INDIAN INSTITUTE OF SCIENCE EDUCATION AND RESEARCH THIRUVANANTHAPURAM

An autonomous institution under the
Ministry of Human Resource Development, Government of India

CURRICULUM AND SYLLABUS FOR
THE INTEGRATED Ph. D. PROGRAMME

2020-21
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Course Structure and Syllabus

School of Biology Curriculum

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Structural Biology
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Developmental Biology
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[3003]</td></tr>
<tr><td>BIO 312
Advanced Genetics &
Genome Biology
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Neurobiology
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<tr><td>BIO 313
Physiology
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Cell Biology
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6 credits</td></tr>
<tr><td>BIO 314
Biochemistry
[3003]</td><td>BIO 324
Molecular Biology
[3003]</td><td rowspan="2">3 Electives
[3003]</td></tr>
<tr><td>BIO 315
Advanced Biology Lab –I
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<tr><td>BIO 316
Bioinformatics
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<tr><td>Credits = 18</td><td>Credits = 18</td><td>Credits = 18</td><td>Credits = 12</td></tr>
</table>

School of Chemistry Curriculum

Semester 1	Semester 2	Semester 3	Semester 4
CHY 311 Coordination Chemistry **[3003]**	**CHY 321** Organometallic Chemistry **[3003]**	**CHY 411** Main Group Chemistry **[3003]**	**CHY 421** Instrumental methods for Structure Determination **[3003]**
CHY 312 Organic Chemistry - Reactions and mechanisms **[3003]**	**CHY 322** Solid-State Chemistry **[3003]**	**CHY 412** Advanced Organic Chemistry **[3003]**	**CHY 422** Physical Organic Chemistry **[3003]**
CHY 313 Quantum Chemistry **[3003]**	**CHY 323** Organic Chemistry- Synthetic methods **[3003]**	**CHY 413** Chemical and Statistical Thermodynamics **[3003]**	Elective I **[3003]**
CHY314 Physical Chemistry II **[3003]**	**CHY 324** Theoretical Spectroscopy **[3003]**	**CHY 414** Chemical Kinetics and Dynamics **[3003]**	
CHY315 Organic Chemistry Laboratory **[0093]**)	**CHY 325** Inorganic Chemistry Laboratory **[0093]**)	**CHY 415** Physical Chemistry Laboratory **[0093]**)	Minor Project (6 credits)
Credits = 15	**Credits = 15**	**Credits = 15**	**Credits = 15**

School of Mathematics Curriculum

Semester 1	Semester 2	Semester 3	Semester 4
MAT 311 Real Analysis **[3003]**	**MAT 321** Complex Analysis **[3003]**	**MAT 411** Measure Theory **[3003]**	**MAT 421** Functional Analysis **[3003]**
MAT 312 Theory of Groups and Rings mechanisms **[3003]**	**MAT 322** Fields, Modules and Algebras **[3003]**	**MAT 412** Commutative Algebra **[3003]**	**MAT 422** Algebraic Topology **[3003]**
MAT 313 Linear Algebra **[3003]**	**MAT 323** General Topology **[3003]**	**MAT 413** Analysis on Manifolds **[3003]**	**MAT 423** Differential Geometry **[3003]**
MAT 314 Numerical Analysis **[3003]**	**MAT 324** Theory of ODE **[3003]**	**MAT 414** PDE **[3003]**	**MAT 424** Number Theory and Cryptography **[3003]**
MAT 315 Mathematical Statistics + Lab **[3034]**	**MAT 325** Probability Theory and Stochastic Processes **[3003]**	**MAT 415** Programming and Data Structures **[3034]**	Elective IV
Elective I Discrete Math (or) Optimization Techniques **[2002]**	Elective II	Elective III	Elective V
Credits = 18	**Credits = 18**	**Credits = 19**	**Credits = 18**

School of Physics Curriculum

Semester 1	Semester 2	Semester 3	Semester 4
PHY 311 Mathematical Methods in Physics **[3003]**	**PHY 321** Statistical Mechanics **[3003]**	**PHY 411** Nuclear & Particle Physics **[3003]**	**PHY 42xx/52xx** Elective – III **[3003]**
PHY 312 Classical Mechanics **[3003]**	**PHY 322** Condensed Matter Physics I **[3003]**	**PHY 412** Condensed Matter Physics II **[3003]**	**PHY 42xx/52xx** Elective-IV **[3003]**
PHY 313 Electronics **[3003]**	**PHY 323** Electrodynamics and STR **[3003]**	**PHY 413** Quantum Mechanics- II **[3003]**	**PHY 42XX/52XX** Elective V **[3003]**
PHY 314 Quantum Mechanics I **[3003]**	**PHY 42XX** Elective I **[3003]**	**PHY 41XX/51XX** Elective II **[3003]**	**PHY 42XX/52XX** Elective VI **[3003]**
PHY 315 Adv. Physics Lab I **[0093]**	**PHY 325** Adv. Physics Lab II **[0093]**	**PHY 415** Adv. Physics Lab III **[0093]**	Research Work (6 credits)
Seminar (1 credit)	Seminar (1 credit)	Seminar (1 credit)	
Credits = 16	**Credits = 16**	**Credits = 16**	**Credits = 18**

Remark 1: As a part of the PhD coursework requirement, all integrated Ph.D. students should complete the zero credit course on "Research Methodology (PHY6xxx)" within the first two years of their joining. They will be awarded satisfactory/non-satisfactory grade based on the evaluation.

Syllabus

School of Biology

BIO311	Advanced Microbiology [3003]
Prerequisite	NA
Learning Outcomes	The course introduces various aspects of microbiology including prokaryotic cellular structure, different types of metabolism utilized by the microbes. Microbial development, microbial organelles are discussed. Basic concepts of microbial communication, chemosensing and pathogenesis are introduced in this course.
Syllabus	1. **Microbial physiology:** structure of microbes - prokaryotic cell structure & function, autotrophic and heterotrophic metabolisms - , growth and its control factors - culturing and measurement of microbial growth, physical & chemical methods of microbe control. [6] 2. **Microbial development:** division - bacterial cell division, sporulation - endospores, organelle, biofilms. Overview of microbial development with examples from model systems such as Bacillus, cyanobacteria, yeast, filamentous fungi and protozoa. [8] 3. **Microbial communication** - quorum sensing and chemosensory response - bacterial chemotaxis, regulatory network of chemotaxis. [3] 4. **Microbial pathogenesis:** types, mode of infection with examples of human and plant pathogens. Antimicrobial agents and their mode of action. [6] 5. **Applied microbiology:** biodegradation, bioremediation, fermentation, recombinant protein production [6] 6. **Bacterial Genetics:** transposition, mapping of mutations, plasmids, bacterial two-hybrid systems, genetics of bacteriophages, conjugation, transformation, transduction as a tool in bacterial genetics. [6]
Text and Reference Books	1. Willey, Joanne M; Sherwood, Linda; Woolverton, Christopher J; Prescott Harley Klein's Microbiology, McGraw-Hill, 7th Edition, 2008. 2. Cardona (2016) The Progress of Therapeutic Vaccination with Regard to Tuberculosis, Frontiers in Microbiology 7 3. Wai-Leung Ng and Bonnie L. Bassler (2009) Bacterial Quorum-Sensing Network Architectures Annu Rev Genet, 2009; 43: 197?222. doi:10.1146/annurevgenet- 102108-134304. 4. chemotaxis: http://chemotaxis.biology.utah.edu/ParkinsonLab/projects/ecolichemotaxis /ecolichemotaxis.html 5. Endotoxin: http://textbookofbacteriology.net/endotoxin.html

BIO312 / 612	Advanced Genetics and Genome Biology [3003]
Prerequisite	NA
Learning Outcomes	This course provides an overview of genome organization, genome variation and methods used to analyze genomes. Recent advances in genome sequencing, genome wide association studies and advanced genetic analysis are also covered. The course will also introduce students to the emerging field of personal genomics and its relevance to human health.

Syllabus	1. Model genomes, Genome organization and features. [1] 2. Genome variation: SNPs, RFLPs, structural variation, ploidy changes, extent of genome variation between individuals. [1] 3. Genomics and medicine: Sanger sequencing, next generation sequencing technologies, Human genome sequencing, Personalized medicine. [3-4] 4. Methods to study genomes: Vectors (Lambda vector, Bacterial Artificial Chromosome, Yeast Artificial Chromosome), PCR, microarrays, comparative genomic hybridization, pulse field gel analysis. [5] 5. Genetic mapping: genetic markers (auxotrophic markers, RFLPs, SSLPs, SNPs), Recombination mechanisms, linkage analysis using markers, tetrad mapping, sperm typing, DNA fingerprinting, linkage disequilibrium analysis, haplotype analysis, meiotic hotspots. [7-8] 6. Physical mapping: Restriction maps, Sequence Tag sites, Radiation hybrid maps, FISH, mapping contigs, shotgun sequencing. [2] 7. Co-relating genotype with phenotype: Mendelian traits, Quantitative traits, Genome wide association studies. [2] 8. Genome evolution: plasticity of genomes, genetic incompatibilities, gene duplication. [1]
Text and Reference Books	1. TA Brown, *Genomes* 4, Garland Science, 4th edition, Published May 24, 2017. 2. Tom Strachan, Andrew Read, *Human Molecular Genetics*, Garland Science, 5th edition, 20-Dec-2018. 3. Greg Gibson and Spencer V. Muse, *A Primer of Genome Science*, Sinauer Associates, Third Edition, February 15, 2010.

BIO313	**Physiology [3003]**
Prerequisite	NA
Learning Outcomes	The objective of the course is to familiarize the students with the functional basis of animal life. Main focus of the course is on mammalian system but examples from lower order animals are used to, 1) appreciate the conservation of some of the fundamental functions of life and 2) to understand the physiological relevance of evolution. Wherever required, the students are exposed to the structural, chemical and physical basis of life. As a whole, emphasis is given to understand the integration between what seems to be very isolated components of mammalian physiology. The course is also extended to pathological basis of some of the most-common/rare pathologies.
Syllabus	1. Nervous system and Sensory processing: The course further treats the systematic and topographic organisation of the nervous system and the structure and function of the neuron. Central and peripheral nervous system; sympathetic and parasympathetic nervous system; molecular basis of sensory systems: vision, hearing, taste, smell and touch. [7] 2. Endocrine system and Reproduction: endocrine glands and functions, hormonal function and regulation of different physiological systems by endocrine system, basics of molecular regulation of function by hormones, neuroendocrine systems; reproductive physiology. Principles behind circadian rhythm, their physiological relevance and the underlying neural and molecular basis. [7] 3. Feeding and Digestive system: nutrition, feeding and digestion; structural basis of digestive system function. Emphasis will be given to anatomical and histological details of the tissues involved. Digestion of macromolecules, absorption and assimilation, energy metabolism. [5] 4. Muscular system and movement: control of movement; neuromuscular junction and regulation of muscle contraction. Muscle types and functions, biochemical basis of muscle contraction, exercise, training and fatigue. [7] 5. Respiratory system: Overall anatomy of the respiratory system and structural basis of gaseous exchange, the physiology of breathing; transport of oxygen and carbon dioxide, oxygen and evolution of animals. [4] 6. Circulatory system: circulatory systems in vertebrates. Structure of heart and relevance in the homeostatic processes. Regulation of heart function and blood pressure. Vascular system and regulation of blood flow. [6] 7. Excretory system: managing water, salt and body fluids in animals. Structure of kidney, regulation of kidney function. [4]

Text and Reference Books	1. Animal Physiology by Richard W Hill, Gordon A Wyse and Margaret Anderson: Sinauer Associates. 4th Edition. 2. Eckert's Animal Physiology: Mechanisms and Adaptations. David Randall, Warren Burggen and Kathleen French: 5th edition.

BIO314	Biochemistry [3003]
Prerequisite	NA
Learning Outcomes	Life matter (unicellular or multicellular) is built using simple precursor molecules present in the biosphere. This course aims to understand the chemistry of life, how all biomolecules that comprise life matter is synthesized starting from simpler molecules by anabolic pathways, how these biomolecules are interconverted to each other by crossover metabolic pathways and ultimately the complex biomolecules are degraded back to simpler molecules by various catabolic pathways, generating bioenergy for the life to tick. At the completion of the course, the students can appreciate that "Life is a redox reaction".
Syllabus	1. **Design principles of metabolism:** Fundamental chemical reaction mechanisms, importance of resonance stabilization, addition-elimination (to both phosphates and carbonyls), reactivity of bond beta to carbonyl emphasizing the repetitive nature of these chemical logic by studying reactions involved glycolysis and krebs cycle pathways [2] 2. Principles of energy release from biological macromolecules: biological oxidation and hydrogen transfer systems: Role of ATP,CoA,NAD(P), NAD(P)H,F AD and FMN in fuel metabolism [1] 3. **Principles of bioenergetics:** Equilibrium constants, free energy changes, coupled reactions: Concepts and misconcepts. Role of ATP in bioenergetics, ATP as energy transducing agent and nature's dehydrating agent in metabolism.[2] 4. **Carbohydrate metabolism:** Glycolysis, energy release from glucose, principles of aerobic, anaerobic respiration and fermentation, Shuttle systems for transport of electrons between cell compartments: Importance of Malate Asparate shuttle and Glycerol -3 phosphate shuttle. Gluconeogenesis, glycogen synthesis and breakdown, enzymatic mechanisms, reciprocal regulations and hormonal regulations. [4] 5. Alternative oxidation of glucose by Pentose Phosphate pathway (PPP). Oxidative and non-oxidative branches of PPP. Importance of PPP in the interconversion of monosaccharides, nucleotide biosynthesis and biosynthesis of aminoacids. Game of pentose phosphate pathway to appreciate the evolution of PPP. Importance of glutathione and NADPH. Inborn errors of metabolism in PPP- Favism. [3] 6. **Krebs /TCA /CAC cycle:** (PDH complex, cofactors, TPP), amphibolic nature of citric acid cycle (CAC), mechanisms of CAC reactions, regulation of CAC, anapleurotic reactions, differential role of CAC in different tissues.[3] 7. Strategies in citrate cycle: Segmental coupling, unidirectional driving and stoichiometric incorporation of reducing equivalent. Evolution of CAC. Importance of glyoxylate bypass in the conversion of fats to carbohydrates. [3] 8. **Oxidative phosphorylation**: principles of electron transport chain, hierarchy of electron carriers, redox potentials of electron carriers, chemiosmotic theory of oxidative phosphorylation, generation of ATP coupled to electron transport, Q cycle. Structure of ATP synthase – F0 and F1 complex, mechanism of proton flow in Fo subunit. Chemical inhibitors of electron transport chain.[4] 9. **Fatty acid metabolism:** fatty acid oxidation, Importance of carnitine shuttle, alpha, beta and omega oxidation of fatty acids, working out the energetics of fatty acid oxidation with carbohydrate oxidation. Fatty acid synthesis: mechanism of fatty acid biosynthesis by FAS complex enzyme. HMG COA pathway, biosynthesis of cholesterol. Formation of ketone bodies and its importance in metabolism.[5] 10. **Amino acid metabolism:** Nitrate and ammonium assimilation; amino acid biosynthesis, degradation, urea cycle and its relationship with gluconeogenesis, shikimate pathway for the biosynthesis of aromatic amino acids, heme synthesis. [3] 11. **Nucleic acid metabolism:** purine and pyrimidine biosynthesis and catabolism of purines and pyrimidines. [3] 12. **One carbon metabolism:** Importance of folate, SAM and Metcobalamine in folic acid pool of one carbon metabolism [1]

	13. **Secondary metabolism:** Isoprenoid metabolism, biosynthesis of IPP and DMAP by Mevalonate and non-mevalonate pathway for biosynthesis of terpenoid precursors, shikimic acid pathway for production of phenolics, alkaloids [2] 14. Interconvertibility of fuels: Relationship between glucose, fat and amino acid oxidation for energy generation. [1] 15. Molecular chaperones in protein folding, experimental strategies to study protein mis-folding and disease, regulation of metabolism through metabolic networks, metabolic messengers, generation of NO and oxygen radicals.[2]
Text and Reference Books	1. Rodney F Boyer, Concepts in Biochemistry. John Wiley & Sons; 3rd Edition edition (2 December 2005) 2. Thomas Millar, Biochemistry Explained: A Practical Guide to Learning Biochemistry. CRC Press; 1 edition (30 May 2002) 3. Lubert Stryer et al., Biochemistry. W. H. Freeman; 6th Edition edition (14 July 2006) 4. John E. McMurry and Tadgh Begley. The Organic Chemistry of Biological Pathways. WH Freeman; 2nd edition (11 December 2015) 5. Laurence A Moran, Principles of Biochemistry. Pearson; 5 edition (30 July 2013) 6. David L. Nelson and Michael M. Cox, Lehninger Principles of Biochemistry WH Freeman; 7th ed. 2017 edition (1 January 2017)

BIO316	Bioinformatics [3003]
Prerequisite	NA
Learning Outcomes	This is a must-have course for a student of biology, who would benefit from learning the computational tools and methods in biological data analysis to take advantage of massively developing biological data. Topics will cover basics of bioinformatics to advanced algorithms in next-generation sequence analysis.
Syllabus	Biological data & sources - origin and types of biological data, public databases, storing biological data and data security. [1] Data mining - concept of data mining, methods of data mining: text-based, mining tasks, applications. [2] DNA sequence analysis - dot plot, basic concepts of sequence similarity, identity and homology, homologs, orthologs, paralogs, concepts behind scoring matrices, dynamic programming pairwise alignment - Smith-Waterman and Needleman-Wunsch algorithm, FASTA. [5] BLAST & Remote homology search - the BLAST algorithm, parsing BLAST results, advanced BLAST algorithms. [3] Multiple Sequence Alignment - methods of MSA: progressive alignments, consistency-based and structure-based alignment, programs for MSA. [3] Motif finding algorithms - sequence motif concepts, algorithms to detect DNA sequence motifs, Gibbs sampler, MEME. [2] Protein bioinformatics - Protein secondary structure calculation – DSSP, membrane topology prediction, ligand-receptor interactions, composition of active sites in functional proteins, conformational change and activity, allostery, effects of point mutations on proteins structure and function. [5] RNA structure analysis - RNA structure, RNA sequence databases, RNA structure prediction: Nussinov algorithm, EM algorithm. [3] Next generation sequencing and principles of NGS data analysis - introductory concepts, types of NGS data, various platforms of NGS, alignment algorithm - BWA, RNA-Seq, ChIP-Seq, single-cell genomics. [4]

	R for bioinformatics - introduction, basic elements of R, plotting high-dimensional data, statistical analysis, programming. [3]
Text & Reference Books	Bioinformatics, David Mount, CSHL, 2003 Bioinformatics & Functional Genomics, Jonathan Pevsner, Wiley 2015 M. Michael Gromiha, Protein Bioinformatics: From Sequence to Function, Elsevier, 2010

BIO321	Structural Biology [3003]
Prerequisite	NA
Learning Outcomes	To introduce Biology major students the importance of Structural Biology in everyday research and to impart in them the knowledge to understand the principles of protein structures and protein structure determination using protein crystallography, single particle cryoEM etc., and their applications in structure-based drug design. The course also aims to introduce the students to other biophysical methods like CD, ITC, SPR, DLS, MALS etc. used to characterize biomolecules and their interaction with ligands.
Syllabus	Principles of proteins and nucleic acid structures, conformation and analysis. Structural Bioinformatics. Molecular phylogenetic analysis.[9] Tools for analysing protein structures to understand the molecular basis of their functions.Structure Based Drug Design.[6] X-ray crystallography, electron microscopy and NMR in structural biology. Graphics and structural validation. Structural databases. Other biophysical and spectroscopic techniques to understand conformations of biomolecules.[19-20]
Text and Reference Books	1. Schulz GE and Schirmer RH, Principles of protein structure, Springer-Verlag, 1979. 2. Branden C and Tooze J, Introduction to protein structure, Garland Science, 2nd Edition. 1999. 3. Stout GH and Jensen LH, X-ray structure determination, John;Wiley and Sons Inc., New York, 1989. 4. Jan Drenth, Principles of protein crystallography, Springer Science & Business Media, 2007. 5. Liljas A, Liljas L, Piskur J, st Lindblom G, Nissen P and Kjeldgaard M. (2009). Textbook of Structural Biology, 1st edition, World Scientific Publishing, 2009. 6. Joachim Frank, Three-Dimensional Electron Microscopy of Macromolecular Assemblies, Academic Press, 1996. 7. A. K. Downing, Protein NMR techniques, Methods in Molecular Biology, Volume 278, 2004.

BIO322	Immunology [3003]
Prerequisite	NA

Learning Outcomes	To introduce students the basic and advanced concepts in Immunology, and emphasize the importance of immunology in health and disease. The course will provide in-depth knowledge on functioning of immune systems, with specific emphasis to humans. Further, the clinical and therapeutic aspects of immunology will be covered.
Syllabus	Introduction, Organization of the immune system (lymphoid tissues and organs). [3] Immune cell development (hematopoiesis, T and B cell development). [6] Innate and adaptive immunity (including cellular and humoral responses). [4] Antigens and Antibodies (antibody classes, Ag/Ab structure and function). [4] Immune signaling (T cell receptor, TLRs, inflammatory and cytokine responses)ancer. [5] The MHC and Ag presentation and T cell development. [6] Immunity mechanisms in disease (allergies, autoimmunity, immuno-deficiency). [6] Immunotherapy (clinical use of monoclonal antibodies).[2] Tumor Immunology [2]
Text and Reference Books	Judith A. Owen, Jenni Punt, Sharon A. Stranford, Patricia P. Jones., Kuby Immunology, W.H. Freeman and Company, 2013. Kenneth Murphy , Paul Travers , Mark Walport, Janeway's Immunobiology, Garland Science, Taylor & Francis Group, 2008.

BIO323	Cell Biology [3003]
Prerequisite	NA
Learning Outcomes	The course will provide in-depth understanding of the fundamental cellular processes that regulate and coordinate growth, division and death of eukaryotic cells and their underlying molecular pathways. Functional links of the processes with human diseases will be touched upon. The course also will introduce advanced methodologies including various microscopy tools employed in modern cell biology research.
Syllabus	Methods used in cell biology: microscopy, cell sorting, fractionation of cellular components, radioisotopes and antibodies as tools to study cellular functions. All light microscopy platforms (while light and fluorescence) covering basic principles and applications. Fluorescence activated cell sorting and radio-isotope/antibody based cellular biochemistry will include isotope based cellular and molecular fractionation and different immunoblot platforms. [4-5] Cell membrane: organization and composition of the cell membrane, structural property of the membrane micro-domains. Details of compositions of the membranes of intracellular organelles and plasma membrane and their properties; and the structural properties of the micro-domains (lipid rafts etc.) of membranes. Understanding of the functional link of the compositional diversity of the cell membrane (plasma membrane and intracellular membrane) to cellular processes pertaining to the organelles and plasma membranes. [2-3] Membrane transport- endocytosis and exocytosis Vesicular transport system and intracellular trafficking, protein targeting. In depth understanding of the molecular pathways pertaining to intra-cellular trafficking/transport and their mechanistic insights in model organisms from unicellular yeast to animal cells, cellular methods/tools/approaches to study these processes. [4-5]

	Organelle biogenesis: Understanding the biogenesis of subcellular structures such as mitochondria, centrosome, kinetochore in cells across eukaryotic kingdom, similarity/diversities in their composition, structural organization and functions. [2-3] Components of the cytoskeleton and their regulations: organization and function of actin, intermediate filaments, microtubules and motor proteins, integrins, cadherins. Compositions and cellular/molecular properties of different types of cytoskeletal elements, studies on the involvement of actin and microtubule cytoskeleton in intra-cellular trafficking, chromosome organization and cell motility. Functions of actin and microtubule-based motor proteins in regulating these processes, and the activation/inactivation of signaling molecules associated with the processes. [4-5] Cell-cell signaling: overview of extracellular signaling, cell surface receptors, cell signaling during growth and differentiation. overview of different cell surface receptor-based signaling with emphasis on receptor tyrosine kinase-mediated RAS signaling and its link to cell growth and division. [4-5] Cell cycle and its control: mechanisms of growth and division of eukaryotic cells, cell cycle checkpoints. Understanding the molecular processes/components that control cells' progression to growth/DNA replication/genome segregation phases in eukaryotic cells, mechanisms underlying activation/inactivation cell cycle check-points and their roles in controlling growth and division of cells. [6-7] Cell death: Apoptosis and autophagy pathways Canonical and non-canonical apoptosis pathways, molecular pathways and cellular processes linked to autophagy. [2-3]
Text and Reference Books	Cell Biology, Gerald Karp, (c2010). Cell Cycle, Tim Hunt, Andrew Murray, (c1993). Molecular Biology of the Cell, Bruce Alberts and co-authors, 6^{th} Edition, 2015.

BIO324	Molecular Biology [3003]
Prerequisite	NA
Learning Outcomes	This course is designed to introduce the concepts of gene expression and regulation starting from basic concepts of transcription, translation, replication and DNA repair. Basics of post-transcriptional, post-translational regulation and epigenetics are also discussed. The course also covers basic molecular biology techniques.
Syllabus	Nucleic acid: building blocks, nucleotide analogs as drugs [1] DNA STRUCTURE- base pairing and stabilizing forces, different forms of DNA. minor and major groves, supercoiling, organization into chromosomes, nucleosomes, heterochromatin, euchromatin, genes and organization, unique genes, operons, gene families, repetitive DNA, genome organization, transposons. [2] Replication: basic processes in bacteria and eukaryotes, telomeres and telomerase [3] DNA damage and repair: ionic radiation induced damage, chemical mutagens, different repair mechanisms, recombination, mechanisms of bacterial DNA repair, SOS response, measuring mutations, mutator strains. [3] Basic steps in gene expression and regulation, transcriptional and post-transcriptional regulation of gene expression [3] Bacterial translation: introduction to codon, tRNA mediated decoding, aminoacylation of tRNA and classes of aminoacyl-tRNA synthetase, basic subunits of ribosome, steps and factors involve in bacterial translation. [3]

	Eukaryotic translation: Basic steps of translation and factors involved in translation. GTPases in translation [3] Molecular aspects of RNA processing, transcription- Basic steps in transcription, splicing, transport across the nuclear membrane, recognition by translational apparatus, IRES [5] Epigenetics: DNA methylation in prokaryotes and eukaryotes, epigenetic gene regulation by DNA methylation in plants and mammals. Methods to detect epigenetic modifications [3] Protein-nucleic acid interactions - nucleic acid recognition by proteins binding motifs - techniques to study protein-nucleic acid interactions. [3] Non-coding RNA: Biogenesis and its function. Function and use of Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR). [3] Recombinant DNA technology and molecular cloning, purification of recombinant protein. [4]
Text and Reference Books	Molecular Biology of the cell by Bruce Alberts et al. 6th edition DNA Repair and Mutagenesis (2nd Edition) Friedberg and others. Mehta, A. and Haber J. E. (2014) sources of DNA double strand breaks and Models of Recombination DNA repair Cold Spring Harb Perspect Biol 6: a016428. Anand, R.P, Lovett, S.T. and Haber J.E. (2013) Break Induced DNA Replication. Cold Spring Harb Perspect Biol 5: a010397.

BIO326	Biostatistics [3003]
Prerequisite	NA
Learning Outcomes	This is an essential and important course for a student of biology, as statistics is critical to conclude any biological results. The course will cover basic of statistics, standard and advanced statistical tests that are routinely used in interpreting biological data and in health sciences. Students will also be trained to use R statistical package.
Syllabus	Introduction to statistics for biologists: importance of statistics, hypothesis testing, overview of statistical tests, variables. [2] Summarizing and visualizing data: types of data, summarizing data, displaying data, descriptive statistics, tools for graphical display. [2] Probability & distributions: basic probability, laws of probability, types of distributions, statistics of distributions, probability distributions.[3] Methods of sampling: populations and samples, sampling & non-sampling errors, various methods of sampling, experimental design. [2] Hypothesis testing: need for statistical testing, acceptable errors, P-values. [2] Parametric & non-parametric tests: concept of parametric & non-parametric statistics, tests for differences. [7] ANOVA: one-way ANOVA, Two-way ANOVA, Three-way ANOVA, Multiway ANOVA, Nested ANOVA, ANCOVA. [4] Correlation & regression: scatter plot, correlation coefficient, partial correlation coefficient, linear regression, non-linearity, non-linearity. [4] Survival analysis: censoring, survival times, summarizing and presentation. [2]

	R for biostatistics: introduction, performing common statistical tests in R, visualizing data in R, exporting data and analysis. [6]
Text and References	Michael C. Whitlock and Dolph Schluter, The Analysis of Biological Data, Roberts And Company Publishers, 2015. Steve McKillup, Statistics Explained: An Introductory Guide for Life Scientists, Cambridge University Press, 2006. Calvin Dytham, Choosing and Using Statistics: A Biologist's Guide, Wiley-Blackwell, c2011.

BIO411 / 611	Developmental Biology [3003]
Prerequisite	NA
Learning Outcomes	In this course students will be introduced to the main principles of development. There will be a strong emphasis on classic developmental model organisms to illustrate fundamental processes in development. Early events in development, developmental processes behind generation of body plan and formation of tissues and organs will be the main focus of the course. Regulation of gene expression, cell signaling pathways and cytoskeletal rearrangements in development will be discussed. Also, sexual maturation, regeneration in adult organisms and developmental diseases will be covered. Finally, evolution of development will be covered to help the students to understand the significance of evolutionary pressures that has converged on development.
Syllabus	Basic Concepts and history of developmental biology. [1] Introduction to Developmental model organisms: Seaurchin, Drosophila, Xenopus, Chick .[3] Early embryonic development: Cleavage, gastrulation and development of germinal layers, Maternal inheritance, Maternal to zygotic transition of gene expression, Early control of cell cycle, Cell-cell communication during early development. [3] Morphogenesis and development of body plan: Formation of body axes (A/P and D/V axis), Maternal effect genes, gap genes, pair-rule genes, segment polarity genes and Hox genes, Morphogen gradients and morphogen signaling. [3] Cellular differentiation and Organogenesis: Development of nervous system in vertebrates, Mechanisms of neural tube development, Neural crest development, migration and fates. Limb development in vertebrates: organizers of the limb (AER and ZPA), FGF and proximal – distal axis, Sonic hedgehog signaling and digit specification. [4] Cytoskeleton and Mechanical forces in development: Cytoskeletal regulation of growth and cell fate changes Cell proliferation and morphogenesis under mechanical control of cytoskeleton Cell adhesion and cell migration in organogenesis. [4] Growth and post-embryonic development: Hormonal control of metamorphosis in Drosophila and amphibians, Germ cells and gonad development. Dosage compensation and sex determination, Regeneration and tissue repair, Ageing, Developmental basis of behavior: courtship behavior, neural circuitry of behavior. [3] Evolution and development. [2] Defects in development and diseases: Neural tube defects, limb formation defects, growth defects. [1]

Text and Reference Books	Scott F Gilbert, Developmental Biology, Sinauer, 10th Ed, 2014 Lewis Wolpert and Cheryll Tickle, Principles of Development, OUP, 4th Ed, 2011 Other references would be provided during the lectures

BIO413 / 613	Neurobiology [3003]
Prerequisite	NA
Learning Outcomes	This course is designed to introduce students to major fields of neurobiology. This course will provide an understanding on the electrical activity of the neuron and how they communicate in the nervous system. They will be introduced to sensory physiology and its function. Students will gain an understanding on ongoing research approaches in neurobiology and techniques in order to develop critical thinking skills and formulate novel research questions.
Syllabus	1. Organization of the nervous system [1] 2. Neuroanatomy [1] 3. Historical overview of neuroscience from Empedocles to Bernstein [1] 4. Electrical properties of the neuron: Equilibrium potential, The Nernst potential and Cable equations; Voltage gated ion channels; Resting and action Potentials [2]; 5. Goldman-Hodgkin-Katz equation, Hodgkin and Huxley model. Electrophysiological recording techniques: Patch-clamp and Voltage-clamp techniques [2]. 6. Energetics of the Nervous System [1]. 7. Synaptic transmission: Ligand gated ion channels; Electrical and chemical synapses. Synaptic plasticity, Short term potentiation, Long term potentiation [4]. 8. Learning and memory [1]. 9. Sensory Physiology: Vision: Photoreceptors, Rods, Cones and Retinal ganglion cells. Electrical response to light. Light signal transduction, Concept of receptive fields. Colour vision Visual pathway, lateral geniculate nucleus and visual cortex [4-5]. Olfaction: Structure of olfactory epithelium and odorant receptors. Role of nasal olfactory neuron in odour detection. Odor coding and perception, Olfactory signal transduction. Spatial encoding of odorant information in the olfactory bulb. Processing of olfactory information in the cerebral cortex [3]. Somatosensory system: Touch, pain, cold and warmth receptors on skin and the signal transduction. Somatosensory map, homunculus, spinal cord and cerebral cortex in somatosensation [3-4]. Hearing: Sound perception and localization. Functional anatomy of ear and cochlea. Mechanotransduction, Converting mechanical stimulus to electrical signals. Cochlear inner and outer hair cells and perception of mechanical stimulus frequency and intensity. Adaptation to stimulus. Central auditory pathways [3]. 10. Motor systems: Upper and lower motor system. Reflex and contractions, rhythmic movements, central pattern generators, Role of basal ganglia and cerebellum on cortical and brain motor mechanisms [3-4]. 11. Experimental methods to study neurobiology [1-3].

	12. Diseases of the nervous system [1-2].
Text and Reference Books	1. John G. Nicholls, A. Robert Martin, David A. Brown, Mathew E. Diamond, David A. Weisblat, and Paul A. Fuchs, From neuron to brain, Sinauer Associates, Inc. Fifth edition, November 2011. 2. Mark F. Bear, Barry W. Connors, Michael A. Paradiso, Neuroscience: Exploring the Brain, Lippincott Williams & Wilkins, Third Edition, April 1995. 3. Eric R. Kandel, James H. Schwartz, and Thomas M. Jessell. Principles of Neural Science. Fifth Edition, October 2012. 4. Arthur C. Guyton and John E. Hall. Textbook of Medical Physiology, Twelfth Edition.

Electives

Electives (Biology)	1. Host-Pathogen Interactions 2. Evolutionary Ecology 3. Cancer Biology 4. Cryo-Electron microscopy and 3D image processing for Life sciences	5. Plant Molecular Biology (Advances in Plant Biology) 6. Stem Cells and Regenerative Medicine 7. Chronobiology 8. Advanced topics in Developmental Biology 9. Genome Stability 10. Animal Behaviour 11. Ecological Interactions (Coevolutionary Interactions)	12. Research Methodology 13. Biosafety and Regulation

BIOXXX	**Host-Pathogen Interactions [3003]**
Prerequisite	NA
Learning Outcomes	Host-pathogen interactions provide information that can help students understand disease pathogenesis and transmission of disease, the biology of a pathogen, as well as the host.
Syllabus	1. Introduction to Host-pathogen interaction [2]. 2. Viral, Bacterial and parasite pathogens [3]. 3. Pathogen external interactions, Viral pathogen attachment and entry into the host cell [3]. 4. Virus replication cycle [3]. 5. Animal models [3]. 6. Experimental approaches to study Microbial pathogenesis: Identification of virulence factors Genome-wide approaches to study host-pathogen interactions [4]. 8. Monitoring host response and immunity to pathogens [3] 9. Pathobiology of Infection: Survival strategies of viral, bacterial and parasite pathogens. Immune response to infectious diseases Mechanisms of pathogenesis, pathogens immune evasion mechanism [6]

	10. Manipulation and reprogramming of the intracellular environment [3] 11. Infection of the human host: Gastrointestinal Infections, Respiratory infections, CNS infections, and organ infections [4].
Text and Reference Books	1. Gerald Karp, Cell Biology, WILEY (Feb. 4th, 2013) 2. Wayne M. Becker et al., World of the Cell; Benjamin Cummings; 7th edition (February 19, 2008) 3. Bruce Alberts et al., Essential Cell Biology; Richard Goldsby and Thomas J, &F/Garland, 4th Edition, (2014) 4. Kindt, Kuby, Immunology, W. H. Freeman; 6th edition (9 October 2006)

BIOXXX	**Evolutionary Ecology [3003]**
Prerequisite	NA
Learning Outcomes	The course will discuss several advanced concepts in evolutionary ecology. Apart from in-depth discussion of the concepts, the course will draw extensively from published research papers, with the intention of helping students better understand experimental rigor and hypothesis testing.
Syllabus	1. Recapitulation of fundamental concepts of evolution: Selection; Fitness; Adaptation; Types of selection; Evolution without selection. [1] 2. Prey-predator interactions: Predation as one of the strongest selective forces; Aposematism; Frequency Dependent Predation and Selection; Batesian and Müllerian mimicry; Crypsis (background matching, disruptive colouration, countershading, deflection, motion dazzle etc); Deimatic displays; Anti-herbivory strategies in plants (constitutive and induced defenses, secondary metabolites). [7-8] 3. Phylogenetics: Recapitulation of basic phylogenetic terminology (rooted and unrooted trees, monophyly and non-monophyly, sister grouping, etc). Phylogenetic reconstruction (datasets, advantages of molecular data, optimality criteria - maximum parsimony and model-based methods, measures of clade support); Gene trees versus species trees; Phylogenomics; Molecular dating. [4] 4. Historical biogeography: Biogeographic realms; Understanding geographic patterns of speciation using phylogenies; Vicariance, dispersal and sympatric speciation; Plate tectonics and its impact on diversification; Importance of dispersal for diversification; Geodispersal [2] 5. Phylogenetic Comparative Methods: Macroevolutionary patterns; Testing evolutionary hypotheses using phylogenetic information, Importance of taking into account phylogenetic non-independence, Order of origin of traits, Correlations across traits, Diversification rates. [2] 6. Phylogeography and Population genetics: Understanding history of populations using Haplotype Networks; HW Equilibrium; Population genetic structuring, Conservation genetics. [2-3] 7. Phenotypic plasticity: Reaction norms; Polyphenisms; Adaptive plasticity; Reversible versus irreversible plasticity; Inducing environment versus adaptive environment; Genetic assimilation. [2] 8. Sensory ecology: How senses are tuned to the environment; Sensory systems (vision, olfaction, acoustic and special senses). [8] 9. Signaling and communication: Sign stimuli and releasing mechanisms; private channels and eavesdropping. Communication in animals and plants.[3] 10. Life-history strategies: What are life-history strategies; Selection pressures on life-history strategies; Interesting case studies on life history evolution; Game theory. [3]
Text and Reference Books	1. Avoiding Attack - The Evolutionary Ecology of Crypsis, Aposematism and Mimicry. By Graeme D. Ruxton, William L. Allen, Thomas N. Sherratt and Michael P. Speed. Oxford University Press 2. Developmental Plasticity and Evolution. By Mary Jane West-Eberhard, Oxford University Press 3. Evolution. By Douglas J. Futuyma and Mark Kirkpatrick. Oxford University 4. Modern Phylogenetic Comparative Methods and Their Application in Evolutionary Biology: Concepts and Practice. Edited by Lszl Zsolt Garamszegi.

	5. Sensory Ecology: How organisms acquire and respond to information. By David B Dusenbery. Freeman and Co. USA

BIOXXX	**Cancer Biology [3003]**
Prerequisite	BIO323, BIO 324
Learning Outcomes	The objective of this course is to introduce students to topics on fundamental cancer biology from basic research to therapy. This course aims to provide an overview of the biology and pathology of cancer. The course will educate students on various genetic and molecular changes normal cells undergo during transformation into malignant cancer cells. These modifications include unregulated cell proliferation, evasion of cell death and metastasis. The course describes factors that contribute to cancer development and discuss cancer prevention and treatment options.
Syllabus	1. Types of cancers (Hematopoetic malignacies leukemia and lymphomas, carcinomas, Sarcomas, melanomas and neuro ectodermal malignancies) and hallmarks of cancers (Self-sufficiency in growth signals, insensitivity to anti-growth signals, evading apoptosis, limitless replicative potential, sustained angiogenesis, tissue invasion and metastasis) [7] 2. The common cellular and molecular mechanisms that are deregulated in cancerous cells, and how does their deregulation contribute to the development of cancer? (General out lay of different pathways, aberrant genes and gene expression, aberrant cell structures and cell behavior, role of the cytoskeleton in cell adhesion, cell division, cell migration, invasion, and metastasis) [8] 3. Oncogenes and their role in tumor development (ex: c-src, Ras, erbB2/neu, myc etc.) [6] 4. Tumor suppressor genes and their role in neoplasia (ex: p53, pRb, VHL, and APC etc.) [6] 5. Gene translocations and types of gene mutations that contribute to tumor formation (ex: Burkitt's lymphomas, chronic myelogenous leukemia (CML), deregulated firing of growth factor receptors etc.) [3] 6. Chronic inflammation and infectious agents and their role in cancer development (Colonic, liver and skin inflammation and tumor promotion) [3] 7. Cancer detection/screening and therapy (Mamography, pop smear, radiation, surgery, and chemotherapy etc.) [3]
Text and Reference Books	1. The Biology of Cancer by Robert A. Weinberg 2. Cancer: Principles & Practice of Oncology: Primer of the Molecular Biology of Cancer by DeVita Jr., Vincent T., Theodore S. Lawrence, Steven A. Rosenberg 3. Molecular Biology Of Cancer by Pecorino

BIOXXX	**Cryo-Electron microscopy and 3D image processing for Life sciences [3003]**
Prerequisite	Preferable: BIO321 course: Structural Biology (not compulsory).
Learning Outcomes	To introduce Biology major students the importance of the new resolution revolution in electron cryo microscopy (that led to the 2017 Nobel Prize in Chemistry) and the kindred subjects. The objective of the course is to provide biology students with information to understand the history of cryoEM, the basic physics behind negative stain and cryo-EM of bio-molecules, its potential and limitations and an introduction to cellular tomography and future challenges of cryo-EM. It will also introduce single particle cryoEM and their applications in structure based drug design.
Syllabus	1. Cryoelectron microscopy and three-dimensional image processing of biological molecules is among the hottest growth areas in biophysics and structural biology at present. This course will introduce the theory of image processing and 3-D reconstruction techniques used in cryo-EM field to solve the structure of macromolecules. Topics covered will include basic principles of light and electron microscopes, types of electron microscopes and their applications. A basic introduction to electron microscopes' physics and optics. Principles of image formation, Basic Concepts of Fourier Transform in TEM image analysis (a biologist's approach), Contrast

	transfer function, Point Spread function and its effect on image acquisition and concepts of convolution etc.**[10]** 2. Single-Particle methods in electron microscopy Past, present and future. EM sample, specimen preparation methods, imaging, data collection techniques, Movie processing, Image selection and Initial Model generation of bio-molecules by negative staining and cryo-electron microscopy. 3D image processing hands-on will be arranged with a standard data set over the duration of the course.**[10]** 3. Potential and limitations of protein crystallography and cryo-EM. Hybrid Methods in structure determination of bio-molecules. Theoretical, computational and practical aspects 3D image processing techniques.**[10]** 4. Cryo-EM map interpretation and data analysis, validation, molecular docking and Flexible Fitting in EM maps.**[5-6]**
Text and Reference Books	1. John J. Bozzola and Lonnie D. Russell. Electron Microscopy, Second Edition, Jones and Bartlett Publishers, Inc., Sudbury, MA, 1999, 2. Joachim Frank (2006). Three-Dimensional Electron Microscopy of Macromolecular Assemblies: Visualization of Biological Molecules in Their Native State. 2nd Ed. (New York, Oxford U. Press). 3. Single-particle Cryo-electron Microscopy: The Path Toward Atomic Resolution/ Selected Papers Of Joachim Frank With Commentaries (Series in Structural Biology) 4. Michael F Moody (2011). Structural Biology using Electrons and X-rays, An Introduction for Biologists. Elsevier Ltd. 5. Natesh R* (2014). Crystallography beyond Crystals: PX and SPCryoEM. Resonance, 19(2), 1177-1196. 6. Natesh R* (2019). "Single Particle Cryo-EM as a pipeline for obtaining atomic structures of drug targets in pharma-industry"

BIOXXX	**Advances in Plant Biology [3003]**
Prerequisite	NA
Learning Outcomes	Students will learn the cutting edge of dynamics of molecular and cellular mechanisms underlying morphodynamics in plants. The course offers the possibility to learn integrating how internal cues respond to changes in external inductive cues in plants, which continuously get exposed to fluctuating environmental conditions throughout their growth phase.
Syllabus	1. Molecular genetic basis of morphological diversity in plants. [3] 2. Regulatory interactions between cell- fate determinants and cell cycle; cell fate, stem-cell behaviors, and cell polarity in plant morphogenesis. [9] 3. Cell biological tools to understand cellular behaviour in live plants and computational modelling to study morphodynamics. [9] 4. Cross talk and integration of hormone signalling pathways driving plant morphogenesis and physiology. [9] 5. Photosynthesis, hormone physiology, photorespiration and transpiration) stresses. [9]
Text and Reference Books	1. Leyser, O. and Dey, S. (2009) *Mechanisms in Plant Development.* John Wiley & Sons.

BIOXXX	**Stem Cells and Regenerative Medicine [3003]**
Prerequisite	NA

Learning Outcomes	The objective of the course is to expose the students to the principles of stem cells and tissue regeneration and introduce them to the potential of the field to revolutionize modern medicine. Starting with the founding principles and history of stem cells, the course will take the steps to introduce the students to their functional regulation and links with regeneration. The course will explore application part of various stem cell types.
Syllabus	1. Introduction to Stem cells: Basics of stem cells and principles of stemness, Early mammalian development, Evolution of stem cells. [1.5] 2. Biology of stem cells: Cell cycle regulation in stem cells, Mechanisms of differentiation, Signal transduction (More elaborative for mechanisms involved in development), Metabolism of stem cells. [3] 3. Pluripotent stem cells: Types of pluripotent stem cells; Isolation, characterization of embryonic stem cells; Generation of iPS cells and disease modeling; Biology of ES and iPS cells; Genome editing technologies; Alternative medicine. [6] 4. Adult stem cells: Properties, identification and separation of various stem cells, Biological principles of HSCs; hematopoietic development, regulation of proliferation and differentiation, Sources of HSCs and their clinical use. [6] 5. Cancer stem cells: Concepts, identification, biology and potential applications of cancer stem cells. [3] 6. Stem Cell niches: Extrinsic factors in the regulation of stem cell function. Biological, physico-mechanical properties of stem cell micro-environment (for HSCs, epidermal, germ and intestinal stem cells). [3] 7. Transplantation biology: Immunology of transplantation and graft rejection, mechanisms of homing of transplanted stem cells. [3] 8. Tissue engineering: Ex vivo expansion of stem cells, Ex vivo construction of tissues, scaffolds, bioreactors. [4.5] 9. Stem cells in clinic: Avenues for stem cell use (metabolic, genetic diseases, cancers and trauma), Potential application of stem cells in clinic and present clinical use. Hurdles and future directions. [4.5] 10. Methods in stem cells: In vitro and in vivo methods to assay stem cells. [6]
Text and Reference Books	1. Essentials of Stem Cell Biology by Robert Lanza Anthony Atala (Eds.): Academic Press. 3rd Edition 2013. 2. *Stem Cells: An Insider's Guide* by Dr. Paul Knoepfler: World Scietific publishing Co. Pvt. Ltd. 1st Edition 2013. 3. The science of stem cells by JMW Slack: Wiley Blackwell publishers. 1st Edition 2017. 4. Stem Cells, Tissue Engineering and Regenerative Medicine by David Warburton (Ed.) World Scietific publishing Co. Pvt. Ltd. 1st Edition 2014. 5. Stem Cells Handbook by Stewart Sell (Ed.). Springer 1st edition 2013. 6. Stem Cells: A Short Course Rob Burgess. Wiley Blackwell publishers. 1st Edition 2016. 7. Principles of Tissue Engineering Robert Lanza Robert Langer Joseph Vacanti (Eds.). Academic Press 4th edition 2013. 8. The Biomedical Engineering Handbook by Joseph D. Bronzino, Donald R. Peterson. CRC Press Taylor & Francis. 1st edition. 2015.

BIOXXX	**Chronobiology [3003]**
Prerequisite	NA
Learning Outcomes	The objective of this course is to provide students a fully textured academic experience in circadian rhythm research. The course will give an overview in terms of the circadian clock and its role in rhythmic behavior, physiology, metabolism and cognitive function. Research articles are discussed throughout the semester to facilitate the learning process by identifying the hypothesis, understand the experiment and statistical methods to critically assess the conclusion and to develop future research question(s).

Syllabus	1. Historical overview of chronobiology. Fundamental properties of circadian clock: Entrainment, masking and zeitgebers, parametric and non-parametric entrainment, phase shift, phase response curves (PRC), temperature compensation of circadian clock [4]. 2. Molecular biology of the circadian clock: The central oscillator, , molecular components of circadian pacemakers, genetics of circadian rhythms, the circadian feedback loops, post-transcriptional regulation of circadian rhythms, circadian clocks in various model organisms [5]. 3. Circadian clock neuronal network: circadian pacemaker neuronal circuit, morning and evening oscillators, neurotransmitters-the chemical signals of the circuit, electrophysiological properties of the clock neurons [4]. 4. Circadian photoreception: Input signals into the circadian clock, molecular pathway of circadian photoreception, light entrainment of circadian clock, extra-ocular photoreception [3]. 5. Neural circuitry of sleep: Circadian and homeostatic drive for sleep, Genetics of sleep, organization of sleep arousal circuit, wake promoting and sleep promoting neurotransmitters-Adenosine, GABA, Acetyl choline, dopamine [5]. 6. Sleep for memory consolidation, sleep and synaptic plasticity, Sleep disorders. Evolution of sleep [4] 7. Circadian clock and metabolism: Central and peripheral circadian clocks, circadian disruptions and metabolic disorders, neuro-degenerative diseases, ageing and circadian clock [4]. 8. Evolution of the circadian timing system: Evolution of circadian clocks, fitness, adaptive significance of circadian clocks [3].
Text and Reference Books	1. Jay C. Dunlap, Jennifer J. Loros, Patricia J. DeCoursey, Chronobiology: Biological time keeping, Sinauer Associates, Inc. Publishers, First Edition, December 2009. 2. D.S. Saunders, Insect clocks, Elsevier science & Technology, Third Edition, November 2002

BIOXXX	**Advanced Topics in Developmental Biology [3003]**
Prerequisite	BIO 411/611
Learning Outcomes	This course is designed to address current advances in the field of Developmental Biology. Developmental Biologists worldwide are combining novel genetic approaches and molecular techniques to understand how a fertilised egg is progressively transformed into a complex multicellular organism. The main emphasis of this course will be on molecular, cellular and genetic tools that aids in the understanding of developmental processes better. The idea is not to cover everything in the field but to highlight some of the key areas of research in Developmental Biology. Who can credit the course: The BS-MS, iPhD and PhD students who have credited BIO411/611 course on Principles of Developmental Biology are encouraged to credit this course. This course could also be credited by PhD students who have not taken BIO411/611, but has done a basic Developmental Biology course during MSc. Mode of teaching and evaluation: The course would be based on cutting edge research articles in the field rather than based on text books. A series student presentations and discussions of various research articles in the areas mentioned below. Evaluation of students would be done based on their presentations, participation in discussions, writing critical comments on a set of papers assigned to each of them, in addition to the mid and end-semester exams. They also have to write a 2-page SoP addressed to a PI in the field and on their interests, a problem that interests them and how they would address this in the lab of the PI.

Syllabus	The following is the outline of broad themes which will be covered by this course. A set of recent papers among the areas mentioned will be identified and assigned during the course. 1. Maternal inheritance and maternal to zygotic transition during early development [3] 2. Cell migration and cell adhesion in development [3] 3. Cell shape in development [3] 4. Regulation of developmental gene expression [3] 5. Interpretation of morphogen gradients [3] 6. Asymmetry in the germ cells and in developing embryo [3] 7. Cell Polarity in development and changes in cell polarity [2] 8. Development and behavior [2] 9. New molecular tools in development [2]
Text and Reference Books	1. Scott F Gilbert, Developmental Biology, Sinauer, 10th Ed, 2014 2. Lewis Wolpert and Cheryll Tickle, Principles of Development, OUP, 4th Ed, 2011 3. Papers to be discussed would be provided at the start of the course

BIOXXX	**Genome Stability [3003]**
Prerequisite	NA
Learning Outcomes	This elective course is designed for advanced undergraduate students interested in learning DNA repair and recombination mechanisms that are necessary for maintaining genome stability. In addition, the course also discusses the relevance of these mechanisms in the context of human diseases (eg cancer) and for genome editing. Lectures are supplemented with presentation and discussion of primary research papers in the field.
Syllabus	1. Mechanisms of meiotic recombination and chromosome segregation: Chromosome pairing and synaptonemal complex assembly, Regulation of meiotic recombination pathways. [5] 2. DNA damage and recognition: sources and types of DNA damage, random and programmed double strand breaks, chromosome structural changes [4] 3. Cellular responses to DNA damage: signalling of DNA damage, choice of DNA repair and recombination pathways. [2] 4. DNA repair mechanisms: mismatch repair, Base excision repair, Nucleotide excision repair, non-homologous end joining, Homologous recombination, processing of Holliday junctions. [4] 5. Genomic instability and human disease: cancer, birth defects, genomic disorders due to chromosome structural changes. [2] 6. Genome editing: targeted modification of the genome. [1] 7. Discussion of research papers [6]
Text and Reference Books	1. James Haber, *Genome Stability,* Garland Science, Edition 1, December 16, 2013 2. Jac A. Nickoloff, Merl F. Hoekstra, *DNA Damage and Repair*, Humana Press, Volume III, October 4, 2014 3. Errol C. Friedberg, *DNA repair and mutagenesis*, American Society for Microbiology Press, 2nd edition, February 23, 2006

BIOXXX	**Animal Behaviour [3003]**
Prerequisite	BIOXXX Evolutionary Ecology
Learning Outcomes	The objective of the course is to gain an appreciation for the evolution of diverse behaviours in animals. The course is designed to expose students to understand the evolutionary framework that guide the evolution of various behaviours. The course is designed to be broad and encompass behaviours that are critical to survival of individuals and groups.

Syllabus	1. The study of Animal Behaviour: a brief history [2] 2. Reproductive strategies, sexual systems: Evolution of differences in sex roles; Alternate mating tactics; Conditional mating strategies; Distinct mating strategies; Sperm competition; Mate guarding; Healthy mates, good genes and runaway selection theories; Monogamy and polygamy[4] 3. Eusociality: Haplodiploid sex determination and evolution of extreme altruism; Eusociality in the absence of close relatedness [6] 4. Social organization, hierarchy and dominance: Costs and benefits of social living; Task partitioning in animal societies; Evolution of helpful behaviour; Importance of relatedness; Inclusive fitness [4] 5. Cooperation and conflict: Kinship and conflict with kin (parent-offspring conflict, sibling rivalry, kin recognition); Aggression; Alarm signals; Social learning [4] 6. Territoriality, Space and information usage: Habitat preferences; Costs and benefits of dispersal; Costs and benefits of migration; Territorial contests [3] 7. Learning, memory and cognition: Adaptive value of learning; Innate behaviours; Spatial orientation and navigation, Central place foragers [4] 8. Foraging behaviour: Optimal foraging theory and its criticisms; Game theory and feeding behaviour[3] 9. Evolution of human behaviour: Evolutionary psychology; How modern evolutionary theory helps understand human behaviour and psychology; Evolutionary psychology as a unifying theme in psychology; Behaviours and psychological conditions that may be explained by natural selection[5]
Text and Reference Books	1. Animal Behaviour. By John Alcock 2. Principles of Animal Behaviour. Lee Alan Dugatkin. W. W. Norton & Company 3. Evolutionary Psychology: The New Science Of The Mind. By David M Buss

BIOXXX	**Coevolutionary Interactions [3003]**
Prerequisite	BIOXXX Evolutionary Ecology
Learning Outcomes	The course will focus on the role interactions between organisms at various levels and how these interactions shape evolution. The course will consist of lectures and student presentations of papers followed by group discussions. In addition to in-depth coverage of the concepts discussed, students will develop a deeper appreciation of the challenges and of hypothesis testing in evolutionary ecology.
Syllabus	1. The central role of interactions in the ecology and evolution of organisms [1] 2. Coevolution: Coevolution of various types of interactions; Diffuse coevolution; Arms race [3] 3. Mutualism and Parasitism: When do mutualistic and parasitic interactions evolve? Continuum between mutualism and parasitism [4] 4. Competition and Facilitative interactions: Inter- and intra-specific competition: Spatial and temporal mechanisms of competition avoidance; Concept of niche and niche partitioning [6] 5. Host-endosymbiont interactions: Diversity of host-endosymbiont interactions in nature; Case studies of the widespread endosymbiont *Wolbachia* and its insect hosts [6] 6. Insect-host plant interactions: Specialisation and generalisation in insect-host plant interactions. Why are herbivorous insects so diverse: diffuse coevolution between insects and their host plants; Oviposition preference hierarchy; Larval performance hierarchy [6] 7. Plant- pollinator interactions: Insect pollination as a key innovation; Specialisation and generalisation in plant-pollinator interactions; Obligate mutualisms [6] 8. Dispersal ecology: Causes and consequences of dispersal in plants and animals; invasive species and their effects on community organisation. [4]
Text and Reference Books	1. Plant-Animal Interactions: An Evolutionary Approach. By Carlos M. Herrera, Olle Pellmyr. Wiley 2. The Geographic Mosaic of Coevolution. By John N. Thompson 3. Parasitism: The Ecology and Evolution of Intimate Interactions. By Claude Combes 4. Plant-Pollinator Interactions: From Specialization to Generalization. Edited By Nickolas M. Waser and Jeff Ollerton. Univ of Chicago Press, 2006.

	5. Dispersal Ecology and Evolution. By Jean Clobert, Michael Baguette, Tim G Benton, James M. Bullock. Oxford University Press

BIOXXX	**Research Methodology [1000]**
Prerequisite	NA
Learning Outcomes	At the end of this course, the students should be able to understand some basic concepts of research and its methodologies - organize and conduct research (advanced project) in a more appropriate manner, identify appropriate research topics and, select and define appropriate research problem.
Syllabus	1. What is the purpose of research? [1] 2. Take examples of Newton and the inverse square law of gravitational force and of the calculus. [1] 3. Ethics, Plagiarism and Fraud [1] 4. Plagiarism and Fraud. Examples of Mark Spector, Mendel and Kepler [1] 5. Ethics of managing data and authorship [1] 6. Research Design [1] 7. Choice of Research Topic and design of experiments: [1] 8. Controls. Controls. Controls. [1]

BIOXXX	**Biosafety and Regulation [1001]**
Prerequisite	NA
Learning Outcomes	To introduce concepts related to safety in Biological laboratories and Biological waste management.
Syllabus	1. Biosafety: Introduction – biosafety issues in biotechnology - historical background. Biological Safety Cabinets, Primary Containment for Biohazards. Biosafety Levels - Levels of Specific Microorganisms, Infectious Agents and Infected Animals. [6] 2. Biosafety Guidelines: Guidelines and regulations (National and International including Cartegana Protocol) – operation of biosafety guidelines and regulations of Government of India; Definition of GMOs & LMOs. Roles of Institutional Biosafety Committee, RCGM, GEAC etc. for GMO applications in food and agriculture. Environmental release of =GMOs - Risk - Analysis, Assessment, management and communication. [6]
Text and Reference Books	1. Sasson A, Biotechnologies and Development, UNESCO Publications 2. Rajmohan Joshi (Ed.). 2006. Biosafety and Bioethics. Isha Books, Delhi. 3. DBT, India Biosafety guidelines: http://dbtindia.gov.in/guidelines-biosafety

SoB Laboratory Courses

BIO315	**Advanced Biology Lab I (semester V)**
Prerequisite	NA
Learning Outcomes	To provide a hands-on training of advanced Biological experimental methods.

Syllabus	1. Microbiology: Microbial growth kinetics, bacterial motility assay; antibiotics susceptibility testing, Construction of bacterial gene deletions by homologous recombination, [24] 2. Genetics: Tetrad analysis in yeast, analysis of genomic data. [24] 3. Biochemistry: Identification of proteins by Western blotting, purification of proteins by chromatography techniques, analysis of protein-protein interaction by biochemical techniques, Determination of binding parameters of protein-ligand interaction. [48]

BIO325	**Advanced Biology Lab II (semester VI, for 2020 batch onwards)**
Prerequisite	NA
Learning Outcomes	To provide a hands-on training of advanced Biological experimental methods.
Syllabus	1. Structural Biology: Basic UNIX commands, shell scripts and C programming; PDB and graphics visualization using Pymol/Chimera, Sequence analysis at Expasy and PDB, Protein Crystallization, Visualizing reciprocal lattice and diffraction using X-Ray View, X-ray diffraction and data collection, Molecular Replacement, Refinement, model building and refinement, Validation of the protein structures, Analyzing protein structures. [32] 2. Immunology & Cell Biology: Purification and analysis of Immunoglobulins, – Immunoprecipitation, – Enzyme-linked immunosorbent assay (ELISA), Fluorescence-activated cell sorting (FACS) and analysis of cells, Immunostaining and imaging, Mammalian Cell Counting, Phagocytosis Cell Biology, Separation of cellular organelles by density gradient, Immunofluorescence imaging of cellular organelles, Analyses of cell cycle. [32] 3. Molecular Biology: Molecular cloning, Site-directed Mutagenesis, qRT-PCR, In vitro transcription and translation [32]

BIO412	**Advanced Biology Lab III (semester VII, for batches prior to 2020 batch)**
Prerequisite	NA
Learning Outcomes	To provide a hands-on training of advanced Biological experimental methods.
Syllabus	1. Molecular Biology: Molecular cloning, Site-directed Mutagenesis, qRT-PCR, In vitro transcription and translation, transduction of mammalian cell line [72] 2. Developmental Biology: Making crosses in Drosophila, cell migration during oogenesis [24]

CHY311	Coordination Chemistry [3003]
Prerequisites	
Learning Outcomes	This course covers theories in bonding for coordination complexes with the application of group. The course also includes electronic spectra, magnetism, reaction mechanisms in coordination chemistry, and a brief discussion on bioinorganic chemistry.
Syllabus	• Application of Group Theory: Reducible and irreducible representations; construction of character tables for point groups; applications of group theory in molecular vibrations and molecular orbital diagram construction of H_2O, NH_3, and BF_3. [15] • Bonding and Electronic Spectra: MO theory of transition metal complexes in various geometries; σ-type, π-type, δ- type interactions in transition metal complexes, electronic spectra of d- and f-block compounds, spectroscopic term symbols, selection rules, Tanabe-Sugano diagram, and charge transfer bands. [10] • Magnetism of Coordination Complexes: Magnetic susceptibility and magnetic moment; spin-orbit coupling; ferromagnetism and antiferromagnetism; anomalous magnetic moment; thermal effects; single molecular magnets. [3] • Reactions of Coordination Complexes: Mechanism and stereochemistry of ligand substitution reactions in square-planar and octahedral complexes; electron transfer reactions (outer–sphere and inner–sphere reactions), photochemical reactions, and ligand centered reactions. [6] • Bioinorganic Chemistry: Oxygen-activating proteins (cytochrome P450 and cytochrome c oxidase), electron transport proteins (blue copper proteins, Fe–S clusters, and cytochromes), photosystems, and hydrolase enzymes (carbonic anhydrase and peptidase). [6]
Text & Reference Books	1. F. A. Cotton, Chemical Applications of Group Theory, 3ed; Wiley, 2010. 2. Y. Jean, Molecular Orbitals of Transition Metal Complexes, Oxford press, 2005. 3. S. F. A. Kettle, Physical Inorganic Chemistry – A Coordination Chemistry Approach, Springer, 1996. 4. K. F. Purcell and J. C. Kotz, Inorganic Chemistry, Cengage, 2017. 5. P. Atkins, T. Overton, J. Rourke, F. Armstrong, and M. Hagerman, Shriver and Atkins' Inorganic Chemistry, 5ed, W. H. Freeman and Company New York, 2009. 6. G. L. Miessler and D. A. Tarr, Inorganic Chemistry, 3ed, Pearson, 2008. 7. J. E. House, Inorganic Chemistry, 3ed, Academic Press, 2019. 8. B. Douglas, D. McDaniel, and J. Alexander, Concepts and Models of Inorganic Chemistry, 3ed, Wiley, 2001. 9. J. E. Huheey, E. A. Keiter, and R. L. Keiter, Inorganic Chemistry – Principles of Structure and Reactivity, 4ed, Pearson Education, 2006. 10. R. L. Dutta and A. Syamal; Elements of Magnetochemistry, 2ed, Affiliated East-West Press, 2004. 11. W. Kaim and B. Schwederski, Bioinorganic Chemistry: Inorganic Elements in the Chemistry of Life, 2ed, Wiley, 2013. 12. R. R. Crichton, Biological Inorganic Chemistry - An Introduction, Elsevier, 2008.

CHY312	Organic Chemistry — Reactions and Mechanisms [3003]
Prerequisites	CHY 121 and CHY 211
Learning Outcomes	The course covers various aspects of organic reaction mechanisms with emphasis on the stereochemistry of the reactions. Stereochemical problems related to chemical reactions are dealt with in detail. The topics covered will include asymmetric synthesis, reactive intermediates and molecular rearrangements.

Syllabus	1. Reactive Intermediates: Carbocations (non-classical carbocation, sigma and π-participation), neighboring group participation; carbanions (homoenolate anion, etc.); free radicals (electrophilic and nucleophilic radicals, radical cations, radical anions, etc.); carbenes and carbenoids; benzyne [10] 2. Molecular Rearrangements: Rearrangements involving reactive intermediates (anionotropic, cationotropic, free radical, inter- and intramolecular processes) – Wagner-Meerwein, pinacol-pinacolone, Demjanov, Beckmann, Hofman-Loffler-Freytag, Hoffman, Curtius, Schmidt, Lossen, Wolff, benzilic acid, Claisen (including Johnson-Claisen, Ireland-Claisen), Cope and oxy-Cope, Favorskii, Fries, Baeyer-Villiger, Dakin, and Wittig rearrangements (both 1,2 and 2,3); rearrangements involving migration from nitrogen to ring carbon such as Hoffman-Martius, Fischer-Hepp, Bamberger, Orton, benzidine, etc. [12] 3. Chemistry of Carbonyl Compounds: Enolization catalysed by acids and bases, generation of thermodynamic vs kinetically controlled enolates; α-alkylation of carbonyl compounds including dianions, alkylation using acyl anion equivalent such as dithiane; C-alkylation vs O-alkylation; generation and reactions of enamines, silyl enol ethers, and boron enolates; diastereoselective-, Mukaiyama-, and intramolecular aldol reactions. [11] 4. Conjugate additions to α,β-unsaturated systems; direct addition versus conjugate addition. [2] 5. Mannich reaction, Henry reaction, Robinson annulation, Dieckmann condensation, Darzens reaction, acyloin condensation, Wittig and Horner-Emmons reactions, Baylis-Hillman reaction. [5]
Text & Reference Books	1. 1. a) F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part A: Structure and Mechanisms, 5ed., Springer, 2008., b) F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part B: Reaction and Synthesis, 5ed., Springer, 2008. 2. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2ed., Oxford University Press, 2012. 3. R. Bruckner, Advanced Organic Chemistry, Reaction Mechanisms, 3ed., Springer, 2010. 4. W.S. Carruthers and I. Coldham, Modern Methods of Organic Synthesis, 4ed., Cambridge University Press, 2004.

CHY313	**Quantum Chemistry [3003]**
Prerequisites	NA
Learning Outcomes	• To provide an understanding of the basic formalisms of quantum theory involving the operator approach • To equip the students with the techniques of obtaining solutions to the Schrödinger equation for exactly-solvable model systems • To appreciate the need to adopt approximation methods for the description of many-electron systems and beyond

Syllabus	• Formal Development of Quantum Mechanics: Operators in quantum mechanics, postulates of quantum mechanics, Born interpretation, properties of Hermitian operators, Gram-Schmidt orthogonalization, expectation values of operators, variance in observable properties, stationary state solutions, time-independent Schrödinger equation, superposition of states, forms of the linear and angular momenta operators, commutators, properties of commuting operators, hypervirial theorem, Ehrenfest theorem, generalized uncertainty principle, orbital angular momenta operators in spherical polar coordinates, ladder operators for orbital and spin angular momenta, and parity operator [12] • Exactly-solvable Model Systems: Free particle, particle in 1D, 2D and 3D boxes, quantum numbers and degeneracies, particle-in-a-box with finite walls, tunneling, scattering state solutions, harmonic oscillator, building up of the solutions from the recursion relations of Hermite polynomials, particle on a ring, particle on a sphere, rigid rotor, hydrogen atom, building up of the solutions from the recursion relations of Laguerre polynomials, and radial distribution function [14] • Approximate Approaches for Many-electron Systems: Introduction to many-electron systems, orbital approximation, anti-symmetry principle, Slater determinants, formal development of non-degenerate perturbation theory up to second order, perturbation treatment of the ground state of He atom, Rayleigh-Ritz variational method, application to the electronic structure of He atom, excited states of He, Coulomb and exchange integrals, Hückel molecular orbital theory, linear combination of atomic orbitals-molecular orbitals (LCAO-MO) approach, valence bond and molecular orbital theory treatments of $(H_2)^+$ and H_2 [10]
Text & Reference Books	1. P. Atkins and R. Friedman, Molecular Quantum Mechanics, 5th Ed., Oxford University Press (2011). 2. I. N. Levine, Quantum Chemistry, 7th Ed., Pearson (2016). 3. T. Engel, Quantum Chemistry and Spectroscopy, 3rd Ed., Pearson (2006). 4. J. P. Lowe and K. A. Peterson, Quantum Chemistry, 3rd Ed., Elsevier Academic Press (2006). 5. D. A. McQuarrie, Quantum Chemistry, Viva Student Edition, Viva (2011). 6. F. L. Pilar, Elementary Quantum Chemistry, 2nd Ed., Dover Publications (2001).

CHY314	Physical Chemistry II [3003]
Prerequisites	Physical Chemistry I
Learning Outcomes	• To provide advanced physical chemistry concepts involving electrochemistry, surfaces, colloids and polymers • To underscore the importance of various physical chemistry principles in understanding molecular processes

Syllabus	1. Fundamentals of Electrochemistry: Electrochemistry as interdisciplinary science, electrochemistry and battery technology, and electrochemical approaches to environmental problems [2] 2. Electrodics: Electrochemical cells and reactions, nature of electrode-solution interface, Faradaic reactions, mass transfer-controlled reactions, coupled chemical reactions, overpotentials, exchange current density, Butler-Volmer equation, Tafel plot, multistep electrode reactions, mass transfer by diffusion, charge transfer at electrode-solution interfaces, quantization of charge transfer, tunneling, and structure of double layer at semiconductor solution interface [8] 3. Ionics: True and potential electrolytes, ion-solvent interactions, solvation of salts, size and structure of solvation shell, solvation number, IR, NMR, X-ray and neutron diffraction methods to study hydration of salts, review of Nernst equation, electrochemical cells, electrolytic conductance, Kohlrausch's law, ionic equilibria, conductometric and potentiometric titrations, Debye-Hückel theory, activity coefficients, theoretical estimation of activity coefficients, triumphs and limitations of Debye-Hückel law, extended Debye-Hückel law based on finite-size ion model, Bjerrum ion-pair formation, ion pairs to triplet ions to cluster of ions, and Onsager limiting law [10] 4. Electrochemical Methods: Controlled potential and current techniques, hydrodynamic techniques, electrochemical instrumentations, scanning probe techniques, linear sweep voltammetry, cyclic voltammetry, square wave voltammetry, chronoamperometry, chronopotentiometry, rotating disk electrode, rotating ring-disk electrode, AC impedance, and spectroelectrochemistry [6] 5. Surfaces: Physisorption and chemisorption, Brunauer-Emmett-Teller (BET) equation, estimation of surface area, surface films of liquids, Freundlich adsorption isotherm, and Langmuir adsorption isotherm [3] 6. Colloids and Interfaces: Colloids, surfactants, micelles, stability and properties, thermodynamics of micellization, surface tension, Gibbs adsorption isotherm, capillary action, viscosity, pressure across curved surface, vapor pressure of droplet, microemulsions, interfacial phenomena, micellar catalysis, and host-guest chemistry [3] 7. Polymers: Molecular weight determination of polymers, thermodynamics and kinetics of polymerization, thermodynamics of polymer and biopolymer solutions, phase separation of polymer solutions, and properties of polymer solutions [4]
Text & Reference Books	1. A. J. Bard and L. R. Faulkner, Electrochemical Methods: Fundamentals and Applications, 2^{nd} Ed., Wiley Student Edition (2004). 2. S. Glasstone, An Introduction to Electrochemistry, Franklin Classics Trade Press (2018). 3. P. Atkins, J. de Paula and J. Keeler, Atkins' Physical Chemistry, 11^{th} Ed., Oxford University Press (2018). 4. G. W. Castellan, Physical Chemistry, 3^{rd} Ed., Narosa Publishing House (2004).F. L. Pilar, Elementary Quantum Chemistry, 2^{nd} Ed., Dover Publications (2001).

CHY321	**Organometallic Chemistry [3003]**
Prerequisites	CHY 311 (Coordination Chemistry)
Learning Outcomes	The course deals with the fundamentals of organometallic chemistry including bonding and reactivity trends of organometallic complexes. Moreover, applications of fundamental organometallic chemistry in catalysis and their underlying mechanisms are included in this course.

Syllabus	1. General Concepts: Types of ligands and their binding modes, metal–ligand frontier orbital interactions, valence electron counting, usefulness and limitations of 18e^{-} rule. [5] 2. Metal Complexes of Carbonyl, Phosphine, N-heterocyclic Carbene (NHC) Ligands: Synthesis, structure, bonding, and reactivity of metal-carbonyl complexes; steric and electronic properties of phosphine ligands; structure and bonding of metal-NHC complexes. [5] 3. Pi-complexes: Synthesis, structure, bonding, and reactivity of metal complexes bound to alkene/ alkyne/ diene/ allyl; chemistry of metallocenes, fluxionality in complexes with cyclopentadienyl ligand. [5] 4. Complexes with Metal–H/C Sigma Bonds: Synthesis, bonding, and reactivity patterns of metal–dihydrogen, metal–alkane, metal–hydride, metal–C(sp^3), metal–C(sp^2), and metal–C(sp) complexes. [5] 5. Organometallic Reactions and Mechanisms: Substitution reactions, oxidative addition, reductive elimination, transmetallation, migratory-insertion, elimination, addition, abstraction, electrophilic and nucleophilic attacks on the coordinated ligands. [5] 6. Metal–ligand Multiple Bonds: Fischer and Schrock type carbene complexes, carbyne complexes, and metal–heteroatom (O/N) multiple bonds. [5] 7. Catalysis: Mechanism driven catalyst/ process developments for various catalytic transformations such as carbonylation, alkene hydrofunctionalization, deuteration reaction, coupling reactions, alkene/ alkyne metathesis, alkene polymerization, and C–H functionalization. [10]
Text & Reference Books	1. R. H. Crabtree, The Organometallic Chemistry of the Transition Metals, 6ed, Wiley, 2013. 2. J. Hartwig, Organo-transition Metal Chemistry: From Bonding to Catalysis, University Science Books, 2010. 3. B. D. Gupta and A. J. Elias, Basic Organometallic Chemistry: Concepts, Syntheses and Applications, 2ed, Universities Press, 2013. 4. G. L. Miessler and D. A. Tarr, Inorganic Chemistry, 3ed, Pearson, 2008. 5. B. Douglas, D. McDaniel, and J. Alexander, Concepts and Models of Inorganic Chemistry, 3ed, Wiley, 2010.

CHY322	**Solid-State Chemistry [3003]**
Prerequisites	No prerequisites
Learning Outcomes	The course aims to provide required knowledge for understanding material science problems. Initially, students are introduced to structure of solids, crystal (dis)order and defects for materials properties. Insight into electronic structure of crystals and magnetic & optical properties of materials are also given. Synthesis and design of materials are also given.

Syllabus	1. Solid State Structure: Types of solids, symmetry in crystals, X-ray diffraction, common crystal structure motifs, quasicrystals. [12] 2. Defects and Non-stoichiometry: Point, line and plane defects; intrinsic and extrinsic defects- vacancies, Schottky and Frenkel defects–charge compensation; non-stoichiometry and defects (thermodynamic & structural aspects); color centers. [3] 3. Thermal Properties: Lattice vibrations - phonon spectrum; lattice heat capacity; thermal expansion; thermal conductivity. [4] 4. Electrical Properties: Electrical conductivity and Ohm's law, Hall effect, band theory, intrinsic and extrinsic semiconductors, hopping semiconductors, semiconductor/metal transition, p-n junctions, superconductors - Meissner effect - type I and II superconductors, basic concepts of BCS theory, manifestations of the energy gap - Josephson devices. [8] 5. Magnetic Properties: Classification of magnetic materials, Langevin diamagnetism, quantum theory of paramagnetism, cooperative phenomena ferro-, antiferro- and ferri-magnetism, magnetic domains and hysteresis, super paramagnetism. [4] 6. Optical properties: Optical reflectance, plasmon frequency, Raman scattering in crystals, photoconduction, photo and electroluminescence, photovoltaic, and photoelectrochemical effects. [3] 7. General Concepts in Materials Synthesis: Phase diagrams, preparation of pure materials, nucleation and crystal growth, crystal growth techniques, and zone refining. [2] 8. Brief Introduction to Different Classes of Materials: High TC superconductors, ionic conductors, polymers, liquid crystals, molecular materials, and nanomaterials. [4]
Text & Reference Books	1. A. R. West, Solid State Chemistry and Its Application, 2ed, Wiley, 2014. 2. C. N. R. Rao and J. Gopalakrishnan, New Directions in Solid State Chemistry, 2ed, Cambridge University Press, 2010. 3. P. A. Cox, The Electronic Structure and Chemistry of Solids, Oxford Science Publications, 1987. 4. G. Gottstein, Physical Foundation of Material Science, Springer, 2004.

CHY323	**Organic Chemistry — Synthetic Methods [3003]**
Prerequisites	CHY312
Learning Outcomes	Emphasis in this course will be on general methods of chemical transformations and general methods and strategies for the synthesis of complex organic molecules. Oxidations and reductions with various reagents will be discussed in detail. Also covered are transformations of carbonyl compounds, focusing on strategies to control the stereochemistry of these reactions.

Syllabus	1. Oxidation: Oxidations involving sulfur (such as Kornblum, Swern, Parikh-Doering, etc.); Cr, Mn, and Ru based reagents; Dess-Martin, and IBX oxidations; Ag_2CO_3/Celite; CAN, DDQ, and selenium in oxidation reactions; chemoselective oxidations of allylic and benzylic alcohols; Babler-Dauben-Michno oxidative rearrangement, and oxidation of aldehydes; oxidation of alkenes with OsO_4, periodic acid, and $Pb(OAc)_4$, Prevost reaction and Woodward modification; Fleming-Tamao oxidation; epoxidation of alkenes (electrophilic and nucleophilic epoxidation). Discussions with emphasis on chemo-, regio-, and stereoselectivities. [10] 2. Reduction: Catalytic hydrogenation; hydrazine based reductions; reductions using hydrides (Al and B based reagents including DIBAL, Luche reduction, L-selectride, K-selectride, Red-Al etc.), tin and silicon based reducing agents including Barton-McCombie deoxygenation; dissolving metal reductions, low valent Ti species mediated reduction reaction (McMurry coupling). Discussions with emphasis on chemo-, regio-, and stereoselectivities. [9] 3. Synthetic aspects of Diels-Alder reaction, inverse Diels-Alder reaction, hetero Diels-Alder reaction and ene-reaction. [5] 4. Dynamic stereochemistry: Effect of conformation on reactivity of acyclic and cyclic molecules dealing with S_N1, S_N2, S_N2' reactions and neighbouring group participation; E2 and syn-eliminations; oxidation of alcohols; enols and enolates; electrophilic addition to alkenes; nucleophilic addition to enones; nucleophilic addition to carbonyl group: Bürgi-Dunitz angle, addition of organometallic reagents (RM; M= Mg, Li, Zn), hydride reductions; Cram and Felkin-Anh models, chelation controlled stereoselectivity; examples of stereospecific reactions; stereoselectivity versus stereospecificity. [10] 5. Asymmetric Synthesis – Fundamental Aspects: Specific rotation, optical purity (enantiomeric excess), racemization (through cationic, anionic and radical intermediates); methods of asymmetric induction – auxiliary control, substrate control, reagent control, and solvent control; chemical and enzymatic resolution, kinetic resolution and dynamic kinetic resolution; desymmetrization – chemical and enzymatic. [6]
Text & Reference Books	1. W.S. Carruthers and I. Coldham, Modern Methods of Organic Synthesis, 4ed., Cambridge University Press, 2004. 2. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2ed., Oxford University Press, 2012. 3. H.O. House, Modern Synthetic Reactions, 2 Revised ed., Benjamin-Cummings Publishing, 1972. 4. R. Bruckner, Advanced Organic Chemistry, Reaction Mechanisms, 3ed., Springer, 2010. 5. a) F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part A: Structure and Mechanisms, 5th Ed., Springer, 2008., b) F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part B: Reaction and Synthesis, 5ed., Springer, 2008. 6. D. Nasipuri, Stereochemistry of Organic Compounds-Principle and Applications, 4 Revised Ed., New Academic Science, 2012. 7. E. L. Eliel, S. H. Wilen and L. N. Mander, Stereochemistry of Carbon Compounds, 1ed., Wiley, 2010.

CHY324	**Theoretical Spectroscopy [3003]**
Prerequisites	Quantum Chemistry
Learning Outcomes	• To develop the theoretical aspects of spectroscopy from the time-dependent perturbation theory formalism • To appreciate the role of quantum mechanics in arriving at the selection rules as well as spectral interpretations
Syllabus	1. Fundamental Aspects of Spectroscopy: Electromagnetic radiation, radiation density and intensity, theory of blackbody radiation, correlation to the coefficients of absorption and emission, time-dependent perturbation theory, Fermi golden rule, Lambert-Beer law, microscopic interpretation for the Einstein coefficients, oscillator strength, line shape functions, homogeneous and inhomogeneous broadening, and lasers [8]

	2. Electronic Spectroscopy of Atoms: Orbital picture of electronic energy levels, derivation of selection rules based on the components of the transition moment integrals, fine structure and hyperfine structure in the atomic spectra, coupling of orbital and spin angular momenta, term symbols, concepts of microstates, Stark and Zeeman effects, and Hund's rules [6] 3. Rotational and Vibrational Spectroscopy: Molecular Hamiltonian, Born-Oppenheimer approximation, nuclear motion in diatomics, separation of translational and relative degrees of freedom, rotation of rigid bodies, moments of inertia, space-fixed and molecule-fixed coordinate systems, linear, spherical, symmetric and asymmetric tops, selection rules, structure determination from rotational constants, isotope effects, vibrational motion in diatomics, dissociation energies, rigid rotor-harmonic oscillator approximation, vibrational-rotational transitions, vibrational selection rules, anharmonicity, Morse oscillator, centrifugal distortion, vibrational motion in polyatomics, mass-weighted coordinates, normal coordinates, group theoretical treatment of normal modes, light scattering and Raman effect, Stokes and anti-Stokes lines, classical and quantum models for scattering, polarizability tensor, selection rules, and resonance Raman process [14] 4. Electronic Spectroscopy of Molecules: Molecular orbitals as linear combination of atomic orbitals, electronic spectroscopy of diatomics, orbitals and states, term symbols, selection rules, vibrational and rotational structures, Frank-Condon principle, photoelectron spectroscopy, photodissociation, predissociation, electronic spectroscopy of polyatomic molecules, Walsh's rules, and vibronic coupling [4] 5. Spin Resonance Spectroscopies: Zeeman interaction, torque exerted by a magnetic field on spins, precession, nuclear magnetic resonance spectroscopy, chemical shift, nuclear g factor, nuclear coupling, electron spin resonance spectroscopy, Bloch equations, Curie susceptibility, pulsed experiments, and classical master equation [4]
Text & Reference Books	1. P. F. Bernath, Spectra of Atoms and Molecules, 2nd Ed., Oxford University Press (2005). 2. J. L. McHale, Molecular Spectroscopy, 2nd Ed., CRC Press, Taylor & Francis Group (2017). 3. I. N. Levine, Molecular Spectroscopy, Wiley (1975). 4. J. M. Hollas, Modern Spectroscopy, 4th Ed., Wiley (2004). 5. M. H. Levitt, Spin Dynamics: Basics of Nuclear Magnetic Resonance, 2nd Ed., Wiley (2008).

CHY411	**Main Group Chemistry [3003]**
Prerequisites	
Learning Outcomes	The course offers an enhanced appreciation of how periodic trends affect the structures, reaction chemistry and applications of the s- and p-block elements. The course also develops a knowledge of a wide range of structures adopted by main group compounds and also an awareness of how structures and reactivity influence their use and application in both synthesis and industry.
Syllabus	1. Hydrogen: Preparation, properties and applications of dihydrogen; molecular, saline and metallic hydrides; hydrogen bonding. [4] 2. s-block elements: Alkali metal solutions in liquid ammonia, oxides, hydroxides, nitrides, halides, and oxoacids; Zintl compounds; crown ether and cryptand complexes; organometallic compounds of Li, Na, Be, Mg and Ca; Na^+, K^+ ion transports, ion channels, and ion pumps in biological systems. [4] 3. Boron group: Structure and bonding of diborane, higher boranes, and borohydrides; Wade's rules, carboranes and metalloboranes, borazine and boron nitrides, hydrides of Al and Ga; organometallic compounds and low oxidation state compounds of Group 13. [6]

	4. Carbon group: Allotropes of carbon, fullerenes and nanotubes, carbides and silicides, silicates, hydrogen and oxygen compounds of Group 14, organometallic compounds of silicon, germanium, tin, and lead. [6] 5. Pnictogens: N_2 and P_4 activation; oxides of nitrogen and phosphorus; pnictogen halides; phosphazenes, rings and clusters; nitrogen fixation, phosphate uptake, metabolism, and feedback. [6] 6. Chalcogens: Hydrides and halides of chalcogens; polyanions of sulphur, selenium, and tellurium; bonding situations in sulphur-nitrogen & phosphorus-based compounds; sulphur and selenium in biology. [5] 7. Halogens: Pseudohalogens; polyhalides; structure and bonding of interhalogen compounds; oxoacids and oxoanions of halogens; chlorofluorocarbons, fluorocarbons and hydrofluorocarbons, effect of halogenated compounds on ozone layer. [5] 8. Noble Gases: Occurrence and chemical properties, Bartlett discovery of reactivity of noble gases; synthesis, structure, and reactivity of fluorides and oxides of xenon. [4]
Text & Reference Books	1. P. Atkins, T. Overton, J. Rourke, F. Armstrong, and M. Hagerman, Shriver and Atkins' Inorganic Chemistry, 5ed, W. H. Freeman and Company New York, 2009. 2. N. N. Greenwood, A. Earnshaw; Chemistry of the Elements, 2ed, Elsevier, 1997. 3. F. A. Cotton, G. Wilkinson, C. A. Murillo, and M. Bochmann, Advanced Inorganic Chemistry, 6e Wiley. 4. A. J. Elias; The Chemistry of p-Block Elements: Synthesis, Reactions, and Applications, 2ed, Un Press, 2019. 5. J. E. House; Inorganic Chemistry, 3ed, Academic Press, 2019.

CHY412	Advanced Organic Chemistry [3003]
Prerequisites	
Learning Outcomes	Advanced synthetic methods in organic chemistry is covered in this course. Topics include enantioselective synthesis, reagents based on sulfur and silicon, chemical synthesis of biomolecules and bioactive molecules and natural product synthesis.
Syllabus	1. Organosilicon chemistry (Brook rearrangement, Peterson olefination, chemistry of allyl and vinyl silane, Saegusa oxidation, etc.); organosulfur chemistry (Corey-Chaykovsky reaction, Julia olefination, Mislow-Evans rearrangement, etc.); cross-coupling reactions such as Heck, Stille, Suzuki, Sonogashira, Negishi, and Buchwald-Hartwig; ring-closing, ring-opening and cross metathesis reactions. (11) 2. Asymmetric Synthesis: Sharpless epoxidation and dihydroxylation; Jacobsen-Katsuki and Shi epoxidation; CBS reduction, Midland-alpine borane reduction, Noyori asymmetric reduction. [9] 3. Enantioselective Alkylation and Aldol Reactions: Diastereoselective reactions of enantiomerically pure starting materials (chiral pool manipulation); auxiliary controlled stereoselection - Evans oxazolidinones, Oppolzer sultam, Meyers amides, Enders RAMP/SAMP; enantioselective allylation and crotylation reactions; asymmetric Diels-Alder reaction. [6] 4. Natural Products: Structure, properties and reactions of mono- and di-saccharides, steroids, terpene and terpenoids, carotenoids, and alkaloids. [8] 5. Heterocyclic Compounds: Structure, preparation, properties and reactions of common heterocyclic compounds containing one or two heteroatoms O, N, and S like furan, pyrrole, thiophene, pyridine, indole, quinoline, isoquinoline. [6]
Text & Reference Books	1. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2ed., Oxford University Press, 2012. 2. R. Bruckner, Advanced Organic Chemistry, Reaction Mechanisms, 3ed., Springer, 2010. 3. E. L. Eliel, S. H. Wilen and L. N. Mander, Stereochemistry of Carbon Compounds, 1ed., Wiley,, 2010.

	4. D. Nasipuri, Stereochemistry of Organic Compounds-Principle and Applications, 4 Revised ed., New Academic Science, 2012. 5. W.S. Carruthers and I. Coldham, Modern Methods of Organic Synthesis, 4ed., Cambridge University Press, 2004. 6. L. Kurti and B. Czako, Strategic Applications of Named Reactions in Organic Synthesis, 1ed., Elsevier, 2005. 7. F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part A: Structure and Mechanisms, 5th Ed., Springer, 2008., b) F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part B: Reaction and Synthesis, 5ed., Springer, 2008. 8. John A. Joule and Keith Mills, Heterocyclic Chemistry, 5ed., Wiley-Blackwell, 2013. 9. I. L. Finar, Organic Chemistry, Volume 2: Stereochemistry and the Chemistry Natural Products, 5ed., Pearson, 2002.

CHY413	Chemical and Statistical Thermodynamics [3003]
Prerequisites	Quantum Chemistry
Learning Outcomes	To provide a molecular level interpretation of the bulk properties of chemical systems in terms of the concepts of probability theory
Syllabus	1. Elementary probability theory and Boltzmann distribution: Probability distributions involving discrete and continuous variables, mean and standard deviations, absolute and relative errors, linear regression, covariance and correlation coefficient, macrostates, microstates, configurations, Boltzmann distribution, classical and quantum particles, and Stirling's approximation [5] 2. Ensembles and averages: Ergodic hypothesis, canonical ensemble, microcanonical ensemble, grand canonical ensemble, partition functions, equivalence of various ensembles, and fluctuations [8] 3. Atomic and molecular degrees of freedom: Translational, rotational, vibrational, electronic, and electronic and nuclear spin degrees of freedom, and equipartition theorem [4] 4. Chemical equilibria: Chemical equilibrium and thermodynamic properties, enthalpy, entropy, free energy, chemical potential, and equilibrium constants in terms of partition functions [4] 5. Quantum statistics: Review of Boltzmann distribution, Bose-Einstein and Fermi-Dirac statistics, and Bose-Einstein condensation [3] 6. Solids: Einstein and Debye models and heat capacities (3h) 7. Gases: Intermolecular potentials, equations of state, non-interacting classical and quantum gases, equipartition theorem, and Gibbs paradox [4] 8. Stochastic processes: Brownian motion, Langevin equation, and random walk problem in one-dimension [3] 9. Non-equilibrium statistical mechanics: Linear response theory, fluctuation-dissipation theorem, time-correlation functions, and applications to transport phenomena [2]
Text & Reference Books	1. D. A. McQuarrie, Statistical Mechanics, Viva Student Edition, Viva (2018). 2. D. Chandler, Introduction to Modern Statistical Mechanics, 1st Ed., Oxford University Press (1987). 3. T. L. Hill, An Introduction to Statistical Thermodynamics, 1st Ed., Dover Publications (1986). 4. D. A. McQuarrie and J. D. Simon, Molecular Thermodynamics, Viva Student Edition (2018). 5. H. B. Callen, Thermodynamics and an Introduction to Thermostatistics, 2nd Ed., Wiley (2006).

CHY414	Chemical Kinetics and Dynamics [3003]
Prerequisites	Physical Chemistry I
Learning Outcomes	• To offer an advanced treatment of chemical kinetics in terms of microscopic theories such as the transition state theory • To provide an understanding of the complex phenomena at surfaces and in presence of electromagnetic radiation
Syllabus	1. Fundamental Aspects of Kinetics: Introductory chemical kinetics, collision theory of reaction rates, Arrhenius equation, activated complex theory, macroscopic reaction rates from microscopic properties, and collision cross-section [6] 2. Molecular Kinetics: Potential energy surfaces for reactive and non-reactive scattering processes, classical trajectories, transition state theory, Eyring equation, quantum and statistical mechanical estimation of rate constants, elementary gas phase reactions, Lindemann-Hinshelwood mechanism, Rice-Ramsperger-Kassel-Marcus (RRKM) theory for unimolecular reactions, study of fast reactions by flow method, relaxation method, flash photolysis, pulsed radiolysis, dynamics of unimolecular reactions, laser and molecular beam methods, energy transfer in gases and liquids, collision dynamics, scattering theory, reaction rate theory, collisional and radiationless energy transfer [18] 3. Kinetics at Surfaces: Physical and chemical adsorption, adsorption isotherms, surface catalysis, Langmuir-Hinshelwood mechanism, Eley-Rideal mechanism, heats of adsorption, and kinetics of solid-state reactions [4] 4. Photochemistry: Kinetics in the excited electronic states, Jablonski diagram, photophysical and photochemical processes, photoisomerization, excimers, exciplexes, sensitization, quantum yields, static and dynamic quenching, Stern-Volmer equation, resonance energy transfer, light-induced electron transfer, and Marcus theory [8]
Text & Reference Books	1. K. J. Laidler, Chemical Kinetics, 3rd Ed., Pearson (2003). 2. M. R. Wright, An Introduction to Chemical Kinetics, John Wiley (2004). 3. P. Atkins, J. de Paula and J. Keeler, Atkins' Physical Chemistry, 11th Ed., Oxford University Press (2018). 4. N. J. Turrro, V. Ramamurthy and J. C. Scaiano, Modern Molecular Photochemistry of Organic Molecules, Viva Student Edition, Viva (2017). 5. J. I. Steinfeld, J.S. Francisco and W. L. Hase, Chemical Kinetics and Dynamics, 2nd Ed., Prentice Hall (1999).

CHY421	Instrumental Methods for Structure Determination [3003]
Prerequisites	
Learning Outcomes	The course deals with the applications and interpretations of major types of spectroscopy: absorption, infrared, nuclear magnetic resonance spectroscopy, and mass spectrometry. Moreover, this course targets to focus heavily on interpretation of various physical methods to identify structures and reactivity patterns of organic, organometallic, and inorganic materials.
Syllabus	1. Infrared and UV Spectroscopy: Functional group characterization using IR technique; classification of UV absorption bands, examples of UV chromophores, Woodward rule. [3] 2. NMR Spectroscopy: ^{1}H-NMR – chemical shift, inductive and anisotropic effects, chemical and magnetic equivalence, spin-spin coupling and coupling constants; Karplus relationship of J on dihedral angle, first order J splitting patterns and structure correlation, strong coupling effects; second order effects, examples of AB, AX and ABX systems, simplification of second order

	spectrum, selective decoupling; use of chemical shift reagents for stereochemical assignments. [5] 3. ^{13}C-NMR: natural abundance, sensitivity, ^{13}C chemical shifts and structure correlations, ^{13}C satellites, and DEPT. [2] 4. 2D NMR: COSY, one-bond (HSQC) and multiple-bond (HMBC) ^{1}H–^{13}C correlations; defining molecular stereochemistry using the Nuclear Overhauser Effect (NOE); dynamic processes by NMR - restricted rotation (DMF, DMA, biphenyls, annulenes), ring inversion etc. [4] 5. Mass Spectrometry: Basic principles; hard (EI, FAB, etc.) and soft (MALDI, ESI, etc.) ionisation methods, interpretation of EI mass spectra, molecular ion, mass analyzers; fragmentation patterns (McLafferty rearrangement). [3] 6. Structure elucidation of organic compounds using above techniques. [5] 7. Multinuclear NMR in Inorganic Structure Analysis: Analysis of spectral patterns of diamagnetic transition metal complexes and main group compounds with multiple NMR-active nuclei in various geometries, fluxionality, elucidation of reaction mechanism, NMR of paramagnetic complexes. [2] 8. Electron Paramagnetic Resonance Spectroscopy: Introduction and analysis of isotropic and anisotropic EPR spectrum with the examples of organic radicals and transition metal ions; introduction to ENDOR spectroscopy. [5] 9. Mössbauer Spectroscopy: Introduction and analysis of spectral patterns of zero-field spectrum to determine oxidation state, spin state, and coordination geometry with examples. [3] 10. X-ray Photoelectron Spectroscopy: Basic concepts and application to determine atomic charges, oxidation state, and catalyst surface structures; analysis of spectrum with examples. [3] 11. X-ray Absorption Spectroscopy: Basic concepts and application to determine oxidation state, spin state, and coordination geometry; analysis of spectrum with examples. [3] 12. Structure elucidation of inorganic compounds using above techniques. [2]
Text & Reference Books	1. R. M. Silverstein, F. X. Webster, D. J. Kiemle, and D. L. Bryce, Spectrometric Identification of Organic Compounds, 8ed., Wiley, 2014. 2. W. Kemp, Organic spectroscopy, 2ed., Macmillan, 2019. 3. L. D. Field, S. Sternhelland, J.R. Kalmann, Organic Structures from Spectra, 5ed., Wiley, 2012. 4. M. H. Levitt, Spin Dynamics, 2ed., Wiley, 2008. 5. S. Braun, H. O. Kalinowski and S. Berger, 150 and More Basic NMR Experiments, 2 Revised ed., Wiley-VCH, 1998. 6. D. Neuhaus and M. Williamson, The Nuclear Overhauser Effect in Structural and Conformational Analysis, 2ed., Wiley-Blackwell, 2008. 7. D. L. Pavia, G. M. Lampman, G. S. Kriz, J. A. Vyvyan, Introduction to Spectroscopy 5ed., C 2014. 8. R. S. Drago; Physical Methods in Inorganic Chemistry, Affiliated East-West Press, 2015. 9. L. Que, Jr.; Physical Methods in Bioinorganic Chemistry, University Science Books, 2000. 10. Encyclopedia of Inorganic and Bioinorganic Chemistry, Wiley, 2011.

CHY422	Physical Organic Chemistry [3003]
Prerequisites	CHY 312 and CHY 323
Learning Outcomes	This course will examine the tools that the modern organic chemist has at his or her disposal for elucidating organic reaction mechanism.
Syllabus	• Basic Principles: Additivity rules for bond distances; enthalpy and entropy; average bond dissociation energies; group additivity; effects of enthalpy and entropy on reaction rates; Arrhenius and Eyring equations as applied to organic reactions; kinetic versus thermodynamic control of reactions; Hammond's Postulate, and Curtin-Hammett Principle; Baldwin's rules of cyclization. [5]

	• Solvent Effects: Solvent effect indices based on physical properties (dielectric constant, dipole moment, viscosity, etc.), chemical reactions (Y parameter) and spectroscopic properties (Z, E_T, a, b, A_N and D_N, etc.); correlation of chemical reactions with solvent parameters and relevance to mechanistic insights. [3] • Chemical Equilibria and Chemical Reactivity: Correlation of reactivity with structure, Hammett equation, substituent constants and reaction constants. [3] • Isotope Effects: Classification – primary, secondary and solvent isotope effects - origin and application for mechanistic interpretations. [3] • Catalysis: Classifications – electrophile catalysis, nucleophile catalysis, specific acid catalysis, specific base catalysis, general acid catalysis, general base catalysis, and general acid-base catalysis - characterization, examples and chemical insights. [3] • Pericyclic Reactions: Conservation of orbital symmetry, and Woodward and Hoffmann rules; cycloadditions, electrocyclizations, sigmatropic rearrangements, and chelotropic reactions; orbital overlap effects in chemical processes; stereochemical consequences, and examples with applications in organic synthesis. [7] • Stereoelectronic Effects: Acetals, esters, amides and related functional group compounds; reactions at sp^3, sp^2, and sp carbons with examples in synthesis and biological processes. [8] • Organic Photochemistry: Energy and electronic spin states, spectroscopic transitions, photophysical processes, fluorescence and phosphorescence, energy transfer and electron transfer, and properties of excited states - representative photochemical reactions of carbonyl compounds, olefins, and aromatic compounds. [6] • Electron-Transfer Reactions: Theoretical basis; examples of photoinduced and chemically induced electron transfer reactions (PETandCET) [2]
Text & Reference Books	1. N. S. Isaacs, Physical Organic Chemistry, 2ed., Pearson, 1995. 2. T. H. Lowry and K. S. Richardson, Mechanism and Theory in Organic Chemistry, 3ed., Pearson, 1997. 3. P. Deslongchamps, Stereolectronic Effects in Organic Chemistry, Pergamon, 1983. 4. E. V. Anslyn and A. Dennis, Modern Physical Organic Chemistry, University Science, 2005. 5. H. Maskill, The Investigation of Organic Reactions and Their Mechanisms, 1ed., Wiley-Blackwell, 2007. 6. H. Maskill, The Physical Basis of Organic Chemistry, Oxford University Press, 1985.

SoC Laboratory Courses

CHY315	Organic Chemistry Laboratory [0093]
Prerequisites	CHY 212
Learning Outcomes	Hands on laboratory experience on the preparation of organic compounds and their characterization using IR, NMR, and mass spectrometric techniques.
Syllabus	1. Experiment No 1: Protection of Alcohol and Amine Groups [9] a. Boc_2O protection of amine. b. Alcohol protection with tosyl chloride. 2. Experiment No 2: Michael Addition [9] a. Hydrolysis of 2-amino-6-methylbenzothiazole b. Aza-Michael addition reaction 3. Experiment No 3: Wittig Reaction [9] a. Preparation of ylide b. Synthesis of ethyl cinnamate

	4. Experiment No 4: Reductive Amination [9] a. Synthesis of imine. b. Reduction of imine. 5. Experiment No 5: Oxidation of Aromatic Amine [9] a. Synthesis of 2,2'-(diazene-1,2-diyl)diphenol. 6. Experiment No 6: Bromination of Binaphthol [9] a. Synthesis of (R)-6,6''-dibromo-2,2''-dihydroxy-1,1''-binaphthyl. 7. Experiment No 7: Acetylation of Glucose [9] a. Acetylation of glucose 8. Experiment No 8: Ketalization of Mannitol [9] a. Ketalization of mannitol 9. Experiment No 9: Pyrylium Tetrafluoroborate [9] a. Coupling of aldehyde and acetophenone. 10. Experiment No 10: $KMNO_4$ Oxidation of Dimethyl Pyridine [9] a. Synthesis of dipicolinic acid 11. Experiment No 11: Synthesis of Diazene [18] a. Coupling of dicarbonate and hydrazine. b. Bromine mediated oxidation of hydrazine to diazene. 12. Experiment No 12: Epoxidation of geraniol acetate [18] a. Preparation of geranyl acetate b. Epoxidation of geraniol acetate
Text & Reference Books	1. Vogel's Text book of Practical Organic Chemistry - Revised by Brian S. Furniss, Antony J. Hannaford, Peter W. G. Smith, and Austin R. Tatchell, - 5ed., John Wiley & Sons, 1991. 2. Relevant literature

CHY325	**Inorganic Chemistry Laboratory [0093]**
Prerequisites	NA
Learning Outcomes	This laboratory course provides the opportunities for hands on laboratory experiences related to the preparation and characterization of transition metal complexes. In addition to the preparation of historically important coordination complexes, preparation of complexes related to bioinorganic and organometallic chemistry are also included.
Syllabus	1. Experiment 1 – Linkage isomers of nitro-pentammine-cobalt (III): (a) Synthesis of $[Co(NH_3)_5Cl]Cl_2$, $[Co(NH_3)_5ONO]Cl_2$ and $[Co(NH_3)_5NO_2]Cl_2$; (b) Characterisation by UV-vis and IR spectroscopic methods. 2. Experiment 2 – Cis-trans isomerism and kinetics in coordination chemistry: (a) Preparation of trans-dichlorobis(ethylenediamine)cobalt(III) chloride; (b) Preparation of cis-dichlorobis(ethylenediamine)cobalt(III) chloride; (c) The kinetics and thermodynamics of cis to trans isomerization. 3. Experiment 3 – Synthesis, optical, and electrochemical studies of metal-acetylacetonato complexes: $M(acac)_3$ (M = Mn^{3+} and Fe^{3+}) 4. Experiment 4 – Effect of symmetry on the infrared spectra of metal-sulfate complexes: Preparation and IR spectroscopic characterisation of (a) Hexamminecobalt(III) sulphate pentahydrate, (b) Sulphato-pentamminecobalt(III) bromide, (c) Sulphato-bis(ethylenediamine)cobalt(III) bromide. 5. Experiment 5 – Electronic spectra of nickel(II) complexes: Preparation and UV-vis spectroscopic characterisation of (a) $[Ni(bipy)_3]SO_4$, (b) $[Ni(en)_3]Cl_2.2H_2O$, (c) $[Ni(NH_3)_6]Cl_2$, (d) $[Ni(DMSO)_6]Cl_2$. 6. Experiment 6 – Synthesis and study of an oxygen-binding cobalt complex: (a) Preparation of $salenH_2$ ligand, (b) Preparation of Co(salen) and its reactivity towards oxygen. 7. Experiment 7 – Synthesis of zinc-porphyrin complex: (a) Preparation of 5,10,15,20-meso-tetra(p-tolyl)porphyrin (H_2TTP) ligand, (b) Preparation of Zn(II)-tetra(p-tolyl)porphyrin (ZnTTP).

	8. Experiment 8 – Preparation of ferrocene derivatives: Synthesis and characterisation of 1,1'-diacetylferrocene and 1,1'-ferrocenecarboxaldehyde.
Text & Reference Books	1. J. Derek Woollins, Inorganic Experiments, 3ed, Wiley, 2010.

CHY415	**Physical Chemistry Laboratory [0093]**
Prerequisites	NA
Learning Outcomes	Physical Chemistry Laboratory offers prospects to explore the fundamentals of physical chemistry through hands on approaches. A detailed understanding on diverse aspects of physical chemistry through a combination of experimental and computational methods is the focus of this course.
Syllabus	1. Thermodynamics: Liquid-Vapour Equilibria of Binary Solvents: Azeotropic Mixtures [8] 2. Kinetics, Spectroscopy: Determination of Stoichiometry and Association/Binding Constant Using UV-Vis Spectroscopy [8] 3. Electrochemistry: Estimation of Diffusion Coefficient of Redox Species on Aqueous and Non-aqueous Medium [8] 4. Surface Chemistry: Validation of Freundlich and Langmuir Adsorption Isotherms [8] 5. Kinetics, Photochemistry: Kinetics-Inversion of Sucrose and Mutarotation of Glucose Using Polarimetry [8] 6. Spectroscopy: [8] a. Construction of Jablonski Diagram of Polyaromatic Compounds b. Estimation of Quantum Yield of Perylene and Pyrene Excimer Formation 7. Supramolecular Chemistry, Electrochemistry: Estimating the Critical Molar Concentration and Aggregation Number of Micelles [8] 8. Computational Chemistry: Theoretical Estimation of Vibrational Frequencies [8] 9. NMR Spectroscopy: [8] a. To Identify the Amino Acids Using COSY Spectrum b. To Find Out the Diffusion Coefficient (D) and the Hydrodynamic Radius (rs) of Folded (ubiquitin) and Unfolded Proteins (K19) Using Diffusion Ordered Spectroscopy (DOSY) Experiment. c. Demonstration of the Application of the NMR Technique to Chemical Exchange Processes-Hydration of Pyruvic Acid d. Simulating NMR Spectra Using Mathematica
Text & Reference Books	1. M. Halpern and G. C. McBane, Experimental Physical Chemistry: A Laboratory Text Book, 3rd Edition, W. H. Freeman, 2006 2. D. P. Shoemaker, G. W. Garland and J. W. Nibler, Experiments in Physical Chemistry, 5th Edition, McGraw Hill, London.

SoC Electives

CHY611	Principles of Inorganic Chemistry [3003]
Prerequisites	Inorganic chemistry knowledge at MSc level
Learning Outcomes	The course deals with various aspects of inorganic chemistry, including coordination chemistry, organometallic chemistry, and main group chemistry.
Syllabus	1. **Bonding models:** Bonding models in inorganic chemistry with appropriate examples. [1] 2. **Group theory in chemistry:** Brief review on symmetry elements, operations, point group classification; reducible and irreducible representations; construction of character tables for point groups; applications of group theory in molecular vibrations and molecular orbital diagram construction. [12] 3. **Coordination compounds:** A review of the basic theories of bonding in coordination complexes, electronic spectra of transition metal compounds (term symbols, selection rules, and charge transfer bands); magnetic properties of transition metal complexes. [8] 4. **Organometallic compounds:** (a) types of ligands and their binding modes, metal–ligand frontier orbital interactions, valence electron counting; (b) synthesis and reactivity trends of various types of organometallic compounds such as metal-carbonyl, metal-phosphine, metal-alkene, metal-dihydrogen, metal-hydride, metal-alkyl, and carbene complexes; (c) mechanisms of various organometallic reactions. [9] 5. **Main group compounds:** (a) Inorganic rings and cages of B, P, Si, and Al; (b) low-valent compounds of main group elements; (c) multiple-bonding in compounds containing main group elements. [10]
Text & Reference Books	1. F. A. Cotton, Chemical Applications of Group Theory, 3ed; Wiley, 2010. 2. Y. Jean, Molecular Orbitals of Transition Metal Complexes, Oxford press, 2005. 3. S. F. A. Kettle, Physical Inorganic Chemistry – A Coordination Chemistry Approach, Springer, 1996. 4. K. F. Purcell and J. C. Kotz, Inorganic Chemistry, Cengage, 2017. 5. P. Atkins, T. Overton, J. Rourke, F. Armstrong, and M. Hagerman, Shriver and Atkins' Inorganic Chemistry, 5ed, W. H. Freeman and Company New York, 2009. 6. G. L. Miessler and D. A. Tarr, Inorganic Chemistry, 3ed, Pearson, 2008. 7. J. E. House, Inorganic Chemistry, 3ed, Academic Press, 2019. 8. B. Douglas, D. McDaniel, and J. Alexander, Concepts and Models of Inorganic Chemistry, 3ed, Wiley, 2001. 9. J. E. Huheey, E. A. Keiter, and R. L. Keiter, Inorganic Chemistry – Principles of Structure and Reactivity, 4ed, Pearson Education, 2006. 10. R. H. Crabtree, The Organometallic Chemistry of the Transition Metals, 6ed, Wiley, 2013. 11. J. Hartwig, Organo-transition Metal Chemistry: From Bonding to Catalysis, University Science Books, 2010. 12. B. D. Gupta and A. J. Elias, Basic Organometallic Chemistry: Concepts, Syntheses and Applications, 2ed, Universities Press, 2013. 13. N. N. Greenwood, A. Earnshaw; Chemistry of the Elements, 2ed, Elsevier, 1997.

CHY5101	Advanced Materials Chemistry [3003]
Prerequisites	CHY 322 (Solid State Chemistry)
Learning Outcomes	The course refreshes the fundamentals of materials chemistry then through specific examples of inorganic and hybrid materials, deals with advanced material chemistry topics that are of prime importance to applications in energy research.

Syllabus	1. **Overview of general chemical and physical principles:** of materials chemistry applied to synthesis, structure and properties of various inorganic & hybrid materials. [8] 2. **Classification based on structure:** Various molecular solids, layered materials, 3D-materials, nanostructures materials with specific examples. [4] 3. **Classification based on function:** Porous materials, optical materials, semiconductors, ionic conductors, superconductors, thermoelectric and magnetic materials. [8] 4. **Structure-function-property relations, illustrative and specific examples with some case studies** from molecular coordination and organometallic complexes, coordination polymers, metal-organic frameworks, hybrid composites, metal hydrides and oxides, ceramics and nanoclusters. [12] 5. **Focus on energy applications:** Batteries, supercapacitors, fuel cells, solar cells, LEDs. [8]
Text & Reference Books	1. A. R. West, Solid State Chemistry and Its Application, 2ed, Wiley, 2014. 2. C. N. R. Rao and J. Gopalakrishnan, New Directions in Solid State Chemistry, 2ed, Cambridge University Press, 2010. 3. P. A. Cox, The Electronic Structure and Chemistry of Solids, Oxford Science Publications, 1987. 4. The Chemistry of Nanomaterials: Synthesis, Properties and Applications, 2 Volume Set C. N (Editor), Achim Müller (Editor), Anthony K. Cheetham (Editor), 2004, Wiley-VCH. 5. Molecules Into Materials: Case Studies in Materials Chemistry - Mixed Valency, Magnet Superconductivity, 2007, World Scientific.

CHY612	**Principles of Organic Chemistry [3003]**
Prerequisites	Organic chemistry knowledge at MSc level
Learning Outcomes	To learn various aspects of stereochemistry, reactive intermediates, oxidation and reduction reactions. To learn various C–C bond forming reactions and their utility in natural products synthesis.
Syllabus	• Stereochemistry: Conformation of acyclic and cyclic molecules, geometrical and optical isomerism; dynamic stereochemistry-conformation and reactivity. [4] • Rearrangements and Reactions: Mechanistic and stereochemical aspects of - Baeyer-Villiger, Claisen (including Johnson and Ireland modifications), Wittig rearrangements; ene and metalloene reactions; Hofman-Loffler-Freytag reaction, Barton, and hypohalite based reactions at unfunctionalized carbons. [6] • Reactive Intermediates: An overview and revision of the chemistry of carbenes, nitrenes, radicals, carbocations (including non-classical carbocation), carbanions (homoenolate anion), and benzynes. [7] • Oxidation: Swern, hypervalent iodine such as Dess-Martin, IBX, etc., Prevost, dimethyl dioxirane, oxaziridines, transition metal-catalyzed oxidations such as Cr, Mn, and Ru, etc.; asymmetric Sharpless epoxidation and dihydroxylation, Jacobsen's epoxidation. Mechanism, stereochemistry and applications in organic synthesis wherever applicable. [8] • Reduction: Reduction of carbonyl compounds and C–C multiple bonds using Al and B based reagents (e.g. DIBAL, Red-Al, superhydride, selectrides, $NaBH_4$-$CeCl_3.7H_2O$ etc.), and low valent Ti species; microbial reductions (NADH models), oxazaborolidine, BINAP, and BINAL based asymmetric reductions. [6] • C–C Bond Formation: [2+2], [3+2] and [4+2] cycloadditions; enolate chemistry (including silicon chemistry); asymmetric alkylations and aldol reactions using Evans' oxazolidinones. [7] • Synthetic Applications: Synthesis of some typical natural products utilizing above mentioned methodologies. [2]

Text & Reference Books	1. D. Nasipuri, Stereochemistry of Organic Compounds-Principle and Applications, 4 Revised ed., New Academic Science, 2012. 2. a) F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part A: Structure and Mechanisms, 5ed., Springer, 2008., b) F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part B: Reaction and Synthesis, 5ed., Springer, 2008. 3. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2ed., Oxford University Press, 2012. 4. W.S. Carruthers and I. Coldham, Modern Methods of Organic Synthesis, 4th Ed., Cambridge University Press, 2004. 5. H.O. House, Modern Synthetic Reactions, 2 Revised ed., Benjamin-Cummings Publishing, 1972. 6. E. J. Corey and Xue–Min Cheng, The Logic of Chemical Synthesis, Revised ed., Wiley-Blackwell , 1995.

CHY5102	Modern Organic Synthesis: Advances in Methods and Reagents [3003]
Prerequisites	CHY 312 and CHY 323
Learning Outcomes	This course is designed to allow learning of frontier aspects of organic synthesis, which include conventional synthetic methods with their recent modifications, various types of catalysis and reagents development.
Syllabus	• **Construction of Ring Systems:** (a) Synthesis of cyclic, spirocyclic and fused systems via cation- and radical-olefin cyclization, Nazarov cyclization, rearrangements, intramolecular McMurry Coupling, Pauson Khand reaction, etc.; (b) Inter-conversion of ring systems (contraction and expansion); (c) Ring closing metathesis for macrocyclic ring formation. [10] • **Transition Metal Catalysis:** (a) Metal-catalyzed C-X (X = N, O, S, etc.) bond forming reactions (Buchwald-Hartwig coupling, Ullmann coupling, Chan-Lam coupling, Hunsdiecker reaction, etc.); (b) Concept of C–H bond activation/functionalization. [6] • **Radical-Based Catalysis:** (a) Thermal metal-promoted and metal-free catalytic radical reactions; (b) Visible-light photocatalysis, including dual catalysis and EDA complexation in organic synthesis; (c) Modern electroorganic synthesis. [8] • **(Asymmetric) Organocatalysis:** (a) Amine Catalysis (iminium catalysis, enamine catalysis, and SOMO catalysis); (b) Hydrogen-bonding catalysis (Thiourea, Squaramide, etc.); (c) Chiral Brønsted Acid and Lewis-Acid/Base catalysis; (d) NHC-catalysis. [8] • **Selected Reagents:** (a) Nucleophilic Fluorinating Reagents (Olah reagent, DAST and its modifications, etc.) and Electrophilic Fluorinating Reagents (NFSI, Selectfluor, etc.); Nucleophilic Perfluoroalkylating(C_nF_{2n+1}) reagents (Langlois's and Baran's reagents, Ruppert-Prakash reagent, etc.) and Electrophilic Perfluoroalkylating(C_nF_{2n+1}) reagents (Togni's and Umemoto's reagents, etc.); (b) Polyvalent iodine reagents; (c) Lawesson's and Woollin's reagent; (d) Coupling reagents in macrolactonization and peptide synthesis (DCC, EDC+HOBt, Ghosez's reagent, Yamaguchi's reagent, etc.). [10]
Text & Reference Books	1. J. J. Li, Name Reactions for Carbocyclic Ring Formations, Wiley-VCH (2010). 2. R. H. Grubbs, A. G. Wenzel, D. J. O'Leary and E. Khosravi, Handbook of Metathesis, Wiley-VCH (2015). 3. M. L. Crawley and B. M. Trost, Applications of Transition Metal Catalysis in Drug Discovery and Development: An Industrial Perspective; Wiley-VCH (2012). 4. P. H. Dixneuf and H. Doucet, C-H bond activation and catalytic functionalization I, Springer (2018). 5. B. König, Science of Synthesis: Photocatalysis in Organic Synthesis, Thieme (2019). 6. M. H. Shaw, J. Twilton and D.W.C. MacMillan, Photoredox Catalysis in Organic Chemistry, J. Org. Chem. 2016, 81, 6898-6926. 7. B. List and S. Arseniyadis, Asymmetric Organocatalysis, Vol. 2, Springer (2010).

	8. A. Berkessel and H. Gröger, Asymmetric Organocatalysis: From Biomimetic Concepts to Applications in Asymmetric Synthesis, Wiley-VCH (2005). 9. Peer Kirsch, Modern Fluoroorganic Chemistry: Synthesis, Reactivity, Applications, 2nd, Completely Revised and Enlarged Edition, Wiley-VCH (2013). 10. W. Carruthers and I. Coldham, Modern Methods of Organic Synthesis, 4th Ed. Cambridge University Press (2004). 11. V. V. Zhdankin, Hypervalent Iodine Chemistry: Preparation, Structure and Synthetic Applications of Polyvalent Iodine Compounds, Wiley-VCH (2013).

CHY613	Principles of Physical Chemistry [3003]
Prerequisites	
Learning Outcomes	To equip the entry-level graduate students with the essentials of various concepts in physical chemistry
Syllabus	• Essentials of quantum chemistry: Review of postulates, exactly-solvable model systems, approximate methods, many-electron systems, Slater determinants, valence bond and molecular orbital theories [6] • Essentials of spectroscopy: Rotational and vibrational spectroscopy of diatomics and polyatomics, selection rules, Raman scattering, electronic spectroscopy, fluorescence and phosphorescence, lifetimes and linewidths, photochemical processes, quantum yield, energy transfer and electron transfer processes, nuclear magnetic resonance spectroscopy, and nuclear spin dynamics [14] • Essentials of statistical mechanics: Molecular energy levels, partition functions, Boltzmann distribution, and calculation of thermodynamic quantities [6] • Essentials of kinetics, dynamics and electrochemistry: Rates of chemical reactions, steady-state approximation, temperature effects, transition state theory, fast reactions, ionic equilibria, activity and activity coefficients, Debye-Hückel theory, Nernst equation, and Onsager law [10]
Text & Reference Books	1. T. Engel and P. Reid, Physical Chemistry, 3rd Ed., Pearson (2013). 2. P. Atkins, J. de Paula and J. Keeler, Atkins' Physical Chemistry, 11th Ed., Oxford University Press (2018). 3. G. W. Castellan, Physical Chemistry, 3rd Ed., Narosa Publishing House (2004). 4. I. N. Levine, Physical Chemistry, 6th Ed., Tata McGraw-Hill (2011). 5. D. A. McQuarrie and J. D. Simon, Physical Chemistry: A Molecular Approach, Viva Student Edition, Viva (2019). 6. R. J. Silbey, R. A. Alberty and M. G. Bawendi, Physical Chemistry, 4th Ed., Wiley Student Edition (2006).

CHY5103	Computational Chemistry [3003]
Prerequisites	Quantum Chemistry
Learning Outcomes	To offer a rigorous theoretical treatment of various electronic structure and molecular modelling strategies To describe the know-how of performing computations

Syllabus	**Electronic Structure Theory:** 1. Review of solutions to the electronic Schrödinger equation for hydrogen and helium atoms, Slater determinants, Pauli's antisymmetry principle, Coulomb and exchange integrals, Rayleigh-Ritz variation method, and effective nuclear charge [4] 2. Born-Oppenheimer approximation, bonding in H_2^+, LCAO-MO approach, confocal elliptic coordinates, evaluation of the Coulomb, resonance and overlap integrals, valence bond and molecular orbital descriptions of H_2, Slater determinants, configuration interaction treatment of H_2, molecular orbital theory (MOT) of diatomics, bond lengths, bond orders, and bond energies [4] 3. Concept of hybridization, sp, sp^2, and sp^3 hybridizations [1] 4. Treatment of unsaturated π-systems, π-electron approximation, free electron MOT, Hückel MOT, π-bond order, σ-bond order, atomic charges, and Hückel (4n+2) rule [2] 5. Band theory of solids, tight-binding approximation, density of states, Kronig-Penney model, and Brillouin zone [2] 6. Many-electron systems, Hartree and Hartree-Fock (HF) methods, Slater orbitals, Koopmans' theorem, Roothaan equations, restricted and unrestricted HF methods, Gaussian-type orbitals, basis sets, complete basis set limit, basis set superposition error, population analysis, and molecular electrostatic potential [4] 7. Configuration interaction (CI), limited CI, CI singles, CI doubles, CI singles and doubles, Brillouin theorem, Slater-Condon rules, static electron correlation, non-dynamical correlation, dynamical correlation, multiconfiguration and multireference methods, size extensivity, and size consistency [3] 8. Moller-Plesset (MP) perturbation theory, MP0, MP1 and MP2 methods (2h) 9. Density functional theory, concepts of functionals and electron density, Thomas-Fermi model, Hohenberg-Kohn theorem, Kohn-Sham equations, and illustration of key exchange-correlation functionals [4] **Molecular Modeling and Simulations:** 1. Born-Oppenheimer approximation, potential energy surfaces, geometry optimization, single point energies, stationary points, gradients, Hessian, transition states, intrinsic reaction coordinates, and minimum energy path [2] 2. Normal modes of vibration, internal coordinates, mass-weighted coordinates, and normal mode analysis in diatomics and polyatomics [2] 3. Molecular mechanics, force fields, stretching, bending, torsions, non-bonded interactions, and illustrative examples [2] 4. Ion-ion, ion-dipole, dipole-dipole, dipole-induced dipole, induced dipole-induced dipole interactions, and quantum mechanical description of dispersion interactions [2] 5. Molecular dynamics, hard sphere potential, Lennard-Jones potential, Verlet and velocity Verlet algorithms, ergodic hypothesis, and estimation of averages [2]
Text & Reference Books	1. P. Atkins and R. Friedman, Molecular Quantum Mechanics, 5th Ed., Oxford University Press (2011). 2. A. Szabo and N. S. Ostlund, Modern Quantum Chemistry: Introduction to Advanced Electronic Structure Theory, Dover Publications (1996). 3. F. Jensen, Introduction to Computational Chemistry, 2nd Ed., John Wiley (2006). 4. D. A. McQuarrie, Quantum Chemistry, Viva Student Edition, Viva (2011). 5. A. Leach, Molecular Modelling: Principles and Applications, 2nd Ed., Pearson (2009).

CHY510X	Fundamentals of Solution-State NMR Spectroscopy: Principles and Applications [3003] *(NKN course with IISER Pune & IISER Bhopal)*
Prerequisites	Quantum Chemistry, Theoretical Spectroscopy
Learning Outcomes	• Define the fundamental concepts in the field of nuclear magnetic resonance (NMR) spectroscopy • To classify, discuss the theoretical origin and explain the background of NMR experiments • To apply and construct the framework developed towards understanding one- and multi-dimensional NMR experiments • To learn to analyze, compare and contrast experiments towards their application in biomolecular systems • To develop a hands-on training model on the basics of data processing and analysis of biomolecular model systems
Syllabus	1. Pertinent introductory notes: Vector calculus - simple problems, Postulates of QM - simple examples with 1D box problem [2] 2. **Classical picture of NMR:** Bloch equations - involving animations and simulations using NMR-SIM, Predicting the spectrum of AX, AX_2, AMX, AM_2X_2 systems, Bloch eq. Limitations [4] 3. **Quantum mechanical picture and application to basic module:** Representation of the wave-function in terms of the density matrix, deduction of the equilibrium density matrix, representation of the density matrix with a complete set of spin operators, time evolution of the density matrix - Liouville von Neumann equation, Baker-Campbell-Hausdorff formula, propagator formalism for deducing evolution of density matrix [7] 4. **Application of density matrix formulation to basic modules and 1D NMR:** spin-echo (chemical shift refocusing, scalar coupling evolution, shift evolution and refocusing of active scalar couplings as in 2D NMR), Insensitive Nuclei Enhancement by Polarization Transfer (INEPT) - provide examples of ^{1}H to X nuclei, ^{13}C to ^{15}N, Spin-state selective coherence transfer [3] 5. **Basic 1D NMR applications:** Brief qualitative description of Fourier Transformation (FT), Basic one-pulse 1D FT NMR - ^{1}H and ^{13}C (without steady-state enhancement), Refocused-INEPT (RINEPT) module for ^{13}C 1D NMR, Distortionless Enhancement by Polarization Transfer (DEPT) - 45°, 90°, 135° and its application to distinguish methyl, methylene and methine group [2] 6. **Basic NMR instrumentation and data processing:** Description of NMR hardware, recent hardware advancements (cryogenic probe and high-field magnets), factors influencing signal to noise, digital quadrature detection, pulse features - bandwidth, pulse phase modulation and phase cycling, shaped pulses, offset dependence, gradient pulses (application in phase cycling, coherence selection, solvent suppression), data processing - phase correction, reasons for phase artifacts, delayed acquisition, aliasing, folding [4] **7. Introduction to 2D NMR:** Basic concepts in multidimensional NMR - "indirect" dimension, Homonuclear 2D experiments: COSY (regular, 60°, DQF), POF of essential modules: constant-time, semi-constant-time modules, Heteronuclear 2D experiments: single-quantum (HSQC), multiple-quantum (HMQC), multiple-bond (HMBC), Other essential concepts: sensitivity enhancement (preservation of equivalent pathways), echo-anti echo, time proportional phase incrementation (TPPI),Transverse Relaxation Optimized SpectroscopY (TROSY) with qualitative discussion on relaxation [7] 8. **Protein NMR spectroscopy:** Theoretical description of protein chemical shift assignment, Hands-on data processing training using NMRPipe, Hands-on training with data in SPARKY/CARA [3] 9. **Nucleic Acids NMR:** Theoretical description of DNA and RNA CS assignment, Hands-on training with data in SPARKY [2]
Text & Reference Books	1. Protein NMR Spectroscopy: Principles and Practice. John Cavanagh, Nicholas J. Skelton, Arthur G. Palmer, III, Wayne J. Fairbrother. ISBN: 9780121644918. 2. Fundamentals of Protein NMR Spectroscopy. Gordon S. Rule, Kevin T. Hitchens.ISBN 978-1-4020-3500-5. 3. Spin Dynamics. Malcolm H. Levitt. ISBN: 978-0-470-51117-6 4. Understanding NMR Spectroscopy. James Keeler. ISBN: 978-0-470-74608-0 D. A. McQuarrie, Quantum Chemistry, Viva Student Edition, Viva (2011). 5. A. Leach, Molecular Modelling: Principles and Applications, 2nd Ed., Pearson (2009).

MAT311	Real Analysis [3003]
Objectives	• Objective is to discuss some of the topological properties of a metric space and study the properties of real valued sequences and functions, such as convergence, limits, continuity, compactness, connectedness, smoothness, integrability.
Syllabus	1. Preliminaries: Zorn's lemma, Axiom of choice (1) 2. Metric spaces Properties and examples, open sets, limit points, Bolzano-Weierstrass theorem, derived sets, closed sets, adherent points, closure of a set, nested intervals, Cantor intersection theorem, cover, open cover, subcover, Heine-Borel theorem, converse of Heine-Borel theorem, compact sets, connected sets, completeness, continuous functions, continuity and compactness, continuity and connectedness. (20) 3. The Riemann-Stieltjes integral: Functions of bounded variation, total variation, bounded variation functions as difference of monotone functions, continuous functions of bounded variations, partitions, definition of Riemann-Stieltjes integral, refinement, existence of the integral, properties of the integral, fundamental theorems of integral calculus, mean value theorems, integration by parts. (12) 4. Sequences and series of functions: Pointwise and uniform convergence, uniform convergence and continuity, uniform convergence and integration, uniform convergence and differentiation, sufficient condition for uniform convergence of a series, power series and convergence, equicontinuity, Ascoli's theorem, Stone-Weierstrass theorem. (7)
Text & Reference Books	1. T. M. Apostol, Mathematical Analysis, 2nd edition, Addison Wesley, 1974. 2. R. G. Bartle and D. R. Sherbert, Introduction to Real Analysis, 4th Edition, Wiley, 2011. 3. R. M. Dudley, Real Analysis and Probability, Cambridge University Press, 2002. 4. S. R. Ghorpade and B. V. Limaye, A Course in Calculus and Real Analysis, Springer, 2006. 5. R. R. Goldberg, Methods of Real Analysis, 2nd edition, Wiley, 1976. 6. S. Lang, Undergraduate Analysis, 2nd edition, Springer, 1996. 7. W. Rudin, Principles of Mathematical Analysis, 3rd edition, McGraw-Hill, 1976. 8. T. Tao, Analysis I, Hindustan Book Agency, 2006. 9. H. L. Royden, Real Analysis, 3rd edition, PHI Learning, 2009.

MAT312	Theory of Groups and Rings [3003]
Objectives	• This first course in algebra introduces group theory, rings and modules. Main focus is abstract group theory. Serves as a prerequisite for several advanced mathematics courses.
Syllabus	1. Definition of group, examples of symmetric groups, cyclic groups, multiplicative group Z_n*, Dihedral groups, subgroups and normal subgroups, homomorphisms. (4.5) 2. Quotient groups, Noether Isomorphism Theorems, Theorems of Lagrange and Cauchy. (4.5) 3. Group actions, examples of group actions, Cayley's Theorems, Orbit Stabilizer theorem, Class Equation, Burnside's Counting lemma, Sylows theorems. (9) 4. Direct Products and Semi-Direct Products, Solvable groups, Nilpotent Groups (6) 5. Rings, Ideals, Ring homomorphisms, subrings, examples of rings, Prime ideals, maximal ideals, Integral domains. (4.5) 6. Noether Isomorphism theorems, Euclidean domains, PID's, UFD's, Gauss theorem, Eisenstein Criterion for Irreducibility, power series rings. (7.5) 7. Modules, definitions and examples, Fundamental theorem of finitely generated modules over a PID. (6)

Text & Reference Books	1. D.S. Dummit and R. Foote, Abstract Algebra, 3rd Edition, WIley India, 2011. 2. Michael Artin, Algebra, Phi Learning Pvt. Ltd., New Delhi, 2011. 3. Serge Lang, Algeba, 3rd Revised Edition, Springer International Edition.

MAT313	Linear Algebra [3003]
Objectives	• The approach in this course on Linear Algebra is a bit more abstract and formal as compared to the first year introductory linear algebra course. The course is a prerequisite for almost all advanced mathematics courses, as well as for several interdisciplinary courses.
Syllabus	1. Vector spaces, subspaces, quotient spaces, basis, change of basis, linear functional, dual space, projection, eigenvalues and eigenvectors. (5) 2. Cayley Hamilton Theorem ,invariant subspaces, simultaneous diagonalization, direct sum decomposition, invariant direct sum, the primary decomposition theorem. (9) 3. Nilpotent Operators, Jordan Canonical form. (6) 4. Inner product spaces, orthonormal basis, Gram-Schmidt process; adjoint operators, least squares problem, normal and unitary operators, self adjoint operators, spectral theorem for self adjoint and normal operators. (12) 5. LU decomposition, QR factorization, Singular Value Decomposition, Orthogoanl matrices. (8)
Text & Reference Books	1. S. Axler,Linear Algebra Done Right, Springer, 1997. 2. W. H. Greub,Linear Algebra, 4th ed., Springer, 1981. 3. K. Hoffman and R. Kunze, Linear Algebra, 2nd edition, Pearson Education,New Delhi, 2006

MAT314	Numerical Analysis [3003]
Objectives	• This introductory numerics course aims to make the students aware of various classical approximation schemes in order to solve algebraic equations and differential equations. The lab component of this course will enable the students to have hand on experience in implementing numerical schemes.
Syllabus	1. Roundoff Errors and Computer Arithmetic. (2) 2. Interpolation: Lagrange interpolation, divided differences, Hermite interpolation, splines. (5) 3. Numerical differentiation, Richardson extrapolation. (3) 4. Numerical integration: Trapezoidal, Simpson, Newton-Cotes, Gauss quadrature, Romberg integration. (6) 5. Solutions of linear algebraic equations: Direct methods, Gauss elimination, pivoting, matrix factorisations; Iterative methods: Matrix norms, Jacobi and Gauss-Siedel methods, relaxation methods. (8) 6. Computation of eigenvalues and eigenvectors: Power method, Householder's method, QR algorithm. (4) 7. Numerical solutions of nonlinear algebraic equations: Bisection, Secant and Newton's method, fixed-point iteration. (4) 8. Initial Value Problems: Euler method, Higher order methods of Runge-Kutta type. Multi-step method, Adams-Bashforth, Adams-Moulton methods. Boundary Value Problems: Shooting methods, Finite differences. (8)
Text & Reference Books	1. K. E. Atkinson, An Introduction to Numerical Analysis, 2nd edition, John Wiley, 1989. 2. E. K. Blum, Numerical Analysis and Computation, Theory and Practice, Addison Wesley Publishing Company, 1972. 3. R. L. Burden and J. D. Faires, Numerical Analysis, 7th edition, Brookes/Cole, 2011. 4. S. D. Conte and C. deBoor, Elementary Numerical Analysis-an algorithmic approach, 3rd edition, McGraw Hill, 1980.

MAT314	Numerical Analysis [3003]
	5. J. W. Dummel, Applied Numerical Linear Algebra, SIAM, 1997. 6. C. F. Gerald and P. O. Wheately, Applied Numerical Analysis, 5th edition, Addison Wesley, 1994. 7. G. H. Golub and C. F. vanLoan, Matrix Computations, John Hopkins University Press, 1996. 8. F. B. Hildebrand, Introduction to Numerical Analysis, McGraw Hill, New York, 1974. 9. E. Sueli and F. D. Mayers, An Introduction to Numerical Analysis, Cambridge University Press, 2003. 10. L. N. Trefethen and D. Bau, Numerical Algebra, SIAM, 1997. 11. D. S. Watkins, Fundamentals of Matrix Computations, Wiley, 1991.

MAT315	Mathematical Statistics [3003]
Objectives	• This is the first theory course on statistics. This course provides students with decision theory, estimation, confidence intervals, and hypothesis testing.
Syllabus	1. Sampling Distributions: Populations and samples; distribution of samples; graphical representation of data; basic distributions, properties, fitting, and their uses; distribution theory for transformations of random vectors; sampling distributions based on normal populations; t, χ^2 and F distributions. (9) 2. Estimation of Parameters: Method of maximum likelihood; applications to different populations; point and interval estimation; method for finding confidence intervals; applications to normal populations; approximate confidence intervals. (9) 3. Bivariate Samples: Sample from a bivariate population; least square curve fitting; maximum likelihood estimation; multivariate samples. (7) 4. Testing of Hypotheses: Statistical hypotheses - simple and composite; best critical region; application to normal population; likelihood ratio testing; normal and bivariate normal populations and comparison; binomial populations and comparison; Poisson population; multinomial population; χ^2- test of goodness of fit. (15) Practicals 1. Objects and functions, Arithmetical and Boolean operators, Importing and Exporting Data sets, Packages, Loops and Conditional statements, Measure of central tendency, basic plots. 2. Density, distribution function, quantile function and random generation for standard discrete and continuous distributions. 3. Q-Q plots and P-P plots. Fitting distributions. 4. Maximum Likelihood estimation. Generating bivariate random sample. • Test for mean, variance, proportion and independency.
Text & Reference Books	1. D. Freedman, R. Pisani and R. Purves, *Statistics,* W. W. Norton & Company; 4th edition (2007). 2. R. V. Hogg, J. McKean and A. T. Craig, *Introduction to Mathematical Statistics,* Pearson Education India; 7 edition (2013). 3. A. Mood, F. Graybill and D. Boes, *Introduction to the Theory of Statistics,* McGraw Hill Education; 3 edition (2017). 4. P.J.Bickel and K.A.Doksum, *Mathematical Statistics: Basic Ideas and Selected Topics,* Volume 1. 2nd edition. Chapman and Hall / CRC (2015). 5. Grolemund, Garrett. *Hands-on programming with R: write your own functions and simulations*. O'Reilly Media, Inc., 2014 6. Schumacker, Randall, and Sara Tomek. *Understanding statistics using R*. Springer Science & Business Media, 2013 7. Zuur, Alain, Elena N. Ieno, and Erik Meesters. *A Beginner's Guide to R*. Springer Science & Business Media, 2009.

MAT321	Complex Analysis [3003]
Prerequisite	MAT311 Real Analysis
Objectives	• Objective is to study the complex valued functions and their analytical properties. Complex analysis has several important theorems/constructions, which are very much relevant for more advanced mathematical topics, such as algebraic topology and differential geometry. Also it has a wide applications in various areas of physics and engineering. This course caters for both purposes.
Syllabus	1. Geometric representation of complex numbers, Analytic functions: limits, derivatives, Cauchy-Riemann equations, sufficient conditions, CauchyRiemann equations in polar form, harmonic conjugate. (6) 2. Mapping by elementary functions: Linear functions, the function 1/z, linear fractional transformations, the logarithmic function and its branches, special fractional transformations. (6) 3. Cauchy's theorem and Cauchy's integral formula for convex regions, Morera's Theorem, power series representation of analytic functions, zeros of analytic functions, open mapping theorem, maximum modulus principle,Schwarz lemma, Weierstrass 'theorem on limits of analytic functions. (12) 4. Laurent's theorem, classification of singularities, residue theorem, the principal part of a function, poles, quotient of analytic functions, evaluation of improper real integrals, improper integrals involving trigonometric functions, argument principle, Rouche's theorem. (9) 5. Riemann Mapping Theorem (7.5)
Text & Reference Books	1. L. V. Ahlfors,Complex Analysis, Mcgraw-Hill, 1980. 2. T. W. Gamelin,Complex Analysis, Springer-Verlag, 2001. 3. R. Greene and S. G. Krantz,Function Theory of One Complex Variable, 3rdEdition, GSM, Vol. 40, AMS, 2006. 4. E. M. Stein and R. Shakarchi,Complex Analysis, Princeton University Press,2003.

MAT322	Fields, Modules and Algebras [3003]
Prerequisite	MAT312 Theory of Groups and Rings
Objectives	• To learn the basics of field theory, finite fields, Fundamental Theorem of Galois Theory, Solvability of radicals. and basics of Module theory
Syllabus	1. Field extensions, algebraic closure, splitting fields, separable and inseparable extensions, normal extensions, Galois extensions, finite fields, fundamental Theorem of Galois theory, cyclic and cyclotomic extensions. (19.5) 2. Noetherian rings and modules, Hilbert Basis Theorem. (4.5) 3. Elementary Algebraic geometry, Hilbert Nullstellensatz (9) 4. Introduction to Representation theory till and including Induced Representations. (7.5)
Text & Reference Books	1. D.S. Dummit and R. Foote, Abstract Algebra, 3rd Edition, WIley India, 2011. 2. Michael Artin, Algebra, Phi Learning Pvt. Ltd., New Delhi, 2011. 3. Serge Lang, Algebra, 3rd Revised Edition, Springer International Edition.

MAT323	General Topology [3003]
Prerequisite	MAT311 Real Analysis
Objectives	• This is a first formal course in topology. The main purpose is to cover the point set topology in full details and then to introduce some basics of algebraic topology.
Syllabus	1. Topological Spaces and Continuous Functions: Topological spaces, Basis for a topology, The order topology, The product topology, The subspace topology, Closed sets and limit points, Continuous functions, The metric topology, The quotient topology. (12)

	2. Connectedness and Compactness: Connected spaces, connected sets in the real line, Components and path components, Local Connectedness, Compact spaces, Limit point compactness, Local compactness. Tychonoff's theorem for finite products. (12) 3. Countability and Separation Axioms: The countability axioms, The separation axioms, The Urysohn lemma, The Tychonoff theorem, Completely regular spaces, one-point compactification. (6) 4. Homotopy, Fundamental Groups, examples and computations, Van Kampen Theorem, covering spaces. (10)
Text & Reference Books	1. J.R. Munkres,Topology, 2nd Edition, Prentice Hall, 2000. 2. G.F. Simmons,Introduction to Topology and Modern Analysis, McGraw-Hill, 1963. 3. J.Dugundji,Topology, Prentice Hall, 1965.

MAT324	Theory of Ordinary Differential Equations [3003]
Prerequisite	MAT311 Real Analysis, MAT313 Linear Algebra
Objectives	• This course aims at developing the theory of existence, uniqueness and continuous dependence on data for initial value problems. It also focuses on qualitative properties of solutions of linear and nonlinear systems. Sturm-Liouville theory for boundary value problems are also discussed.
Syllabus	1. General theory of initial value problems: Cauchy - Peano existence theorem, sufficient condition for uniqueness, Picard - Lindeloef theorem, existence via fixed point theory, dependence oninitial conditions and parameters, continuation and maximal interval of existence. (10) 2. Linear systems and qualitative analysis: existence and uniqueness of solutions of systems, general properties of linear systems, fundamental matrix solution, stability theory and phase plane analysis, periodic systems. (14) 3. Nonlinear systems and qualitative analysis: two-dimensional autonomous systems, limit cycles and periodic solutions, Lyapunov's method for autonomous systems, Poincare-Bendixson theory in 2-dimensions. (10) 4. Boundary value problems: Linear BVP, Green's function, Sturm-Liouville theory, comparison principle, eigenfunction expansion. (6)
Text & Reference Books	1. A. K. Nandakumaran, P. S. Datti and R. K. George, Ordinary Differential Equations - Principles and Applications, Cambridge-IISC Series, Cambridge University Press, 2017. 2. Philip Hartman, Ordinary Differential Equations, 2nd edition, SIAM, 2002. 3. E. A. Coddington and N. Levinson, Theory of Ordinary Differential Equations, McGraw-Hill, 1984. 4. L. Perko, Differential Equations and Dynamical Systems, 3rd edition, Springer, 2006. 5. G. F. Simmons, Differential Equations with Applications and Historical Notes, 2nd edition, McGraw-Hill, 1991. 6. M. W. Hirsch and S. O. Smale, Differential Equations, Dynamical Systems and Linear Algebra, Academic Press, 1974. 7. I. Stakgold, Green's Functions and Boundary Value Problems, Wiley, New York, 1979. 8. G. Birkhoff and G.-C. Rota, Ordinary Differential Equations, 4th edition, Wiley, 2004.

MAT325	Probability Theory and Stochastic Processes [3003]
Objectives	• This course will introduce the theory in discrete and continuous time stochastic processes with the aim towards applications in queuing theory, random network and financial market.
Syllabus	1. Review of Probability: Events and probability; random variables; conditional probability; independence. (2) 2. Conditional Expectation: Conditioning on an event; conditioning on a discrete random variable; conditioning on an arbitrary random variable; some applications (e.g. Polya's urn model, a random graph). (6) 3. Markov Chains: Chapman-Kolmogorov equations; classification of states; limiting probabilities; the Gambler's Ruin problem; birth and death chains; branching and queuing chains. (10) 4. Markov Pure Jump Processes: Poisson process - exponential distribution and lack of memory, construction of the Poisson process, properties; birth and death processes; properties of a Markov pure jump process; applications. (10) 5. Brownian Motion: General notions; Brownian motion - Definition and basic properties, increment of Brownian motion, sample paths; hitting times; variations on Brownian motion - Brownian motion with drift, geometric Brownian motion; the Gaussian and Wiener processes; applications (12)
Text & Reference Books	1. S.M.Ross, *Introduction to Probability Models*, 11thedition (2014), Elsevier. 2. *P. G. Hoel, S. C. Port and C. J. Stone, Introduction to Stochastic Processes, Waveland Pr Inc (1986).* 3. *G. R. Grimmett and D. R. Stirzaker, Probability and Random Processes, 3rd edition (2001), Oxford University Press.* 4. *G. R. Grimmett and D. R. Stirzaker, One Thousand Exercises in Probability, Oxford University Press (2001).* *5. J.R.Norris, Markov chains, Cambridge University Press (1997).*

MAT411	Measure Theory [3003]
Prerequisite	MAT311 Real Analysis
Objectives	• The Riemann integral, dealt with in calculus courses and also in Real Analysis course, is well suited for computations but less suited for dealing with limit processes. In this course, we will introduce the so called "Lebesgue integral", which keeps the advantages of the Riemann integral and eliminates its drawbacks. At the same time we will develop a general theory which serves as the basis of contemporary analysis and probability.
Syllabus	1. Outer measure, σ-algebra of measurable sets and its properties, Lebesgue measure and its properties, a non-measurable set, measurable functions. (9) 2. Lebesgue integral of Simple functions, Lebesgue integral of a bounded function, bounded convergence theorem, Lebesgue integral of nonnegative measurable functions, Fatou's Lemma, monotone convergence theorem, the general Lebesgue integral, Lebesgue dominated convergence theorem. (12) 3. Differentiation and integration: Differentiation of monotone functions, functions of bounded variation, differentiation of an integral, absolute continuity. (9) 4. Lp-spaces: Definition and properties, Minkowski's inequality and Holder's inequality, convergence and completeness of Lp, approximation in Lp, bounded linear functionals on Lp spaces. (10)
Text & Reference Books	1. K. B. Athreya and S. N. Lahiri, Measure Theory, Hindustan Book Agency, 2006. 2. G. Debarra, Measure Theory and Integration, New Age International,1981. 3. G. B. Folland, Real Analysis: Modern Techniques and Their Applications, 2nd edition, John Wiley and Sons, 1999.

MAT411	Measure Theory [3003]
	4. P. R. Halmos, Measure Theory, Springer, 2009. 5. H. L. Royden, Real Analysis, 3rd edition, PHI Learning, 2009. 6. W. Rudin, Real and Complex Analysis, 3rd edition, McGraw-Hill Education (India) Ltd, 2007. 7. E. M. Stein and R. Shakarchi, Real Analysis: Measure Theory, Integration, and Hilbert Spaces, Princeton University Press, 2005. 8. T. Tao, An Introduction to Measure Theory, GSM, Vol.126, AMS, 2011. 9. M. Taylor, Measure Theory and Integration, American Mathematical Society, 2006.

MAT412	Commutatve Algebra [3003]
Prerequisite	MAT312 Theory of Groups and Rings
Objectives	• This course is a must for anyone wanting to pursue a PhD in Algebra. The student learns basics of Ring theory, Module Theory, Integral Extensions, Going up-Going Down theorems, Primary Decomposition of Ideals and Modules, Noetherian and Artinian Rings, Dedekind Domains and Dimension Theory.
Syllabus	1. Basic facts on Rings and Ideals: Nilradical Jacobson radical, operations on ideals, extensions and contractions.(3) 2. Modules: Basic definitions, direct sum, direct product, operations on submodules, finitely generated modules, exact sequence, tensor product of modules, injective modules, projective modules, direct limit, inverse limit, restriction and extensions of scalars. (10) 3. Rings and modules of fractions: Local properties, extended and contracted ideals in ring of fractions. (5) 4. Chain conditions: Noetherian ring, Arinian ring, Hilbert basis theorem, Primary decomposition, primary decomposition in Noetherian rings. (6) 5. Integral dependence and valuations: Integral dependence, going-up theorem, integrally closed integral domain, going-down theorem, valuation rings. (5) 6. Discrete valuation ring and Dedekind domains. (3) 7. Dimension Theory: Grades ring and modules, Hilbert function, dimension theory of Noetherian local rings, regular local rings. (9)
Text & Reference Books	1. Introduction to Commutative Algebra by M. F. Atiyah and I. G. Macdonald. 2. Commutative Algebra with a view towards Algebraic Geometry by D. Eisenbud. 3. Commutative Ring Theory by H. Matsumura

MAT413	Analysis on Manifolds [3003]
Prerequisite	MAT311 Real Analysis and MAT313 Linear Algebra
Objectives	To learn the basic theorems and techniques in analysis on R^n; Understanding the notion of an embedded submanifold in Rn and their tangent spaces. Application of the various theorems and techniques learned above to study differential geometry of the surfaces.
Syllabus	1. Functions of several Variables: Differentiation, directional derivatives, chain rule, Inverse function theorem and implicit function theorem. (10) 2. Integration: Integration over a rectangle, surface and volume integrals, Fubini's theorem, Change of variables formula, Partitions of unity. (12) 3. Submanifolds in Rn, tangent spaces. (6)

	4. Differential forms: Multilinear algebra, tensors, tensor products, alternat- ing tensors, wedge product, tangent vectors, differential forms, orientation, Stoke's theorem, derivations of the classical formulations. (12)
Text & Reference Books	1. J. R. Munkres, Analysis on Manifolds, Westview Press, 1997. 2. W. H. Flemming, Functions of Severable Variables, Springer, 1987. 3. M. Spivak, Calculus on Manifolds, Westview Press, 1971. 4. C. C. Pugh, Real Mathematical Analysis, Springer, 2010. 5. S. Shirali and H. L. Vasudeva, Multivariable Analysis, Springer, 2010.

MAT414	Partial Differential Equations [3003]
Prerequisite	MAT314 Theory of Ordinary Differential Equations
Objectives	• This course aims at developing theory of first order partial differential equations as well as three second order linear partial differential equations
Syllabus	1. Second order linear partial differential equations: Laplace's equation, fundamental solution, mean value formulas, Green's function, maximum principle, energy methods; Heat equation, fundamental solution, mean value formulas, energy methods; Wave equation, solution by spherical means, non-homogeneous problem, energy methods. (30) 2. First order partial differential equations: semilinear equations, quasilinear equations, solution of a Cauchy problem; first order nonlinear equations, Charpit's equations, Cauchy problem, the complete integral; Hamilton-Jacobi equations, calculus of variations, Hopf-Lax Formula. (10)
Text & Reference Books	1. L. C. Evans, Partial Differential Equations, 2nd Edition, American Mathematical Society, 2010. 2. R. Mc Owen, Partial Differential Equations: Methods and Applications, 2nd edition, Pearson, 2002. 3. G. B. Folland, Introduction to Partial Differential Equations, 2nd Edi- tion, Princeton University Press, 1995. 4. F. John, Partial Differential Equations, 4th edition, Springer, 1981. 5. M. E. Taylor, Partial Differential Equations I, 2nd Edition, Springer, 2010. 6. S. Kesavan,Topics in Functional Analysis and Applications, Wiley, 1989.

MAT415	Programming and Data Sructure [3003]
Objectives	• Learn to define operations on data structures like arrays, linked lists, trees and graphs • Learn to design algorithms involving these data structures • Learn to analyze simple algorithms and solve recurrences, asymptotic analysis
Syllabus	1. Introduction- Algorithm Analysis, Finding Complexity. Fundamental data structures - List- Sorted Lists, Double Linked Lists, Stack & Queue application. (10) 2. Binary Trees – Insertion and Deletion of nodes, Tree Traversals, Polish Notations, Red Black Trees, B-Trees, Heaps, Priority Queues. (10) 3. Sorting – Bubble, Selection, Insertion, Merge Sort, Quick Sort, Radix Sort, Heap sort. Searching. (10) 4. Graphs- Shortest path algorithms, Minimum Spanning Trees, BFS, DFS. (10)

Text & Reference Books	1. Clifford A Shaffer, Data Structures and Algorithm Analysis, Edition 3.2 (Java Version), 2011. 2. Michael T. Goodrich, Roberto Tamassia, Michael H. Goldwasser. Data Structures And Algorithms In Java™ Sixth Edition, Wiley Publishers, 2014. 3. Mark Allen Weiss Data Structures And Algorithm Analysis In Java, Third Edition, 2012. 4. Robert L. Kruse, Data Structures And Program Design In C++, Pearson Education, Second Edition, 2006. 5. Ellis Horowitz, Fundamentals of Data Structures in C++, University Press, 2015. 6. Ajay Agarwal, Data Structure through C, A Complete Reference Guide, Cyber Tech Publications, 2005.

MAT421	Functional Analysis [3003]
Prerequisite	MAT321 Complex Analysis and MAT411 Measure Theory
Objectives	• Based on core analysis courses and linear algebra, this course builds further on the study of Banach and Hilbert spaces. The theory and techniques studied in this course support, in a variety of ways, many advanced courses, in particular in analysis and partial differential equations, as well as having applications in mathematical physics and other areas.
Syllabus	1. Normed linear spaces, Riesz lemma, characterization of finite dimensional spaces, Banach spaces. Operator norm, continuity and boundedness of linear maps on a normed linear space. (6) 2. Fundamental theorems: Hahn-Banach theorems, uniform boundedness principle, divergence of Fourier series, closed graph theorem, open mapping theorem and some applications. (8) 3. Dual spaces and adjoint of an operator: Duals of classical spaces, weak and weak* convergence, adjoint of an operator. (5) 4. Hilbert spaces: Inner product spaces, orthonormal set, Gram-Schmidt ortho-normalization, Bessel's inequality, orthonormal basis, separable Hilbert spaces. Projection and Riesz representation theorems: Orthonormal complements, orthogonal projections, projection theorem, Riesz representation theorem. (10) 5. Bounded operators on Hilbert spaces: Adjoint, normal, unitary, self-adjoint operators, compact operators. (5) 6. Spectral theorem: Spectral theorem for compact self adjoint operators, statement of spectral theorem for bounded self adjoint operators. (5)
Text & Reference Books	1. R. Bhatia, Notes on Functional Analysis, Texts and Readings in Mathematics, 2009. 2. S. Kesavan, Functional Analysis, Hindustan Book Agency, 2014. 3. B. V. Limaye, Functional Analysis, New Age International, 2014. 4. V. S. Sundar, Functional Analysis: Spectral Theory, Birkhauser, 1998. 5. J. B. Conway, A Course in Functional Analysis, Springer, 1997. 6. M. Schechter, Principles of Functional Analysis, AMS (Indian Edition Uni. Press), 2009. 7. P. D. Lax, Functional Analysis, Wiley-Inter Science, 2002. 8. M. Reed and B. Simon, Functional Analysis (Methods of Modern Mathematical Physics - Volume 1), Academic Press, 1981. 9. Y. Eidelman, V. Milman and A. Tsolomitis, Functional Analysis: An Introduction, GSM, Vol. 66, AMS, 2004. 10. B. Bollabas, Linear Analysis, Cambridge University Press (Indian edition), 1999.

MAT422	Algebraic Toplogy [3003]
Prerequisite	MAT312 Theory of Groups and Rings and MAT325 General Topology
Objectives	• Understanding basic homotopy theory. • Familiarity with the language of categories to express various results in algebraic topology (in particular Van Kampen theorem). • Understanding the notions of simplicial and singular homologies, their homotopy invariances. • Understanding cohomology as a dual notion of homology. • Learning computational techniques for homologies and cohomologies and their applications.
Syllabus	1. Homotopy. Homotopy equivalence. Relative homotopy, Paths. Fundamental group. Induced homomorphism, Fundamental group of a product., Fundamental group of the circle., Homotopy lifting property. (4.5) 2. Some basic category theory(upto Natural transformations and push forward) , Van Kampen theorem. (6) 3. Existence of covering spaces, and classification of covering spaces. (3) 4. Deck Transformations and Group actions, simplicial homology, singular homology, Homotopy invariance. (9) 5. Relative and reduced homology, long exact sequence of a pair. (3) 6. Mayer-Vietoris, Applications of Mayer Vietoris, Homology with coefficients etc. (4.5) 7. Cohomology, cup-product, Poincare Duality. (7.5)
Text & Reference Books	1. Algebraic Topology, Allen Hatcher, Cambridge Univ Pr; 1 edition (September 1, 2005). 2. HomologyTheoryAnIntroductiontoAlgebraicTopology,JamesWVick,Springer; 2nd ed. 1994., 3. An Introduction to Algebraic Topology, Joseph Rotman, Springer; 1st edition (July 22, 1998)

MAT423	Differential Geometry [3003]
Prerequisite	MAT413 Analysis on Manifolds
Objectives	• Understanding the classical interpretation of various curvatures of a surface and their relation to geodesics. • Understanding the local and global geometry of smooth manifolds and smooth vector bundles.
Syllabus	1. Gauss curvature, Gauss curvature formula in terms of first and second fundamental forms. Intrinsic property of the Gauss curvature. (6) 2. Covariant derivative of a vector field along a curve; Relation between covariant derivative and total curvature of a curve; A geodesic as a curve with vanishing covariant derivative. (6) 3. Manifolds: Definition, examples, Tangent vector space at a point, Basis of the tangent vector space. smooth functions on a manifold, maps between Manifolds. Differential of a map. (6) 4. Sub-manifolds; Regular value theorem. Lie groups, examples; Submersion, Immersion and Embeddings. (6) 5. Smooth vector bundles, smooth sections, Dual bundles, existence of local sections. 6. Tangent bundles; Smooth vector fields; Lie bracket of smooth vector fields; Co-tangent bundles; Differential 1-forms. 7. Differential p-forms. Orientation. Exterior derivative. Closed and exact forms. Integration of a p-form on a p-dim sub manifold. Stokes theorem.
Text & Reference Books	1. M. Spivak, A Comprehensive Introduction to Differential Geometry, vol. 1, Publish or perish, 1970. 2. M.P. do Carmo, Differential Geometry of Curves and Surfaces, Prentice-Hall, 1976. 3. Loring W Tu, An Introduction to Manifolds, Springer, 2011

	4. J.M. Lee, Introduction to Smooth Manifolds, Springer 2002. 5. J.M. Lee, Manifolds and Differential Geometry, American Mathematical Society, 2009. 6. S. Kumaresan, A Course in Differential Geometry and Lie Groups, Hindustan Book Agency, 2002.

MAT424	Number Theory and Cryptography [3003]
Objectives	• To introduce elementary number theory, such as modular arithmetic, chinese remainder theorem, continued fractions, quadratic residues, Fermat's little theorem, quadratic forms, etc. • Most of the cryptosystem relies on number theory. Applications of Number theory in cryptography like RSA cryptosystem, discrete logarithm problem, Elliptic curve cryptosystem, primality testing, digital signatures are also discussed.
Syllabus	1. Divisibility, greatest common divisor, Euclid's algorithm, Linear diophantine equations, prime numbers, fundamental theorem of arithmetic, prime number theorem statement, Bertrand's postulate. Congruences, complete and reduced residue systems, Chinese remainder theorem. (9) 2. Wilson's theorem,Fermat's little theorem, pseudo-primes, Euler's theorem, primitive roots, Arithmetic functions,Eulers totient function, perfect numbers, Mobius inversion formula. (6) 3. Quadratic residues, Legendre symbol, law of quadratic reciprocity, Jacobi symbol, binary quadratic forms. (9) 4. Pythagorean triples, Fermat's Last Theorem, Lagrange's theorem, continued fractions, best approximations, quadratic irrationals, Pell's equation. (7) 5. Classical cryptography, block ciphers, public key cryptography, RSA crypto system, discrete logarithm problem,Diffie-Hellman key exchange, Elliptic curve crypto- systems. Algorithms for primality testing, Fermat's factorisation, Pollard's rho method. (9)
Text & Reference Books	1. Niven, H. S. Zuckerman and H. L. Montgomery, An Introduction to the Theory of Numbers, 5th Edition, Wiley, 1991. 2. Neal Koblitz, A Course in Number Theory and Cryptography, 2nd Edition,Springer, 1994. 3. Kenneth Ireland and Michael Rosen,A Classical Introduction to Modern Number Theory, 2nd Edition, Springer, 1990. 4. M. H. Weissman, An Illustrated Theory of Numbers, American Mathematical Society 2017.

MAT41XX	Discrete Mathematics [2002]
Objectives	• To study discrete structures in mathematics rather than continuous. To develop logical thinking, constructing mathematical proofs. • Main formulas in combinatorics using countable sets, classical theorems and algorithms in graph theory, and several practical applications of combinatorics and graph theory.
Syllabus	1. Set Theory and Boolean Algebras: Partially ordered sets, Posets, Zorn's Lemma, Principle of inclusion and exclusion, Lattices, Cantor-Schroder-Berstein Theorem, Recursion theorem, Boolean Algebras and Boolean functions. (2) 2. Introduction to Logic: Logic in Language, Predicate Logic, Logical operators, Logic Proposition and logical proofs (by logical arguments), Logical Puzzles, Logic of statements. (2)

	3. Graph Theory and Combinatorics: Counting words, Counting subsets, Patterns in Pascal's triangle, Pascal's Identitiy and its combinatorial proof, Generating numbers and Recurrence relation, Catalan numbers, Bell numbers, Stirling numbers. (7) 4. Graphs, Paths, Cycles, Euler's solution to Konigsberg Bridge problem, Travelling salesman's problem, Connectivity and components, First theorem of Graph Theory. Representing graphs as matrices, Adjacency and Incidence matrices, Eulerian graphs, Bipartite graphs, Representation of relation by binary matrices and digraphs, Graph Isomorphism, Diameter and Eigen values, Trees, Spanning Subgraphs, Kruskal's Algorithm. (7) 5. Mobius Inversion and Graph Colouring, Chromatic Number, Sudoku puzzles and Chromatic Polynomials, Burnside's Lemma, Polya Theory, Matching Theory, Marriage Theorem, Systems of distinct and common representatives, Bruck-Byser-Chowla Theorem, Codes and designs. (4) 6. Euler's polyhedron formula,The Five colour Theorem, Ramsey Theory, Ramsey number, Regular graphs, Ramanujan graphs, Cayley graphs. (4) 7. Counting paths in Regular graphs, The Ihara Zeta function of a Graph. (2)
Text & Reference Books	1. Harary F., Graph Theory, Narosa, 1969. 2. A first course in Graphy Theory and Combinatorics, Sebastian M. Cioaba and M. Ram Murty, Hindustan Book Agency, 2009. 3. Discrete Mathematics and Its Applications, Kenneth Rosen, McGraw Hill Higher Education, 2006. 4. Van Lint, J. H.; Wilson, R. M. A course in combinatorics. Second edition. Cambridge University Press, Cambridge, 2001. 5. C.L. Liu, Elements of Discrete Mathematics, Tata McGraw-Hill, 2000.

MAT41XX	Optimization Techniques [2002]
Objectives	• To apply optimization techniques. • Understanding of linear and nonlinear techniques
Syllabus	1. Classification and general theory of optimization. (1) 2. Linear programming (LP): Formulation and geometric ideas, simplex and revised simplex method. (5) 3. Duality and sensitivity, interior-point methods for LP problems. (5) 4. Transportation- assignment-and integer programming problems. (5) 5. Nonlinear optimization: Method of Lagrange multipliers. (2) 6. Karush-Kuhn-Tucker theory. (2) 7. Numerical methods for nonlinear optimization. (2) 8. Convex optimization, quadratic optimization. (2) 9. Dynamic programming. (2)
Text & Reference Books	1. D. G. Luenberger and Y. Ye, Linear and Nonlinear Programming, Third Edition, Springer India, 2008. 2. N. S. Kambo, Mathematical Programming Techniques, East-West Press, 1997. 3. E. K. P. Chong and S. H. Zak, An Introduction to Optimization, Second Edition, Wiley India, 2001. 4. M. S. Bazarra, H. D. Sherali and C. M. Shetty, Nonlinear Programming Theory and Algorithms, Third Edition, Wiley India, 2006. 5. K. G. Murty, Linear Programming, Wiley, 1983.

MAT4XXX/51XX	Sobolev Spaces and Elliptic Boundary Values Problems [3003]
Prerequisite	MAT414 Partial Differential Equations
Objectives	• The notions of weak derivatives, test functions and the space of distributions are introduced. Some elementary operations on distributions, such as convolution, the Fourier transform via the Scwartz class are done. The theory of Sobolev spaces forms the major part of the course which is then used to establish the well-posedness of elliptic boundary value problems (BVPs). The finite element formulation of elliptic BVPs is done as application of the theory.
Syllabus	1. Preliminaries: weak derivatives, test functions and distributions; convolution product of distributions; the Schwartz space, the Fourier transform and the Fourier inversion formula, Plancherel's theorem, tempered distributions. (10) 2. Sobolev spaces: definition and basic properties of Sobolev spaces; approximation by smooth functions; extension theorems; embedding theorems; compactness theorems; the Poincaré inequality; dual and fractional order spaces; trace theory. (18) 3. Variational formulation of elliptic boundary value problems: weak solutions; maximum principles; regularity results; the Galerkin approximation method and introduction to the finite element method. (12)
Text & Reference Books	1. L. C. Evans, Partial Differential Equations, 2nd Edition, American Mathematical Society, 2010. 2. R. A. Adams and J. J. F. Fournier, Sobolev Spaces, Academic Press, 2nd Edition, Academic Press, 2003. 3. S. Kesavan, Topics in Functional Analysis and Applications, Wiley, 1989. 4. P. G. Ciarlet, Linear and Nonlinear Functional Analysis with Applications. SIAM, 2013. 5. L. Hörmander, The Analysis of Linear Partial Differential Operators I: Distribution 6. Theory and Fourier Analysis, 2nd Edition, Springer-Verlag, 1990. 7. P. G. Ciarlet, Lectures on Finite Element Method, TIFR Lecture Notes Series, Bombay, 1975. 8. J. T. Marti, Introduction to Finite Element Method and Finite Element Solution of Elliptic Boundary Value Problems, Academic Press, 1986.

MAT4XXX/51XX	An Introduction to Stochastic Calculus and Its Applications [3003]
Prerequisite	MAT 325, MAT 411
Objectives	Measure Theory and Integration. A course on Probability Theory will be an added advantage, however is not a mandatoryrequirement. Concepts from Probability Theory, as and when require will be presented in the course.
Syllabus	1. Measure theory preliminaries, probability spaces, random variables, distributions, expectation, conditional probability, stochastic processes. 2. Construction of Brownian motion. 3. Martingales in continuous time. 4. The integral calculus. 5. Stochastic differential equations. 6. Giranoy's theorem; Martingale representation. 7. The Feynman-Kac formula, Applications to resonance and PDE (contents will depend on the available time).
Text & Reference Books	1. Stochastic Differential Equations: : An Introduction with Applications by B. Oksendal, 6th edition (2014), Springer. 2. Brownian Motion and Stochastic Calculus by I. Karatzas and S. Shreve, 2nd edition (2004), Springer. 3. Stochastic Calculus and Financial Applications by J. M. Steele,1st edition (2001), Springer.

	4. An Introduction to Stochastic Differential Equations by L.C. Evans, 1st edition (2014), American Mathematical Society.Finite Element Solution of

MAT4XXX/51XX	Introduction to Computational Fluid Dyanmics [3003]
Prerequisite	Prerequisites will be developed as needed.
Objectives	Grasp the basic theory of hyperbolic PDEs and nonlinear conservations laws; Understand the development of high-resolution shock-capturing finite volume methods for solving these equations; Learn about some applications of hyperbolic problems; Gain experience in using softwares for solving these equations, including how to set up a new problem.
Syllabus	Mathematical theory of linear and nonlinear systems of hyperbolic PDEs and conservation laws: eigenstructure of Jacobian matrix, shock and rarefaction waves, contact discontinuities. Phase plane analysis: Hugoniot loci and integral curves, solution to the Riemann problem for linear and nonlinear systems of equations, entropy functions and admissibility criteria. Theory of finite volume methods: upwind method, Godunov's method, use of exact and approximate Riemann solvers, high-resolution methods with limiters, TVD methods, concepts of dissipation, dispersion, Lax-Wendroff method, stability, CFL condition etc. Programming and use of softwares: implementing some simple methods from scratch, setting up a problem, defining a Riemann solver, plotting solutions, case studies. Applications: linear advection, acoustics, and elasticity, nonlinear Burgers' equation, traffic flow, shallow water equations, Euler equations of compressible gas dynamics.
Text & Reference Books	1. D. Kröner, Numerical Schemes for Conservation Laws, Wiley, 1997. 2. R. J. LeVeque, Finite Volume Methods for Hyperbolic Problems, Cambridge University Press, 2002. 3. R. J. LeVeque, Numerical Methods for Conservation Laws, ETH-Zurich, Birkhauser Verlag, Basel, 4. 1990. J. A. Trangenstein, Numerical Solution of Hyperbolic Partial Differential Equations, Cambridge University Press, 2009. 5. E. Godlewski, and P.-A. Raviart, Numerical Approximation of Hyperbolic Systems of Conservation Laws, Springer, 1996.

MAT4XXX/51XX	Wavelet Analysis [3003]
Prerequisite	MAT 311: Real Analysis, MAT 313 Linear Algebra, MAT 322 Measure Theory
Objectives	NA
Syllabus	Fourier Analysis and Wavelet Transforms: Fourier and inverse Fourier transforms - Continuous time convolution and the delta function - Fourier transform of square integrable functions - Poisson's summation formula. The Gabor transform - Short time Fourier transforms and the uncertainty principle - The integral wavelet transform - Diadic Wavelets and inversions – Frames and wavelet series. Multiresolution Analysis and wavelets: The Haar wavelet construction - Multi resolution analysis - Riesz basis to orthonormal basis - Sealing function and scaling identity -

	Construction of wavelet basis. Compactly Supported Wavelets and Spline Wavelets: Vanishing moments property - Meyer's wavelets - Construction of a compactly supported wavelet - Smooth wavelets. Cardinal spline spaces-B-splines-computation of cardinal splines-spline wavelets - Exponential decay of spline wavelets. Frames and Gabor Frames: Frames sequences- Frame operators-Characterization of Framesdual frames-frames containing Riesz basis- Gabor frames in L^2-Shift invariant systems- duals of Gabor frames- tight Gabor frames.
Text & Reference Books	1. Charles Chui, An Introduction to wavelets, Academic Press, 1992 2. Ole Christensen, An Introduction to Frames and Riesz Bases, Birkhauser, 2016. 3. Chan Y.T., "Wavelet Basics", Kluwer Academic Publishers,1995. 4. David F. Walnut, An introduction to wavelet analysis, Birkhauser, 2002. 5. Daubechis I., Ten Lectures on wavelets, SIAM. 1992. 6. Y. C. Eldar, Sampling Theory-Beyond Band limited systems, Cambridge press, 2015. 7. Willi Freeden and M. Zuhair Nashed, Lattice Point Identities and Shannon-Type Sampling, Chapman & Hall/CRC Monographs and Research Notes in Mathematics, 2020. 8. Mallat S., A wavelet tour of signal processing, Elsevier, 2008. 9. Wojtaszczyk P., A Mathematical introduction to Wavelets, Cambridge University Press, 1997. 10. Yves Meyer, Wavelets and Operators, Cambridge University Press, 2009

MAT4XXX/51XX	Topics in Number Theory [3003]
Prerequisite	MAT312, MAT 313, MAT 322 Algebraic Number theory(useful, but if you have not take a course, then the required results and constructions will be introduced in the course, and some results will be stated without proof)
Objectives	This is a advanced course useful for students pursuing algebra and Number theory.
Syllabus	1. Artin-Schreier-Witt Theory: We first review Kummer's Theorem and Artin-Schreier theory of degree p from Galois theory, State and prove Kummer Correspondence, Witt vectors, State and Prove Artin-Schreier-Witt Theorem.(20) 2. Cohomology of Groups: Basics of Group Cohomology, Hopf's formula, five term exact sequence in cohomology, cup prodcts, Tate's Theorem, stating some open problems related to _rst and second cohomology groups like Gaschutz's Conjecture and Schurs conjecture. Brauer Group and Central Simple Algebra Wedderburn Structure Theorem, Central Simple algebras, Brauer Group. (12) 3. Local Class Field Theory: Local Fields, Ramification groups, Solvability of Galois groups of Local Fields, Corollary will be that over Qp all polynomials are solvable by radicals, Using Tate's Theorem we will prove the Local Reciprocity Isomorphism. Kronecker-Weber Theorem (Time Permitting. (8)
Text & Reference Books	1. J. P. Serre, Local Fields, Springer, 1969. 2. Philippe Gille and Tamas Szamuely, Central Simple Algebras and Galois Cohomology, Cambridge

	3. Kenneth Brown, Cohomology of Groups, Springer 1st ed. Corr. 2nd Printing, 1994.4. 4. Serge Lang, Algebra, Springer 3rd Edition, 2005.

MAT4XXX/51XX	**Hyperebolic Geometry [3003]**
Prerequisite	MAT312 Abstract Algebra; MAT321 Complex Analysis; MAT325 General Topology.
Objectives	This is a basic and useful course for students pursuing PhD in Geometry and Analysis.
Syllabus	• Course Contents: Euclid's axioms, Motivation for non-Euclidean geometry; The upper half-plane (Lobachevskii) model: hyperbolic distance, area, geodesics; The unit disc (Poincare) model; Hyperbolic triangles, polygons; Hyperbolic trigonometry; Isometries, Mobius maps: parabolic, elliptic and hyperbolic transformations; Fuchsian groups: characterisation, limit set, elementary and non-elementary Fuchsian groups, centralisers, Abelian Fuchsian groups, first and second kind; Fundamental domains, Dirichlet polygons; Side-pairing transformations, The special case of Dirichlet octagon; Mobius classification theorem; Poincare-Koebe uniformisation Theorem.
Text & Reference Books	1. J. Anderson, Hyperbolic Geometry, Springer Undergraduate Mathematics Series, 2005. 2. R. Benedetti and C. Petronio, Lectures on Hyperbolic Geometry, Springer-Verlag, 1992. 3. . J.W. Cannon, W.J. Floyd, R. Kenyon and W.R. Parry, “Hyperbolic Geometry”, Flavors of Geometry, MSRI Publications, vol 31, (1997), 59 - 115. 4. H.S.M. Coxeter, Non-Euclidean Geometry, Mathematical Association of America, 1998. 5. S. Katok, Fuchsian Groups, Chicago Lectures in Mathematics, 1992. 6. D. Mumford, C. Series and D. Wright, Indra's Pearls: The Vision of Felix Klein, Cambridge University Press, 2002. 7. A. Ramsay and R. Richtmeyer, Introduction to Hyperbolic Geometry, Springer-Verlag, 1995.

PHY311	Mathematical Methods in Physics [3003]
Learning Outcomes	• Illustrate the properties of a Sturm Liouville eigenvalue problem. • Solve homogeneous linear Ordinary Differential Equation (ODE) using the series method and Wronskians. • Solve homogeneous linear Partial Differential Equation (PDE) using separation of variables. • Apply special functions to several physical problems. • Solve non-homogeneous ODE/PDE using Green's function. • Classify a complex function and its singularities. • Perform Taylor/Laurent expansion of complex functions. • Perform non trivial real integrals using the method of contour integrals and residue theorem.
Syllabus	1. Ordinary differential equations [12]: Linear equations: Solution space, linear independence, Wronskians. Eigenvalue problems: Boundary conditions, self-adjointness, completeness of Eigen functions, Fourier series, continuous spectrum and Fourier integrals. Series solution; Green Functions for ordinary differential operators. 2. Partial Differential equations [10]: Preliminaries, important partial differential equations (e.g. heat and wave equations, Poisson and Laplace equations, Helmholtz equation), Solution by separation of variables in Cartesian and spherical polar coordinate systems; Green's function for partial differential operators. 3. Special functions and Applications [2]. 4. Complex Analysis [12]: Functions of complex variable, limits and continuity, derivatives, analyticity, Cauchy-Riemann conditions, Types of singularities with examples, Contour integrals, Cauchy's theorem, Cauchy's integral formula, Morera's theorem, Taylor series, Laurent series, Calculus of residues: Residue theorem, definite real integrals using residue theorem, Cauchy's principal value.
Text & Reference Books	1. G. B. Arfken and H. J. Weber, Mathematical methods for physicists, Academic press. 2. Murray Spiegel, Seymour Lipschutz, John Schiller and Dennis Spellman, Schaum's Outline of Complex Variables, 2ed (Schaum's Outline Series).

PHY312	Classical Mechanics [3003]
Learning Outcomes	• Compute the motion of objects within a classical framework like motion under a central force, motion of rigid bodies, oscillators etc. using the mathematical techniques developed over the 17th, 18th and 19th centuries. • Apply techniques like least action principles and calculus of variations on intuitively understandable models of classical objects in motion.
Syllabus	1. Variational Principle and Lagrange's equation: [9 hours] Review of Newtonian mechanics, Hamilton's Principle, Calculus of Variations, Constraints and generalized coordinates, Derivation of Lagrange's equation using Hamilton's principle, Extension of Hamilton's principle for non-holonomic systems, The Lagrangian for a free particle and for a system of particles, Symmetries, Conservation laws and Noether's theorem, Conservation of energy, momentum and angular momentum. 2. Central Force Motion: [6 hours] Reduction of the two body central force problem to the equivalent one body problem. Integrating the equations of motion: Equivalent problem in one dimension and classification of orbits. Conditions for closed orbits (Bertrand's theorem). Kepler's problem, Laplace-Runge-Lenz vector. Scattering in a central force field and Rutherford's formula. 3. Rigid Body Motion: [6 hours] coordinates of a rigid body, orthogonal transformation and its properties, Euler angles, Euler's theorem on motion of rigid bodies, Finite Rotations and Infinitesimal Rotation, Motion in a non-inertial frame. Motion of a rigid body, Angular velocity and Kinetic energy, Inertia Tensor, Moment of inertia, Principal axis transformation. Euler's equations, Example of a heavy symmetrical top with one point fixed. 4. Small oscillations: [6 hours] Eigenvalue equation and principal axis transformation, frequency of free vibration and normal coordinates, Example of a linear triatomic molecule. Forced, damped and anharmonic oscillations.

	5. Hamiltonian Formulation: [9 hours] Legendre transformations, The Hamilton equations of motion, Cyclic coordinates, Routhian; Principle of least action, Invariance properties of the Lagrangian and Hamiltonian descriptions, Canonical Transformations, Poisson and Lagrange brackets; Hamilton-Jacobi theory and action-angle variables with examples (Harmonic oscillator, Kepler problem).
Text & Reference Books	1. H. Goldstein, C. Poole and J. Safko, Classical Mechanics, 3 rd Ed. Addison Wesley, 2005. 2. L. D. Landau and E. M. Lifshitz, Mechanics, Vol. 1 of course of Theoretical Physics, Pergamon Press, 2000.

PHY313	Electronics [3003]
Learning Outcomes	• Differentiate between conduction band, valence band, Fermi level, intrinsic and extrinsic semiconductors • Apply PN junction device physics and its characteristics for designing devices • Analysis of transistors and apply the concept to device design • Applications of operational amplifier to waveform generation, filters and mathematical function implementation and analysis of operational amplifier • Differentiate between analog and digital devices
Syllabus	1. Introduction to conductors, semiconductors and insulators. Band structure, Fermi level, mechanism of conduction in metals and semiconductors, mobility and conductivity, intrinsic and extrinsic semiconductors, doping, donor and acceptor levels, carrier lifetime (8 hours). 2. PN junction formation. Basic semiconductor devices: PN junctions, band structure in open circuit PN junction, depletion region, PN Diode: IV characteristics and its temperature dependence, space charge capacitance, diode resistance, half-wave and full-wave, ripple factor, filters: L, C, RC, LC and LCR filters. (6 hrs) 3. Bipolar transistors and operation: PNP and NPN transistors, transistor currents, active, saturation and cut-off regions. Common emitter amplifier. *AC and DC analysis of transistor circuits amplifiers and differential amplifiers.* Operating principles of FET, MOSFET. (8 hours) 4. Operational amplifiers: Ideal op-amp characteristics, common-mode rejection ratio, inverting and non-inverting configurations. FET amplifier, Op-Amp based circuits e.g. summing amplifier, logarithmic amplifier, pulse generator, differentiator, and integrator. (10 hours) 5. Digital Electronics: Boolean algebra, De Morgan's theorem, Karnaugh Map, Logic gates, adder circuits. Digital analog and Analog Digital Converters. Flip-flops, Counters and Shift registers. (4 hrs)
Text & Reference Books	1. A. Malvino and D. J. Bates, Electronic principles, Mcgraw-hill, 2006. 2. J. Millman, C. C. Halkias and S. Jit, Electronic devices and circuits, Tata Mcgraw Hill, 2007. 3. J. Millman, and C. C. Halkias, Integrated electronics, Tata Mcgraw Hill, 2008. 4. S. M. Sze, Semiconductor Devices, Physics and Technology (2nd Ed.), Wiley India, 2008. 5. T. L. Floyd and R. P. Jain, Digital Fundamentals (8th Ed.), Pearson Education, 2005.

PHY314	Quantum Mechanics I [3003]
Learning Outcomes	• Solving time independent and time dependent Schrodinger equations for wave functions for simple 1D potentials. Calculate probability, probability current density, and reflection and transmission coefficients. • Learn linear algebra, linear vector space and operator methods and apply principles of quantum mechanics to determine wave functions and calculate observables. • Solve Schrodinger equation for simple three-dimensional/ spherically symmetrically potentials and determine the wave function and various quantum numbers
Syllabus	1. Quantum Origins: (3): Particle aspect of radiation, Wave aspect of particles, Quantum measurements 2. Mathematical tools of Quantum Mechanics: The state vector, Dirac Bra and Ket notation, Hilbert space and some general properties of linear vector spaces, Rays and vectors in Hilbert space, Normalization, Basis vectors.(4) 3. Non-commutating operators and observables, Operators, eigenvalues, eigenvectors, observables and expectation values Quantum amplitudes, probabilities and the Born rule. (4)

	4. A basis labelled by a continuous parameter and the wave function, The position and momentum bases, Fourier transforms, Delta function normalization, Function spaces, The uncertainty principle revisited, The probability current and the continuity equation. (4) 5. Postulates of Quantum mechanics: (3) Quantum Kinematics, Quantum measurements, Quantum Dynamics (Hamiltonian and Schrodinger equation) 6. General properties of the Schrodinger equation: (4) Properties of wave functions; Probability density, Current density, and Continuity equation; The time-independent Schrodinger equation, Energy eigenstates; Time-dependent Schrodinger equation; Stationary states; Decomposition of initial state in terms of stationary states; Evolution of the state in terms of the stationary states and their eigenvalues; Finite time evolution and unitary transformations, properties of unitary transformations; Time evolution of expectation values; 7. Applications: (14)_One dimensional motion, free particle, Particle in a box, Potential Barrier and Well, Infinite and finite square well potential (5) 8. Harmonic oscillator, Spin of an electron, (5) 9. The Schrodinger equation in three dimensions: The Schrodinger equation in spherical coordinates, Separation of variables, The radial equation and energy quantization, the angular equation, spherical harmonics and introduction to quantized angular momentum. Spin, the Hydrogen atom; Charged Particle in a Magnetic Field: Oscillator algebra; Energy spectrum and Eigenstates; Landau levels, Wave functions. (4)
Text & Reference Books	1. Zettili, Quantum Mechanics: Concepts And Applications, 2nd Edn, Wiley India, 2016, 2. D. J. Griffiths, Introduction to quantum mechanics, 2004 3. J. J. Sakurai, Modern quantum mechanics, Addison-Wesley, 1994., 4. R. Shankar, Principles of quantum mechanics, Plenum Publishers, 1994.

PHY321	Statistical Mechanics [3003]
Learning Outcomes	• To calculate the most probable macrostate of a given Thermodynamical system in equilibrium • Distinguish the nature distributions (workout the number of microstates) in microcanonical, canonical and grand canonical ensembles. To relate the resulting statistics with thermodynamics parameters with applications to physical systems • Evaluate the distribution of particles in Maxwell Boltzman's, Fermi-Dirac and Bose-Einstein distributions along with their applications. • To estimate the phase transitions and order parameters.
Syllabus	1. Review of thermodynamics and Probability theory: The Laws of Thermodynamics. Interactions The Conditions for Equilibrium, Thermal Interaction Temperature, and Volume change Pressure, Particle interchange chemical potential. Random variable, Distribution function, Central limit theorem; (4) 2. Statistical Picture of Mechanics: Statistical description of a classical particle, Dynamics in Phase space, Ergodicity, Stationary states and Liouville theorem, Micro canonical and Canonical states. (4) 3. Methodology of Statistical Mechanics: Definition of counting and partition function Density of states, Classical Partition function, Examples Two level system, Harmonic oscillator, Particle in a 1D and 3D box. Equipartition theorem, Virial theorem; (4) 4. Thermodynamic Averages: The Partition Function, Generalized Expression for Entropy Gibbs entropy, Free Energy and Thermodynamic Variables, The Grand Partition Function, Grand Potential and Thermodynamic variables, Examples of non-interacting systems Einstein and Debye model, Ideal Paramagnet (negative temperature). (6) 5. Quantum Distributions: Bosons and Fermions, Grand Potential for Identical Particles, The Fermi and Bose Distribution, The Classical Limit, the Maxwell Distribution, Examples: Black-body radiation, Bose Einstein Condensation and Fermi gas at low temperatures. (6) 6. Weakly interacting Systems: Cluster Expansion, Van der Waals gases; Phase transitions - Phenomenology: Phase diagrams, Symmetry, Order of phase transitions and Order parameter, Conserved and non-conserved order parameters, Critical exponents, Scaling theory and scaling of free energy. (6) 7. Strongly interacting systems – Phase transitions: Introduction to the Ising model. Magnetic case, lattice gas and phase separation in alloys and Bragg-Williams approximation. Transfer matrix method in 1D. Landau theory, Symmetry breaking, Distinction between second order and first order transitions, Discussion of ferroelectrics. Broken symmetry, Goldstone bosons, fluctuations, scattering, Ornstein Zernike, soft modes. (6)

Text & Reference Books	1. F. Reif, Statistical Physics: Berkeley Physics Course Vol. 5, Tata Mcgrawhill, 2011. 2. F. Mandl, Statistical Physics (2nd Ed.), John Wiley & Sons, 1991 3. H.B.Callen,Thermodynamics and an Introduction To Thermostatistics,Wiley, 2006. 4. R. K. Pathria, Statistical Mechanics (2nd Ed.), Elsevier, 2002.

PHY322	Condensed Matter Physics- I [3003]
Learning Outcomes	To provide an exposure to the basic principles and essential concepts in condensed matter physics.
Syllabus	1. Crystal structure: Bravais lattice, two and three dimensional lattices, primitive cells, symmetry, space group and point groups, classification of lattices by symmetry; [4] 2. Experimental determination of crystal structure: Scattering from crystals, Laue method, rotating crystal method, powder method, interaction of X-rays with matter, deciphering the structure; [4] 3. Electronic structure: The single electron model, free electron model, specific heat of non-interacting electrons; The Schrodinger equation and symmetry: Bloch's theorem, Fermi surface, density of levels, van Hove singularities, Kronig-Penney model, band structure, rotational symmetry and group representations. [8] 4. Models: Nearly free electrons, Brillouin zones, tightly bound electrons, Wannier functions, tight binding model, electron-electron interactions, Hartree Fock equations, density functional theory; [8] 5. Mechanical properties: elasticity, liquid crystals, phonons, Einstein and Debye models, inelastic scattering from phonons; [6] 6. Electron transport: Drude theory, semi classical electron dynamics, non-interacting electrons in an electric field, Zener tunnelling.[6]
Text & Reference Books	1. Michael P. Marder, Condensed matter physics, John Wiley, 2000. 2. N. W. Ashcroft, N. David Mermin, Solid state physics, Harcourt, 1976. 3. C. Kittel, Introduction to solid state physics, 7th edition, John Wiley, 2004. 4. A. J. Dekker, Solid state physics, Macmillan India, 2005.

PHY323	Electrodynamics and Special Theory of Relativity [3003]
Prerequisites	Classical Mechanics [PHY 312]
Learning Outcomes	• Perform basic calculations in relativistic kinematics and dynamics. • Express Maxwell's equations in a relativistically covariant form. • Solve Maxwell's equations given the sources of charge and current distribution. • Solve problems involving the calculation of fields, the motion of charged particles and the production of electromagnetic waves.
Syllabus	1. Special Theory of Relativity [4]: Principle of Relativity, Lorentz Transformation, Velocity transformation Four vector; velocity and momentum, Notion of Tensors; covariant and contravariant with examples. 2. Relativistic Mechanics [4]: Principle of least action, Energy and momentum, Transformation of distribution functions, Elastic collisions, Angular momentum. 3. Charges in electromagnetic fields [6]: Elementary particles in special theory of relativity, four potential of a field, Gauge invariance, Electromagnetic field tensor, Lorentz transformation of the electromagnetic field, Invariants of the field. 4. Electromagnetic field equations [6]: The action for the electromagnetic field and the first pair of Maxwell’s equations, Four dimensional current vector, Continuity equation; The second pair of Maxwell’s equations, Energy density and energy flux, The energy-momentum tensor of the electromagnetic field. 5. Constant electromagnetic fields [3]: Coulomb’s law, Electrostatic energy of charges, The field of a uniformly moving charge, Motion in the coulomb field, The dipole and multipole moments, System of charges in an electric field, Magnetic field and moments. Larmor’s theorem. 6. Electromagnetic waves [4]: The wave equation, Plane waves; Poynting Vector and Energy Carried by the plane wave. Polarisation. 7. Electromagnetic field of moving charges [3]: Retarded and advanced potentials. Lienard-Wiechert potentials. Radiation of Electromagnetic fields [6]: Dipole radiation; Quadropole and

	magnetic dipole radiation; radiation from rapidly moving charge; near and far field solutions and properties of radiation.
Text & Reference Books	1. L. D. Landau and E. M. Lifshitz, Classical Theoryof Fields, Vol-2 of course of theoretical physics, Pergamon, 2000. 2. J. D. Jackson, Classical Electrodynamics, 3rd Ed., John Wiley, 1999.

PHY411	Nuclear and Particle Physics [3003]
Prerequisites	Quantum Mechanics-I (PHY 314) & Electrodynamics and Special Theory of Relativity (PHY324)
Learning Outcomes	• Calculate Rutherford scattering cross section, estimate nuclear radius, matter and charge distributions and explain various experimental results • Remember semi-empirical mass formula and explain the origin of different correction terms • Apply nuclear models to explain magic numbers and various nuclear properties • Calculate the kinematics of various reactions and decay processes by relativistic calculations • Classify elementary particles and nuclear states in terms of their quantum numbers. Analyze various particle physics processes in terms of conserved quantities
Syllabus	1. Introduction: Origin of nuclear physics - Becquerel's discovery of radioactivity, Rutherford scattering experiment. (2) 2. Static properties of nuclei: Nuclear size and shape – matter distribution and charge distribution, nuclear mass, nuclear angular momentum, spin and parity, nuclear electric and magnetic moments, binding energy. (4) 3. Nuclear interaction: properties of nuclear force, nucleon-nucleon potential, two-nucleon system - example with deuteron. (2) 4. Nuclear models: liquid drop model, Fermi gas model, shell model - infinite square well, harmonic oscillator, spin-orbit potential. (4) 5. Dynamic properties of nuclei: radioactive decay, alpha, beta and gamma decay, nuclear fission and fusion, chain reaction, nuclear reactions. (4) 6. Nuclear astrophysics: particle and nuclear interactions in the early universe, primordial nucleosynthesis, stellar nucleosynthesis. (2) 7. Detectors: ionization detectors, scintillation detectors, Cherenkov detectors, semiconductor detectors, calorimeters. (2) 8. Accelerators: electrostatic accelerators, cyclotron, linear accelerator, colliding beams. (2) 9. Classification of fundamental forces and elementary particles, quantum numbers - charge, spin, parity, isospin, strangeness, flavor. (6) 10. Gellmann-Nishijima formula, quark model, baryons and mesons, the eightfold way, continuous symmetry, discrete symmetry - C, P, and T, parity violation, CP violation - kaon oscillation, neutrino oscillation. (8)
Text & Reference Books	1. Introduction to nuclear and particle physics, A. Das and T. Ferbel 2. Introductory nuclear physics, Kenneth S. Krane 3. Nuclear and particle physics: an introduction, B. R. Martin

PHY412	Condensed Matter Physics II [3003]
Prerequisites	PHY 322: Condensed Matter Physics I
Learning Outcomes	• Solve problems related to electronic properties of intrinsic and extrinsic semiconductors, p-n junctions etc. • Estimate concentration of simple defects like point defects in a solid in thermal equilibrium. • Calculate the magnetic susceptibilities of a solid for simple cases like insulating solid, free electron metal etc. • Solve the ferromagnetic/antiferromagnetic Heisenberg Hamiltonian using mean field theory. • Application of Landau's phenomenological theory to calculate the observable properties of a homogeneous superconductor. • Solve the BCS Hamiltonian for superconductors using mean field theory.

Syllabus	1. Semiconductors: intrinsic and extrinsic semiconductors, hole, effective mass, laws of mass action, electron and hole mobilities, impurity band conduction , p-n junction , Shottky barrier , quantum Hall effect [4]; Crystal defects: Schottky vacancies, Frenkel defects, F-center etc.[2]; Optical Processes: Optical reflectance, Kramers-Kronig relations, Electronic interband transitions, Frenkel excitons, Mott-Wannier excitons, Raman effect in crystals etc.[6] 2. Magnetism: dia-, para- magnetism, Curie-Weiss law, Van-Vleck and Pauli paramagnetism, ferro-, anti- and ferrimagnetism.[2] Classical and quantum theories, Hunds rule, Exchange interaction, Heisenberg model, mean field theory, spin wave.[6] 3. Superconductivity: Experimental survey, Thermodynamics of superconductors, Meissner effect, Londons equation,[2] BCS theory, Ginzburg-Landau theory, flux quantization, coherence length, Type-I and Type-II superconductors,[4] Superconducting tunneling, DC and AC Josephson effects SQUIDs, High-T superconductivity: structure and transport properties.[3] 4. Dielectric and Ferroelectrics: General concept, dielectric constant and polarizability, Structural phase transitions, Ferroelectric crystals, Displacive transitions:[3] Soft phonon modes, Landau theory of the phase transition, first and second order phase transitions, Ferroelectric domains, Piezoelectricity, and Ferroelasticity; Magnetic resonance.[6]
Text & Reference Books	1. Michael P. Marder, Condensed matter physics, John Wiley, 2000. 2. N. W. Ashcroft, N. David Mermin, Solid state physics, Harcourt, 1976. 3. C. Kittel, Introduction to solid state physics, 7th edition, John Wiley, 2004. 4. J. Dekker, Solid state physics, Macmillan India, 2005.

PHY 413	Quantum Mechanics II [3003]
Prerequisites	Quantum Mechanics I (PHY314) & Classical Mechanics (PHY 312)
Learning Outcomes	• Extend quantum description to systems in 3 dimensional space. • Construct representations of rotation groups. • Solve motion in a centrally symmetric field. • Use various time-independent perturbation techniques to analyze spectrum of Hamiltonians • Use time-dependent perturbation methods to determine transition rates and decay widths. • Apply scattering theory in elastic and inelastic collisions.
Syllabus	1. Angular Momentum: Angular Momentum algebra, Eigenvalues and Eigenstates of Angular Momentum, SU(2) Representations, Addition of Angular Momentum [6]. 2. Motion in Central Potential, Spherical waves, Resolution of a plane wave, Asymptotic properties of Radial wavefunctions, Coulomb potential, Accidental Degeneracy. [4] 3. Time-independent Perturbation Theory (nondegenerate case, degenerate case), and Applications (Fine structure of hydrogen, relativistic and spin-orbital effects, Zeeman effect, Stark effect) [6] 4. Variational Methods and Applications (Ground and Excited states of Helium); Semi-classical (WKB) approximation, Bohr-Sommerfeld quantization rule [4] 5. Time-dependent Potentials and the Interaction Picture: Time-dependent Perturbation Theory, Applications to Interactions with the Classical Radiation Field, Fermi's Golden rule; Transition rates, Spontaneous emission, Energy Shift and Decay Width .[6] 6. Scattering theory: Scattering cross-section, Lippmann-Schwinger Equation, Born Approximation and application to scattering from various spherically symmetric potentials, including Yukawa and Coulomb, Optical theorem, Method of Partial Waves, Low-Energy Scattering and Bound States. [8] 7. Identical particles, Permutation Symmetry, Symmetrization Postulate, Two electron system [2]
Text & Reference Books	1. J. J. Sakurai, Modern quantum mechanics, Addison-Wesley, 1994. 2. R. Shankar, Principles of quantum mechanics, Plenum Publishers, 1994. 3. Cohen-Tannoudji and Diu-Laloe, Quantum Mechanics (2 volumes), Wiley, 2000. 4. L. D. Landau and E. M. Liftshitz, Quantum Mechanics Vol-3 of course of theoretical physics, Butterworth-Heinmann, 2000.

Advanced Laboratory Courses (SoP)

PHY315	Advanced Physics Experiments I [0093]
Learning Outcomes	Develop practical skills, which includes understanding of objectives, related experimental design and operation, record observations in a logical order, reaching final results and conclusions, and finally make a detailed discussion by identifying the sources of error.
Syllabus	1. Viscosity of a liquid - Oscillating disc method 2. Young's modulus: Cornu's method 3. Spectrometer- i -i' curve 4. Spectrometer- Hartmann's constant 5. Young's modulus- Optic lever method 6. Surface tension- Capillary method 7. Beam profile of laser 8. Diffraction by ultrasonic waves- velocity of sound in liquid 9. e/m - Thomson's method 10. Fabry-Perot interferometer 11. Michelson's interferometer 12. LCR circuit (series and parallel)- Frequency response and the value of unknown L 13. Transistor characteristics and transistor as an amplifier 14. Phase shift oscillators

PHY325	Advanced Physics Experiments II [0093]
Learning Outcomes	Develop practical skills, which includes understanding of objectives, related experimental design and operation, record observations in a logical order, reaching final results and conclusions, and finally make a detailed discussion by identifying the sources of error.
Syllabus	1. Velocity of light- Foucoult's method 2. Photoelectric effect 3. Arc Spectrum- Iron or Brass 4. X-ray diffractometer 5. FET characteristics and amplifier using FET 6. Op-Amp: Frequency response and mathematical tools 7. Op-Amp: Square, triangular and saw-tooth wave generator 8. Band pass and band reject filters 9. Differential amplifier using transistor 10. Amplitude modulation 11. Digital electronics using trainer kit-Binary to decimal, decimal to binary and D/A converter 12. Schmitt trigger 13. Chaotic Oscillator 14. Scanning Tunneling Microscope - Topography

PHY415	Advanced Physics Experiments III [0093]
Learning Outcomes	• Relate and reinforce modern physics concepts dealt in the classes room lectures • Develop enhanced observational, thinking and data analytic skills, correlate experimental results and identify the sources of errors • Independently plan, design, construct and demonstrate experiments that levels to advanced research laboratories • Self-trained toward writing project reports, research articles, manuscripts to journals etc.

Syllabus	1. Zeeman effect 2. Hall effect 3. Electron spin resonance spectrometer 4. Electrical resistivity of semiconductor and noble metal resistor 5. Magnetic susceptibility - Quincke's Method 6. B - H Curve 7. Two slit Interference - one photon at a time 8. GM counter and gamma ray spectrometer 9. Optical fiber communication 10. Thin film deposition and characterization 11. Atomic Force Microscope

Electives/Modules (SoP)

Even Semesters

1. PHY4201/PHY6201 Quantum Information Theory (3003)
2. PHY4202/PHY6202 Nonlinear Dynamics (3003)
3. PHY4203/PHY6203 Nonlinear Optics and Photonics (3003)
4. PHY4204/PHY6204 Electronic Devices and Computer Interfacing (2103)
5. PHY4206/PHY6206 Astrophysics (3003)
6. PHY5201/ PHY6201 Probes in Condensed Matter Physics (3003)
7. PHY5202/ PHY6202 Quantum Transport (3003)
8. PHY5204/ PHY6204 Sensor Technology
9. PHY5205/PHY6205 Numerical Simulation Techniques in Physics (3003)
10. PHY5206/PHY6206 Introduction to Cosmology (3003)
11. PHY5207/PHY6207 Particle Physics (3003)
12. PHY5208/ PHY6208 Principles of Digital imaging (3003)
13. PHY5209/ PHY6209 Organic Semiconductors: Fundamentals and Applications (3003)
14. PHY5210/PHY6210 Materials Growth and Processing Techniques [2013] (SoP Open Elective)
15. PHY5211/ PHY6211 Theory of open quantum systems (3003)
16. PHY5212/PHY6212 Quantum Field Theory I (3003)

Odd Semesters

1. PHY4101/PHY6101 Fluid Mechanics & Transport Phenomena (3003)
2. PHY4102/PHY6102 Experimental Methods (3003)
3. PHY4103/PHY6103 Modelling Materials (3003)
4. PHY4104/PHY6104 Semiconductor Physics and Technology (3003)
5. PHY4105/PHY6105 Material & Device Characterization Techniques (SoP Open Elective) (2013)
6. PHY5101/PHY6101 Lasers and Fiber Optic Communications (3003)
7. PHY5102/PHY6102 Physics at Low Temperatures (3003)
8. PHY5103/PHY6103 Nanoscale Physics (3003)
9. PHY5104/PHY6104 Superconductivity(3003)
10. PHY5105/PHY6105 Foundations of Quantum Mechanics (3003)
11. PHY5106/PHY6106 Advanced Statistical Physics (3003)
12. PHY5107 /PHY6107 Fluid Dynamics (3003)
13. PHY5108/PHY6108 Advanced Mathematical Methods in Physics (3003)
14. PHY5109/PHY6109 General Relativity and Cosmology (3003)
15. PHY5110/PHY6110 Quantum Many-body Theory (3003)
16. PHY5111/PHY6111 Digital Image Processing (3003)
17. PHY6112 Quantum field theory II (3003) (Grad level only)

Not all electives will be offered every year and advanced electives listed in the odd semester may be offered in the even semester and vice versa, if required.

PHY4201/6201	Quantum Information Theory [3003]
Prerequisites	Quantum Mechanics -I
Learning Outcomes	• Compute quantitative measures of information and solve problems involving transformation of information from one form to another. • Apply the connection between the laws of motion of the physical entities on which information resides and to compute the ways and means available for processing this information • Obtain exposure to quantum computation, quantum algorithms etc and their implementation in real physical systems.

Syllabus	1. Probabilities (3 hours): Review of probabilities, betting odds and the Dutch book. The probability simplex. 2. Classical Information theory (2 hours): Shannon entropy and Shannon's theorems. 3. Bits and Qubits (2 hours): The quantum two level system and its Hilbert space. 4. Quantum states (4 hours): Mixed quantum states and the density matrix. Quantum super-position, multipartite states and entanglement. 5. Quantum measurements (3 hours): The measurement super operator, generalized measurements and POVMs 6. Quantum dynamics, open and dosed dynamics (3 hours): Unitary evolution, Super operators and dynamical maps 7. The circuit model (5 hours): The circuit model of quantum computation, operations on qubits, distinguishability of states. 8. Quantum entropy and quantum correlations (4 hours): Quantum versions of the fundamental theorems in information theory, non-classical correlations, discord etc. 9. Elements of quantum computing (5 hours): Quantum algorithms, possible implementations
Text & Reference Books	1. M. A. Nielsen and I. L Chuang, Quantum Computation and Quantum Information 2. J. Preskill, Quantum Information and Quantum Computation, Available online (Caltech). 3. J. J. Sakurai, Modem quantum mechanics Addison-Wesley（1994)

PHY4202/6202	Nonlinear Dynamics [3003]
Prerequisites	Mathematical Methods in Physics
Learning Outcomes	• Analyse the basic difference between the linear and nonlinear dynamical systems along with the nature of dynamics (solutions) exhibited by them. • Able to apply various nonlinear techniques to analyse the dynamical systems. • Able to unravel the bifurcations leading to chaotic dynamics and its properties along with various applications in real world systems. • Estimate the stability criterion using linear stability analysis. • Calculate the Lyapunov exponents, power spectra and Poincare' section.
Syllabus	1. Linear and Nonlinear Systems: Linear and nonlinear forces - Nonlinear dynamical systems - Effects of Nonlinearity • Liouville theorem • Solution of damped and forced linear oscillator • Resonance phenomenon - Jump phenomenon. 2. Fixed Points and Stability Analysis: Stable and unstable fixed points - Classification of fixed points in first and second order systems - Limit cycle motion. Bifurcations: Saddle node, Pitchfork, Transcritical and Hopf bifurcations. 3. Bifurcation and Chaos: Logistic map - Stability of period • 1 and 2 fixed points • period doubling phenomenon - Onset of chaos - Bifurcation diagram • Different routes to chaos: Period doubling route, quasiperiodic route and intermittency route - Necessary conditions for chaos. Characterization of chaos: Lyapunov exponents and Power spectrum. 4. Fractals: Self similarity - Self-similarity in Henon attractor - Properties of fractals - Examples of fractals • Fractal dimension. 5. Soliton: Linear and nonlinear waves - cotiidial and solitary waves - John Scott Russel's observation of solitary wave - Korteweg-de vries equation and solitons.
Text & Reference Books	1. M. Lakshmanan and S. Rajasekar, Nonlinear Dynamics: Integrability, Chaos and Patterns (Springer - Verlag, Berlin, 2003). 2. E. Ott, Chaos in Dynamical Systems (Cambridge University Press, Cambridge, 1993). 3. H. G. Schuster, Deterministic Chaos (Verlag, Weintein, 1998) 4. H. 0. Peitgen, P. H. Richter, The Beauty of Fractals (Springer, Berlin, 1986). 5. P. G. Drazin and R. S. Johnson, Solitons (Cambridge University Press, Cambridge, 1985). 6. M. J. Ablowitz and P，A. Clarkson, Solitons, Nonlinear Evolution Equations and Inverse Scattering (Cambridge University Press, Cambridge, 1991).

PHY4203/6203	Nonlinear Optics and Photonics [3003]
Prerequisites	Mathematical Methods in Physics
Learning Outcomes	• Write wave equation using nonlinear polarization • Analysis of wave equation for second- and third order optical nonlinearities under different conditions • Analyse the effect of dispersion and nonlinearities on wave propagation • Write Nonlinear Schrodinger equation and simulate pulse broadening and self-phase modulation • Use coupled wave equations to analyse the evolution of the probe field in stimulated Brillouin and Raman scattering under different conditions.
Syllabus	1. Light-matter interaction, Polarization, Nonlinear Polarization, Wave Equation with driving polarization 2. Optical Fibre, Dispersion in optical fibre anomalous and normal, modes of fibre. Losses in fibre, Nonlinear polarization, Second order nonlinearities, Third-order optical nonlinearities, Parametric vs non-parametric process, Introduction to Lasers 3. Pulse propagation in optical fibre, Nonlinear pulse propagation, Group Velocity dispersion, Dispersion induced pulse broadening, Gaussian pulses, chirped Gaussian pulse, Dispersion management, Intensity dependent refractive index, nonlinear phase shift and Instantaneous frequency, self-phase modulation, change in pulse spectra, Cross-phase modulation. Optical Solitons, Fundamental soliton and higher-order solitons, Soliton self-frequency shift 4. Introduction to four-wave mixing, third harmonic generation, Phase matching techniques, Stimulated Raman Scattering, Stimulated Brillouin scattering, Electromagnetically Induced Transparency, 5. Applications of nonlinear optics, slow-light, microwave photonics, Ultra-fast communication and signal processing 6. Project
Text & Reference Books	1. Nonlinear Optics by Robert W. Boyd, Academic Press. 2. Nonlinear Fibre Optics by Govind P Agarawal, Academic Press.

PHY4204/6204	Electronic Devices and Computer Interfacing [2013]
Prerequisites	Basics of Programming, Electronics
Learning Outcomes	Hands on experience in interfacing data acquisition and control systems
Syllabus	1. Heterojunctions, Special purpose diodes: Zener, Varactor diode, Tunnel diode, Diac, Triac, LED, PV cell, Photodetectors, SCR, UJT, IGBT. 2. Oscillator design and applications. 3. Review of ADC and DAC. Analog and Digital data acquisition and generation. Counters and Timers, real-time data acquisition and instrument control and acquisition speed. Brief overview of microprocessors and microcontrollers. 4. 5. Practical aspects of interfacing external hardware with a computer. Serial and Parallel Interfacing. Virtual instrumentation using IEEE GPIB, RS232, USB interfaces. Interfacing external hardware platforms like Arduino 6. Softwares: Labview, Python, Arduino IDE, C++ etc 7. Project: Interfacing project to be conceived and executed by each student, using any one of the software.
Text & Reference Books	1. Basic Digital Electronics, Springer, J A Strong 2. Digital Electronics: Fundamental Concepts and Applications, Prentice Hall, C E Strangio 3. S. Gupta and J. John, Virtual Instrumentation using LabVIEW, Tata McGraw-Hill Publishing Company Limited, 2010. 4. Jovitha Jerome, Virtual Instrumentation Using Labview, Prentice Hall of India, 2010 5. Bruce Mihura, LabVIEW for Data Acquisition, Prentice Hall of India, 2013

	6. R Bitter, T Mohiuddin, M Nawrocki, LabVIEW: Advanced Programming Techniques, CRC Press, 2007

PHY4206/6206	Astrophysics [3003]
Prerequisites	ED & STR, classical mechanics, Statistical Mechanics
Learning Outcomes	• Understand the basic tools of astrophysical observations such as the celestial sphere, galactic coordinates, and various units for measurements. • Learn about the interplay between the thermal and gravitational energy in stars, collapse of stars and the formations of astrophysical objects such as black holes, white dwarf and neutron stars. • Learn about the basic characteristics of galaxies such as galactic rotations and stellar mass distribution • Understand the conditions of matter and radiation in the early universe and how the universe has evolved through expansion.
Syllabus	1. Overview of the universe. Astronomical scales, Coordinates, Magnitudes. Telescopes and Observations in various EM bands. 2. Basics of radiative transfer and radiative processes. Stellar interiors. Nuclear energy generation. Stellar Structure and evolution. End stages of stars; white dwarfs, neutron stars, black holes. Stellar evolution in HR diagrams. Binary stars. 3. Interstellar medium, Jeans instability. 4. Shape, size and contents of our galaxy. Basics of stellar dynamics. Normal and active galaxies. High energy and plasma processes. Clusters of Galaxies, Expansion of the universe. Microwave background. Early universe.
Text & Reference Books	1. Astrophysics for Physicists - Arnab Rai Choudhuri 2. The Physical Universe - Frank Shu 3. G.B. Rybicki and A.P. Lightman, Radiative Processes in Astrophysics

PHY4101/6101	Fluid Mechanics &Transport Phenomena (i2P) [3003]
Prerequisites	Classical Mechanics, Statistical Physics
Learning Outcomes	• Apply the laws of discrete mechanics to continuous systems Model or analyse static fluid systems - conditions for hydrostatic equilibrium. • Identify relevance of macroscopic and microscopic balances and their applications • Newtonian vs non-Newtonian fluids - properties and models • Model Mass, Momentum and Energy transport and their applications.
Syllabus	1. Ideal Fluids (The Equation of Continuity, Euler's Equation) 2. Hydrostatics and Potential Flow 3. Viscous Fluids (The Equations of Motion, Energy Dissipation) 4. Thermal Conduction in Fluids (Equation of Heat Transfer) 5. Thermal Conduction in an Incompressible Fluid 6. Free Convection and Convective Instability of a Fluid at Rest
Text & Reference Books	1. J.O. Wilkes, Fluid Mechanics for ChE, 2nd Ed. 2. R.B. Bird, W.E. Stewart and E.N. Lightfoot, Transport Phenomena, 2nd Ed., Wiley, India, 2005. 3. Duderstadt, J. J., and W. R. Martin. Transport Theory. Wiley, 1979. 047104492XF.P. Incropera and D.P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th Ed., Wiley India, 2006. 4. Landau and Lifshitz, Fluid Mechanics, Pergamon Press

PHY4102/6102 (I2P 411)	**Experimental Methods [3003]**
Prerequisites	Electronics
Learning Outcomes	• Describe methods of examining the micro/nanostructure of materials (structure, morphology and physical properties) • Comprehend the physical principles of various experimental techniques in characterising the microscopic and nanoscopic properties of materials and devices. • Layout a protocol for characterising materials and systems for specific applications (e.g. solar cells, batteries, biosensors and electronic devices)
Syllabus	1. Electrical characterisation techniques: Resistance measurement, various configurations (2/4 probe and van der Pauw). AC/DC techniques and their range of application. Voltage and current sourcing techniques, source meter and sample impedance matching; Low current measurement, leakage current; AC measurement techniques, lock-in-amplifiers - operating principle (phase locking); [6] 2. Fitting bare data by linearisation techniques, obtaining best fit; Introduce calibration curve of a sensor and its predictive value. Error Analysis [3] 3. Imaging and microanalysis: Concepts in microscopy: Brightness, contrast, resolution. Principle and limitations of optical microscopy, Scanning Electron microscopy: Construction, electron gun, EM lenses, detectors. Energy dispersive spectroscopy: X-ray sources, detection principle, analysis and instrumentation. Transmission electron microscopy: Imaging [7] 4. Diffraction: Crystal systems, X-ray diffraction, single crystal, powder XRD. Unit cell determination. electron diffraction, pattern analysis. [6] 5. Scanning probe techniques: Atomic force and Scanning tunnelling microscopy [6] 6. Spectroscopy: Infra red, Raman, x-ray and UV photoelectron spectroscopy. 7. Optical Spectroscopy : Review of Properties of Light, wavelength and energy scale, Interaction of electromagnetic waves with matter, Beer Lambert's Law, Transmission, absorption, reflection, elastic and inelastic scattering, Rayleigh scattering, Raman scattering, Vibrational spectroscopy, [3] 8. Magnetic Characterisation: Types of magnetic interactions and their experimental signatures. Principle of Vibrating Sample Magnetometer (VSM) and SQUID magnetometer; Magnetic circular dichroism. Principle of NMR and ESR. [7]
Text & Reference Books	1. R. A. Dunlap, Experimental Physics - Modern Methods, Oxford University Press, 1988. 2. JH. Moore, C C. Davis, M A Coplan, S C. Greer, Building Scientific Apparatus, Cambridge University Press, (4th Ed) 2009. 3. Low Level Measurements Handbook (6/7th Ed) Keithley Instruments Publication 4. G. L. Weissler, R W Carlson, Methods of Experimental Physics Volume 14 : Vacuum Physics and Technology , Academic Press, 1990. 5. G K. White, P. Meeson, Experimental Techniques in Low Temperature Physics (3rd/4th Ed) , Oxford University Press, 1979. 6. C. J. Chen, Introduction to Scanning Tunnelling Microscopy (2nd Ed), Oxford University Press, 2008. 7. Shailaja Mahamuni, Deepti Sidhaye, Sulabha Kulkarni, Foundation of experimental Physics, CRC Press London, 1st edition, June 2020.

PHY4103/I2P 414	**Modelling Materials (2033)**
Prerequisites	Quantum Mechanics, Condensed Matter Physics I
Learning Outcomes	1. Apply computational methods to model, comprehend and predict material properties and material design. 2. Apply first-principles approaches, molecular dynamics simulations, stochastic methods for optimization and sampling. 3. Hands-on training using open-source software packages provide experience with simulations of classical force fields, electronic-structure approaches, molecular dynamics, and Monte Carlo.

Layout	• Energy models from classical potentials to first-principles approaches [4L] • Density Functional Theory and the total-energy pseudopotential method [6 L] • Errors and accuracy of quantitative predictions [2L] • Monte Carlo sampling and molecular dynamics simulations [4L + 12P] • Free energy and phase transitions; fluctuations and transport properties; and coarse-graining approaches and mesoscale models. [8L] • Predictive Simulations of Novel Functional Materials [24P]
Text & Reference Books	1. Allen, M. P., and D. J. Tildesley. Computer Simulation of Liquids. New York, NY: Oxford University Press, 1989. ISBN: 9780198556459. 2. Frenkel, D., and B. Smit. Understanding Molecular Simulation. 2nd ed. San Diego, CA: Academic Press, 2001. ISBN: 9780122673511. 3. Jensen, F. Introduction to Computational Chemistry. New York, NY: John Wiley & Sons, 1998. ISBN: 9780471984252. 4. Kaxiras, E. Atomic and Electronic Structure of Solids. Cambridge, UK: Cambridge University Press, 2003. ISBN: 9780521523394. 5. Martin, R. Electronic Structure: Basic Theory and Practical Methods. Cambridge, UK: Cambridge University Press, 2004. ISBN: 9780521782852. 6. Phillips, R. Crystals Defects and Microstructures. Cambridge, UK: Cambridge University Press, 2001. ISBN: 9780521793575. 7. Thijssen, J. M. Computational Physics. Cambridge, UK: Cambridge University Press, 1999. ISBN: 9780521575881.

PHY4104/6104	**Semiconductor Physics and Technology [3003]**
Prerequisites	Quantum Mechanics, Condensed Matter I
Learning Outcomes	• Understand the origin of electrical, optical and optoelectronic properties of selected semiconductors based on band structure and the role played by dopants and defects. • Identify semiclassical equations of motion and apply Boltzmann transport to describe electrical transport in semiconductors, in the presence of electromagnetic fields. • Describe optical properties of solids and formulate suitable observables for semiconductors. • Apply Quantum Mechanical models to describe the working principle of quantum heterostructure based devices. • The scope of reduced dimensional semiconductor systems and heterostructures in tuning the electrical and optical properties of devices. • Fabrication, characterization and application of semiconductors.
Syllabus	1. Review of Bulk semiconductor physics: crystals, compound semiconductors, band-structure, density of states, doping and carrier concentration, Fermi statistics. [4] 2. Electrical Transport in Bulk Semiconductors: Drude model, Boltzmann transport; equations i electric and magnetic field; moments of transport equation, continuity equation, diffusion, drif thermal gradient etc.[6] 3. Semiconductor Junctions: Schottky and heterojunctions, role of interfaces, band bending co self-consistent band bending equations (Poisson - Schrodinger etc). Band bending near surf and interfaces. Forward and reverse biased diodes. Special diodes: pin, tunnel diodes etc. [7 4. Optical Properties of metals and semiconductors: Optical interactions in metals and semiconductors, reflection, refraction, optical absorption, free carrier absorption, refraction, Kramers Kronig relation; classical and quantum mechanical description of optical absorption excitons; spontaneous and stimulated emission, Einstein coefficients; Photoluminescence a Electroluminescence. [7] 5. Quantum Heterostructures & Reduced dimensional systems: 3D, 2D, 1D electron gas and q dot systems; engineering heterostructures and superlattices; optical properties of reduced dimensional systems; Quantum confined Stark effect. [6] 6. Screening in 3D and 2D electron systems: Lattice polarisation; screened Coulomb potential, doping and mobility. [3] 7. Photovoltaic Devices: photoconductors, photodiodes, Light Emitting Diodes, Laser Diodes; Quantum cascade lasers etc. [3]

Text & Reference Books	1. Semiconductor Devices: Physics and Technology, S M Sze and M Lee, Wiley India, 3rd Ed, 2007 2. Seeger, K., Semiconductor Physics, Springer-Verlag, 1990. 3. Optical Properties of Solids, Oxford University Press, M Fox 4. Physics of Low-Dimesnional Semiconductors, J. H. Davies, Cambridge, 1997 5. Solid State Physics, N. W. Ashcroft and D. Mermin, Brooks/Cole, 1976 6. Semiconductor Device Fundamentals, R F PIERRET, Pearson India, 2006

PHY5201/6201	**Probes in Condensed Matter Physics [3003]**
Prerequisites	None
Learning Outcomes	• To understand how the various scattering probes work. • To learn how to use the various scattering probes for real experiments and to analyse the data. • To understand how the various thermal properties measurement probes work. • To learn how to use the various thermal properties measurement probes for real experiments and to analyse the data.
Syllabus	1. Scattering probes: X-ray diffraction, neutron scattering, scanning electron microscopy, transmission electron microscopy, Raman scattering, electron paramagnetic resonance, nuclear magnetic resonance, nuclear quadrupole resonance. 2. Spectroscopic probes: Fourier-transform infrared spectroscopy, Mossbauer spectroscopy, positron annihilation technique. 3. Thermal properties measurement probes: specific heat, thermal conductivity, thermal expansion, differential scanning calorimetry (DSC), thermogravimetric analysis (TGA) 4. Transport properties measurement probes: ac and dc conductivity, Hall effect, magnetoresistance, magnetic susceptibility, dc and ac magnetization. 5. Optical probes: Optical conductivity
Text & Reference Books	1. Elements of X-ray Diffraction B. D. Cullity 2. Magnetism in Condensed Matter Stephen Blundell 3. Transmission Electron Microscopy D. B. Williams and C. B. Carter 4. Handbook of Microscopy, Applications in Materials Science, Solid-State Physics and Chemistry S. Amelinckx et al. (Editors) 5. Electronic properties of materials R. E. Hummel 6. Theory of neutron scattering in condensed matter S. W. Lovesey 7. Heat Capacity and Thermal Expansion at Low Temperatures T. H. K. Barron and G. K. White 8. Techniques of Metals Research, R. F. Bunshah (Editor)

PHY5202/6202	**Quantum Transport [3003]**
Prerequisites	Condensed Matter Physics-I, Quantum Mechanics-I
Learning Outcomes	• Gain insights on how quantum mechanical effects are manifested in electrical transport in mesoscopic systems. • Calculate conductivity and magnetoresistance in 2D, 1D and quasi-zero dimensional devices. • Determine the nature of transport and parameters such as mobility, carrier concentration, phase coherence times in quantized dimensional systems • Determine charging energy, single particle energies, shell-filling pattern of quantum dots from transport spectroscopy. • Single charge sensing and quantum electrical amplification using QPCs and superconducting SETs
Syllabus	1. Review of transport in 3D, Drude theory of electrical conduction, Sommerfield theory, Density of states. Magnetotransport in 3D, conductivity & Resistivity tensors. 2. Transport regimes & quantization effects: Classical diffusive, quantum diffusive & Quantum Ballistic transport regimes. 3. Micro and Nanoscale device fabrication, Photo-lithography, e-beam lithography 4. Two-dimensional systems: Quantum well heterostructures, remote doping, band bending, surface states, Schottky & Ohmic contacts, Graphene and other 2D layered systems.

	5. Magnetotransport in the Quantum diffusive regime: Quantization of electronic orbits in magnetic fields, Real space & k-space, Landau tubes/levels, de Haas van Alphen effect Quantum Hall effect, edge state conduction, Subnikov de Haas effect, introduction to fractional quantum Haal effect 6. Electron-electron interactions and weak localization, quantum interference effects in disordered systems. Aharanov Bohm effect in metals and semiconductors. 7. One-dimensional transport: Quantum point contacts, atomic-scale junctions & nanowires, 1-D sub bands, electrostatic gating, Landauer-Buttiker formalism of conduction, conductance quantization.Quantum point contact electrometers, 8. Zero-dimensional structures: Quantum dots, Coulomb-Blockade, conductivity oscillations, Fock-Darwin states, Quantum dots and spin or charge qubits, spin-blockade, Charge read-out in quantum dots using QPCs 9. Mesoscopic Superconductivity: Introduction to superconductivity, superconducting tunnel junctions, Giever tunnelling, N-I-N, S-I-N, S-I- S · S-S-I-S junctions, Josephson junctions, Cooper pair tunneling, 10. DC josephson effect. AC josephson effect Shapiro steps, SQUID, Superconducting quantum dots. Coulomb Blockade and charge quantization effects in Superconducting quantum Dots
Text & Reference Books	1. Electronic transport in mesoscopic systems, S datta 2. Quantum Transport, Nazarov & Blanter 2. Transport in nanostructures, Ferry, Goodnick & Bird

PHY5204/6204	Sensor Technology [3003]
Prerequisites	Condensed Matter Physics - I, Electronics
Learning Outcomes	• Understand the working principles and designs of sensors used to monitor gases, humidity, and pressure. • design miniature nanoscale and microscale sensors • Apply of sensor devices in technological areas.
Syllabus	1. Overview, definition and classifications of sensors, principles of ceramic sensors, Physical-chemical and technological principles of ceramic sensors: basic concepts, technological principles, operating principles of porous ceramic sensors. Ceramic humidity sensor: classification, basic parameters and characteristics, control of the sensitivity of ceramic humidity sensors. 2. Ceramic gas sensor: classification, parameters and characteristics of resistive gas sensor, selectivity and sensitivity of gas sensor, operating principles, reducing gas sensor, alcohol sensor, odor and product quality sensor, oxygen sensor, ceramic sensor for other gases, Composite material based *sensors,* ChemFETs and eNose, manufacturing of gas sensor. 3. Surface Acoustic Wave based sensors, introduction and principles. Microcantilever technology. Thermal sensors, Optical and radiation sensor, Pressure sensors, smart sensors and other methods of transduction in sensors. 4. Application of ceramic sensors 5. MEMS based sensor, Nanotechnology in Sensor applications, recent developments in this area.
Text & Reference Books	1. Handbook of Modem Sensors: Physics, design and applications, 3rd Edition 2. Jacob Fraden, ISBN 0-387-00750-4, Publisher: Springer-Verlag, Inc. 2004 3. Sensor Technology Handbook *Edited by:Jon S. Wilson.* ISBN: 978-0-7506-7729-5, Publisher Elsivier 4. Advances in Chemical Sensors *Edited by* Wen Wang , *ISBN 978-953-307-792-5, Publisher: InTech* 5. Chemical Sensors: An Introduction for Scientists and Engineers, 6. Peter Grundler, ISBN 978-3-540-45742-8 Springer Berlin Heidelberg New York 2007

PHY5205/6205	Numerical Simulation techniques in Physics [3003]
Prerequisites	Condensed Matter Physics-II
Learning Outcomes	● Ability to write advanced level code for scientific computation in C/C++. ● Learn how to use software library packages. ● Implement the algorithms for Monte Carlo simulations for both classical and quantum many-body systems. ● Perform molecular dynamics simulation for classical systems.
Syllabus	1. Programming In C/C++: Introduction, Basic programming constructs of C/C++. Manipulation of various data types, such as arrays, strings, and pointers. Memory handling, allocation/deallocation procedures. Classes, object oriented programming (OOP). Generic programming using templates. 2. Parallel programming; Introduction to parallel programming using OpenMP and MPI. 3. Monte Carlo simulations: Random numbers. Pseudo Random number generators, simple sampling, importance sampling, Markov chain , Metropolis algorithm, application *of* Monte Carlo to various physical systems of interests (such as the Ising model). 4. Molecular dynamics simulations: Basic concepts, algorithms, application to various model systems. 5. Quantum Monte Carlo (time permitting): QMC for spin systems, World Line algorithms, Stochastic Series Expansion algorithms etc.
Text & Reference Books	1. Stephen Prata, Primer Plus", Sixth Ed. 2. Bjame Stroustrup. *The C++ Programming Language*, Fourth Ed. 3. Peter Pacheco, "An Introduction to Parallel Programming". 4. K. Binder. D.W. Heermann, "Monte Carlo Simulation in Statistical Physics". 5. Allen & Tildesley, "Computer Simulation of Liquids*. 6. Daan Frenkel & Bercnd Smit. "Understanding Molecular Simulation: From Algorithms to Applications*.

PHY5206/6206	Introduction to Cosmology [3003]
Prerequisites	General Relativity and Cosmology
Learning Outcomes	• Define the principles and equations that are the foundation of models of the universe in the general theory of relativity. • Explain important cosmological observations and how they are used to determine the characteristics of the Universe. • Describe important eras in the history of the universe: inflationary phase, radiation dominated phase with disengagement of dark matter and neutrinos, nucleosynthesis, matter dominated universe and the formation of CMB. • Describe how quantum fluctuations during inflation are the source of fluctuations of CMB.
Syllabus	1. Historical overview and expansion of the Universe (3 hours): Ptolemaic Universe – Copernican Revolution – Expanding Universe -Measurement of motion – Redshift – Hubble's law – Cosmological principle 2. Friedman-Robertson-Walter (FRW) metric (4.5 hours): Metric of constant curvature – Standard forms of the FRW metric – Open, closed and flat Universes - Friedman equation – Acceleration equation – Energy conservation 3. Cosmological Models (3 hours): Relation between matter/energy densities and curvature – Critical density and density parameter – Classic cosmological models - Einstein–de-Sitter model –Matter and radiation dominated models – Age of the Universe 4. Cosmological distances (3 hours): Proper distance – Angular diameter distance - Luminosity distance – Horizon distance 5. Nucleosynthesis (4.5 hours): Thermal history of the early Universe - Equilibrium process - Neutron free-out - Deuterium bottleneck – Formation of light elements 6. Inflation (4.5 hours): Problems with Big Bang Theory – Horizon Problem – Flatness Problem –Accelerated expansion in early Universe – Solving Horizon and Flatness problem 7. Cosmic Microwave Background (7.5 hours): Origin of CMB - Preservation of Black-body spectrum – Monopole, Dipole and fluctuations of CMB – Sachs-Wolfe effect - Polarization of

	CMB – CMB energy density – Photon-baryon ratio - Dark Matter – Dark energy - Structure formation 8. Precession measurement of CMB (3 hours): Satellite experiment – Ground–based measurements – Balloon-bourne measurement 9. Numerical cosmology (4.5 hours): Age of the Universe – Evolution of matter, radiation, dark matter and dark energy - Angular diameter distance - Luminosity distance –Horizon distance – Simulation and statistical analysis of CMB
Text & Reference Books	1. Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity by Steven Weinberg (John Wiley & Sons Inc., 1st Edition, July 1972). 2. Introduction to Cosmology by Barbara Rayden (Addison-Wesley, 1st edition, October 2002). 3. An Introduction to Cosmology by J. V. Narlikar (Cambridge University Press, 3rd edition February 2002).

PHY5207/6207	Particle Physics [3003]
Prerequisites	Electrodynamics and Special Theory of Relativity, Nuclear and Particle Physics, Quantum Mechanics-II
Learning Outcomes	• Apply symmetries to classify mesons and baryons • Solve problems related to relativistic kinematics • Reproduce the solutions of free Klein-Gordon, Dirac and Maxwell's equations • Calculate cross sections of simple particle scattering processes and decay widths • Explain spontaneous symmetry breaking and analyze various interaction terms of a Lagrangian
Syllabus	1. Review of particle physics [3] 2. Symmetries, groups and quarks: Abelian and non-Abelian Lie groups, finite symmetry groups; baryon, meson and quark hypothesis. [10] 3. Recap of relativistic kinematics. [2] 4. Relativistic wave equation: Free Klein-Gordon and Dirac fields, Solutions to the Dirac equation, completeness relations, photon field and interaction with Dirac fields, solutions to the free Maxwell's equations, gauge symmetry. [9] 5. Calculation of the 2 -> 2 scattering cross sections in QED. [3] 6. Local and global symmetries, spontaneous symmetry breaking, Higgs mechanism, GSW model, weak interactions. [9]
Text & Reference Books	1. An Introductory course of particle physics, Palash B Pal 2. Introduction to Elementary Particles, David Griffiths 3. Quarks and Leptons: An introductory course in modern particle physics, Halzen and Martin

PHY5208/6208	Principles of Digital Imaging [3003]
Prerequisites	None
Learning Outcomes	• To differentiate among analog, discrete, and digital signals • To learn representation of image by matrix (1D, 2D, 3D, and higher dimension) and its vice-versa • To learn fundamental theories of discretization and digitization of signals or images, and its processing • To learn various techniques for reconstruction of distribution of physical quantities from a set of boundary measurements • To build-up or develop imaging system with a given theory • To establish theory of a given imaging system

Syllabus	1. Introduction and overview of imaging - photography, microscopy and tomography; Aspects and prospects in - dinic» industry, and laboratory research; theories of matrix and its application in imaging (using MATLAB software); basics of signal processing and image processing; image artifacts; temporal, spatial and contrast resolution, numerical methods (12 lectures) 2. Forward model and inverse problems; Tomographic imaging with non-diffracting sources • Radon transform. Fourierslice theorem, filtered back projection convolution back projection, reconstruction from parallel and fan projections; Computed tomography (CT) - transmission* reflection, emission; tomographic imaging with diffracting sources - Born and Rytov approximations, Fourier diffraction theorem; filtering and interpolation; Algebraic reconstruction algorithms - algebraic reconstruction technique (ART), simultaneous iterative reconstructive technique (SIRT); simultaneous algebraic reconstructive technique (SART) (14 lectures) 3. Wave propagation in diffusive medium • ultrasound and optical wave propagation in homogeneous and inhomogeneous media, and soft tissues; Radiation transport equation (RTE); Recovery of physical parameters; Multispectral technique (6 lectures) 4. Tomography in selective imaging modalities - X-ray, ultrasound, magnetic 5. resonance imaging (MRI), positron emission tomography (PET), photoacoustic tomography (PAT), diffuse optical tomography (DOT) (4 lectures)
Text & Reference Books	1. Principle of computerised tomographic imaging, Avinash C Kak and Malcolm Slaney, IEEE Press. 2. Fundamentals of digital image processing, A K lain, Prentice Hall. 3. Discrete time signal processing, Oppenheim Schafer, Pearson

PHY5209/6209	Organic Semiconductors: Fundamentals and Applications [3003]
Prerequisites	Condensed matter physics-I
Learning Outcomes	• Describe physical models and applications of unconventional semiconductors and organic molecules. • Analyse the of photophysics of organic semiconductors and identify their difference with inorganic counterparts • Comprehend applications of organic semiconductors in optoelectronics • Device physics of the optoelectronic devices based on organic semiconductors
Syllabus	PART I. 1. Organic Molecules: Electronic structure of atoms, Atomic and Molecular Orbitals, LCAO, Bonding and antibonding orbitals, Covalent Bond, Sigma and Pi Bonds, Energy Levels, Spectroscopic properties [4 Lectures] 2. Photophysics of Molecules and Aggregates: Excited states: Absorption and emission, Singlet and triplet states, Radiative and non-radiative transitions, Aggregates, Van der Waals Bonding, Hydrogen Bonding, Dimer, and Excimers. [2 Lectures] 3. Excitons : Wannier Exciton, Charge-transfer Exciton Frenkel Exciton, Exciton Diffusion, Excitonic Energy Transfer. [2 Lectures] 4. ConductionMn Organic Solids: Conductivity: carrier concentration versus mobility, Carrier generation, Hopping transport, Mobility measurements, Traps. [2 Lectures] 5. Photovoltaics and Photodetectors: Photovoltaic Devices: Organic Heterojunction Photovoltaic Cells, Organic/Nanorod hybrid Photovoltaics, Gratzel Cells (Dye sensitized solar [1] cells),Photodetector Devices [5 Lectures] 6. Organic Light Emitting Devices: Basic OLED Properties, Charged Carrier Transport, Organic LEDs, Quantum Dot LEDs. [8 Lectures] 7. Lasing Action in Organic Semiconductors: Lasing Process, Optically Pumped Organic Lasers, Electrical Pumping of Organic Lasers. [2 Lectures] 8. Organic Thin Film Transistors: OFETs: Materials, Contacts, Applications, And Nanotube Transistors. [2 Lectures] 9. Device Fabrication Technology: Growth Techniques: Evaporation, Langmuir-Blodgett, Chemical Vapor Phase Deposition, Ink-Jet Printing, Self-Assembly. [3 Lectures] PART II. 1. Project: Literature review on a certain relevant topic. [10 Lectures]

Text & Reference Books	1. Essentials of Molecular Photochemistry, Gilbert &Baggott, CRC Press, 1991. 2. Fundamentals of Photochemistry, K. K. Rohatgi-Mukherjee, NewAge International, 1978. 3. Electronic Processes of Organic Crystals and Polymers, Pope & Swenberg, Oxford University press, 2nd edition (1999). 4. Organic Semiconductors, H. Meier, Verlag Chemie GmbH, 1974 - 5. Physics Of Organic Semiconductors" Wolfgang Brutting, John Wiley & Sons Canada; 1 edition (2005) 6. Organic Electronics: Materials, Manufacturing, and Applications, Hagen Klauk, John Wiley & Sons; 1st edition (2006), 7. **7.** Electrical transport in solids: with particular reference to organic semiconductors, Kao, Pergamon Press; 1st edition (1981).

PHY5211/6211	Theory of Open Quantum Systems [3003]
Prerequisites	Quantum mechanics-II
Learning Outcomes	• Ability to describe open dynamics of open quantum systems using the language of dynamical maps as well as that of master equations. • Understanding of models of open quantum systems like Jaynes-Cummings model, Caldeira-Leggett model etc. • Ability to distinguish between Markovian and non-Markovian open evolution and ability to solve corresponding master equations for specific models.
Syllabus	1. Elements of quantum mechanics [4 Lectures] a. The density matrix representation of quantum states b. Composite quantum systems c. Quantum entropies d. Theory of quantum measurements 2. Quantum master equations [8 Lectures] a. Closed and open quantum systems: von Neumann equation, open evolution b. Classical and Quantum Markov Processes c. Derivation of generic master equations from microscopic considerations d. Example: The quantum optical master equation e. The Caldeira-Leggett Model f. Nonlinear quantum master equations 3. Decoherence theory [6 Lectures] a. The decoherence function b. Markovian decoherence c. Models exhibiting decoherence d. Decohrence and the quantum environment– pointer states and einselection 4. Quantum dynamical maps [5 Lectures] a. Completely positive trace preserving maps b. Choi-Jamiolkovski isomorphism c. Going beyond complete positivity d. Quantum information and open quantum dynamics 5. Stochastic Dynamics in Hilbert Space [6 Lectures] a. Dynamical semigroups and piecewise deterministic processes b. Stochastic representation of continuous measurements c. Example: Photodetection 6. Non-Markovian open quantum dynamics [8 Lectures] a. Quantifying non-Markovianity in quantum systems b. Projection operator techniques and the Nakajima-Zwanzig equation c. Time convolution less master equation d. Example: Spontaneous decay of a two level system e. Example: The spin boson model
Text & Reference Books	1. The Theory of Open Quantum Systems, Heinz-Peter Breuer, Francesco Petruccione, Oxford University Press 2007

PHY5212/6212	Quantum Field Theory I [3003]
Prerequisites	Quantum Mechanics-2, ED & STR
Learning Outcomes	• Construct Fock spaces for bosons and fermions, and illustrate their connection to many-particle quantum mechanics. • Establish Lorentz algebra and determine its representations. • Use canonical quantization prescription to quantize free fields. • Establish relation between scattering amplitudes and Green functions of interacting QFTs. • Develop perturbative QFT methods including diagramatics suitable for analyzing scattering experiments.
Syllabus	• Introduction: Need for quantum field theory, Many-particle quantum mechanics, Bosons and fermions, Many-body theory, Fock spaces. • Symmetries: Lorentz and Poincare symmetries in QFT, Lorentz algebra and representations • Classical field theory: Continuous Symmetries and Noether theorem, Conserved currents and charges • Klein-Gordon Field: Canonical quantization, Klein-Gordan Propagator, real and complex scalar fields. • Dirac Field: Relativistic covariance, Dirac equation, Dirac matrices, Quantization, Discrete symmetries *C, P,* T. • Interacting Field theory: Interaction picture and relativistic perturbation theory, Wick's theorem, Feynman Rules, S-matrix, Diagrammatics • QED: Maxwell field, Canonical quantization of the gauge field, interactions with Dirac fields
Text & Reference Books	1. Peskin and Schroeder, An introduction to Quantum field theory, Persus (1995). 2. Maggiore, A modern introduction to quantum field theory, Oxford (2005). 3. Srednicki, Quantum field theory, Cambridge (2006).

PHY5101/6101	Lasers and Fiber Optic Communications [3003]
Prerequisites	Quantum Mechanics -I and Mathematical Methods in Physics
Learning Outcomes	• Write rate equations for 2- 3- and 4-level atomic systems and its application to lasing • Analysis of the laser gain medium using Lorentz oscillator model • Analyze Fabry-Perot cavity and role of cavity resonances in lasing • Use level lifetime and dephasing to define linewidths: homogeneous and inhomogeneous • Apply analog and digital modulation formats for communications • Use data multiplexing to develop Terabit/sec data stream • Use eye-diagrams and other detection methods to analyse the output data stream fidelity
Syllabus	1. Introduction to lasers: cavity, gain medium, rate equations, population inversion, lasing condition, level lifetime, spontaneous and stimulated emission. Dephasing time, line broadening mechanisms: homogeneous and inhomogeneous broadening, hole burning, spatial hole burning; examples of laser systems: DFB and DBR lasers, semiconductor lasers, He-Ne laser, Raman laser, Brillouin laser, mode-locked lasers, Vertical Cavity Surface Emitting Lasers (VCSELs). 2. Optical communications: data sampling and Nyquist criteria, analog to digital conversion, analog 3. Modulation formats: amplitude modulation, frequency modulation, phase modulation; digital modulation: amplitude shift keying (ASK), frequency shift keying (FSK), phase shift keying, quadrature phase shift keying (QPSK), terabit per second (Tb/s) communication: time division multiplexing (TDM), wavelength division multiplexing (WDM), polarization division multiplexing (PDM), data de-multiplexing of Tb/s data using four-wave mixing. Effect of dispersion and nonlinearity on data propagation, Erbium doped fiber amplifier (EDFA). Detectors: photodiode, PIN photodiode, avalanche photodetector, detector as low pass filter, receiver noise, thermal noise, shot noise, signal-to-noise ratio, noise figure, bit error rate (BER), eye-diagram, Shannon limit, basic coding schemes.

Text & Reference Books	1. Lasers by Siegman, Anthony E. (1986), University Science Books. 2. Fiber-Optic Communication Systems by Govind P. Agrawal, Wiley Interscience

PHY5102/6102	Physics at Low temperatures [3003]
Prerequisites	None
Learning Outcomes	• To understand the properties of cryogens used to achieve low temperatures. • To understand how solids behave at low temperatures via measurement of their transport and thermodynamic properties. • To understand how to produce low and ultra-low temperatures. • To understand how temperature scales work and how temperature measurements are done.
Syllabus	1. Quantum fluids: Physical properties of Helium. Superfluidity in ^{4}He: experimental findings, two fluid model, Bose-Einstein Condensation, macroscopic quantum state, vortex flow, critical velocities and second sound. 2. Normal and superfluid ^{3}He, Quantum states of pairs of coupled quasi particles - Spin triplet pairing – macroscopic quantum effects, mixture of ^{3}He and ^{4}He, phase diagram, properties of this mixture, topological defects in superfluid ^{4}He and superfluid ^{3}He and salient properties of quantum solids. 3. Solids at low temperatures: Electrical transport, thermal, mechanical and magnetic properties, Kondo effect, Superconductivity and heavy fermion materials. 4. Production of low and ultra low temperatures, Liquid helium cryostats, Closed Circuit refrigerators: Gifford-McMahon refrigeration cycle, Pulse tube refrigerator, Physics of adiabatic and nuclear demagnetization, Pomeranchuk cooling, dilution refrigerators. Advanced materials for magnetic refrigeration, Special problems of thermal insulation, thermal contact and heat transfer at ultra low temperature and Kapitza resistance. Experimental techniques in Laser cooling. 5. International temperature scales – Temperature fixed points, Measurement of temperatures and different kinds of thermometers: (Primary and secondary)-Gas thermometer, vapour pressure thermometry, resistance thermometer: metal resistances like platinum, doped semiconductors like germanium, carbon and carbon glass, Ruthenium oxide, Cernox thermometers – thermoelectric thermometer, Capacitance thermometers, magnetic thermometers, measurement of temperature in the presence of high magnetic field.Materials: Sapphire, substrate, below 10 K.
Text & Reference Books	1. Guy K White and Phillips J Meeson, Experimental Techniques in Low-Temperature Physics, 4th Edition, Clarendon Press – Oxford (2002). 2. H.M. Rosenberg, Low Temperature Solid State Physics, Oxford University Press (1963). 3. D.R. Tilley and J. Tilley, Superfluidity and Superconductivity, IoP Publishing, Bristol, 3rd Edition (1990). 4. James F Annett, Superconductivity, Superfluids and Condensates, Oxford Master Series in Physics, Oxford University Press, 1st Edition (2004). 5. A.C. Rose-Innes and E.H.Rhoderick, Low Temperature Laboratory Techniques, English University Press (1973). Reference Books: 6. Frank Pobell, Matter and Methods at Low Temperatures, 3rd revised and expanded Edition, Springer (2007). 7. V.E. Mclintock, D.H. Meredith and J.K. Wigmore, Matter at Low Temperatures, Blackie, Glassglow (1984). 8. Christian Enns and Siegfried Hunklinger, Low Temperature Physics, Springer Verlag (2005). 9. Anthony Kent, Experimental Low Temperature Physics (Macmillan Physical Science Series), AIP (1993). 10. D.S. Betts, Introduction to Millikelvin Technology, Cambridge University Press (1989). 11. O.V. Lounasmaa, Experimental Principles and Methods below 1 K, Academic Press (1974). 12. Robert Coleman Richardson and Eric N. Smith, Experimental Techniques in Condensed Matter Physics at Low Temperatures, Advanced Books Classics (1998)

	13. J. W. Ekin, Experimental Techniques in Low Temperature Measurements, Oxford University Press (2006) 14. P. M. Chaikin and T. C. Lubensky, Principles of Condensed Matter Physics, Cambridge University Press (2000)

PHY5103/6103	**Nanoscale Physics [3003]**
Prerequisites	Condensed Matter Physics-I and Quantum Mechanics-I
Learning Outcomes	• To obtain basic understanding of nanomaterials in terms of their unique physical properties. • To learn the various techniques for fabrication of nanostructured materials along with basic understanding of specific nanotools for their characterization. • Application of nanomaterials in nanoscale devices will also be explored.
Syllabus	1. Overview of nanoscience- historical perspective, nanotechnology in nature. Basic physical principles of quantum confinement 2. Size matters: effect on structural, physical and chemical properties Nanomagnetism Nanophotonics. Electronic structure of semiconductor nanoparticles, size dependent optical properties: photoluminescence, absorption spectra, excitons and plasmons, vibrational and thermal properties of nanosystems; zone folding. Raman characterization. 3. Synthesis of nanomaterials: Bottom up and top down approaches - Physical and chemical methods. 4. Story of carbon nanoscience: Fullerenes, carbon nanotubes, graphene and beyond graphene - physics and applications. 5. Nanotools: Scanning probe techniques - tools for characterization, manipulation and constructions of the nanoscale structures and devices. 6. Applications of nanomaterials, nanoscale devices.
Text & Reference Books	1. Introduction to Nanoscience & Nanotechnology: Homyak et *al.,* CRC Press, 2009 2. Introduction to Nanoscience & Nanotechnology: Chris Binns, Wiley, 2010 3. Physical Properties of Carbon Nanotubes, Imperial College Press.

PHY5104/6104	**Superconductivity [3003]**
Prerequisites	Condensed Matter Physics-I
Learning Outcomes	• Understand the difference between the normal state and superconducting state. • Learn the thermodynamics and phenomenological theory of superconductivity • Learn the microscopic theory of superconductivity • Understand tunneling • Understand the difference between Type-I and Type-II superconductors • Learn about the vortex state and experimental techniques to probe superconductivity

Syllabus	1. A historical overview: Superconductivity in Hg, cuprates, MgB2 and Fe pnictides. 2. Basic properties of metals in normal state: Resistivity, electronic and phonon specific heats, thermal conductivity, magnetic susceptibility and Hall effect. 3. Phenomenon of superconductivity: Zero resistance, persistent currents, superconducting transition temperature Tc , isotope effect, perfect diamagnetism and Meissner effect, penetration depth and critical field. 4. Thermodynamics of superconducting transition: First-order and second-order transition, specific heat above and below Tc , thermal conductivity. 5. Phenomenological theory of superconductivity: Free energy, order parameter, Ginzburg-Landau equations, predictions of Ginzburg Landau equations, flux-quantization, penetration depth. 6. Microscopic theory of superconductivity: Electron-phonon interaction, Cooper pairs, Bardeen-Cooper-Schrieffer (BCS) Hamiltonian, variational approach, canonical transformation, finite temperatures, properties of the BCS ground state, macroscopic properties of superconductors. 7. Tunneling and the energy gap: Tunneling phenomenon, energy-level diagram, Josephson effect, quantum interference. 8. Type-I and Type-II superconductivity: Type-I and type-II superconductors, intermediate states, mixed states. 9. Experimental methods for probing the nature of the superconducting state: superconducting quantum interference device and point-contact spectroscopy. 10. Basics of High-Tc superconductivity.
Text & Reference Books	1. C. Kittel, "Introduction to Solid State Physics", 7 th Edition, John Wiley & Sons, Inc., Singapore (1995). 2. A.C. Rose-Innes and E.H. Rhoderick, "Introduction to Superconductivity", 2 nd Edition, Pergammon, Oxford (1978). 3. M. Tinkham, "Introduction to Superconductivity", 2 nd Edition, Dover Publications, Inc., New York (1996). 4. P.G. de Gennes, "Superconductivity in Metals and Alloys", W.A. Benjamin, New York (1966). 5. C.P. Poole Jr., H.A. Farach, R.J. Creswick, and R. Prozorov, "Superconductivity", 2nd Edition, Academic Press (2007). 6. D.R. Tilley and J. Tilley, Superfluidity and Superconductivity, IoP Publishing, Bristol, 3rd Edition (1990). 7. James F Annett, Superconductivity, Superfluids and Condensates, Oxford Master Series in Physics, Oxford University Press, 1st Edition (2004). 8. A.C. Rose-Innes and E.H.Rhoderick, Low Temperature Laboratory Techniques, English University Press (1973).

PHY5105/6105	Foundations of Quantum Mechanics [3003]
Prerequisites	PHY 314: Quantum Mechanics I
Learning Outcomes	• Will be able to explain the basics mathematical formulation of quantum theory and will be able to identify it as an operational theory rather than an ontological theory • Will learn some of the most profound debates regarding the foundational status of quantum theory, viz. Bohr-Einstein debate and Einstein–Podolsky–Rosen paradox, Wigner's friend paradox, Pusey-Barrett-Rudolph theorem • Will Identify in what sense quantum theory provides a completely new world view than the old classical physics. In particular, will learn Bell's theorem, the most profound discovery of science • Will be able to apply Bell's theorem to certify device-independent randomness and will learn how device independent cryptography shared key can be obtained from quantum nonlocal correlation • Will appraise Kochen-Specker theorem and its remarkable application in Binary constraint system games, also learn some use of graph theory at this point • Will recognize that quantum world allows very peculiar causal structure than what we generally perceive in our classical macroscopic world

Syllabus	1. Review [3]: Mach-Zehnder interferometer; Stern-Gerlach experiment; Linear Algebra 2. Introduction [4]: Postulate of Quantum Theory; Einstein-Podolsky-Rosen paradox 3. Programme of Hidden Variable Theory (HVT) [3]: Operational theory & Ontological Model; von Veumann `no-go' theorem; Bell's criticism on von Neumann's theorem; Deterministic HVT for Qubit (Bell model and Kochen-Specker model) 4. Bell's Nonlocality [4]: Proof of Bell's theorem; Quantum entanglement; Quantum violation of Bell inequality; Study of different sets of correlations 5. Application of Bell's theorem [4]: Device independent (DI) randomness certification; Quantum cryptography protocols (BB84 and E91); DI cryptography 6. Kochen-Specker contextuality [4]: State independent / dependent contextuality proof; Generalized contextuality of Spekkens 7. Application of Kochen-Specker contextuality [3]: Some basic topics in graph theory; Binary Constraint System Games, Parity-oblivious multiplexing task 8. Reality of quantum wavefunction [4]: Pusey-Barrett-Rudolph theorem; Maroney's theorem 9. Quantum Measurement Problem [3]: Wigner's friend paradox and its extended version 10. X. Indefinite causal order [4]: Oreshkov-Costa-Brukner game; Quantum switch
Text & Reference Books	1. Quantum Theory: Concepts and Methods (Fundamental Theories of Physics) -- Asher Peres 2. Foundations of Quantum Mechanics: An Exploration of the Physical Meaning of Quantum Theory --- Travis Norsen 3. Bell nonlocality; Nicolas Brunner, Daniel Cavalcanti, Stefano Pironio, Valerio Scarani, and Stephanie Wehner; Rev. Mod. Phys. 86, 419 (2014) 4. Hidden variables and the two theorems of John Bell; N. David Mermin; Rev. Mod. Phys. 65, 803 (1993) 5. Class notes and few relevant research papers

PHY5106/6106	Advanced Statistical Physics [3003]
Prerequisites	Statistical Mechanics
Learning Outcomes	• Recall phase transitions, and characterize critical phenomena by their symmetries (order parameter) and critical exponents. • Establish connection between statistical and quantum systems, transfer matrix and path integrals. • Solve Ising model in 1D and 2D using transfer matrix methods, and determine large-distance correlation functions. • Use Landau-Ginzburg theory to describe Ising model, and apply various mean-field methods to obtain correlation functions and exponents. • Use Renormalization group techniques to identify relevant couplings, determine their flow under scaling, and find the critical exponents.
Syllabus	1. Phase Transitions and Critical Phenomena: Origin of phase transition, thermodynamic instabilities. Classification of order of transitions, Phase transitions in different systems (e.g. liquid-gas and paramagnet ferromagnetic transition). Order parameter, critical exponents, concept of long-range order. 2. Introduction to lattice models: Description of lattice models and their ground states. (Examples include Potts Model, X-Y model, Heisenberg Model). Qualitative description of the nature of phase transitions in these models and their critical exponents. 3. Collective excitations: Continuous symmetry breaking and Goldstone modes, Mermin-Wagner theorem, spin-waves in ferromagnets. 4. Exact solution of Ising model in one and two dimensions, Relation between transfer matrix method and path integrals in quantum mechanics. 5. Landau-Ginzburg theory: Mean-field approach. Saddle-point approximation, Breakdown of mean-field and Ginzburg criterion. 6. Renormalization Group: Scaling hypothesis and universality, Renormalization group transformations, Upper and lower critical dimensions, the expansion, 0(N) model, Quasi-long-range order, Kosterlitz-Thouless transition.

Text & Reference Books	1. Kardar, Statistical Physics of Fields, CUP (2007). 2. Chaikin and Lubensky, Principles of condensed matter physics, CUP (1995). 3. Plischke and Bergerson, Equilibrium Statistical Physics (3rd ed.), World Scientific (2006). 4. Brezin, Introduction to Statistical Field Theory, CUP (2010)

PHY5107/6107	Fluid Dynamics [3003]
Prerequisites	Classical Mechanics, Electrodynamics & STR, Statistical Mechanics
Learning Outcomes	• Assimilate hydrodynamic principles, and identify the relevant dissipative processes, transport coefficients and Onsager relations. • Apply the entropy principle to construct the constitutive relations in non-relativistic (simple and multi-component) fluids, in relativistic fluids, and in superfluids. • Solve relativistic fluid dynamical equations for stationary flows and irrotational flows. • Rectify non-causal behaviour of first-order relativistic fluids by adding higher-order corrections.
Syllabus	1. Foundations of fluid dynamics: Hydrodynamic variables, symmetries and conservation laws, local equilibrium, constitutive relations, entropy principle. [3] 2. Nonrelativistic fluid dynamics: Dynamical equations of Ideal fluids, constructing constitutive relations and equations of viscous fluids (Navier-Stokes equation, equation of heat transfer). [4] 3. Multi-component fluids (Mixture of fluids): Equations of motion, coefficients of mass transfer and thermal diffusion, kinetic coefficients and Onsager reciprocal relations. [6] 4. Relativistic fluid dynamics: The energy-momentum tensor, the equations of ideal relativistic fluid dynamics, symmetries of ideal fluids, Newtonian limit, relativistic stationary flows and irrotational flows, linear hydrodynamic waves, variational principles. [7] First-order corrections of constitutive relations and frame dependence, the equations of viscous fluids in Landau and Eckart frames. [4] Non-causal behaviour of viscous relativistic fluids in first-order theories, Extended irreversible thermodynamics, Israel-Stewart formulation and higher-order theories. [5] 5. Dynamics of superfluids: Properties and dynamics of superfluids, Dissipative processes in superfluids, propagation of sound in superfluids. [7]
Text & Reference Books	1. Landau and Lifshitz, Fluid mechanics, Pergamon. 2. Rezzolla and Zanotti, Relativistic hydrodynamics, Oxford University Press. 3. de Groot and Mazur, Nonequilibrium thermodynamics, Dover publications.

PHY5108/6108	Advanced Mathematical Methods in Physics [3003]
Prerequisites	Mathematical Methods in Physics.
Learning Outcomes	• Classify Topological Spaces and functions on Topological Spaces • Calculate the homotopy groups of a Topological space. • Apply homotopy theory to some Physical problems. • Define differentiable manifolds and analyze various properties of a differentiable manifold. • Perform calculus on manifolds. • Define and classify groups and their representations. • Analyze local structure of a Lie group by the study of Lie algebras and its representations. • Classify Lie algebras by studying its root structure and Dynkin diagrams.
Syllabus	1. Topology [4.5]: Topological Spaces, Metric Spaces, Basis, Closure, Connected and Compact Spaces, Continuous functions, Homeomorphisms and Topological Invariants, Separability 2. Homotopy [4.5]: Paths and Loops, Homotopy, Fundamental Group, Higher Homotopy Groups, Applications in Physics 3. Differential Geometry [9]: Differentiable Manifolds, Functions on Manifolds, Orientability, Calculus on Manfolds (Tensor fields and Forms), Riemannian Geometry, Induced maps (Pull Back and Push forward), Lie derivative, Exterior derivative, Interior derivative, Integration of differential forms, Stokes Theorem

	4. Introduction to Group Theory [4.5]: Definition of a group, Subgroups, Cosets, Normal subgroup, Factor group, Abelian groups, Commutator subgroup, Solvable, Nilpotent, semisimple and simple groups 5. Group Representations [3]: Definition of representation, Invariant subspaces, Reducibility of representations, Equivalence of Representations, Unitary, orthogonal, contragradient, adjoint and complex conjugate representations. 6. Lie groups and Lie algebras [4.5]: Topological groups, Lie groups and compact Lie groups, Local coordinates of a Lie group, Lie algebra of a given Lie group, Abelian Lie algebra, Normal subalgebra, commutator subalgebra, solvable and nilpotent Lie algebras, simple and semi simple Lie algebra, Representation of Lie algebras. 7. More Lie algebras [6]: Complexification and classification of Lie algebras, Cartan Weyl Basis and roots of a Lie algebra, Positive roots, simple roots and Dynkin diagrams.
Text & Reference Books	1. Lectures on Advanced Mathematical Methods for Physicists: Mukhi and Mukund 2. Geometry, Topology and Physics: M Nakahara

PHY5109/6109	General Relativity and Cosmology [3003]
Prerequisites	Classical Mechanics, ED & STR
Learning Outcomes	• Describe physical phenomena using tensors and differential forms. • Calculate covariant derivative and the components of the Riemann curvature tensor from a given line element. • Solve Einstein's field equations for static spherically symmetric problems. • Calculating the relativistic frequency shifts for sources moving in a gravitational field, as well as the bending of light passing a spherical mass distribution. • Give a mathematical description of gravitational waves, the ripples of space-time.
Syllabus	1. Covariance of Physical Laws Special (1 Relativity (2 lec) 2. The Equivalence Principle (2 lec) 3. Space and Spacetime Curvature Tensors in Curved Spacetime (4 lect) The Geodesic equation (4 lectures) 4. Curvature and Einstein Field Equations (2 lect) Geodesic Deviation Equation Geometry (4 lectures)Outside of a Spherical Star Tests of caslativity (2 lectures) 5. Gravitational Radiation 6. Black Holes (3 lectures) 7. Cosmology (3 lectures)
Text & Reference Books	1. Gravity- An introduction to Einstein's general relativity - James Hartle (Addison-Wesley) 2. Gravitation and Cosmology • S. Weinberg (Wiley, 1972) 3. Introduction to General Relativity • J. V. Narlikar (Cambridge) Classical Theory of Fields • L D. Landau and E. M. Lifshitz (Butterworth-Heinemann)

PHY5110/6110	Quantum Many-body Theory [3003]
Prerequisites	Quantum Mechanics -II
Learning Outcomes	• Describe and solve quantum mechanical problems using the language of second quantization. • Solve quantum many-body problems using path-integral formulation. • Calculate observable properties of a quantum many-body system using Green's functions. • Understand the nature of collective modes of some typical condensed matter systems.
Syllabus	1. Second Quantization: Identical particles, Many-particle states, Symmetric and Antisymmetric states; Fock Space, Creation and Annihilation operators, and many-body operators of Bosons and Fermions. Applications of second quantization (in nearly free electron systems and weakly interacting bosonic systems) 2. Path integral formulation: Coherent states, Construction of the many-body path integral, Perturbation theory and diagramatics

	3. Green*s functions: Evaluation of observables, Analytic properties of Green*s functions, Physical content of self-energy, Linear response, Dynamical Susceptibility, Dispersion Relations, Spectral Representation, Fluctuation-Dissipation Theorem, Symmetry Properties, Sum Rules. 4. Fermi Liquid theory: Quasi-particles and their interactions, Observable prop-erties of normal Fermi liquid, Collective modes
Text & Reference Books	1. F Schwabl, Advanced Quantum Mechanics (3rd Ed), Springer (2005) 2. Altland Alexander, Simons Ben, Condensed Matter Field Theory (2nd Ed) CUP (2010) 3. Nolting W, fundamentals of Many body Physics, Springer (2009) 4. Abrikosov, Gorkov and Dzyaloshinski, Methods of quantum field theory in statistical physics, Courier Dover Publications (1975). 5. Fetter and Walecka, Quantum theory of many-particle systems (Dover). 6. Mahan, Many-partide physics, Springer {2000). 7. Negele and Orland, Quantum many-particle systems, Westview Press (1998).

PHY5111/6111	Digital Image Processing [3003]
Prerequisites	None
Learning Outcomes	• To learn representation of image by matrix (1D, 2D, 3D, and higher dimension) and its vice-versa • To learn theories of matrices and transformations • To learn techniques of image processing and analysis and subsequent computational implementations • To learn fundamental techniques for reconstruction of distribution of physical quantities from a set of boundary measurements
Syllabus	1. Introduction – overview and applications. Mathematical preliminaries – mathematical function (dirac-delta function, shifting and scaling properties, linear transformation), matrix theory (vectors and matrices, orthogonality, and unitary matrices), Fourier transform and its properties, Z-transform, point spread function (PSF) and impulse response (finite impulse response (FIR) and infinite impulse response (IIR)), convolution and linear time invariant (LTI), correlation, random signals and random processes (Markov random process), probability distribution function (pdf) (Gaussian or normal). 2. Image representation and modelling – matrix element and image pixel, visual perception (luminance, brightness, contrast), monochrome and color image representation, sampling (Nyquist theorem and aliasing), quantization (uniform quantizer, Lloyd-Max quantizer, optimum mean square quantizer, compander quantizer, contour and its effects); Image transform – orthogonal and unitary, cosine, sine, Karhunen Loeve (KL), Hadamard, Haar, slant, wavelet; Image enhancement – point and spatial operation, histogram modelling, transform operation; Image filtering and restoration – image model and inverse filtering, Wiener filtering, filtering in frequency domain, single value decomposition (SVD) and recursive filtering; Image analysis – feature extraction, registration, segmentation (point, line, and edge detection; thresholding; region growing and region splitting), classification, SVD and principle component analysis (PCA); Morphological image processing – erosion and dilation, opening and closing, Hit-or-Miss transform, morphological reconstruction; Image reconstruction – Radon transform, Fourier slice theorem, projection, sectioning, tomography (numerical method); Image data compression – pixel coding, predictive technique, transform coding theory, interframe coding.
Text & Reference Books	1. A K Jain, *Fundamentals of Digital Image Processing*, Prentice Hall, 2009. 2. Rafael C Gonzalez and Richard E Woods, *Digital Image Processing*, Prentice-Hall India, 2002. 3. Avinash C. Kak and Malcolm Slaney, *Principles of Computerized Tomographic Imaging*, IEEE Press (1999).

PHY6112	Quantum field theory-2 [3003] (Grad level)
Prerequisites	Quantum field theory-1
Learning Outcomes	• Develop perturbative QFT methods using path integral formulation. • Use grassmann variables and calculus over grassmann variables to formulate path integrals for fermions. • Apply path integral formulation to Quantum Electrodynamics (QED). • Use the Fadeev-Popov trick for quantization of non-abelian gauge theories. • Apply renormalization procedure for extracting finite values of physical quantities. • Use renormalization group to see how a physical quantity changes with scales.
Syllabus	1. Path integral formulation of quantum mechanics [3] 2. Field Theory Path Integrals: Path integral for interacting scalar field theory, Generating Functional, Correlation function, Perturbation Theory, Feynman rules [6] 3. Path integrals for fermions: Grassman variables, Differentiation and Integration over grassmann variables, Path integrals for Dirac fields. [6] 4. Path integral formulation for QED [3] 5. Non Abelian Gauge Theory: Lie groups and Lie algebras, Fundamental and adjoint representations, Yang-Mills action, Path integrals for Non Abelian gauge theories, Faddeev Popov Trick, Feynman rules for pure gauge theories, Inclusion of fermions [9] 6. Ultraviolet Divergences and Renormalization: UV Divergence, General procedure of renormalization, Dimensional regularization, Renormalization of scalar field theories, Renormalization of gauge theories, Renormalization group [9]
Text & Reference Books	1. An introduction to quantum field theory by Peskin and Schroeder. 2. Quantum theory of fields Vol-1 and 2 by Steven Weinberg 3. Quantum field theory by M. Schwartz 4. Quantum field theory by L. H. Ryder

SoP Open Electives

PHY4105/6105	Material & device characterization techniques [2013]
Prerequisites	None
Learning Outcomes	• To provide the basics of each technique including instrumentation, samples preparation and the applicability of these techniques. • Develop the concepts on the several materials characterization techniques at the morphological, structural and chemical level. • Demonstrate knowledge about the characterization methods based on microscopy, microanalysis and diffraction techniques, and surface and spectroscopy analysis. • Finally, develop the acquisition skills in the use and selection of advanced experimental techniques for characterization of materials and application of these techniques to solving problems in materials science and engineering.
Syllabus	1. Microscopy & Optical techniques: Optical Microscopy, Confocal Optical Microscopy, X-ray, Neutron diffraction, TEM, SEM, XPS, EDAX/EDS, Raman, PL, Ellipsometry, AFM & STM. 2. Electrical properties & characterization techniques: I-V measurement: 2-probe and 4-probe, low noise electronics; C-V measurements, 3Terminal devices and characterization, FET, BJT; Hall effect, Mobility and Carrier concentration; Microwave measurements, ESR, NMR; Defects: DLTS, Channelling; Photoconductivity-Carrier-lifetime, Kelvin-probe. 3. Magnetic Properties & Characterization: Magneto-transport, MFM, VSM, SQUID
Text & Reference Books	1. Semiconductor material and device characterization, D. K Schroder, 2006 John Wiley & Sons. 2. Materials Characterization: Introduction to Microscopic and Spectroscopic Methods, Second Edition, Yang Leng, Wiley-VCH 2013

PHY5210/6210	Materials Growth and Processing Techniques [2013]
Prerequisites	None
Learning Outcomes	• Develop thorough understanding of growth techniques of materials, with a knowledge on various growth mechanisms involved. • Develop skills to design growth parameters to achieve controllable growth of materials. • Analysis of experimental data obtained through various structural, spectroscopic and microscopic characterization techniques. • Develop skills for materials related interdisciplinary experimental research.
Syllabus	1. Physical and chemical techniques for material synthesis, sol-gel, hydrothermal, mechanical alloying and mechanical milling, ion implantation, Gas phase condensation, Chemical vapour deposition, fundamentals of nucleation growth, controlling nucleation & growth. 2. Self-assembly, Langmuir-Blodgett (LB) films, clusters, colloids, Templated synthesis, anodic oxidation of alumina films, porous silicon, and pulsed electrochemical deposition. 3. Basic concepts and experimental methods of crystal growth: nucleation phenomena, mechanisms of growth, dislocations and crystal growth phase diagrams and material preparation, growth from liquid-solid equilibria, vapour- solid equilibria, mono-component and multi-component techniques. 4. Thin film growth techniques: Thermal and electron beam evaporation. Vapor deposition and different types of epitaxial growth techniques. Pulsed laser deposition, Molecular beam epitaxy. Sputtering methods: DC, RF and Magnetron sputtering.
Text & Reference Books	1. The Growth of Single Crystals, R. A. Laudise. Prentice-Hall publishing 2. M. Ohring, 'Materials Science of Thin Films' (Academic, New York, 1992).