:** Usage of subroutines and functions. The structure of a complex Fortran programme. The dummy and global variables. **Applications of Fortran Programming:** Numerical computation of series, sequence. Interpolation and extrapolation. Finding the roots of functions. Testing the convergence and divergence of a series. Introduction to numerical differentiation and integration. Applications of numerical methods in physical problems. Vector manipulation (including other interesting problems, viz., inverting an integer number, finding the factors of a number, HCF and LCM, prime numbers, etc.) **Project:** Web programming – Rudimentary web page, Computer graphics – GIMP.

GL-201	**Electronics Laboratory** Analogue electronics: Introduction to passive electronic components -resistance, capacitance, inductance; Circuit theorems: Thevenin's theorem, Norton's theorem and Maximum power transfer theorem; basic concepts of semiconductor diode and transistor; Principle of DC power supply; half and full wave bridge rectifier, capacitor filter – ripple factor, concept of load and line regulation, concept of constant voltage source and constant current source; concept of short circuit protection and current limit protection; Zener regulator; concept of Switch Mode Power Supply (SMPS), power supply ICs, charge pump ICs for stepping up voltage and for bipolar supply; application of Bipolar Junction Transistor (BJT) - biasing circuits: The CE configuration, fixed base bias, emitter bias, and potential-divider or voltage divider bias; CE amplifier, amplifier as a switch, concept of negative feedback, differential amplifier; Operational Amplifier (OPAMP): principle, basic characteristics and parameters relevant for general use; non-inverting and inverting amplifier, voltage follower, difference amplifier, summing amplifier, voltage controlled current source; OPAMP comparator, Schmidt trigger; Digital to Analogue Converter (DAC) with weighted resistance and R-2R ladder network; Analogue to Digital Converter (ADC); filters: low pass, high pass; band pass; Butterworth filter. Digital electronics: Review of basic logic gates; DeMorgan's theorem, Use of NAND / NOR as universal building blocks; arithmetic circuits; binary addition, half adder, full adder, binary subtraction - 1s and 2s complement, controlled inverter, adder / subtracter, parity checker; Flip-Flops (FF): RS-FF, D-FF, JK-FF; counters and shift registers: binary counter, ripple counter. **References** 1. Electronic Principles, 7th Edition, A. Malvino and D.J. Bates, Tata McGraw–Hill Education 2006. 2. Electronic Devices and Circuits, 5th Edition, David A. Bell, Oxford University Press 2008. 3. Digital Principles and Applications, 7th Edition, D. Leach, A. Malvino and G. Saha, McGraw-Hill Education (India), 2010.
H-101	**Communication Skills: I (3 Credits, 45 lectures)** Objective of Communication Skill course is to help students to acquire abilities (i) to listen and understand classroom as well as other scientific lectures, (ii) to develop proper reading habit and skills, (iii) to speak well and deliver lectures, and also (iv) to write scientific material in a correct (both factually and grammatically), coherent and readable form. Social communication skill and learning usage of grammatically correct English, as well as creative writing skill are also aimed at. 1. **Listening and comprehending:** Students would be asked to listen to passages (through audio and/or video) of different kinds (lectures/speeches, discussions, etc), graded for competence levels, on different scientific subjects. They would then evaluate their comprehension of these passages. The passages would then be repeated to the students to enable them to identify their own shortcomings in the comprehension. 2. **Reading Skills:** Focus will be on different kinds of reading skills such as skimming, scanning and detailed reading. The passages selected would be graded for linguistic competence. The teacher would also use the passages to show students how language is structured in different rhetorical patterns such as narrative, analytical, argumentative and interpretative.

	3. **Speaking Skills:** Focus will be first on conversational practice in small groups, at the one-to-one as well as one-to-many level. It will be followed by scientific presentations, participation in debates and group discussions (in small groups). 4. **Writing Skills (mainly scientific writing):** The focus will be on teaching students how to write scientific material in a coherent and readable style. Discussion will involve style (descriptive, explanatory, argumentative, analytical and interpretative), complexity of sentences, specialist vocabulary, proper usage of nouns and verbs and also different kinds of writing (reports, papers, summaries, synopses, etc 5. **Remedial Grammar:** Additionally, some sessions can be reserved for remedial English grammar exercises based on the need of the students. **References** 1. Vernon Booth, 'Communicating in Science: Writing a Scientific Paper and Speaking at Scientific Meetings', Cambridge University Press, 1993. 2. Robert Barras, 'Scientists Must Write: A Guide to Better Writing for Scientists, Engineers and Students', Routledge, London, 2002. 3. Martin Heidegger, 'The question concerning technology, basic writings', Harper Collins, New York, 2008. 4. Jean Baudrillard, 'The Ecstasy of Communication', Cambridge: MIT Press, 2012.
H-201	**Introduction to Psychology (3 Credits, 45 lectures)** **Positive Psychology and Life Skills:** This course is specially designed for science students. The aim is to make students aware about the concept of positive psychology and life skills which will empower them to make their life better. The course covers the following topics:

1. Introduction to positive psychology (Positive thinking, Mind – Body Flourishing)	2 Lectures
2. Self Esteem	2 Lectures
3. PERMA (Positive Emotions /Thinking, Engagement/flow, Relationship, Meaning and Accomplishment Quality of life and Life Satisfaction)	8 Lectures
4. Mindfulness	3 Lectures
5. Mind-Sets	2 Lectures
6. Character Strength and Virtues (Gratitude, Happiness, Well-Being, Resilience)	4 Lectures
7. Emotional Intelligence and Social Intelligence	4 Lectures
8. Stress and related problems (Anxiety and Depression, Psychosomatic etc.)	4 Lectures
9. Cognitive Behaviour Therapy and REBT	8 Lectures
10. Life-Skills (Individual life skills, social skills and effective decision-making skills. Problem-solving, critical thinking, communication skills, decision-making, creative thinking, interpersonal relationship skills, self-awareness building skills, empathy, and coping with stress skills, assertiveness skills and time management	8 Lectures

References

1. R. A. Baron, 'Psychology (5th ed), PHI New Delhi, 2018.
2. R. S. Feldman, 'Introduction to Psychology' (6th ed) Tata McGraw-Hill, 2004
3. C. T. Morgan, R. A. King, J. R. Weisz and J. Scopler, 'Introduction to Psychology' (7th ed), Tata McGraw-Hill, 1993.

H-301	**Communication Skills - II and Introduction to Literature (3 Credits, 45 Lectures)** **(a) Communication Skills (22 Lectures):** Advanced topics on scientific writing and lecturing skills. Development of skills which are multifaceted and which lead to overall holistic development of personality. Techniques to master group discussion and succeed in interviews. Enhancement of public speaking and presentation skills. **(b) Introduction to Literature (23 Lectures):** An overview of Indian and world Literature. Introduction to ancient, medieval and modern literature in different Indian languages, literary traditions in different parts of India, literary techniques and style. Global trends in Cinema, The language of cinema, global and Indian film makers and their work.
H-401	**History and Philosophy of Science (3 Credits, 45 lectures)** **History of World Science up to the Scientific Revolution:** Introduction about stone age, beginning of agriculture, urban civilization and science. Science in Samaria, Babylonia and Egypt. Natural philosophy of pre-Socratic Greece. Natural philosophy in Athens. Greek science in the Alexandrian period. Rome and decline of Ancient European science. Science and technology in China. Science and technology in the Muslim world. Technology and the craft tradition in medieval Europe. The scholarly tradition during the Middle Ages. Renaissance, the Copernican system of the world. Gilbert, Bacon and the experimental method. Galileo and the science of mechanics. Descartes – the mathematical method and the mechanical philosophy. The Protestant reformation and the scientific revolution. Newton –the theory of universal gravitation and optics. Alchemy and iatrochemistry. Medicine, theory of circulation of blood. Growth and characteristics of the scientific revolution. **History of Ancient Indian Science:** Indian civilization from pre-historic times to the Indus Valley Civilization. Ancient Indian mathematics and astronomy. Ancient 53 Indian medicine and biology. Chemistry, metallurgy and technology in general in ancient India. Strengths, weaknesses and potentialities of ancient Indian science. **Introduction to Philosophy of Science**: What is science? Scientific reasoning; Explanation in science; Realism and instrumentalism; Scientific change and scientific revolutions. **Great Scientific Experiments**: Group wise study and presentations by students of historically significant experiments in science. **References** 1. Stephen F. Mason, 'A History of the Sciences', Collier Books, Macmillan Pub. Co. (1962) 2. D. M. Bose, S. N. Sen and B. V. Subbarayappa, 'A Concise History of Science in India', INSA, 1971. 3. Samir Okasha, 'Philosophy of Science – A Very Short Introduction', Oxford University Press, 2002. 4. Ron Harre, 'Great Scientific Experiments', Oxford University Press, 1983. 5. Lloyd Motz and Jefferson Hane Weaver, 'The Story of Physics', Avon Books, 1992. 6. Colin A. Ronan, 'The Cambridge Illustrated History of World Science', Cambridge University Press, 1983. 7. Helaine Selin and Roddam Narasimha, Eds, 'Encyclopaedia of Classical Indian Sciences', University Press, 2007 8. Thomas S. Kuhn, 'The Structure of Scientific Revolutions: 50th Anniversary Edition', University of Chicago Press, 2012.

H-501	**(a) Ethics of Science, and (b) Intellectual Property Rights (IPR) (3 Credits, 45 lectures)** **Introduction to a Collective, Participatory Teaching-learning Program:** A Science of our own. Science stands the test of ethics: Some indicators. Levels of Moral Development - Does it mean anything? Medical Ethics: Different themes pertaining to medical ethics including ethical issues in public health. History, Philosophy and Psychology of Ethics: History of Political Economy and Modern Ethics. Environmental Ethics. **Journals and Publishers:** Monopolistic practices by Academic Publishers. Quest for Determining what Virtuous is: Ethics in Practice. Collaborative Projects by the Class. Teaching the Teachers and other Virtuous Inquiries. **Intellectual Property Rights and Associated Issues:** History of Patenting. Digitalizing Culture-I: Free Software and Free Culture. Digitalizing Culture-II: Concentration and appropriation of Power by the few as well as Possibility of Distributive Justice. **References** 1. David B. Resnik, 'The Ethics of Science: An Introduction', Routledge, New York, 1998 2. V. K. Ahuja, (a) 'Intellectual Property Rights in India', 2015 (b) 'Law Relating to Intellectual Property Rights', 2017.
H-601	**(a) Introduction to Economics, and (b) Introduction to Innovation and Entrepreneurship (3 Credits, 45 lectures)** **(a) Introduction to Economics: (20 Lectures)** **Objective:** Students will be exposed to basics of economics and economic problems, concepts of demand, supply, consumer, market, inflation, trading, revenue, economic policy of government, macro- and micro-economics, different theories and models, etc. **Basics of economics:** Scope and concepts in economics. Its role in maximization of human welfare in situation of resource constraints. Concepts and laws of demand and supply, resources, consumer and market, price fixation and inflation: causes, consequences, control and remedies, consumption, saving, and investment, market fluctuations, trading, macro- and micro-economics, etc. Introduction to Bombay Stock Exchange (BSE) and National Stock Exchange (NSE), Sensex, trading in stock market, etc. Foreign exchange rates, Banking sector and interest rates, Sources of revenues and expenditure at the government level, Economic policies of Government of India, etc. **(b) Introduction to Innovation and Entrepreneurship: (25 Lectures)** The objective of this course is to introduce the students to the world of Innovation and Entrepreneurship, helping them with identification of the opportunities, generation of ideas, customer acquisition, and Technology evolution/disruption and business life-cycles. **Basics of innovation and entrepreneurship:** What it takes to be an entrepreneur, Type of start-up ventures: Product (Material/Know-how) manufacturing (science and

	technology-based), Service provider/consultancy firm (knowledge-based), etc. Understanding legal framework and compliances involved. **Business fundamentals:** Generation of idea (Opportunity identification and evaluation), incubation, product niche identification, generation of blue-print (Business model canvas), Prospective Customer identification and evaluation, Marketing and Sales, go to market strategy, Evaluation of Entrepreneurial/Business Finance, Intellectual Property (IP) knowledge. **The Start-up process/New venture creation:** Leadership & team building, Technology evolution and business life cycles, pitching: Satisfying experience of seeing the acquired knowledge bearing its fruit. **Important Possibilities of Start-up Ventures:** (i) Energy generation: Solar energy, Wind, hydro-, Waste product-based energy source (ii) Driving to Clean Environment, (iii) Data science, Artificial Intelligence, Machine learning, (iv) Software as a Service (Saas) based start-up. **References** 1. P. A. Samuelson & W. D. Nordhaus, Economics, McGraw Hill, New York, 1995. 2. K. E. Case, R. C. Fair and S. M. Oster, Principles of Economics, 10th Edition, Pearson Education Inc, 2012 3. P. Drucker, Innovation and Entrepreneurship, Harper Collins Publishers, New York, 1993. 4. Charles Hampden-Turner, Teaching Innovation and Entrepreneurship, Cambridge University Press, New York, 2009 5. H. J. Harrington, Creativity, innovation, and entrepreneurship, CRC Press, Taylor & Francis Group, USA, 2019. 6. Anil Lamba, Romancing the Balance Sheet, 2nd Edition, 2016. 7. John Adair, Decision making & problem solving, Kogan page, London, 2013
M-100	**Remedial Mathematics-I** **Trigonometry and Vectors:** arc lengths and areas of sector, polar coordinates, relations between different trigonometric functions, periodicity, graphical representation, fundamental identities, addition formulae, multiple angles, factorization formulae, Scalers and vectors, norm of a vector, dot product, projections, cross product. (3 weeks) **Sets and Functions:** Sets, Functions, Inequalities, graphical representation. (1 week) **Numbers:** Numbers of Different Types ($\mathbb{N}$, $\mathbb{Z}$, $\mathbb{Q}$, $\mathbb{R}$, $\mathbb{R} \setminus \mathbb{Q}$), Algebraic Properties, Factorial notation, Mathematical Induction, Division Algorithm, Divisibility, Prime Numbers, Fundamental Theorem of Arithmetic, Order Properties and Completeness Property of $\mathbb{R}$, concept of congruences. (3 weeks) **Series:** AP, GP and HP and inequalities of the mean, Sum of a series, Sigma notation, Convergence, Limit Theorems, Divergence Tests for Convergence (Absolute Convergence and Non-absolute Convergence), Series of Functions, Taylor's Series, Power Series. (2 weeks) **Limits and Continuity:** Limits of Functions, Convergence and Divergence, Boundedness, Squeeze Theorem. Graphical idea of monotonic function and Continuity, Continuous Functions, Continuous Functions on Intervals, Uniform Continuity. (2 weeks) **Derivatives and Differentiation:** Definition and Graphical Representation of Derivatives, Differentiability and Continuity, Chain Rule, Product and quotient rules,

	Higher Derivatives. Derivatives of e^x, $\log x$, Trigonometric and Inverse Trigonometric Functions, derivatives of inverse functions, Derivatives of Power Series. Mean Value Theorem, Derivatives and Extrema, L'Hospital's Rule. (3 weeks) **References** 1. R. G. Bartle and D. R. Sherbert, Introduction to Real Analysis, John Wiley and Sons Inc., 1994. 2. T. M. Apostol, Mathematical Analysis, Pearson Education, 2004. 3. G. S. Strang, Calculus, Wellesley-Cambridge Press, 1991. 4. D. M. Burton, Elementary Number Theory, McGraw-Hill Education, 2010
M-101	**Mathematics-I** **Introduction** (1 week) **Reading and Writing Mathematics:** Illustration of mathematical proofs via examples, Illustration of Conjunction, Disjunction, Negation of Statements and Conditional Statements via examples. (1 week) **Functions and Relations:** Sets, De Morgan's Laws, Relations, Cartesian Products, Functions and Graphical Representation, Injective and Surjective functions, Composition and Inverse of Functions, Level Sets, Equivalence Relations and Equivalence Classes. (3 weeks) **Numbers:** Natural Numbers, Algebraic Properties, Mathematical Induction. Real Numbers, Order Properties and Completeness Property of $\mathbb{R}$, Intervals on $\mathbb{R}$, Infinity, Infinite Sets and Cardinality. (3 weeks) **Sequences:** Sequences, Convergence, Limit Theorems, Divergence, Cauchy Sequences. (3 weeks) **Infinite Series:** Convergence and Divergence of Series, Geometric Series, Tests for Convergence. (1 week) **Limits:** Limits of Functions, Boundedness, Squeeze Theorem, Limits at Infinity. (2 weeks) **References** 1. R. G. Bartle and D. R. Sherbert, Introduction to Real Analysis, John Wiley and Sons Inc., 1994. 2. P. D. Lax and M. S. Terell, Calculus with Applications, Springer, 2014. 3. K. A. Ross, Elementary Analysis, UTM, Springer, 2013. 4. G. S. Strang, Calculus, Wellesley-Cambridge Press, 1991. 5. T. M. Apostol, Mathematical Analysis, Pearson Education, 2004. 6. J. P. D'Angelo and D. B. West, Mathematical Thinking - Problem Solving and Proofs, Second Edition, Prentice Hall, 2000.
M-200	**Remedial Mathematics-II** **Integration:** Notion of an integral, integral as limit of sums, anti-derivatives, area under a curve, Fundamental theorem of calculus, definite integrals, indefinite integrals, Rules of integration: integration by parts, integration by substitution, Properties of definite integrals, Application of integrals (path lengths, areas, volumes, etc.) (3 weeks) **Complex Numbers:** real and imaginary parts, the complex plane, complex algebra (complex conjugate, absolute value, complex equations, graphs, physical applications). Consequences of Euler's formula. (2 weeks) **Matrices and Linear Equations:** System of linear equations, notion of a matrix,

	determinant. Row and Column Operations, Gauss Elimination, Simple properties of matrices and their inverses. (2 weeks) **Combinatorics and Probability:** Permutations and combinations, Binomial theorem for integral and non-integral powers, Pascal's triangle, Introductory probability theory, Conditional probability, Binomial probability distribution. (3 weeks) **Coordinate Geometry:** Introduction to coordinate geometry. Concept of a Locus, Equation of a straight line, circle, parabola, ellipse and hyperbola. Basic properties, slope and tangent line, (2 weeks) **Curvilinear coordinates:** Spherical and cylindrical coordinates, area and volume elements, illustrations, unit vectors, coordinate conversion matrices (1 week) **Basic Statistics:** frequency tables, mean, median, mode, standard deviation. (1 week) **Additional Topics:** Scalar functions of several variables, partial derivatives, properties of partial derivatives, chain rule, applications. Gradient of a function, geometric interpretation, properties and applications, Vector functions. Derivatives of a vector function, divergence and curl, geometric interpretation, properties and applications. **References** 1. R. G. Bartle and D. R. Sherbert, Introduction to Real Analysis, John Wiley and Sons Inc., 1994. 2. T. M. Apostol, Mathematical Analysis, Pearson Education, 2004. 3. G. S. Strang, Calculus, Wellesley-Cambridge Press, 1991.
M-201	**Mathematics-II** **Continuity:** Continuous Functions, Graphical Representation, Composition and Inverse of Continuous Functions, Continuous Functions on Intervals. (2 weeks) **Differentiation:** Definition and Graphical Representation of Derivatives, Differentiability and Continuity, Chain Rule, Higher Derivatives. Mean Value Theorems, Derivatives and Extrema, L'Hospital's Rule, Taylor's Theorem and Applications. (4 weeks) **Integration:** Riemann Integral and its Properties, Statement of Fundamental Theorem of Calculus. (3 weeks) **Complex Numbers:** Complex Numbers, Statement of Fundamental Theorem of Algebra, Polar Coordinates, Euler's and de Moivre's Formulae, Formulae for Sine and Cosine, Roots of a Complex Number. (1 week) **Vector Spaces:** Vector Spaces (finite dimensional, over $\mathbb{R}$ or $\mathbb{C}$. Illustrate concepts with 2- or 3- dimensional examples), Linear Independence, Basis, Dimension, Rank of a Matrix, Span. Linear Transformations, Matrix Representation of a Linear Transformation, Kernel and Image, Change of Bases, Invertibility and Rank. (4 weeks) **References** 1. M. Artin, Algebra, Prentice Hall, 1991. 2. R. G. Bartle and D. R. Sherbert, Introduction to Real Analysis, John Wiley and Sons Inc., 1994. 3. P. D. Lax and M. S. Terell, Calculus with Applications, Springer, 2014. 4. K. A. Ross, Elementary Analysis, UTM, Springer, 2013. 5. T. M. Apostol, Mathematical Analysis, Pearson Education, 2004. 6. G. S. Strang, Calculus, Wellesley-Cambridge Press, 1991.

M-301	**Foundations**

1. Logic: Quantifiers and negations, illustrated by examples of mathematical and non-mathematical statements.
2. Set Theory: Unions and intersections of arbitrary families, illustrated by examples. Complements. De Morgan's laws for arbitrary collection of sets. Symmetric difference. Power set of a set. Cartesian product of two sets.

3. Relations and maps:
(a) Relations between two sets, including the case when the two sets are the same.
(b) Definition of a map. Composite of two maps. Injective, surjective and bijective maps and their composites. A map is bijective if and only if it is invertible.
(c) Image and inverse image under a map. Relation between images (resp. inverse images) and set theoretic operations. Inverse images under a composite map. Clarify a common misconception: If $f : X \to Y$ is a map and $B \subseteq Y$ then the definition of $f^{-1}(B)$ does not require the existence of f^{-1}.
(d) Equivalence relations. Lots of examples including fibres of map and congruence of integersmodulo n.. Equivalence classes. Giving an equivalence relation on a set X is equivalent to giving a partition of X. Quotient set. Construction of Z as a quotient of N × N.

4. Cardinality:
(a) Finite and infinite sets.
(b) Bijection relates to same cardinality.
(c) Countable sets. Countably infinite and uncountable sets. Examples.
(d) Every infinite set has a proper, countably infinite subset.
(e) Uncountability of R and P(N). Algebraic numbers are countable. This yields existence of transcendental numbers.
(f) Schroeder-Bernstein theorem.

5. Partially Ordered Sets:
(a) Concept of partial order and total order. Examples.
(b) Upper bound. lub, lower bound, glb.
(c) Maximum and maximal. Minimum and minimal.
(d) Chains, Zorn's Lemma.
(e) Lexicographic order.

6. (a) Well-ordering Principle.
(b) Weak and Strong Principles of Mathematical Induction. (c) Axiom of Choice, product of an arbitrary family of sets.
(d) Statement (without proof) of the equivalence of Axiom of Choice, Zorn's Lemma and Well Ordering Principle.

7. Additional Topics (Optional)
(a) Dedekind's Construction of Real Numbers.
(b) Binary, ternary, hexadecimal etc expansions of integers (and real numbers).
(c) Cantor Sets.

References

[1] Naive Set Theory, P. Halmos.
[2] Set Theory and Logic, R. Stoll.
[3] Topology, J. Munkres.
[4] Real Analysis, Bartle and Sherbert.

M-302	**Analysis-I (Single Variable Analysis)**

1. Real number system: Construction via Cauchy sequences. (Note: Dedekind cuts is an optional topic in M301.)
2. Concept of a field, ordered field, examples of ordered fields, supremum, infimum. Order completeness of R, Q is not order complete. Absolute values, Archimedean property of R. The fact that C is a field that cannot be made into an ordered field. Denseness of Q in R. Every positive real number has a unique positive *n*-th root.
3. Sequences: A monotone increasing sequence which is bounded above converges to its supremum.
   Sandwich $\lim \left(1+\frac{1}{n}\right)^n = e, \lim \sqrt[n]{n}$ theorem.= 1 and *liman* = 1.
4. Subsequence and Cauchy sequences: Every sequence of real numbers has a monotone subsequence. Cauchy completeness of R; Q is not Cauchy complete.
5. Infinite Series: Absolute and conditional convergence. Comparison test, ratio test, root test, Abel's alternating series test. Dirichlet's test for convergence of $\Sigma a_n b_n$. Statement of Riemann's rearrangement theorem. Power series, radius of convergence, uniform convergence via examples.
6. Continuous functions: Sequential and neighbourhood definitions; sums and products of continuous functions are continuous. Intermediate value property; continuous functions on closed and bounded intervals are bounded and attain their bounds; monotone continuous functions, inverse functions. Uniform Continuity, examples and counter-examples.
7. Differentiable functions: Definition as a function infinitesimally approximal by a linear map, equivalence with Newton's ratio definition. One-sided derivatives. The *O, o* and ~ notations with illustrative examples. Chain rule with complete proof (using the above definition). Relation between the sign of f^0 and local monotonicity. Proofs of Rolle's theorem, Lagrange's and Cauchy's mean value theorems. L'Hospital's rule.
   Higher order derivatives. Convex functions. Local maxima/minima, saddle points; examples of curve sketching in the plane.
   Taylor's theorem, estimation of the remainder in Taylor's theorem.
   Power series expansions of elementary functions. Validity of term by term differentiation and integration. Binomial theorem for arbitrary real coefficients.
   Standard example:
$$f(x) = \begin{cases} e^{-\frac{1}{x^2}}, & x \neq 0 \\ 0, & x = 0 \end{cases}$$
8. Riemann Integration: Upper and lower Riemann sums, basic properties. Riemann integrability, $f : [a,b] \longrightarrow \mathbb{R}$ continuous implies *f* is Riemann integrable, examples of Riemann integrable functions which are not continuous on [*a,b*]. If $f : [a,b] \longrightarrow \mathbb{R}$ is Riemann integrable then so is
   |*f*| and $\left|\int_a^b f(x)dx\right| \leq \int_a^b |f(x)|dx$. Cauchy-Schwarz inequality: $\left|\int fg\right| \leq \sqrt{\int f^2}\sqrt{\int g^2}$, $\left|\int fg\right| \leq$ $(\int f^p)^{\frac{1}{p}}(\int g^q)^{\frac{1}{q}}$, where $\frac{1}{p}+\frac{1}{q}$= 1. Mean value theorem for integrals.
9. (Optional, if time permits): Improper integrals. Cauchy's condition for the existence of improper integrals, test for convergence. Gudermannian and other examples.

	References [1] Introduction to Real Analysis: Robert G. Bartle and Donald R. Sherbert, 4th ed., Wiley Publications, 2011 [2] A First Course in Analysis: George Pedrick, Undergraduate Texts in Mathematics, SpringerScience and Business Media, 2012. ISBN: 1441985549, 9781441985545 [3] Principles of Mathematical Analysis, Walter Rudin, (Indian Edition), 3rd ed,. McGraw-Hill, 1976. ISBN: 9780070542358. [4] Tom M. Apostol, Mathematical Analysis, 2nd ed., Pearson Education, 1974. ISBN: 9780201002881. [5] Michael Spivak, Calculus, 4th ed., Publish or Perish, 2008. ISBN: 9780914098911.
M-303	**Algebra-I (Groups and Rings)** 1. Division algorithm in Z, fundamental theorem of arithmetic. 2. Recollection of equivalence relations and equivalence classes, illustrate by congruence classes of integers modulo *n*. 3. Definition of a group, examples including matrices, permutation groups, groups of symmetry, roots of unity. 4. First properties of a group, laws of exponents, finite and infinite groups. 5. Subgroups and co-sets, order of an element, Lagrange theorem, normal subgroups, quotient groups. 6. Detailed look at the group S_n of permutations, cycles and transpositions, even and odd permutations, the alternating group. 7. Homomorphisms, kernel, image, isomorphism, the fundamental theorem of group homomorphisms. 8. Cyclic groups, subgroups and quotients of cyclic groups, finite and infinite cyclic groups. 9. Cayleys theorem on representing a group as a permutation group. 10. Conjugacy classes, centre, class equation, centre of a *p*-group. 11. (Optional, if time permits) Sylow theorems. 12. Definition of a ring, examples including congruence classes modulo *n.* 13. Ideals, quotient rings, homomorphisms, units, fields, non-zero divisors, integral domains, field offractions of an integral domain. 14. Division algorithm in $K[X]$, where K is a field; $K[X]$ and Z are PID's. 15. (Optional, if time permits) Unique factorization domains, Gauss Lemma. **References** [1] M. Artin, Algebra, Prentice Hall of India, 1994. [2] D.S. Dummit and R.M. Foote, Abstract Algebra, 2nd Ed., John Wiley, 2002. [3] Joseph Gallion, Contemporary Abstract Algebra, Narosa. [4] N. Jacobson, Basic Algebra (volumes I and II), Hindustan Publishing Corporation, 1983.
M-304	**Elementary Number Theory** 1. Fundamental theorem of arithmetic, divisibility in integers. 2. Prime numbers and infinitude of primes. Infinitude of primes of special types. Special primes like Fermat primes, Mersenne primes, Lucas primes etc. 3. Euclidean algorithm, greatest common divisor, least common multiple. 4. Equivalence relations and the notion of congruences. Wilson's theorem and Fermat's little theorem. Chinese remainder theorem. 5. Gaussian integers. 6. Continued fractions and their applications. 7. Primitive roots, Euler's Phi function. 8. Sum of divisors and number of divisors, M¨obius inversion. 9. Quadratic residues and non-residues with examples. 10. Euler's Criterion, Gauss' Lemma.

	11. Quadratic reciprocity and applications. 12. Applications of quadratic reciprocity to calculation of symbols. 13. Legendre symbol: Definition and basic properties. 14. Fermat's two square theorem, Lagrange's four-square theorem. 15. Pythagorean triples. 16. Diophantine equations and Bachet's equation. The duplication formula. **References** [1] D. Burton, Elementary Number Theory. [2] Kenneth H. Rosen, Elementary number theory and its applications. [3] Niven, Ivan M.; Zuckerman, Herbert S.; Montgomery, Hugh L, An Introduction to the Theory of Numbers.
M-401	**Analysis-II (Multi-variable Analysis)** 1. Linear maps from R^n to R^m, partial derivatives. Tangent plane and normal line to a surface at a point. Directional derivative. Jacobian, polar and spherical polar coordinates. Chain rule. Mean value property and Taylor's theorem for several variables. 2. Parametrized surfaces, coordinate transformations, Inverse function theorem, Implicit function theorem, Rank theorem. 3. Critical points, maxima and minima, saddle points, examples of quadric surfaces in 3-space. Lagrange multiplier method. 4. Multiple integrals, Riemann and Darboux integrals, Iterated integrals. Area and volume. Improper-integrals. 5. Integration on curves and surfaces: Green's theorem, Differential forms, Gauss' Divergence theorem, Stokes' theorem. 6. (Optional, if time permits): Beta and gamma functions; $\Gamma(\frac{1}{2}) = \sqrt{\pi}$ **References** [1] Michael Spivak, Calculus on Manifolds, A Modern Approach to Classical Theorems of Advanced Calculus, Westview Press, 1965. ISBN: 0805390219. [2] James Munkres, Analysis on Manifolda, Westiew Press, 2nd ed.,1997. ISBN: 0201315963. [3] Wendell H. Fleming, Functions of Several Variables, Undergraduate Texts in Mathematics, 2nd Ed., Springer-Verlag, 1977. [4] Jerrold E. Marsden, Anthony J. Tromba and Alan Weinstein, Basic Multivariable Calculus, W. H. Freeman and Co. Ltd., 2001. ISBN: 9780716724438 [5] Principles of Mathematical Analysis, Walter Rudin, (Indian Edition), 3rd ed,. McGraw-Hill, 1976. ISBN: 9780070542358.
M-402	**Algebra-II (Linear Algebra)** **Note 1**: This is essentially a first course on vector spaces. However, as modules over a general ring are needed later in several courses and as it is desirable to give students time to become comfortable with this concept, modules are already introduced in the first item of this syllabus. Emphasize that vector spaces are special cases of modules, in which case several properties are available as discussed in the remaining items. 1. Modules over a commutative ring, submodules and quotient modules, homomorphisms, fundamental theorem of module homomorphisms, exact sequences, finitely generated modules, free modules. 2. Vector spaces as modules over a field, subspaces, quotient spaces. 3. Span and linear independence, basis, dimension.

	4. Linear maps and their correspondence with matrices with respect to given bases, change of bases. 5. Eigenvalues, eigenvectors, eigenspaces, characteristic polynomial, Cayley-Hamilton. 6. Bilinear forms, inner product spaces, Gram-Schmidt process, diagonalization, spectral theorem. 7. (Optional) Classical groups. **Note 2**: Jordan and rational canonical forms to be done in ***M-602*** *in Semester-VI* as an application of the structure of finitely generated modules over a PID. **References** [1] M. Artin, Algebra, Prentice Hall of India, 1994. [2] D.S. Dummit and R. M. Foote, Abstract Algebra, 2nd Ed., John Wiley, 2002. [3] K. Hoffman and R. Kunze, Linear Algebra, Prentice Hall, 1992. [4] N. Jacobson, Basic Algebra II, Hindustan Publishing Corporation, 1983. [5] S. Lang, Algebra, 3rd ed. Springer (India) 2004.
M-403	**Topology-I** 1. Metric spaces: Definition and basic examples including the following: (i) The discrete metric on any set. (ii) R and R^n with Euclidean metrics, Cauchy-Schwarz inequality, definition of a norm on a finite dimensional R-vector space and the metric defined by a norm. (iii) The set C[0,1] with the metric given by sup$\|f(t) - g(t)\|$ (resp.$\int_0^1 \|f(t) - g(t)\|dt$). (iv) Metric subspaces, examples. 2. Topology generated by a metric: Open and closed balls, open and closed sets, complement of an open (closed) set, arbitrary unions (intersections) of open (closed) sets, finite intersections (unions) of open (closed) sets, open (closed) ball is an open (closed) set, a set is open if and only if it is a union of open balls, Hausdorff property of a metric space. 3. Equivalence of metrics, examples, the metrics on R^2 given by $\|x_1 - y_1\| + \|x_2 - y_2\|$ (resp. $\max\{\|x_1 - y_1\|, \|x_2 - y_2\|\}$) is equivalent to the Euclidean metric, the shapes of open balls under these metrics. 4. Limit points, isolated points, interior points, closure, interior and boundary of a set, dense and nowhere dense sets. 5. Continuous maps: ε-δ definition and characterization in terms of inverse images of open (resp. closed) sets, composite of continuous maps, pointwise sums and products of continuous maps into R, homeomorphism, isometry, an isometry is a homeomorphism but not conversely, uniformly continuous maps, examples. 6. Complete metric spaces: Cauchy sequences and convergent sequences, a subspace of a completemetric space is complete if and only if it is closed, Cantor intersection theorem, Baire category theorem and its applications, completion of a metric space. 7. General topological spaces, stronger and weaker topologies, continuous maps, homeomorphisms, bases and subbases, finite products of topological spaces. 8. Basic separation axioms and first and second countability axioms. 9. Compactness for general topological spaces: Finite sub-coverings of open coverings and finite intersection property, continuous image of a compact set is compact, compactness and Hausdorff property. 10. Compactness for metric spaces: Bolzano-Weierstrass property, the Lebesgue number for an open covering, sequentially compact and totally bounded metric spaces, Heine-Borel theorem, compact subsets of R, a continuous map from a compact metric space is uniformly continuous.

	11. Connectedness: definition, continuous image of a connected set is connected, characterization in terms of continuous maps into the discrete space N, connected subsets of R, intermediate value theorem as a corollary, countable (arbitrary) union of connected sets, connected components. **References** [1] E. T. Copson, *Metric spaces.* [2] M. Eisenberg, *Topology.* [3] R.H. Kasriel, *Undergraduate topology.* [4] W. Rudin, *Principles of mathematical analysis.* [5] G. F. Simmons, *Topology and modern analysis*. [6] W. A. Sutherland, *Introduction to metric and topological spaces.*
M-404	**Discrete Mathematics** 1. Basics: Pigeonhole Principle, Elementary Counting Techniques, Permutations and Combinations, Binomial and Multinomial Theorems, Partitions, Stirling Numbers. 2. Formal Series: Formal series, Generating functions, Formal convergence, Infinite sum and products. 3. Generating Functions: Recurrences, Catalan numbers, Convolutions, Evaluating sums, Exponential formula, Partition functions, Infinite series. 4. Sieve Methods: Inclusion-Exclusion, Mobius inversion, Involution principle. 5. Enumeration of Patterns: Symmetries and patterns, Burnside's Lemma, Symmetries on R and N. 6. Partitions and Young Tableaux: An Introduction to the Combinatorics of Young Tableaux. 7. Additional Topics: Lattice Paths and Gaussian Coefficients. Infinite Matrices and Inversion of Sequences. Probability Generating Functions. Symmetric Polynomials and Functions. Schur Functions. RSK Algorithm. Hypergeometric Sums and Hypergeometric Series. **References** [1] Martin Aigner - *A Course in Enumeration.* [2] W. Fulton - *Young Tableaux.* [3] Ronald Graham, Donald Knuth, Oren Patashnik - *Concrete Mathematics.* [4] Richard Stanley - *Enumerative Combinatorics.* [5] Ioan Tomescu, Robert Melter - *Problems in Combinatorics and Graph Theory.*
M-405	**Complex Analysis** 1. Complex numbers and Riemann sphere. M¨obius transformations. 2. Analytic functions. Cauchy-Riemann conditions, harmonic functions, Elementary functions, Powerseries, Conformal mappings. 3. Contour integrals, Cauchy theorem for simply and multiply connected domains. Cauchy integralformula, Winding number. 4. Moreras theorem. Liouvilles theorem, Fundamental theorem of Algebra. 5. Zeros of an analytic function and Taylors theorem. Isolated singularities and residues, Laurentseries, Evaluation of real integrals. 6. Zeros and Poles, Argument principle, Rouchs theorem. **References** [1] L. Ahlfors, Complex Analysis. [2] R.V. Churchill and J. W. Brown, Complex Variables and Applications, International Student Edition, Mc-Graw Hill, 4th ed., 1984. [3] B. R. Palka, An Introduction to Complex Function Theory, UTM Springer-Verlag, 1991.

	[4] Donald Sarason, Notes on Complex Function Theory, HBA.
M-501	**Analysis-III (Measure and Integration)** 1. Sigma algebra of sets, measure spaces. Lebesgues outer measure on the Real line. Measurable set in the sense of Caratheodory. Translation invariance of Lebesgue measure. Existence of a non-Lebesgue measurable set. Cantor set-uncountable set with measure zero. 2. Measurable functions, types of convergence of measurable functions. The Lebesgue integral for simple functions, nonnegative measurable functions and Lebesgue integrable function, in general. 3. Convergence theorems- monotone and dominated convergence theorems. 4. Comparison of Riemann and Lebesgue integrals. Riemanns theorem on functions which are continuous almost everywhere. 5. The product measure and Fubinis theorem. 6. The L^p spaces and the norm topology. Inequalities of H¨older and Minkowski. Completeness of L^p and L^∞ spaces. **References** [1] H.L. Royden, Real Analysis, Pearson Education. [2] G. DeBarra, Introduction to Measure Theory, Van Nostrand Reinhold. [3] I. K. Rana, An Introduction to Measure and Integration, Narosa. [4] H.S. Bear, A Primer on Lebesgue Integration, Academic press.
M-502	**Algebra-III (Field Theory)** 1. Prime and maximal ideals in a commutative ring and their elementary properties. 2. Field extensions, prime fields, characteristic of a field, algebraic field extensions, finite field extensions, splitting fields, algebraic closure, separable extensions, normal extensions, 3. Finite Galois extensions, Fundamental Theorem of Galois Theory. 4. Solvability by radicals. 5. Extensions of finite fields. **References** [1] M. Artin, Algebra, Prentice Hall of India, 1994. [2] D. S. Dummit and R. M. Foote, Abstract Algebra, 2nd Ed., John Wiley, 2002. [3] N. Jacobson, Basic Algebra I & II, Hindustan Publishing Corporation, 1983. [4] R. Lidl and H. Niederreiter, Introduction to Finite Fields and Their Applications, Cambridge University Press, 1986. [5] TIFR pamphlet on Galois Theory.
M-503	**Topology-II** 1. Products and quotients. Tychonoff's theorem. Product of connected spaces is connected. Weak topology on X induced by a family of maps $f_\alpha : X \longrightarrow X_\alpha$ where each X_α is a topological space. The coherent topology on Y induced by a family of maps $g_\alpha : Y_\alpha \longrightarrow Y$ where Y_α are given topological spaces. Examples of quotients to illustrate the universal property such as embeddings of RP^2 and the Klein's bottle in R^4. 2. Completely regular spaces and its embeddings in a product of intervals. One-point compactification. 3. Normal spaces and the theorems of Urysohn and Tietze. 4. Local compactness, local connectedness and local path-connectedness and their basic properties. If $q : X \longrightarrow Y$ is a quotient map and Z is locally compact Hausdorff space then $q \times \mathrm{id} : X \times Z \longrightarrow Y \times Z$ is also a quotient map.

	5. Locally finite families of sets and Partitions of unity. Baire Category theorem for locally compact Hausdorff spaces. 6. Paths, homotopy of paths. The fundamental group and its basic properties. The fundamental group of a topological group is abelian. Homotopy of maps, retraction, deformation retraction, contractibility. Homotopy type and homotopy equivalence. Covering projections, path-lifting. The fundamental group of a product space. The fundamental group of the circle, torus, *n*-sphere, lens spaces. 7. Covering spaces, equivalence of covering spaces, deck transformation group and its action, regular covering spaces, homotopy lifting property, universal covering space, fundamental group of orbit space. **References** [1] G. F. Simmons, *Topology and modern analysis* [2] W. A. Sutherland, *Introduction to metric and topological spaces.* [3] S. Willard, *General Topology*, Dover, New York.
M-504	**Graph Theory** 1. Basics: Vertices and edges, Vertex degree and counting, Matrices and Isomorphisms, Decomposition and Special Graphs, Extremal Problems, Graphic Sequences, Travelling Salesman Problem, Koenisburg Seven-Bridges problem. 2. Paths, Cycles and Trails: Walks, Paths, Circuits, Bipartite Graphs, Eulerian Graphs, Directed Graphs, Hamiltonian Paths and circuits. 3. Trees: Basic Properties, Spanning Trees, Enumeration, Optimization and Trees. 4. Matchings and Factors: Halls Condition, Matchings in Bipartite Graphs, Applications and Algorithms, Matchings in General, Stable Matchings. 5. Connectivity and Paths: Connectivity, Edge Connectivity, Structure of 2-connected and 3connected graphs, k-connected and k-edge connected graphs, Mengers Theorem, Maders Theorem, Edge-disjoint Spanning Trees, Paths between given pair of vertices, Network Flow Problems. 6. Colouring: Vertex colourings, Structure of k-chromatic graphs, Chordal graphs, Perfect graphs, List of colourings, Counting proper colourings. 7. Planar Graphs: Plane graphs, Embeddings, Drawings, Kuratowski's Theorem, Algebraic Planarity Criteria, Plane duality. 8. Edges and Cycles: Line Graphs and Edge Colourings, Hamiltonian Cycles, Planarity, Colouring and Cycles. 9. Additional Topics: Ramsey Theory, Random Graphs, Extremal Problems. **References** [1] Douglas West - *Introduction to Graph Theory.* [2] Reinhard Diestel - *Graph Theory.* [3] J.A. Bondy and U.S.R. Murty - *Graph Theory with Applications.* [4] D.A. Marcus - *Graph Theory - A Problem Oriented Approach.* [5] Ioan Tomescu, Robert A. Melter - *Problems in Graph Theory and Combinatorics.*
M-601	**Analysis-IV (Fourier Analysis)** 1. Fourier series. Discussion of convergence of Fourier series. 2. Uniqueness of Fourier Series, Convolutions, Cesaro and Abel Summability, Fejer's theorem, Dirichlets theorem, Poisson Kernel and summability kernels. Example of a continuous function with divergent Fourier series. 3. Summability of Fourier series for functions in L^1, L^2 and L^p spaces. Fourier-transforms of integrable functions. Basic properties of Fourier transforms, Poisson summation formula, Hausdorff-Young inequality, Riesz-Thorin Interpolation theorem.

	4. Schwartz class of rapidly decreasing functions, Fourier transforms of rapidly decreasing functions, Riemann Lebesgue lemma, Fourier Inversion Theorem, Fourier transforms of Gaussians, Plancheral theorem, Paley-Weiner theorem. 5. Distributions and Fourier Transforms: Calculus of Distributions, Tempered Distributions: Fourier transforms of tempered distributions, Convolutions, Applications to PDEs. **References** [1] Y. Katznelson, Introduction to Harmonic Analysis, Dover. [2] R. E. Edwards, Fourier Series, Academic Press. [3] E. M. Stein and R. Shakarchi, Fourier Analysis: An Introduction, Princeton University Press, Princeton 2003. [4] W. Rudin, Fourier Analysis on groups, Interscience.
M-602	**Algebra-IV (Module Theory)** 1. Recollection of modules, submodules, quotient modules, homomorphisms. 2. External and internal direct sums of modules. 3. Tensor product of modules over a commutative ring. Functorial properties of $\otimes$ and Hom. 4. Definitions and elementary properties of projective and injective modules over a commutative ring. 5. Structure of finitely generated modules over a PID. Applications to matrices and linear maps overa field: Jordan and rational canonical forms. 6. Simple modules over a not necessarily commutative ring, modules of finite length, Jordan-H¨older Theorem, Schur's lemma. 7. (Optional, if time permits) Semisimple modules over a not necessarily commutative ring, Wedderburn Structure Theorem for semi-simple rings. **References** [1] M. Artin, Algebra, Prentice Hall of India, 1994. [2] D.S. Dummit and R. M. Foote, Abstract Algebra, 2nd Ed., John Wiley, 2002. [3] N. Jacobson, Basic Algebra I & II, Hindustan Publishing Corporation, 1983. [4] S. Lang, Algebra, 3rd ed. Springer (India) 2004.
M-603	**Differential Equations and Special Functions** **Module 1 – Ordinary Differential Equations** 1. Basic existence and uniqueness of systems of ordinary differential equations satisfying the Lipschitz' condition. Examples illustrating non-uniqueness when Lipschitz or other relevant conditions are dropped. Gronwall's lemma and its applications to continuity of the solutions with respect to initial conditions. Smooth dependence on initial conditions and the variational equation. Maximal interval of existence and global solutions. Proof that if (a, b) is the maximal interval of existence and $a < \infty$ then the graph of the solution must exit every compact subset of the domain on the differential equation. 2. Linear systems and fundamental systems of solutions. Wronskians and its basic properties. The Abel Liouville formula. The dimensionality of the space of solutions. Fundamental matrix. The method of variation of parameters. 3. Linear systems with constant coefficients and the structure of the solutions. Matrix exponentials and methods for computing them. Solving the in-homogeneous system. The Laplace transform and its applications.

	4. Second order scalar linear differential equations. **Module 2 – Special Functions** 1. Beta Functions, Gamma Functions, Riemann Zeta Function. 2. Series Solution for Ordinary Differential Equations, Behaviour of Solutions near Regular Points, Solutions of Bessel's Equation. 3. Theory of Orthogonal Polynomials. **References** 1. G. F. Simmons, *Differential equations with applications and historical notes*, McGraw Hill. 2. George Andrews, Richard Askey, Ranjan Roy, *Special Functions (EMSAA- 71),* Cambridge University Press. 3. Ernst Hairer, Gerhard Wanner, S.P. Norsett, *Solving Ordinary Differential Equations I – Nonstiff Problems,* Springer-Verlag. 4. V. I. Arnold, *Ordinary Differential Equations*, Springer. 5. R. Courant and D. Hilbert, *Methods of Mathematical Physics, Volume – I,* Wiley Classics Library. 6. W. Hurewicz, *Lectures on ordinary differential equations*, Dover, New York.
M-604	**Probability Theory** 1. Probability as a measure, Probability space, conditional probability, independence of events, Bayes formula. Random variables, distribution functions, expected value and variance. Standard Probability distributions: Binomial, Poisson and Normal distribution. 2. Borel-Cantelli lemmas, zero-one laws. Sequences of random variables, convergence theorems, various modes of convergence. Weak law and the strong law of large numbers. 3. Central limit theorem: DeMoivre-Laplace theorem, weak convergence, characteristic functions, inversion formula, moment generating function. 4. Random walks, Markov Chains, Recurrence and Transience. 5. Conditional Expectation, Martingales. **References** [1] Marek Capinski and Tomasz Zastawniak, Probability through Problems, Springer, Indian Reprint 2008. [2] P. Billingsley, Probability and Measure, 3rd ed., John Wiley & Sons, New York, 1995. [3] J. Rosenthal, A First Look at Rigorous Probability, World Scientific, Singapore, 2000. [4] A.N. Shiryayev, Probability, 2nd ed., Springer, New York, 1995. [5] K.L. Chung, A Course in Probability Theory, Academic Press, New York, 1974.
M-701	**Functional Analysis** 1. Normed linear spaces. Riesz lemma. Heine-Borel theorem. Continuity of linear maps. 2. Hahn-Banach extension and separation theorems. 3. Banach spaces. Subspaces, product spaces and quotient spaces. Standard examples of Banach spaces like ℓ^p, L^p, $C([0,1])$ etc. 4. Uniform boundedness principle. Closed graph theorem. Open mapping theorem. Bounded inverse theorem. 5. Spectrum of a bounded operator. Eigen spectrum. Gelfand-Mazur theorem and spectral radius formula. 6. Dual spaces. Transpose of a bounded linear map. Standard examples. 7. Hilbert spaces. Bessel inequality, Riesz-Schauder theorem, Fourier expansion, Parseval's formula.

	8. In the framework of a Hilbert space: Projection theorem. Riesz representation theorem. Uniquenessof Hahn-Banach extension. 9. Sobolev spaces. **References** [1] J.B. Conway, A course in Functional Analysis, Springer-Verlag, Berlin, 1985. [2] G. Goffman and G. Pedrick, First course in functional analysis, Prentice-Hall, 1974. [3] E. Kreyszig, Introductory Functional Analysis with applications, John Wiley & Sons, NY, 1978. [4] B.V. Limaye, Functional Analysis, 3rd ed., New Age International, New Delhi, 2014. [5] A. Taylor and D. Lay, Introduction to functional analysis, Wiley, New York, 1980.
M-702	**Commutative Algebra** 1. Prime and maximal ideals in a commutative ring, nil and Jacobson radicals, Nakayamas lemma, local rings. 2. Rings and modules of fractions, correspondence between prime ideals, localization. 3. Modules of finite length, Noetherian and Artinian modules. 4. Primary decomposition in a Noetherian module, associated primes, support of a module. 5. Graded rings and modules, Artin-Rees, Krull-intersection, 6. Hilbert-Samuel function of a local ring, dimension theory, principal ideal theorem. 7. Integral extensions, Noether's normalization lemma, Hilberts Nullstellensatz (algebraic and geometric versions). **References** [1] M.F Atiyah and I.G MacDonald, Introduction to Commutative Algebra, Addison-Wesley, 1969. [2] D. Eisenbud, Commutative Algebra with a view toward algebraic geometry, Springer-Verlag, Berlin, 2003. [3] H. Matsumura, Commutative ring theory, Cambridge Studies in Advanced Mathematics No. 8, Cambridge University Press, Cambridge, 1980. [4] S. Raghavan, B. Singh and R. Sridharan, Homological methods in commutative algebra, TIFR Math. Pamphlet No.5, Oxford, 1975. [5] B. Singh, Basic Commutative Algebra, World Scientific, 2011.
M-703	**Algebraic Topology** 1. Review of quotient spaces, connectedness, path-connectedness, compact-open topology. Examples of projective spaces, Klein's bottle, M¨obius band, $SO(n,\mathbb{R})$. Topological groups and their basic properties. Proof that if H is a connected subgroup such that G/H is also connected (as a topological space) then G is connected. 2. Free groups, free products with amalgamations. Concept of push outs in the context of topological spaces and groups. Seifert Van Kampen theorem and its applications. Fundamental group of a torus, n-sphere, lens space. Structure of fundamental group of a compact surface. 3. Introduction to Singular Homology Theory. Relation between fundamental group and first homology (also co-homology) group. Axioms of Homology Theory. 4. Degree of a map, Brouwer's fixed point theorem, Fundamental Theorem of Algebra, Borsuk-Ulamtheorem. 5. Simplices and simplicial complexes, simplicial maps. CW-complexes. Geometric complexes and orientation. Simplicial Approximation Theorem. Chain complexes and homology groups. Examples and structure of simplicial homology groups. Induced homomorphisms of homology groups and applications. Euler - P¨oincare

	Theorem. Relative homology groups. Identification of simplicial and singular homology. **References** [1] F.H. Croom, *Basic Concepts of Algebraic Topology*, **UTM**, Springer-Verlag, 1978. [2] A. Hatcher, Algebraic Topology, Cambridge, 2001. [3] C. Kosniowski, *A First Course in Algebraic Topology*, Cambridge University Press, 1980. [4] L. Lima, *Fundamental Groups and Covering Spaces*, A. K. Peters, 2003. [5] W.S. Massey, *A Basic Course in Algebraic Topology.*, **GTM-127**, Springer-Verlag, 1991. [6] J.R. Munkres, *Topology (Second Edition)*, Prentice Hall, 2000.
M-704	**Differential Geometry and Applications** 1. Curvature of curves in E^n: Parametrized Curves, Existence of Arc length parametrization, Curvature of plane curves, Frennet-Serret theory of (arc-length parametrized) curves in E^3, Curvature of (arc-length parametrized) curves in E^n, Curvature theory for parametrized curves in E^n. Significance of the sign of curvature, Rigidity of curves in E^n. 2. Euler's Theory of curves on Surfaces: Surface patches and local coordinates, Examples of surfaces in E^3, curves on a surface, tangents to the surface at a point, Vector fields along curves, Parallel vector fields, vector fields on surfaces, normal vector fields, the First Fundamental form, Normal curvature of curves on a surface, Geodesics, geodesic Curvature, Christoffel symbols, Gauss' formula, Principal Curvatures, Euler's theorem. 3. Gauss' theory of Curvature of Surfaces: The Second Fundamental Form, Weingarten map andthe Shape operator, Gaussian Curvature, Gauss' *Theorema Egregium*, Guass-Codazzi equations, Computation of First/Second fundamental form, curvature etc. for surfaces of revolution and other examples. 4. More Surface theory: Mean Curvature and Minimal Surfaces (introduction), surfaces of constant curvature, Geodesic coordinates, Notion of orientation, examples of non-orientable surfaces, Euler characteristic, statement of Gauss-Bonnet Theorem. 5. Modern Perspective on Surfaces: Tangent planes, Riemannian metrics on surfaces. **References** [1] Elementary Differential Geometry: Andrew Pressley, Springer Undergraduate Mathematics Series. [2] Elementary Differential Geometry: J. Thorpe, Elsevier. [3] Differential Geometry of Curves and Surfaces: M. do Carmo. [4] Elements of Differential Geometry: R. Millman & G. Parker.
M-801	**Partial Differential Equations** 1. Generalities on the origins of partial differential equations. Generalities on the Cauchy problem for a scalar linear equation of arbitrary order. The concept of characteristics. The Cauchy-Kowalevskya theorem and the Holmgren's uniqueness theorem. The fundamental equations of mathematical physics as paradigms for the study of Elliptic, Hyperbolic and Parabolic equations. 2. Quasilinear first order scalar partial differential equations and the method of characteristics. Detailed discussion of the inviscid Burger's equation illustrating the formation of discontinuities in finite time. The fully nonlinear scalar equation and Eikonal equation. The Hamilton-Jacobi equation.

	3. Detailed analysis of the Laplace and Poisson's equations. Green's function for the Laplacian and its basic properties. Integral representation of solutions and its consequences such as the analyticity of solutions. The mean value property for harmonic functions and maximum principles. Harnack inequality. 4. The wave equation and the Cauchy problem for the wave equation. The Euler-Poisson-Darboux equation and integral representation for the wave equation in dimensions two and three. Properties of solutions such as finite speed of propagation. Domain of dependence and domain of influence. 5. The Cauchy problem for the heat equation and the integral representation for the solutions of the Cauchy problem for Cauchy data satisfying suitable growth restrictions. Infinite speed of propagation of signals. Example of non-uniqueness. 6. Fourier methods for solving initial boundary value problems.
M-802	**Algebraic Number Theory** 1. Field extensions and examples of field extensions of rational numbers, real numbers and complex numbers. Monic polynomials, Integral extensions, Minimal polynomial, Characteristic polynomial. 2. Integral closure and examples of rings which are integrally closed. Examples of rings which are not integrally closed. The ring of integers. The ring of Gaussian integers. Quadratic extensions and description of the ring of integers in quadratic number fields. 3. Units in quadratic number fields and relations to continued fractions, connections with quadratic forms. 4. Noetherian rings, Rings of dimension one. Dedekind domains. Norms and traces. Derive formulae relating norms and traces for towers of field extensions. 5. Discriminant and calculations of the discriminant in the special context of quadratic number fields. Different and it's applications. 6. Cyclotomic extensions and calculation of the discriminant in this case. Factorization of ideals into prime ideals and its relation to the discriminant. 7. Ramification theory, residual degree and its relation to the degree of the extension. Ramified primes in quadratic number fields. 8. (Optional, if time permits) Ideal class group. Geometric ideas involving volumes. Minkowski's theorem and its application to proving finiteness of the ideal class group. 9. (Optional, if time permits) Real and complex embeddings. Structure of finitely generated abelian groups. Dirichlet's Unit Theorem and the rank of the group of units. Discrete valuation rings, Local fields. **References** [1] G.J. Janusz, Algebraic Number Fields, Second Edition, AMS, 1996. [2] J. Neukirch, Algebraic Number Theory, Springer, 2013. [3] D.A. Marcus, Number Fields, Springer, 2013. [4] P. Samuel, Algebraic Theory of Numbers, Dover, 2008. [5] TIFR pamphlet on Algebraic Number Theory, 1966.
M-803	**Differential Topology** 1. Differentiable functions on R^n: Review of differentiable functions $f: R^n \to R^m$, Implicit and Inverse function theorems, Immersions and Submersions, critical points, critical and regular values. 2. Manifolds: Level sets, sub-manifolds of R^n, immersed and embedded sub-manifolds, tangent spaces, differentiable functions between sub-manifolds of R^n, abstract differential manifolds and tangent spaces.

	3. Differentiable functions on Manifolds: Differentiable functions $f : M \to N$, critical points, Sard's theorem, non-degenerate critical points, Morse Lemma, Manifolds with boundary, Brouwer fixed point theorem, *mod 2* degree of a mapping. 4. Transversality: Orientation of Manifolds, oriented intersection number, Brouwer degree, transverse intersections. 5. Integration on Manifolds: Vector field and Differential forms, integration of forms, Stokes' theorem, exact and closed forms, Poincar Lemma, Introduction to de Rham theory. **References** [1] Topology from a Differentiable Viewpoint: J. Milnor. [2] Differential Topology: V. Guellemin & A. Pollack. [3] Differential Topology: M. Hirsch.
M-804	**Computational Mathematics** **Objective:** Learning basics of python programming language and using it to learn the open-source computer algebra system SAGE. Furthermore, using SAGE to explore symbolic and numerical computations in toics such as calculus, Linear Algebra, Group-Theory and Number-Theory, etc. **Module I: Python Programming** 1. Introduction to python, basic operations, data types, use of 'math' and 'cmath' modules to do basic computations. 2. Decision making (if-else) and loops 3. Creating user defined functions and modules 4. Lists, tuples, dictionaries and strings 5. Plotting graphs in various forms using 'matplotlib' 6. Reading and writing data in files 7. Brief introduction to python classes 8. Numerical computations in python using **numpy**, **scipy** and **sympy** packages. 9. Developing python programmes to solve problems in numerical analysis. **Module II: Numerical and Symbolic computations with SAGE** 1. Introduction to SAGE, using SAGE as an advanced calculator 2. Plotting graphs of 2d and 3d objects in various forms 3. Use of SAGE to explore calculus of single and multi-variables 4. Use of SAGE to explore row transformations, linear transformations, Gram-Schmidt process, application of matrix diagonalization, matrix factorizations with applications to least square problems and image processing etc. 5. Use of SAGE to explore concepts in Group-Theory, Number-Theory and Combinatorics. **References** [1] Learning Python, Mark Lutz, Orielly Publication [2] A Premier on Scientific Programming with Python, Hand Peter langtangen, Springer [3] Numerical Methods in Engineering with Python, Jaan Kiusalaas, Cambridge [4] Calculus with Sage, Sang-Gu Lee, Ajit Kumar and other, Kyongmoon Publication [5] A First Course in Linear Algebra, Robert Beezer, a free online textbook availableon http://linear.ups.edu/ [6] Linear Algebra with Sage, Sang-Gu Lee, Ajit Kumar and other, a free online available at http://matrix.skku.ac.kr/2015-Album/Big-Book-LinearAlgebra-Eng-2015.pdf [7] Numerical Analysis Using Sage, Anastassiou, George A., Mezei, Razvan, Springer [8] Richard Stanley, Enumerative Combinatorics, Vol 2, Cambridge, 2001.

MPr-701	To be assigned by the Supervisor
MPr-801	To be assigned by the Supervisor
MPr-901	To be assigned by the Supervisor
MPr-1001	To be assigned by the Supervisor
P-101	**PHYSICS-I (Classical Physics)** **Mechanics:** Review of concepts of energy, mass, momentum; Newton's laws - illustrations from real life; Conservative forces, Friction; One-dimensional random walk and locomotion of micro-organisms. (**6 hours**) **Electricity and magnetism:** Electrostatics, electric fields for various charge configurations, Gauss' law for electric fields; Moving charges, magnetic field, Gauss' law for magnetic fields; Faraday's law; The Ampere-Maxwell law. (**8 hours**) **Electromagnetism and Optics:** Fermat's principle of least time; Electromagnetic waves and dipole radiation – qualitative ideas without using calculus; Interference of two dipole radiators (qualitative discussion); Diffraction, diffraction grating, resolving power of grating, coloured films, crystals, opaque screen; Origin of refractive index, energy carried by an electric wave; Scattering of light; Polarization; Colour vision and its mechanism. **(14 hours)** **References** 1. The Feynman Lectures on Physics, vol. I, R. P. Feynman, R. B. Leighton, and Matthew Sands (Pearson, 2012). 2. Electricity and Magnetism (Berkeley Physics Course volume 2), E. M. Purcell (McGraw Hill, 2017). 3. Mechanics, waves, and thermodynamics: an example-based approach, Sudhir R. Jain (Cambridge Univ. Press, 2016). 4. Physics – Structure and Meaning, Leon N. Cooper (Brown Univ. Press, 1992). 5. Principles and Practice of Physics, Eric Mazur (Pearson, 2015).
P-201	**PHYSICS-II (Modern Physics)** **Review of classical physics and its limits**: the equipartition theorem, degrees of freedom, specific heat, Blackbody radiation, Photoelectric effect, Compton effect, Electron interference and diffraction (double slit experiment with electrons and Davisson-Germier experiment). Wavelike properties of particles, de Broglie hypothesis, wave packets, uncertainty relation, bedarken experiment with Heisenberg microscope for measurement of electron position **(5 hours**) **Elementary Quantum Mechanics**: Schrödinger wave equation and its heuristic derivation, operators, eigenvalues and eigen-functions, wave function and its probabilistic interpretation, superposition of eigenstates, collapse of wave function. Simple one-dimensional problems: Particle in a box, finite square well, bound and unbound states, potential step, transmission and reflection coefficients, Potential barrier, tunneling phenomena with examples (alpha decay, scanning tunneling microscope), 1 dimensional harmonic oscillator, estimate of ground state energy using uncertainty principle, generalization to 2 and 3 dimensions, concept of degeneracy. Brief overview of hydrogen atom problem, Bohr's model of atom and atomic spectra, intrinsic spin.

	Franck-Hertz experiment, energy levels and spectroscopic notation, hydrogen fine structure and Zeeman effect (no detailed derivation) **(10 hours**) **Elements of Statistical Physics**: Microscopic and macroscopic variables, classical phase space, distribution of molecular velocities, Maxwell-Boltzmann statistics, indistinguishable particles, Fermi Dirac and Bose Einstein statistics, applications of quantum statistics (**4 hours**) **Elements of Solid-State Physics**: Free electron theory, Drude and Sommerfeld models of specific heat, introduction to Fermi energy, Fermi velocity, Fermi temperature, concepts of density of states, electrons in periodic potential, Bloch theorem, Krönig-Penny model (no derivation), Band theory of solids, metals, semiconductors and insulators, intrinsic and extrinsic semiconductors, concept of holes, elementary semiconductor devices. (**5 hours**) **Nuclear Physics**: Structure of nuclei and their stability, Binding energy curve, Shell model, nuclear transformations (alpha, beta and gamma decay, nuclear reactions, cross sections, Fusion and Fission, Energy of stars. (**4 hours**) **References** 1. H. S. Mani and G. K. Mehta, Introduction to Modern Physics, Affiliated East-West Press (2000). 2. R. Eisberg and R. Resnick, "Quantum Physics of Atoms, Molecules, Solids, Nuclei and Particles", Wiley (2nd Edition, 2006). 3. Arthur Beiser, Shobit Mahajan and S. Rai Chaudhury, "Concepts in Modern Physics", McGraw Hill Education (7th Edition, 2017). 4. P. A Tipler and R. Liewellyn, "Modern Physics", W. H. Freeman & Co. (6th Edition 2012). 5. K. S. Krane, "Introductory Modern Physics", Wiley (2008).
P-301	**Classical Mechanics-I** **Recap:** Newton's laws, vector algebra, gradient; momentum, energy, constraints, conservative forces, potential energy, angular momentum. Inertial and non - inertial frames, fictitious forces, Foucault pendulum, effects of Coriolis force. Central forces, conservation of energy and angular momentum, trajectories, orbits, 1/r potential (quadrature), classical scattering, two body problem, centre of mass and relative motions. Rigid body motion, moment of inertia tensor, energy and angular momentum, Euler's theorem, motion of tops, gyroscope, motion of the Earth. Introduction to Lagrangian through variational principle, applications of variational principle. **Relativity:** Historical background, inconsistency of electrodynamics with Galilean relativity. Einstein's hypothesis and Lorentz transformation formula, length contraction, time dilation, Doppler shift. Energy, momentum and mass, mass - energy equivalence. Four vector notations, consistency of electrodynamics with relativity. **References** [1] An Introduction to Mechanics, 1st Edition, D. Kleppner and R. J. Kolenkow, Tata McGraw - Hill Education, 2007 [2] Classical Mechanics, 5th Edition, T. W. B. Kibble, F. Berkshire, World Scientific 2004. [3] Introduction to Special Relativity, R. Resnik, Wiley (India), 2012 [4] Spacetime Physics, 2nd Edition, E. F. Taylor, J. A. Wheeler, W. H. Freeman and Co. 1992. Classical mechanics, N. C. Rana, P. S. Joag, Tata McGraw-Hill Education, 2001.
P-302	**Mathematical Physics-I** **Vector Analysis**: Vector algebra, Basis vectors, Linear independence, Scalar product, Cross product, Triple products

	Partial derivatives, Curvilinear coordinates (cylindrical and spherical polar), Vectors as derivatives, Gradient, Divergence, Curl, Laplacian – all in Cartesian, cylindrical and spherical polar coordinates Vector integration, line, surface, volume integrals, Green's theorem, Stokes' theorem, Gauss divergence theorem **Differential equations:** Real analytic functions, Revision of first-order differential equations, Ordinary differential equations with constant coefficients, equidimensional equations, Riccati equations, Applications **Tensors:** Coordinate system transformations, Basis-vector transformations, Basis-vector vs. component transformations, non-orthogonal coordinate systems, Dual basis vectors, finding covariant and contravariant components, Index notation, quantities that transform covariantly or contravariantly **References** 1. "About vectors", Banesh Hoffmann (Dover, London, 1975) 2. "Vector analysis", Second Edition, M. R. Spiegel, S. Lipschutz, D. Spellman (Tata McGraw-Hill, New Delhi, 2010). 3. "A Student's Guide to Vectors and Tensors", D. Fleisch (Cambridge Univ. Press, New Delhi, 2013). 4. "Differential equations with applications and historical notes", G. F. Simmons (McGraw-Hill, New Delhi, 1980).
P-303	**Electromagnetism-I** **Review of Vector calculus:** gradient, curl, divergence and Laplacian; Cartesian, spherical polar and cylindrical coordinates; volume and surface integrals, divergence theorem, Stoke's theorem. **Electrostatics:** superposition principle for continuous charge distribution, Gauss's law in integral and differential form, electric potential, energy of electrostatic field, Poisson's and Laplace's equations, properties of conductors, method of images, polarization and bound charges, vectors **D** and **P**. **Magnetostatics:** Lorentz force, Ampere's and Biot-Savart's law, divergence and curl of **B**, vector potential and concept of gauge, charged particle in electromagnetic field; magnetism in matter, volume and surface currents, magnetization vector **M** and vector **H**. Faraday's law in integral and differential forms; displacement current, Maxwell's equations. Electromagnetic waves, Poynting vector, radiation pressure. **References** 1. "Introduction to Electrodynamics", D. J. Griffiths, 4th Edition, Pearson India (2017). 2. "Foundations of Electromagnetic Theory", J. Reitz, F. J. Milford and R. W. Christie, 4th Edition, Addison Wesley (2008). 3. "Electricity and Magnetism: Berkeley Physics Course, Vol. II", Edward Purcell, McGraw Hill (2011).
P-304	**Waves, Oscillations and Optics** Free oscillations, Simple harmonic motion, damped and forced oscillations; Coupled oscillators, normal modes, beats, infinite coupled oscillators and dispersion relation of sound; vibrating string; travelling and stationary waves; Amplitude, phase and energy. Derivation of wave equation for a string; Longitudinal and transverse waves.

	Waves in two and three dimensions, the wave vector, wave equation, linearity, superposition, Fourier decomposition of a wave, notion of wave packets, phase and group velocity. Example of mechanical waves (sound waves), speed of sound in air, effect of bubbles, natural observations and qualitative explanations, string and wind instruments. Chaldni plates. Propagation in changing media, continuity conditions, characteristic impedance. Snell's laws and translation invariant boundary, prism, total internal reflection, evanescent waves. Water waves, ocean waves, Tsunami. Electromagnetic waves, polarisation, interference, Fraunhofer diffraction. Shocks waves, boat wakes, linear analysis of the Kelvin wake. Alfven waves (qualitative). **References** 1. Waves, Berkeley Physics Course Vol. 3, Frank S. Crawford, Tata McGraw – Hill Education, 2011 2. Introduction to the Physics of Waves, Tim Freegarde, Cambridge Univ. Press 2012 3. The Physics of Waves, Howard Georgi (http://www.people.fas.harvard.edu/~hgeorgi/new.htm)
P-401	**Mathematical Physics-II** **Linear vector space:** Definition, Scalar product, Dual vectors and Cauchy - Schwarz inequality, Real and complex vector spaces, Metric spaces, linear operators, Algebra of linear operators, Some special operators (adjoint, Hermitian, unitary etc.), Eigenvalues and eigenvectors, Orthogonalization theorem, N-dimensional vector space, Matrix algebra, Inverse of a matrix, Change of basis in N-dimensional vector space, Orthogonal bases and some special matrices, Introduction to tensor calculus, Invariant subspaces, The characteristic equation and Hamilton-Cayley theorem, The decomposition of an N-dimensional space, The canonical form of a matrix, Hermitian matrices and quadratic forms **Differential equations:** Second-order Differential equations, classification of singularities, Series solution, Frobenius method with all cases studied, local analysis, applications to equations leading to Special functions (Airy function, Bessel functions), Introduction to asymptotic methods for the case of equations with irregular singular points **Partial differential equations:** General theory for the first-order equation, classification of second-order equations, method of characteristics, Fundamental solutions of Laplace equation, Helmholtz equation, and heat equation, Boundary-value problems, Green functions **References** 1. “Advanced mathematical methods for scientists and engineers”, C. M. Bender and S. A. Orszag (Springer, Heidelberg, 1978). 2. “Mathematical methods for physicists”, G. B. Arfken, H. J. Weber, F. E. Harris (Academic Press, New Delhi, 2013). 3. “Special functions”, G. E. Andrews, R. Askey, R. Roy (Cambridge Univ. Press, New Delhi, 2000). 4. “Mathematics for Physicists”, Philippe Dennery and Andre Krzywicki (Dover, London, 1996). 5. “Mathematics for Quantum Mechanics: An introductory Survey of Operators, Eigenvalues and Linear Vector Spaces”, J. D. Jackson (Dover, London, 1990). 6. “Methods in Theoretical Physics”, vols 1 and 2, P. M. Morse and H. Feshbach (McGraw-Hill, New York, 1953). 7. “Introduction to Matrices and Linear Transformations”, D. T. Finkbeiner (W. H. Freeman, 1978).

P-402	**Quantum Mechanics-I** Review of introductory wave mechanical formalism, simple one-dimensional potential problems: particle in an infinite potential well, delta function potential, a finite potential well, potential barrier and tunneling, motion of a wave packet. Mathematical preliminaries, linear algebra, Hilbert space, observables, Dirac notation, Schrödinger and Heisenberg pictures. Linear harmonic oscillator, wave mechanical solution, Hermite polynomials, algebraic method, ladder operators. Central force, orbital angular momentum, intrinsic spin angular momentum, angular momentum algebra, raising and lowering operators. Hydrogen atom, reduction to one body problem, reduced mass, energy spectrum and wavefunctions. Addition of angular momenta, Clebsch Gordan coefficients, spherical tensors, Wigner-Eckart Theorem. **References** 1. "Introduction to Quantum Mechanics" D. J. Griffiths, 2nd Edition, Pearson Education (2005). 2. "Principles of Quantum Mechanics", R. Shankar, 2nd Edition, Springer (2010).
P-403	**Classical Mechanics-II** Principle of virtual work, d'Alembert's principle, Degrees of freedom, Generalized coordinates, Lagrange's equation of motion, Ignorable coordinates. Principle of least action and Hamilton's principle, Derivation of Euler Lagrange equation. Symmetry and conservation laws, Noether's theorem, generalized momenta, energy function, gauge freedom of Lagrangian. Systems with constraints, Lagrange multipliers, generalized forces. Electromagnetic Lagrangian. Small oscillations and normal modes, matrix formulation of coupled oscillator problems, damped and forced oscillations, Rayleigh's dissipation function. Hamiltonian formalism, derivation of Hamilton's equations motion, particle in an electromagnetic field. Phase space flow in second order autonomous systems, special case of Hamiltonian systems, comparison to incompressible fluids, examples of Hamiltonian phase space flows, elliptic and hyperbolic fixed points. Canonical transformations, different types of generating functions, simplectic criterion, infinitesimal canonical transformations, generators, Poisson's brackets, Jacobi identity, phase space volume conservation, Liouville's theorem. Hamilton Jacobi equation, discussion of quantum to classical limit. **References** 1. "A course in Theoretical Physics, Vol. 1, Mechanics", L. D. Landau and E. M. Lifshitz, Elsevier (Indian Reprint, 2010)

	2. “Classical Mechanics”, H. Goldstein, C. Poole and J. Safco, 3rd Edition, Addition Wesley (Pearson Edition, 2011). 3. “Classical Mechanics”, N. C. Rana and P. S. Jog, Tata McGraw Hill (1991).
P-501	**Electromagnetism-II** Topics in Electrostatics: Solutions of Poisson and Laplace’s equations, Uniqueness theorem, formal solution of boundary value problems with Green’s function, method of images with conducting sphere, solution of Laplace’s equation in Cartesian, spherical and cylindrical coordinates using separation of variables, Multipole expansion of potential due to a charge distribution, boundary value problems with dielectrics, molecular polarizability, Clausius-Mossotti relation. Maxwell’s equations, scalar and vector potentials, gauge transformations, Lorentz and Coulomb gauge, Stress tensor and conservation laws, Electromagnetic waves, reflection and refraction of electromagnetic waves at interface between dielectrics, Fresnel equations; electromagnetic waves in conductors, skin depth. Rectangular Wave Guides, TE and TM modes; resonant cavity. Radiation theory: electric and magnetic dipole radiation, power radiated by a point charge, radiation reaction. Electrodynamics and relativity, transformation of electromagnetic fields, field tensors, relativistic potentials, field of a moving charge, retarded and advanced potentials. **References** 1. “Introduction to Electrodynamics”, D. J. Griffiths, 4th Edition, Pearson India (2017). 2. “Classical Electrodynamics”, J. D. Jackson, 3rd Edition, Wiley (2016). 3. “Classical Electricity and Magnetism”, W. K. H. Panofsky and M. Phillips, 2nd Edition, Sarat Book House (2006).
P-502	**Quantum Mechanics-II** Approximation methods in quantum mechanics : Time independent perturbation theory, non-degenerate and degenerate perturbation, fine structure of hydrogen atom;, Zeeman effect, Stark effect; Time dependent perturbation theory, Schrödinger, Heisenberg and interaction pictures, harmonic perturbations, sudden approximations, Fermi’s Golden rule, second order transitions, two level systems, Rabi oscillation, semi-classical radiation theory; Variational principle, ground state of helium atom, adiabatic approximation, Berry’s phase, Aharonov Bohm effect; WKB approximation. Identical Particles, classical case, symmetric and antisymmetric states, bosons and fermions. Scattering theory, Green’s function, Born approximation. Density matrix formulation of quantum mechanics. EPR paradox, Bell’s inequalities. Dirac equation: free particle Dirac equation, negative energy solutions, antiparticles, Dirac equation for hydrogen atom, hydrogen fine structure (qualitative). **References** 1. “Introduction to Quantum Mechanics”, D. J. Griffiths, 2nd Edition, Pearson Education (2005). 2. “Principles of Quantum Mechanics”, R. Shankar, 2nd Edition, Springer (2010). 3. “Quantum Mechanics”, E. Merzbacher, 3rd Edition, John Wiley (2003).

P-503	**Statistical Physics-I** Elementary probability theory; random walk; binomial, Poisson, log-normal distributions; the Gaussian. Brief Review of the Laws of Thermodynamics. Kinetic theory of dilute gases in equilibrium. Introduction to Ensembles; micro-canonical ensemble; canonical ensemble, grand canonical ensemble. Canonical Ensemble. calculation of thermodynamic quantities; Gibbs paradox; the equipartition theorem; Harmonic Oscillator, two level system and paramagnetism. Energy, density fluctuations, Validity of the classical approximation. Identical particles and symmetry; quantum distribution functions; Bose-Einstein statistics; Fermi-Dirac statistics. The free electron gas – heat capacity and Pauli paramagnetism; Bose Einstein Condensation. Interacting systems: Equation of State of the non-ideal gas and virial coefficients; Weiss molecular field approximation. Black body radiation and the Planck radiation law **References** 1. "Fundamentals of Statistical and Thermal Physics", F. Reif, Sarat Book Distributors (2010) 2. "Statistical Mechanics", 3rd Edition, by R. K. Pathria and Paul D. Beale, Elsevier (2011) 3. "Elementary Statistical Physics", C. Kittel, Dover publications (2004) 4. "Thermodynamics and an Introduction to Thermo-statistics", 2nd Edition, H. B. Callen, Wiley (2006)
P-601	**Nuclear Physics** **Nuclear Properties:** Size – nuclear radius, charge distribution, matter distribution. Mass- binding energy, liquid drop model/mass formula. Spin, Parity, isospin. Electromagnetic moments- magnetic dipole and electric quadrupole moments/nuclear shapes. Nuclear stability, alpha, beta, gamma decays, fission. Experimental methods for size, mass, spin, moments to be included. **Nuclear Forces:** Nuclear interaction, saturation of nuclear density, constancy of binding energy per nucleon. Bound two nucleon system, Deuteron problem, absence of bound pp, nn. N-N scattering – as a function of energy, phase shift, cross section. Salient features of nuclear force. Yukawa's theory of nuclear interaction (basics). **Nuclear Structure:** Magic numbers, shell model, spin orbit interaction, deformed shell model. Nuclear excited states vibration, rotation, Collective model. Electromagnetic interactions in nuclei: multipole transitions, selection rules, life times, electron capture, internal conversion, isomers, Coulomb excitation. **Nuclear Reactions:** Kinematics, Q value, excitation energy, conservation laws, cross section, mean free path. Types of nuclear reactions, experimental observables, excitation function, angular distribution, spectra. Compound nuclear reactions, Resonances, level density, temperature, Bohr model. Direct nuclear reactions, optical model, pick up and stripping reactions, spectroscopic factor Nuclear fission and fusion reactions. **References** 1. Introductory Nuclear Physics, K.S. Krane, Wiley 2008. 2. Concepts of Nuclear Physics, B. L. Cohen, McGraw Hill 1971. 3. Introductory Nuclear Physics, S. S. M. Wong, Prentice – Hall 2010. 4. Introduction to Nuclear and Particle Physics, 2nd Edition, A. Das and T. Ferbel, World Scientific 2004.

P-602	**Condensed Matter Physics-I** **Crystal Structure and X-ray diffraction:** Bravais lattices, space groups, reciprocal space, Brillouin zones, X-ray diffraction, structure factor, Diffraction of waves in periodic structures. **Lattice Vibrations:** Thermal properties: Einstein's and Debye's theories of specific heats of solids, thermal expansion and thermal conductivity, quantization of lattice vibrations, phonons. **The Free Electron Theory:** Drude Model: Electron conductivity, Heat capacity, Somerfield model: Thermal conductivity, AC conductivity and optical properties. **Band theory of solids**: Bloch theorem, Kronig-Penny model, Nearly Free electron model, effective mass, Tight binding model, Density of states, Fermi surface; Metals, insulators and semiconductors, Intrinsic and extrinsic semiconductors, energy gap, mobility, electrons and holes, Hall effect and cyclotron resonance, carrier lifetime, semiconductor devices. **Magnetic properties of materials:** dia, para and ferromagnetism. Quantum theory of paramagnetism, Curie's law. Ferromagnetism, exchange interactions, Heisenberg and Ising models, magnetic ordering and spin waves, anti-ferromagnets. **Superconductivity:** Introduction and important properties, Type-I and type-II superconductors, Electrodynamics of superconductivity: London's equation, Thermodynamics of the transition, Flux Quantization, Cooper pairs, BCS theory (qualitative), Josephson effect. **References** 1. Introduction to Solid State Physics, 8th edition, C. Kittel, Wiley (2012). 2. Solid State Physics, N. W. Ashcroft and N. D. Mermin, Cengage (2003).
P-603	**Atomic and Molecular Physics** **Many – electron atoms:** One – electron wavefunctions and energies in Coulomb potential (revision); Atomic orbitals, spin – orbit coupling, Thomas precession, fine structure; Alkali atoms; Helium ground state and excited states, direct and exchange integrals; Many – electron atoms: LS and jj coupling schemes; Hartree – Fock method; Pauli's principle and the Periodic Table; Nuclear spin and hyperfine structure. **Atoms in External Fields:** Quantum theory of normal and anomalous Zeeman effect, Linear and quadratic Start effect; Semi – classical theory of radiation; Absorption and induced emission; Einstein's A and B coefficients, dipole approximation, intensity of radiation, selection rules. Two level atoms in a coherent radiation field, Rabi frequency, radiative damping, optical Bloch equation, Broadening of spectral lines (Doppler, pressure and power broadening). **Lasers:** Basic concepts, rate equation and lasing conditions, working of some common lasers. Doppler free laser spectroscopy; Crossed – beam method, saturated absorption spectroscopy, two photon spectroscopy, Laser cooling and trapping (descriptive); Atom interferometry (descriptive). **Molecules:** Ionic and covalent bonding, Hydrogen molecular ion (H_2^+), Born – Oppenheimer approximation; Bonding and anti – bonding orbitals, Hydrogen molecule; Heitler – London method, Molecular orbital method, hybridisation, quantum mechanical

	treatment of rotational and vibrational spectra (diatomic and polyatomic molecules); Electronic spectra, Raman effect (classical and quantum theory); Vibrational and rotational Raman spectra; Electron spin resonance. **References** 1. Atomic Physics, Christopher Foot, Oxford University Press, 2005. 2. Intermediate Quantum Mechanics, 3rd Edition, H. A. Bethe and R. W. Jackiew, Persius 1997 3. The Physics of Atoms and Quanta: Introduction to Experiments and Theory, H. Haken, H. C. Wolf and W. D. Brewer, Springer 2005 4. Molecular Physics and Elements of Quantum Chemistry: Introduction to Experiments and Theory, H. Haken, H. C. Wolf and W. D. Brewer, Springer 2010.
P-604	**Mathematical Physics-III** **Complex analysis**: Elementary functions, stereographic projection, limits, continuity, complex differentiation, Analytic functions, Cauchy-Riemann equations, Multi-valued functions and Riemann surfaces, Complex integration, Cauchy's theorem, Cauchy's integral formula, Liouville theorem, Morera theorem, Maximum-modulus theorem, singularities of complex functions, Cauchy residue theorem, Principal value integrals, Rouché's theorem, Contour integration, Fourier and Laplace transforms **Fourier series** and its applications **Calculus of variations:** Fundamental ideas illustrated by problems involving shortest distances, brachistochrone, surfaces of revolution of minimum area, Weierstrass, Legendre, and Jacobi conditions, Envelope theorem, Euler-Lagrange equations, Connection of eigenvalue problems and Calculus of variations, Functional derivative **References** 1. "Complex variables: Introduction and applications", M. J. Ablowitz and A. S. Fokas (Cambridge University Press, New Delhi, 1997). 2. "Complex analysis", L. V. Ahlfors (McGraw-Hill, New Delhi, 2013). 3. "Integral transforms in mathematical physics", C. J. Tranter (Metheun, London, 1966). 4. "An elementary treatise on Fourier series", W. E. Byerley (Ginn and company, Boston, 1893). 5. "Calculus of variations", G. A. Bliss (Carus monographs, Mathematical Association of America, 1978). 6. "Mathematical methods of Physics", J. Mathew and R. L. Walker (Benjamin Cummings, Mumbai, 1979).
P-701	**Fluid Mechanics** Validity of hydrodynamical description. Kinematics of the flow field. Stress-strain relationship. Basic equations governing conservation of mass, momentum & energy. Navier-Stokes equation for viscous flows. Shear and bulk viscosity and radiative diffusivity in fluids. Viscous and thermal boundary layers. Potential flows. Water waves. Kelvin's circulation theorem. Stokes's flow Lubrication theory. Virial theorem in the tensor form. Magnetohydrodynamic flows. Generalized Ohm's law in the presence of Hall current &Ambipolar diffusion. Magneto-gravity-acoustic modes. Classical hydrodynamic and hydromagnetic linear stability problems: Rayleigh-Taylor and Kelvin-Helmholtz instabilities. Jeans' gravitational instability; Benard convection. Parker instability and magnetic buoyancy. Thermal instability. Non-linear Benard problem. Spherical accretion flows onto compact objects and accretion disks. High Speed flow of gases. Shock waves and blast waves. Supernova hydrodynamics. Physiological hydrodynamics. Blood flow in human heart.

	References 1. Hydrodynamics, 6th Edition, H. Lamb, Dover 1945. 2. An Introduction to Fluid Dynamics, G.K. Batchelor, Cambridge University Press, 2000. 3. Fluid Mechanics, 2nd Edition, L.D. Landau and E.M. Lifshitz, Elsevier 1987. 4. Magnetohydrodynamics, 2nd Edition, T.G. Cowling, Hilger 1976. 5. Introduction to Physics of Fluids and Solids, J. Trefil, Dover 1975.
P-702	**Statistical Physics-II** **Critical Phenomena:** Phase transitions in different systems, First and second order transitions, Lattice models to describe phase transitions such as Ising Models, X-Y and Heisenberg models, critical exponents. **Techniques**: 1) Mean Field Theory: Mean Field Theory for Ising model, Landau theory of second order phase transitions, Correlation functionsp; 2) Transfer matrix: Setting up the transfer matrix, Calculation of free energy and correlation functions Transport theory using the relaxation time approximation; Boltzmann differential equation formulation; examples of the Boltzmann equation method Diffusion equation; Einstein relation and the Langevin derivation. Fluctuation-Dissipation theorem. Semiconductor Statistics **Optional**: Renormalization Group: Scale invariance and scaling hypothesis. universality, scaling and critical exponents. Block spins and the Kadanoff construction, Application to 1D Ising model. 2D Ising model, Peierls criterion. Introduction to Monte-Carlo Methods in statistical mechanics; Metropolis algorithm; Gilespie method. **References** 1. "Fundamentals of Statistical and Thermal Physics", F. Reif, Sarat Book Distributors (2010). 2. "Statistical Physics part 1", 3rd Edition, L. D. Landau and E. M. Lifshitz, Elsevier (2008). 3. "Statistical Mechanics", K. Huang, John Wiley & Sons (1987). 4. "A Modern Course in Statistical Physics", L. E. Reichl, Wiley (2009).
P-703	**Condensed Matter Physics-II** **Introduction to many-body theory:** Second quantization and its application to free particle theory. **Correlated systems and interactions*:*** The electron gas: Hartree-Fock and Random phase approximation, Hubbard model: basic features, The Mott transition. **Response theory:** Fluctuation-dissipation theorem, Linear response, Kubo formula **Superconductivity and superfluidity:** Ginzburg Landau theory, BCS theory, Bogoliubov transformation, Boundary between normal metal and superconductor, Andreev Reflection and Proximity effect. **Magnetism:** Quantum theory of magnetism: Rationalization of the Heisenberg Hamiltonian, Hubbard model: Derivation of susceptibility, Origin of exchange, Spin wave, Band Magnetism and Stoner Theory **Integer and Fractional Quantum Hall effect:** Landau levels, Disorder, localized and extended states, Edge states, introduction to FQHE

	Kondo Physics: Magnetic impurities and their interactions, Anderson model, s-d exchange model, Kondo effect and RKKY Interactions, spin glasses. **Graphene physics:** Crystal structure, properties and applications, band structure by Tight Binding, Dirac fermions, pseudospin, Berry phase - Blocking of backscattering, weak anti-localization **Plasmonics and photonic band gap materials:** Electromagnetics of metals, surface plasmons at metal-insulator interfaces, waveguides and excitation of surface plasmons, transmission and detection **References** 1. Many-Particle Physics, by Gerald D. Mahan, Springer Verlag, 3rd edition 2000. 2. The Physics of Solids by J. B. Ketterson. 3. Principles of Condensed Matter Physics by P. M. Chaikin & T. C. Lubensky. 4. Introduction to Superconductivity by M. Tinkham. 5. Quantum theory of Magnetism by R. M. White. 6. Plasmonics: Fundamentals and Applications by S. A. Maier.
P-801	**Astronomy and Astrophysics** **Stellar Physics:** Equations governing the structure of stars: Mechanical & Thermal equilibrium. Virial theorem. Modes of energy transfer in stars: radiative & convective transport of energy. Auxiliary input: equation of state, opacity and energy generation by thermonuclear processes. Boundary conditions at the stellar surface & at the centre. Models with linear & quadratic density profiles. Polytropic models. Mass-luminosity-radius relations for low, intermediate & high mass stars. Sources of opacity and nucleosynthesis in stars. Manufacturing of iron-peak and heavier elements by rapid neutron capture processes. Mixing length theory of convective transport of hear. Completely convective stars. Hertzsprung-Russel diagram. Pre-main sequence contraction and the Hayashi phase. Zero-age main sequence. Stellar evolution: main sequence, red giant and asymptotic giant branch. Advanced stages of stellar evolution: white dwarfs, neutron stars & black holes. Physics and astrophysics of collapsed objects: pulsars, X-ray &gamma ray sources. Spherical accretion and Bondi solution. Physics of accretion discs. Stellar rotation and magnetism. **Galactic Physics:** Units in astronomy, co-ordinate system, multi-wavelength sky (radio, IR, Optical, UV, X-ray, Gamma ray), distance ladder, Milkyway Galaxy, interstellar medium, basics of star formation, spiral and elliptical galaxies (morphology, content and kinematics), evidences for dark matter, AGNs, evidences for supermassive black holes, M-sigma and similar correlations, radio galaxies, synchrotron radiation, accretion onto black hole, physical processes behind black hole-galaxy co-evolution (merger, infall and feedback), clusters of galaxies (contents and kinematics), high redshift galaxies, cosmic evolution of galaxies and black holes, hierarchical structure formation, cosmic-web, GMRT, astronomy and society (including citizen science), constraints and prospects of astronomy and astrophysics research in India. **References** 1. The Internal Constitution of Stars, A. S. Eddington, Cambridge University Press, 1988. 2. An Introduction to the Study of Stellar Structure, S. Chandrasekhar, Dover Publications, 2003. 3. The structure & Evolution of the Stars, M. Schwarzschild, Dover Publications, 1962. 4. Cox and Giuli's Principles of Stellar Structure, 2nd Ed., A. Weiss et al., Cambridge, 2003. 5. The Physical Universe: An Introducing to Astronomy, F. H. Shu, University Science Books, 1982. 6. Galactic Astronomy, James Binny and Michael Merrifield, Princeton University Press, 1998. 7. An Introduction to Active Galactic Nuclei, B. M. Peterson, Cambridge University Press, 1997. 8. Extragalactic Astronomy and Cosmology: An Introduction, Peter Schneider, Springer, 2006.

	9. Physics of the Interstellar & Intergalactic Medium, Bruce T. Draine, Princeton Univ. Press, 2011.
P-802	**Nonlinear Dynamics and Chaos** Dynamical Systems, phase portraits, vector fields, nullclines, flows, discrete dynamical systems, 1-d maps. Fixed points, linearization of vector fields, canonical forms, generalized eigenvectors, semisimple – nilpotent decomposition, Jordan canonical form, classification of fixed points. Hartman-Grobman theorem, homeomorphism, Stable Manifold Theorem, Centre Manifold Theorem, examples of manifolds. Index theory, Lyapunov functions and stability analysis, Limit cycles, Poincare-Benedixon Theorem. Gronwall's inequality, the Variational Equation, exploring neighbourhoods, Lyapunov exponents, Monodromy matrix, Floquet exponents. Bifurcations: Saddle-Node, Transcritical, Pitchfork and Hopf Bifurcation. 1-d maps, linear stability of fixed points and higher order fixed points, chain rule, lyapunov exponent, bifurcation diagram, finding period-n orbits in 1-d maps. 2-d maps, Linearization, the Henon map, Poincare surface of section. Symbolic dynamics, Sensitivity to initial conditions, Chaos, Partitions, Transition matrix, Entropies, Smale Horseshoe. Invariant density, the Perron-Frobenius operator. Fractals. Hamiltonian Dynamics. **References** 1. Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry and Engineering, S. Strogatz, Addison-Wesley 2001 2. Chaos: An Introduction to Dynamical Systems, K.T. Aligood, T.D. Sauer, J.A. Yorke, Springer, 2000. 3. Differential Equations, Dynamical Systems and an Introduction to Chaos, M. Hirsh, S. Smale and R. Devaney, Elsevier Academic Press, 2012 4. Chaos and Integrability in Nonlinear Dynamics: An Introduction, M. Tabor, John Wiley & Sons, 1989. 5. Classical and Quantum, P. Cvitanovic *et al.,* ChaosBook.org, Neils Bohr Institute, Copenhagen 2016
P-803	**Computational Physics** Ordinary Differential Equations: Brief review of methods covered, Stiff equations, Numerov Method and its applications to Schrodinger Equation. Root finding: Brief review of methods covered, System involving many variables, Brayden and the complementary Brayden method. Matrix Diagonalization: The Lanczos approach, Davidson method Fourier Analysis: Discrete and Fast Fourier Transform, Spectrum Analysis, Chaos in non-linear differential equations, Computerized Tomography Partial Differential Equations: the vibrating string, the steady state heat equation, the pseudo spectral method, the potential step problem, wave packets in two dimensions. Optimization: Constrained and Unconstrained minimization, Penalty function methods, Metropolis algorithm and its applications to calculation of partition function and path integrals, Gillespie algorithm. Treatment of integral equations and nearly singular integrals. **References** 1. Computational Physics, P. L. DeVries and J. E. Hasbun, Jones and Bartlett, Sudbury, Massachusetts, 2011.

	2. Numerical Methods that Work, F. Acton, F. S. Acton, Harper and Row, New York, 1970. 3. Introduction to Non-Linear Optimization, D. A. Wismer and R. Chatterggy, North Holland, N. Y. 1978. 4. Numerical Recipes in Fortran, 2nd Edition, W. H. Press *et al.*, Cambridge University Press 2000. 5. Number Crunching, P. Nahin, Princeton University Press, Princeton, 2011. 6. For Brayden method: "New Method for Self-Consistency in Disordered Systems", Vijay A. Singh and Paul Bendt, *Phys. Rev.,* B 27 (1983) 6464-6468. 7. For nearly singular integrals: "A Simple Scheme for the Numerical Evaluation of Nearly Singular Integrals", G. C. John, J. E. Hasbun, and Vijay A. Singh, *Computers in Physics,* **11** (1997) 293-298.
PL-101	**Physics Laboratory-I** Introduction to experimental physics – conceptual and procedural understanding, planning of experiments; Plots (normal, semi-log, log-log); uncertainty / error in measurements and uncertainty / error analysis. Introduction to measuring instruments – concepts of standards and calibration; determination of time periods in simple pendulum and coupled strip oscillator system with emphasis on uncertainty in the measurements and accuracy requirements; study of projectile motion – understand the timing requirements; determination of surface tension of a liquid from the study of liquid drops formed under the surface of a glass surface; determination of Young's modulus of a strip of metal by double cantilever method (use of travelling microscope); study of combination of lenses and nodal points and correspondence to a thick lens; study of thermal expansion of metal – use of thermistor as a thermometer; measurement of small resistance of a wire using Carey-Foster-bridge and determine electrical resistivity of the wire; study of time dependence of charging and discharging of capacitor using digital multimeter – use of semi-log plot. **References** 1. Advanced Practical Physics for Students, B. L. Worsnop and H. T. Flint, Methuen and Co. Ltd., London
PL-201	**Physics Laboratory** Review of uncertainty / error analysis; least squares fit method; introduction to sensors / transducers; determination of 'g' (acceleration due to gravity) by free fall method; study of physical pendulum using a PC interfaced apparatus – study variation of effective 'g ' with change of angle of plane of oscillation - investigation of effect of large angle of oscillation on the motion; study of Newton's laws of motion using a PC interfaced apparatus; study of conservation of linear and angular momentum using 'Maxwell's Wheel' apparatus; study of vibrations of soft massive spring; study of torsional oscillatory system; study of refraction in a prism - double refraction in calcite and quartz; study of equipotential surface using different electrode shapes in a minimal conducting liquid medium; determination of electrical inductance by vector method and study effect of ferromagnetic core and study the effect of non-linearity of inductance with current. **Suggested Texts and References:** 1. Advanced Practical Physics for Students, B. L. Worsnop and H. T. Flint, Methuen and Co. Ltd., London
PL-301	**Physics Laboratory** Frequency response of R-C circuit (concept of cut-off freq and filter) and frequency response of L-C circuit; concepts of phase difference between voltage and current in these circuits, phase factor for appliances using AC mains supply; R-L-C (series / parallel) resonance; transient response in R-L-C series circuit; study of Newton's rings

	and interference in wedge shaped films; study of double refraction in calcite / quartz prisms, polarisation of the refracted light rays, optical activity in dextrose and fructose; soldering experience – make a gated timer with indicator; measurement of heat capacity of air; Use of thermocouple / platinum resistance thermometer, use of instrumentation amplifier in amplifying signal from thermocouple; study of the laws of a gyroscope; determination of the charge of an electron by Millikan's oil drop experiment. **Reference** 1. Advanced Practical Physics for Students, B. L. Worsnop and H. T. Flint, Methuen and Co. Ltd., London
PL-401	**Physics Laboratory** Application of PHOENIX (IUAC, New Delhi) microcontroller system for automation in experiments (six sessions); study of acoustic resonance in Helmholtz resonator using PHOENIX system; Resolving power of optical grating; study of atomic spectra in hydrogen, helium, mercury; Application of gamma counts from detected by G.M. counter for study of Poisson and Gaussian distributions; study of black body radiation by optical and thermal radiations; study of electrically coupled oscillators – normal and transient response. Assembling components for an experiment on thermal and electrical conductivity of metals and making of measurements. **References** 1. Phoenix: Computer Interfaced Science Experiments – http://www.iuac.res.in/~elab/phoenix/ 2. The Art of Experimental Physics, D. W. Preston and D. R. Dietz, Wiley 1991 3. Manual of Experimental Physics with Indian Academy of Sciences, Bangalore kit, R. Srinivasan and K.R.S. Priolkar
PL-402	**Computational Laboratory** Computing special functions (using recurrence relations, Attn: loss of accuracy and its effects), making subroutines/functions for these. Computing derivatives numerically. Zeros (roots) of functions (single variable, multivariable). Solving differential equations (single variable, any order), Euler and Runge-Kutta, initial and boundary value problems. Numerical integration: trapezoidal and Simpson rules, Gaussian quadrature rules. Linear equations, inverse of a matrix, determinant using Gauss elimination. Matrix eigenvalue problems (Power method and recursive QR decomposition), principal component analysis and Singular Value Decomposition by taking examples from biological systems. Data fitting, least square method. Random number generators, Monte-Carlo methods, Gillespie Algorithm. **References** 1. Gillespie, Daniel T. (1977). "Exact Stochastic Simulation of Coupled Chemical Reactions". *The Journal of Physical Chemistry*. 81 (25): 2340–2361. 2. W. H. Press *et al*., Numerical recipes in FORTRAN (2nd ed.): the art of scientific computing
PL-403	**Statistical and Computational Techniques** Basic tools for numerical analysis in science: Solution of algebraic functions – Fixed point method, Newton-Raphson method, Secant method. Numerical Integration – Rectangular method, trapezoidal method. Lagrange's interpolation. **Matrix Algebra:** Approximate solution of a set of linear simultaneous equations by Gauss-Sidel iteration method. Exact solution by Gaussian elimination. Inversion of a matrix by Gaussian elimination. Determining all the eigenvalues of a real symmetric

	matrix by Householder's method of tridiagonalization followed by QR factorization of the tridiagonalized matrix. Purpose of Statistics, Events and Probabilities, Assignments of probabilities to events, Random events and variables, Probability Axioms and Theorems. Probability distributions and properties: Discrete, Continuous and Empirical distributions. Expected values: Mean, Variance, Skewness, Kurtosis, Moments and Characteristics Functions. Types of probability distributions: Binomial, Poisson, Normal, Gamma, Exponential, Chi-squared, Log-Normal, Student's t, F distributions, Central Limit Theorem. Monte Carlo techniques: Methods of generating statistical distributions: Pseudorandom numbers from computers and from probability distributions, Applications. Error Analysis: Statistical and Systematic Errors, Reporting and using uncertainties, Propagation of errors, Statistical analysis of random uncertainties, Averaging Correlated/ Uncorrelated Measurements. Least-squares fitting: Linear, Polynomial, arbitrary functions: with descriptions of specific methods; Fitting composite curves. Covariance and Correlation, Analysis of Variance and Covariance. **References** 1. Statistics: A Guide to the Use of Statistical Methods in the Physical Sciences, R.J. Barlow, John Wiley 1989 2. The Statistical Analysis of Experimental Data, John Mandel, Dover Publications 1984 3. Data Reduction and Error Analysis for the Physical Sciences, 3rd Edition, Philip Bevington and Keith Robinson, McGraw Hill 2003
PL-501	**Physics Laboratory** Study of diffraction by single slit, double slit and multiple slits leading to grating, quantitative determination and compare with simulation; Study of Michelson interferometer and determination of refractive index of air; study of Fabry-Perot interferometer; Study of Zeeman effect using Fabry-Perot Interferometer; study of characteristics of scintillation counter used in nuclear radiation detection; study of Hall effect in semiconductors; Introduction to Labview software for automation and use of NI data acquisition card in PC (six sessions). **Reference** 1. The Art of Experimental Physics, D. W. Preston and D. R. Dietz, Wiley 1991.
PL-502	**Numerical Methods Laboratory** Error, its sources, propagation and analysis; Errors in summation, stability in numerical analysis. Linear algebraic equations: Gaussian elimination, direct triangular decomposition, matrix inversion, SVD. Root-finding: review of bisection method, Newton's method and secant method; real roots of polynomials, Laguerre's method. Matrix eigenvalue problems: Power method, eigenvalues of real symmetric matrices using Jacobi method, applications. Interpolation theory: Polynomial interpolation, Newton's divided differences, forward differences, interpolation errors, Hermite interpolation, cubic splines. Approximation of functions: Taylor's theorem, remainder term; Least squares approximation problem, Orthogonal polynomials, Near minimax approximation. Numerical integration: review of trapezoidal and Simpson's rules, Newton – Cotes integration formulas, Gaussian quadrature; Error estimation. Numerical differentiation. Random numbers; Monte Carlo methods, Metropolis algorithm. Least squares problems: Linear least squares, examples; Ordinary differential equations: predictor – corrector method, Runge – Kutta methods.

	References 1. An introduction to Numerical Analysis, 2nd Edition, Kendall Atkinson, Wiley 2012 2. Numerical Methods for Scientists and Engineers, H. M. Antia, Hindustan Book Agency 2012. 3. Numerical Recipes in Fortran, 2nd Edition, W. H. Press *et al.*, Cambridge University Press 2000
PL-601	**Physics Laboratory** Study of quantum mechanics through acoustic analogue (four sessions); Fourier analysis / synthesis – use of simulation; Study of characteristics of a coaxial cable and determination of speed of electromagnetic waves in the coaxial cable; determination of specific charge (e/m) of electron; Study of Faraday rotation and determination of Verdit's constant in a glass material; investigation of chaos in a spring based coupled oscillator system; Introduction to workshop practice (two sessions); Introduction to vacuum practice (two sessions). **References** 1. The Art of Experimental Physics, D. W. Preston and D. R. Dietz, Wiley 1991.
PL-701	**Advanced Physics Laboratory** **Nuclear Physics** Spectral features of photoelectric absorption and Compton scattering with scintillation detectors (i) Inorganic: NaI(Tl), BaF2 (ii) Organic: BC501A and plastic. Energy calibration, energy resolution, photopeak and total efficiency, relative intensity, photoelectric and Compton cross-sections, radiation shielding. Alpha spectroscopy with a silicon surface barrier detector. Fine structure of alpha spectrum and determination of age of source. Fast timing and coincidence measurements using BaF2 and BC501A detectors. Angular correlation of gamma rays using NaI(Tl) detectors. High resolution, low-energy photon measurements with a silicon drift detector: Internal conversion studies, elemental composition through X-Ray Fluorescence (XRF) analysis. Geiger-Muller counter: operating characteristics, dead time measurement, determination of mass absorption coefficient, verification of inverse square law. Lifetime measurements: from nanoseconds through minutes using fast coincidence and decay studies. High-resolution gamma ray measurements with high-purity germanium detectors. Classic experiments: Rutherford scattering, cloud chamber, beta spectrometer. Spectrum analysis techniques and fitting routines: data/peak fitting, energy and efficiency calibration, 1D and 2D histograms. (Selected experiments from the above list are performed based on number of contact hours prescribed) **Condense Matter Physics** Growth of metallic thin films by physical vapor deposition techniques like thermal evaporation and DC magnetron sputtering. Tuning of growth parameters to change the deposition rate and hence thickness of the films. Introduction to vacuum techniques: vacuum pumps, rotary pump, diffusion pump and turbo molecular pumps. Measurement of vacuum: thermocouple gauges, hot and cold cathode gauges. Thickness measurement of thin films by quartz crystal monitor. Structural characterization of materials (some known and some unknown) by X-ray diffraction (XRD) and X-ray fluorescence (XRF) (a) Phase identification (b) Chemical composition (c) difference between powder diffraction pattern of single and polycrystalline systems (d) Reasons for line broadening in XRD: Rachinger correction and estimation of particle size from Debye-Scherer formula. (e) Identifying crystal structure and determination of lattice constant.

	Introduction to low temperature measurements: operation of a closed cycle cryostat, low temperature thermometers, controlling temperatures using PID feedback using temperature controllers, making electrical contacts on thin films and measuring DC resistance with sourcemeter using four probe method-advantages and disadvantages of the technique, temperature dependent (300-20K) measurement of electrical resistivity of metallic thin films and comparing the room temperature value with the standard. Determination of superconducting transition temperature of a high temperature superconductor using electrical transport measurements. Determination of band gap of a semiconductor: highly doped Si by fitting the temperature dependent resistance to the standard variation in semiconductors. Concepts of measuring electrical resistance in labs: from metals to dielectrics. Introducing GPIB interfacing of electronic instruments with the computer and writing LABVIEW programs to interface temperature controller and sourcemeter. Introduction to phase sensitive measurements: using of a dual phase lock-in amplifier. Measurement of the superconducting transition temperature of a superconducting thin film using a mutual inductance technique down to 2.6K (working of a cryogen free system). Measuring AC resistance of a milliohm resistor using phase sensitive detection and studying the frequency and amplitude variation of the resistance: introduction to noise, White noise and 1/f noise. **References** 1. Radiation Detection and Measurement, Glenn F. Knoll, John Wiley 2010. 2. Techniques for Nuclear and Particle Physics Experiments: William R. Leo, Springer 1995. 3. Basic Vacuum technology, 2nd Edition, A. Chambers, R. K. Fitch and B. S. Halliday, IOP 1998. 4. Physical Vapor Deposition, R. J. Hill, McGraw-Hill 2005. 5. Elements of X-ray Diffraction, 3rd Edition, B. D. Cullity and S. R. Stock, Prentice Hall 2001. 6. Introduction to Solid State Physics, 8th Edition, C. Kittel, Wiley 2012.
PL-801	**Advanced Physics Laboratory** **Introduction to Observational Astronomy:** Transmission of radiation through atmosphere in different bands, need for space platforms for invisible astronomies, Introduction to Optical, Infrared, Ultra-violet, X-ray and Gamma-ray astronomy, what do me measure and learn from different wavebands. **Introductory Astronomy and Different types of Optical Telescopes**: Astronomical parameters like Apparent and Absolute magnitude, Flux, Luminosity and its dependence on size and temperature of stars, Atmospheric Extinction, Coordinate System in Astronomy Refracting and Reflecting telescopes, different focal plane configurations, their applications and relative merits and demerits. Reflectivity and its wavelength dependence, “seeing” and factors affecting it, use of active and adaptive optics in modern telescopes to overcome atmospheric and thermal effects, calculation of focal length, focal ratio, magnification, field of view, plate scale, diffraction limit of telescopes. **Introduction to Focal Plane Detectors for Optical, infrared and UV astronomy:** Developments and evolution of modern Optical and Infrared imaging detectors: Photographic Plates, Phototubes, Image Intensifiers, Charge Coupled Devices (CCDs), Bolometers and how they work, their characterization and parameters (charge transfer efficiency, quantum efficiency, flat fielding etc.). CCDs uses in Imaging, morphological and Spectroscopic studies, Infrared Detectors and IR Arrays, UV Imaging and Photon Counting Detectors. **Different types of Focal Plane Instruments**: Imagers, Photometers, Fast Photometers for photon counting, limitations of PMT and CCD bases photometers,

	Importance of spectroscopy, Design and description of Low and High-resolution Spectrometers and their applications, Polarimeters and their applications. **Interaction of radiation with matter**: (a) Passage of charged and neutral particles through matter, Ionization loss formulae and dependence on different parameters, relativistic rise in ionization loss, detection of neutrons, Bremsstrahlung process, Cerenkov radiation and its application (b) Interaction of photons with matter: Photoelectric interaction, mass absorption formula and dependence on energy, atomic number etc., Thompson scattering, Compton scattering, Pair production process, formula and dependence on energy, atomic number, radiation length, critical energy **Introduction to Different Types of Gas-Filled Radiation Detectors:** Role of development of new detection techniques in new discoveries in high energy physics and astrophysics, different kind of detection techniques for charged and neutral radiation Dependence of charge multiplication on high voltage and pressure, Townsend coefficient, need for use of inert gases, quench gas, mobility of electrons and ions (a) Ionization Chamber (IC), description of a typical IC, its characteristics, application of IC in physics (b) Proportional Counters (PC): Single and multi-cell PCs, filling gases, Penning effect, charge multiplication process, energy resolution of PC, Fano factor, use of PCs in high energy physics, and astronomy especially in X-ray astronomy (c) Geiger Mueller (GM)Counter: Typical GM counter, its characteristics, applications of GM counter **Scintillation Counters, Cerenkov Detectors and other Solid State Detectors:** Scintillation processes, dependence on energy, charge and atomic number, Photomultiplier (PMT) for detection of light, PMT characteristics, charge multiplication and use of PMTs with scintillators (a) Organic Scintillation Counters: Plastic Scintillators and light yield, their use in charged particle detection, a typical PS detector and its characteristics (b) Inorganic Scintillation Counters: Scintillation medium and need for activators, Sodium Iodide (NaI) and Caesium Iodide detectors, their light output, application of these detectors in physics and astrophysics (c) Silicon detectors and their applications in X-ray Astronomy, Germanium Detectors, Cadmium -Telluride devices and their arrays **Observational X-ray Astronomy:** Birth and evolution of X-ray Astronomy, different types of X-ray sources, Discovery of X-ray Binaries, their broad properties, optical identification, classification in Low Mass X-ray binaries (LMXBs) and High Mass X-ray Binaries (HMXBs), their unique characteristics, estimation of mass of the compact star in X-ray binaries from the binary parameters (a) Neutron Star Binaries (NSB): X-ray Pulsars in Binaries, Rotation powered pulsars in SNRs, detailed discussion of their timing and spectral properties, New physics and astrophysics learnt from their studies (b) Black Hole Binaries (BHB): Inference about black hole nature, time variability, spectral measurements, mass of black hole **X-ray Radiation Processes:** (a) Thermal Emission, Black Body emission, Thermal Bremstrahlung (free-free emission),spectral line formation in thermal plasma, examples of thermal spectra, measurement of temperature and elemental abundances from spectral data (b) Non-thermal Emission: Synchrotron mechanism (magnetic bremstrahlung), spectral shape, polarized emission, Inverse Compton Scattering, spectrum of radiation, examples of non-thermal spectra, Cyclotron process in strongly magnetized stars and formation of cyclotron lines, determination of magnetic field of the stars

	Experiments to be performed: 1. Measuring energy resolution (R) of a Cadmium Telluride Detector using X-rays of different energies (E) from radioactive sources and deriving expression for variation of R with E. 2. Solar Constant measurement. 3. Measurement of Solar Limb Darkening. 4. Observing an Optical Binary Star and deriving its light curve. 5. Determine Pulsation period and binary light curve of an accreting Neutron star from X-ray data. 6. Measuring X-ray Energy Spectrum of a Black Hole Binary and fit it with different spectral models. 7. Characteristics of a Proportional Counter and dependence of its energy resolution on different parameters of the PC.
PPr-701	To be assigned by the Supervisor
PPr-801	To be assigned by the Supervisor
PPr-901	To be assigned by the Supervisor
PPr-1001	To be assigned by the Supervisor

Elective courses offered by different disciplines

Biology	Chemistry	Mathematics	Physics
1. Molecular modelling and drug design 2. Advanced Methods in Biology 3. Protein folding and Conformational Diseases 4. Cancer Biology 5. Metabolism and Metabolic Disorders 6. Advanced Genetics and Epigenetics 7. Forensic science 8. On-line courses with Supervision by Core Faculty 9. Reproductive biology 10. Synthetic Biology 11. Nanoscience 12. Parasitology 13. Clinical Biology 14. Plant pathology 15. Industrial Biotechnology 16. Transgenics	1. Experimental Biophysical Chemistry 2. Biochemistry and biophysical chemistry laboratory 3. Elective NMR Laboratory Course - Experimental NMR 4. Advanced NMR spectroscopy and its applications 5. Advanced bio-organic chemistry 6. Advanced theoretical chemistry 7. X-ray crystallography 8. Protein chemistry and conformational diseases 9. Medicinal chemistry and drug designing 10. Radioisotopes – production and applications 11. Chemical Applications	1. Advanced Commutative Algebra & Applications 2. Advanced Differential Topology 3. Advanced Numerical Techniques. 4. Analytic Number Theory 5. Coding Theory & Cryptography. 6. Combinatorics / Combinatorics & Enumeration. 7. Financial Mathematics 8. Fractals & Applications 9. Advanced Graph Theory 10. Introduction to Ergodic Theory 11. Lie Groups & Geometry 12. Quantum Computing 13. Topics in Algebraic Geometry	1. Quantum Chemistry 2. Molecular Biology 3. Discrete Mathematics 4. Particle Physics 5. Quantum Mechanics III 6. Quantum Field Theory 7. Quantum computing and Information Theory 8. Plasma Physics 9. Quantum Optics 10. General Relativity and Cosmology 11. Non-equilibrium Statistical Mechanics 12. Dis-ordered Systems 13. Advanced Atomic Physics 14. Computational Electrodynamics 15. Nanoscience and Nanotechnology

17. Physical biology / Biophysics 18. Astrobiology	of Group Theory 12. Environmental chemistry 13. Advanced topics in inorganic chemistry	14. Advanced Algebraic Topology & Applications 15. Advanced Complex Analysis 16. Advanced Differential Geometry & Applications 17. Algebraic curves 18. Class field theory 19. Combinatorial Design Theory 20. Econometrics 21. Elliptic curves 22. Finite Fields & Applications 23. Fluid Mechanics 24. Geometric algebra 25. Homological Algebra & Applications 26. Industrial Mathematics 27. Introduction to Algebraic Groups. 28. Mathematical Applications to Engineering 29. Mathematics & Nano Technology. 30. Modular forms. 31. Operator Theory. 32. Perturbation Theory 33. Wavelet Analysis & Applications. 34. Representation Theory of Finite Groups. 35. Stochastic Analysis.	16. Advanced Nuclear Physics 17. Accelerator Physics 18. Radiation Physics 19. Reactor Physics 20. Dynamical Systems and Nonequilibrium Statistical Mechanics 21. Postmodern Quantum Mechanics 22. Soft Condensed Matter 23. Statistical Field Theory 24. Many Body Theory 25. Biophysics 26. Few Body Systems