INDIAN INSTITUTE OF SCIENCE EDUCATION AND RESEARCH

THIRUVANANTHAPURAM

COURSE CATALOGUE

BS-MS & i² SCIENCES – Batch 2020, 2021 & 2022

MSc, IPHD & PHD – Batch 2023 & 2024

IISER
THIRUVANANTHAPURAM

2024 - 25

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Contents

About the Booklet

IISER Thiruvananthapuram offers Undergraduate and Graduate Programs. Each of these programs have different requirement and course structure. All the schools offer array of courses for students to choose from. This booklet enlists all the courses offered by various schools at IISER Thiruvananthapuram. Various under graduate and graduate programs offered by IISER Thiruvananthapuram are:

1. Integrated BS MS degree in basic Sciences (Biology, Chemistry, Mathematics and Physics)
2. Integrated and Interdisciplinary BS Ms degree (Biology, Chemistry, Data Science Mathematics and Physics)
3. Master of Sciences degree in basic Sciences (Biology, Chemistry, Mathematics and Physics)
4. Integrated Ph.D degree in degree in basic Sciences (Biology, Chemistry, Mathematics and Physics)
5. Ph. D degree in basic Sciences (Biology, Chemistry, Mathematics and Physics)

There are mainly two types of courses:

- Core Courses
- Elective Courses (Within the department and Across the institute)

The booklet lists the courses starting from foundation courses, which are common to all BSMS degree students for the first 2 years.

At the beginning of the list of school wise courses, a table is provided to get the glimpse of requisite CORE and Elective courses for each program.

The course numbering can be understood using the following format:

- The CORE courses of the BSMS programme are numbered in the format: XYZ LSC (LTPC)
- The CORE courses of the MS programme are numbered in the format: MSQ LSC (LTPC)
- ELECTIVE courses are numbered in the format: XYZ LSCD (LTPC)
- CORE/ELECTIVE MODULES carrying less than 3 credits are numbered as MSQ/XYZ LSC*m* (LTPC)/ MSQ/XYZ LSCD*m* (LTPC) or MSQ/XYZ LSC*mn* (LTPC)/ MSQ/XYZ LSCD*m* (LTPC)

The numbering may be understood as

XYZ	:	Programme/Subject code for CORE and Elective courses
MS Q	:	Prefix MS followed by Programme code (B-Biology, C-Chemistry, M-Mathematics, P-Physics)
L	:	Level of the course (1, 2, 3, 4, 5 or 6)
S	:	Semester (1-Varsha, 2-Vasanth)
C (CD)	:	Course number
m (mn)	:	Module position – Applicable only to 1 and 2 credit modules

- *a* : Module spans 1st one-thirds of the semester (12 to14 lectures)
- *b* : Module spans 2nd one-thirds of the semester (12 to14 lectures)
- *c* : Module spans 3rd one thirds of the semester (12 to14 lectures)
- *ab* : Module spans 1st two-thirds of the semester (24 to 28 lectures)
- *bc* : Module spans 2st two-thirds of the semester (24 to 28 lectures)

L	:	Lecture hours per week
T	:	Tutorial hours per week
P	:	Practical (laboratory) hours week
C	:	Credits

Subject/Programme codes (XYZ)

BIO: Biological Sciences	CHY: Chemical Sciences
MAT: Mathematical Sciences	PHY: Physical Sciences
IDC: Interdisciplinary Studies	HUM: Humanities
DSC: Data Sciences	I2B: i^2 Biological Sciences
I2C: i^2 Chemical Sciences	I2D: i^2 Data Sciences
I2M: i^2 Mathematical Studies	I2P: i^2 Physical Sciences

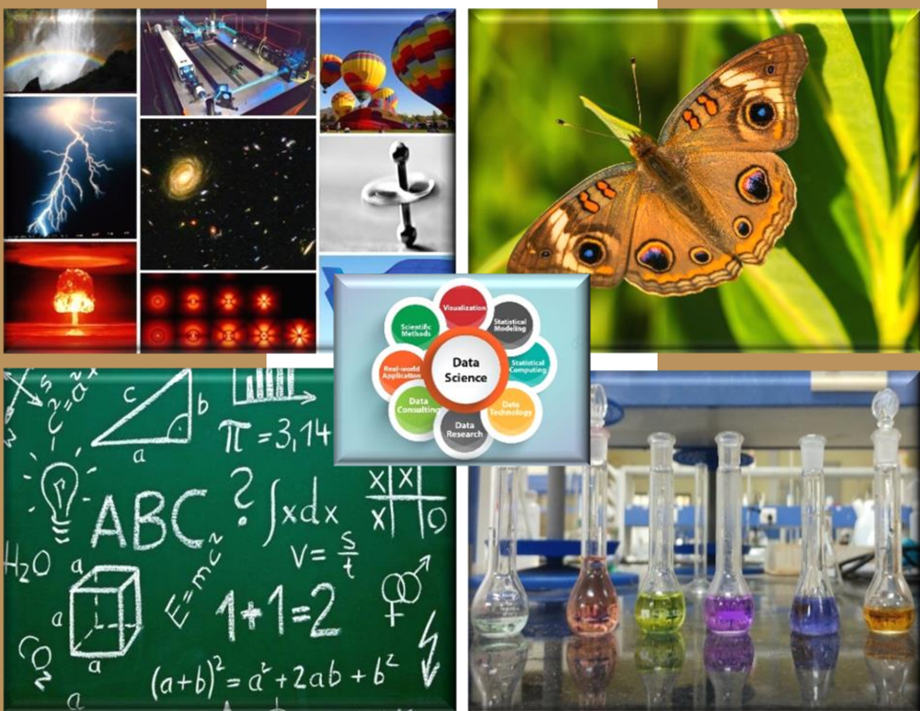
For all Schools:

1. The semesters 5 and 6 of the IPHD program are reserved for Project work.
2. Apart from these courses the mandatory Research Methodology course will be offered by respective schools for PhD and IPhD students. The grades for this course are Satisfactory/ Unsatisfactory. Students need to complete this course with Satisfactory grade before submission of thesis.

FOUNDATION COURSES

CURRICULUM FOR BS-MS (SEM: 1 - 4)

i^2 Sciences (SEM: 1 - 4)



Foundation Courses (Semesters 1 – 4)

Semester 1	Semester 2	Semester 3	Semester 4
Ecology and Evolution [3 1 0 3]	Biomolecules [3 1 0 3]	Genetics and Molecular Biology [3 1 0 3]	Introduction to Cell Biology and Microbiology [3 1 0 3]
Atomic Structure & Chemical Bonding [3 1 0 3]	Basic Concepts in Organic & Inorganic Chemistry I [3 1 0 3]	Basic Concepts in Organic & Inorganic Chemistry II [3 1 0 3]	Physical Chemistry I [3 1 0 3]
Single Variable Calculus [3 1 0 3]	Introduction to Linear Algebra [3 1 0 3]	Multivariable Calculus [3 1 0 3]	Introduction to Probability [3 1 0 3]
Mechanics [3 1 0 3]	Electromagnetism [3 1 0 3]	Optics [3 1 0 3]	Thermal and Statistical Physics [3 1 0 3]
Biology Lab I [0 0 3 1]	Biology Lab II [0 0 3 1]	Biology Lab III [0 0 3 1]	
Chemistry Lab I [0 0 3 1]		Chemistry Lab II [0 0 3 1]	Chemistry Lab III [0 0 3 1]
Physics Lab I [0 0 3 1]	Physics Lab II [0 0 3 1]		Physics Lab III [0 0 3 1]
Mathematical Tools I [2 1 0 2]	Mathematical Tools II [3 1 0 3]	Physical Principles in Biology [3 1 0 3]	Principles of Spectroscopy [3 1 0 3]
Fundamentals of Programming [0 0 3 1]	Numeric Computing [0 0 3 1]	Data Handling and Visualisation [0 0 3 1]	Scientific Computing [0 0 3 1]
Communication Skills I [1 0 0 1]	Communication Skills II [1 0 0 1]	Economics [1 0 0 1]	Languages [1 0 0 1]
[19]	[19]	[19]	[19]

Biology Foundation Courses

Course Name: Ecology and Evolution [3 1 0 3]	
Course Code: BIO 111	
Learning Outcomes	The course will introduce students to the basics of what life is, scales of biological organization and how interactions between an organism and its environment shape all aspects of the organism's biology. A student of the course will understand the fundamentals of biological evolution, how evolution has shaped phenotypic diversity & behavior, and why evolution is a unifying theme in biology.
Syllabus	• Overview of Biology: What is life? Characteristics of living organisms; Importance of studying biology; Scales in biology (molecules (including DNA), organelles, cells, tissues, organs, organisms, populations, communities and ecosystems); Disciplines of biology in relation to these scales; Origins of life. [3] • Principles of Evolutionary Biology: History of evolutionary thinking - ideas that formed the basis of modern understanding of evolution; Genes and alleles; Fundamental concepts (variation, selection, units of selection, fitness, adaptation); Prerequisites for evolution by natural selection; Evidence for natural selection and evolution; Types of selection (directional, stabilizing, disruptive); Evolution without selection (genetic drift, gene flow); Species concepts and speciation; Phylogenetics (basic terminology, tree of life, phylogenetic reconstruction, molecular dating); Macroevolutionary patterns (mass extinction, adaptive radiation, convergent evolution, divergent evolution). [10-12] • Principles of Ecology: Biomes; Ecosystems (trophic levels, trophic structure, energy transformation, gross and net production, primary productivity, secondary productivity); Ecosystem types (tropical, temperate, subtropical); Population ecology (population characteristics, growth, life history strategies, population regulation, metapopulations); Community ecology (ecological succession, microhabitats, niche, structure of communities); Species interactions (predation, parasitism and mutualism).[6] • Behavioural ecology: Adaptive value of behaviour; Sexual selection; Mating systems; Kinship; Cooperation; Sociality (altruism, cooperation, kin selection, reciprocal altruism, etc.); Optimal foraging theory; Parental care; Social symbiosis. [10] • Biodiversity and conservation biology: Taxonomy and phylogenetic systematics; Diversification of life - a phylogenetic perspective; Diversification of life - a timeline; Measuring extant diversity; Threats to extant biodiversity (habitat loss and degradation, Invasive species, Pollution, Over-exploitation, Global climate change); In-situ and ex-situ conservation; Biodiversity of India; Island biogeography. [4-5]
Text & Reference Books	1. Manuel C. Molles, Ecology: Concepts and Applications, Mc Graw Hill, 7th ed., 2014. 2. Douglas J Futuyma, Evolution, Oxford University Press, 3rd ed., 2013. 3. Barton et al., Evolution, Cold Spring Harbor Laboratory Press, 1st ed., 2007. 4. Stephen C. Stearns and Rolf F. Hoekstra, Evolution: An Introduction, Oxford University Press 1st ed., 2000. 5. Nicholas J. Gotelli, A primer of Ecology, Oxford University Press, 4th ed., 2008. 6. Begon et al., Ecology: From Individuals to Ecosystem, Wiley-Blackwell, 4th ed., 2005.

<table>
<tr><th colspan="2">Course Name: Biomolecules [3 1 0 3]</th></tr>
<tr><th colspan="2">Course Code: BIO 121</th></tr>
<tr><td>Learning Outcomes</td><td>To understand the importance of biomolecules (carbohydrates, lipids, proteins and nucleic acids) and its chemical diversity in shaping the biological structure and function. Students can appreciate how complex living systems are built from a handful of simple atoms and how their molecular interactions in the aqueous environment of the cells interior bring about unique functions to life matter which is essential to sustain diverse life forms in our planet.</td></tr>
<tr><td>Syllabus</td><td>

Chemical Characteristics of living matter: Biological macromolecules and importance of carbon in life’s chemistry, role of inorganic/monoatomic ions in living organisms. [2]
Water and life: Unique physical and chemical properties of water that support life: high specific heat, high surface tension, high latent heat of vaporization, high heat of fusion, high tensile strength, transparency to light, universal solvent, density. Hydrogen bonding in water and its importance in maintaining the shape, stability and properties of biological macromolecules. [3]
Stabilizing interactions in biological macromolecules: Importance of hydrogen bonds, ionic interactions, salt bridge, hydrophobic interactions, van der Waals forces, concept of dipole, instant and induced dipole. Importance of these noncovalent interactions in macromolecular interaction using an example of antigen-antibody interaction and higher order protein structure. [2]
Principles of biophysical chemistry: Bioenergetics and laws of thermodyanamics, reaction kinetics: differences between ΔG, ΔG^o, $\Delta G^{o'}$. Acid dissociation constants, pH, pka and relationship between. Importance of Henderson-Haselbach equation and calculation of problems associated with this equation. [4]
Biological macromolecules:

Carbohydrates: Structure and function of important mono, oligo and polysaccharides present in the kingdom of life: Cellulose, starch, glycogen, Raffinose family of Oligosaccharides, dextrins, dextrans, agar and agarose. Stereochemical relationship between aldo and keto monosaccharides, anomers, epimers. Cyclization of monosaccharides, acetal, hemiacetal, ketal and hemiketal linkages. Derivatives of carbohydrates and their importance in biological structure and function: sugar acids, sugar alcohols, deoxy sugars, sugar esters, amino sugars, glycosides. Carbohydrates in blood group determination, biochemistry of Bombay blood group to demonstrate the structural diversity of carbohydrates. Glycemic Index and Glycemic Load and its importance in metabolism. Importance of proteoglycans and glycoproteins in cell structure and function. [5]
Proteins: Structure and importance of proteinogenic amino acids: Physical and chemical properties of amino acids : Nonionic and zwitter ion forms of amino acids: pH,pKa and titration curve characteristic of amino acids, concept of dihedral angles phi and psi, importance of these dihedral angles in protein structure and function, Ramachandran plot and its importance in protein structure determination: Hierarchy of protein structures: Primary, secondary, tertiary and quaternary structure of proteins. Important secondary structures alpha helix, beta sheets, turns and loops, protein domain and motifs, supersecondary structures and its importance in determining protein function. [8]
Lipids: Classification of Lipids: Introduction to fatty acids and its nomenclature. Simple and complex lipids: Types, structure and importance of phospholipids,

</td></tr>
</table>

Course Name: Biomolecules [3 1 0 3]	
Course Code: BIO 121	
	glycolipids, sphingolipids, glycerophospholipids with examples in biological structure and function. Introduction to sterols and sterol-based derivatives in life matter. [3] ○ Nucleic acids: Introduction to nucleic acid bases and nucleotides. Structure and function of DNA and RNA, physicochemical properties of these informational macromolecules. Ambiguous codes of nucleotide bases and amino acids. Central dogma of life: introduction of transcription, translation and protein synthesis. Concept of gene and its regulatory elements in bringing out gene function. Conceptual understanding of Polymerase Chain reaction learning about primer design, concept of sense, antisense, template and non-template strands. [7] • Biological catalysis: Functioning of enzymes, classification of enzymes, Michael Menten reaction kinetics to understand the enzyme function, Line-Weaver burke plot, competitive and non-competitive inhibition of enzyme kinetics [3] • Introduction to metabolic pathways: Principles of energy release from fuels, importance of ATP and NADH in energy transduction during glycolysis, Krebs cycle and oxidative phosphorylation. [2]
Text & Reference Books	1. Rodney F. Boyer, Concepts in Biochemistry, John Wiley & Sons, 3rd ed., 2005. 2. Thomas Miilar, Biochemistry Explained: A Practical Guide to Learning Biochemistry, CRC Press, 1st ed., 2002. 3. Lubert Stryer et al., Biochemistry, W. H. Freeman, 6th ed., 2006. 4. David L. Nelson, and Michael M. Cox et al., Lehninger principles of biochemistry, W. H. Freeman, 7th ed., 2017.

Course Name: Genetics and Molecular Biology [3 1 0 3]	
Course Code: BIO 211	
Learning Outcomes	This course will introduce basic concepts of genetic inheritance and genetic interactions. It also introduces the primary concepts of gene, gene expression, genome organization and replication and use of model organisms.
Syllabus	• Introduction to genetics [1] • Mendelian genetics: Mendel's law and examples, Monohybrid and di- hybrid cross, recessive and dominant mutation, concept of allele [3] • Non-Mendelian genetics: incomplete dominance, semi-dominance, and introduction to epigenetics, Cytoplasmic inheritance, infection heredity [6] • Genetic interactions: approach towards generating a network (epista- sis, redundancy, synthetic lethality, lethal interactions) [4] • Model organisms and studies on molecular and genetic interactions [4] • Basics of Expression genetics, transcription, translation [6] • Genome composition and organization, Cot analysis [3]

Course Name: Genetics and Molecular Biology [3 1 0 3]	
Course Code: BIO 211	
	• Chromosome structure and function [3] • Mitosis and Meiosis [3] • DNA replication, Mutations [3]
Text & Reference Books	1. Anthony J. F. Griffiths et al., An Introduction to Genetic Analysis, W. H. Freeman, 7th ed., 2000. 2. Watson et. al., Molecular Biology of the Gene, Pearson, 7th ed., 2013. 3. Jocelyn E. Krebs et al., Lewin's Gene Jones & Bartlett Learning, 11th ed., 2012. 4. Richard Kowles, Solving Problems in Genetics Springer, 2001 ed., 2001.

Course Name: Introduction to Cell Biology and Microbiology [3 1 0 3]	
Course Code: BIO 221	
Learning Outcomes	Students will understand the structures and functions of prokaryotic and eukaryotic cells as whole entities and in terms of their subcellular process and communications. Students will understand the biology of bacteria, viruses and other pathogens related with infectious diseases in humans.
Syllabus	• Structure of prokaryotic and eukaryotic cells Introduction of cell biology, classification of living organisms, Prokaryotic cells, eukaryotic cells. [3] • Membrane structure and function Structure and Composition of the Cell Membrane, Membrane Proteins, Transport across the Cell Membrane [4]. • Structural organization and function of intracellular organelles Structure and function of cytoplasm, Cytoskeletal elements and architecture, Structure and Function of mitochondria, Ribosomes, Endoplasmic reticulum, Rough endoplasmic reticulum and protein secretion, Lysosomes, The Golgi Complex, Peroxisomes, Vacuoles, , plant cell organelles, Cell locomotion [6]. • Cell division and cell cycle Cell division and its significance, Mitosis, Meiosis, Cell cycle regulation [4]. • Principles of signal transduction and role of secondary messengers [basic level] Characterization of signaling components: signaling molecules, receptors, second messengers, effectors, signaling complexes [3]. • Basic classification and characterization of membrane receptors. G protein-coupled Receptors, Receptor Tyrosine Kinases [3] • Hormones and their receptors Human Endocrine system, types of hormone receptors, insulin, thyroid hormone, steroid hormones [3]

<table>
<tr><th colspan="2">Course Name: Introduction to Cell Biology and Microbiology [3 1 0 3]</th></tr>
<tr><th colspan="2">Course Code: BIO 221</th></tr>
<tr><td></td><td>• History of Microbiology - discovery of microbes and important milestones, microbial diversity - evolution & taxonomy, microbial nutrition - growth requirements, culture media and growth kinetics - cell cycle, growth curve [3].
• Viruses and prions: Introduction - development of virology, general characteristics - virus structure, reproduction, cultivation, taxonomy, viruses of bacteria and archaea [4].
• 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 [3]</td></tr>
<tr><td>Text & Reference Books</td><td>1. Gerald Karp, Cell Biology, WILEY, 2013.
2. Wayne M. Becker et al., World of the Cell, Benjamin Cummings; 7th ed., 2008.
3. Bruce Alberts et al., Essential Cell Biology, Garland Science Taylor & Francis Group, 4th ed., 2014.
4. Alberts Bruce.; Molecular Biology of the Cell, Garland Science, 5th ed., 2008.
5. Thomas J. Kindt, Richard A. Goldsby, Barbara A. Osborne, Janis Kuby, Immunology, W. H. Freeman, 6th ed., 2006.
6. Willey Joanne M, Sherwood Linda, Woolverton Christopher J, Prescott Harley Klein's Microbiology, McGraw-Hill, 7th ed., 2008.</td></tr>
</table>

Biology Laboratory Courses:

Course Name: Biology Laboratory I [0 0 3 1]	
Course Code: BIO 112	
Learning Outcomes	To provide a basic hands-on learning of Biological experimental methods.
Syllabus	• Hypothesis testing and sampling – [12] ○ -How to formulating a hypothesis? ○ -Understanding Type I and Type II errors ○ -What is a sample? Why is sampling required? How to sample? ○ -Classroom exercises in hypotheses testing and sampling • Life under a microscope – [12] ○ - Plant and animal cells under a microscope ○ - Structure and function of plant tissues • Analysis of light reaction of photosynthesis by DCPIP method – [3] • Analysis of microbial world – [9] ○ - Isolation of microorganisms ○ - Gram staining ○ - Plaque assay

Course Name: Biology Laboratory II [0 0 3 1]	
Course Code: BIO 122	
Learning Outcomes	To provide a basic hands-on learning of Biological experimental methods.
Syllabus	• Biological solutions preparation and quantification of biomolecules (proteins, lipids, carbohydrates, DNA) – [12] • Genomic DNA isolation- [6] • PCR – [9] • Enzyme assays – [9]

Course Name: Biology Laboratory III [0 0 3 1]	
Course Code: BIO 212	
Learning Outcomes	To provide a basic hands-on learning of Biological experimental methods.
Syllabus	• Mutation frequencies, fluctuation tests – [6] • Analyze data from crosses: theoretical problem solving – [9] • Plasmid DNA isolation – [9] • SDS-PAGE – [6] • Mitosis – [3] • Meiosis – [3]

Chemistry Foundation Courses

Course Name: Atomic Structure and Chemical Bonding [3 1 0 3]	
Course Code: CHY 111	
Learning Outcomes	▪ To introduce quantum theory with the aim of understanding the structure of atoms ▪ To describe various aspects of molecular symmetry and theories of bonding
Syllabus	Atomic Structure: • Thomson's and Rutherford's models of atoms, spectral emissions from atoms, Bohr's model of atom, quantization of angular momentum, discrete energy level structure, concept of quantum numbers, and Franck-Hertz experiment [4] • Photo-electric effect, dual nature of light and matter, de-Broglie's relation, blackbody radiation, electron diffraction by crystals, double slit experiments with light and matter, Stern-Gerlach experiment, and concepts of spin and orbital angular momenta [4] • Classical wave equation, Schrödinger equation, operators, postulates of quantum mechanics, solutions of Schrödinger equation for a free particle, particle-in-a-box, applications of particle-in-a-box solutions for describing electronic levels and spectra in conjugated molecules [8] • Schrödinger equation for the hydrogen atom, qualitative description of solutions, concepts of orbitals and quantum numbers, qualitative description of many-electron systems, effective nuclear charge, and orbital approximation [4] Chemical Bonding: • Molecular symmetry, symmetry elements, symmetry operations, point groups and character tables [6] • Valence bond and molecular orbital descriptions of bonding, linear combination of atomic orbitals (LCAO) approach, hybridization, bonding in $(H_2)^+$ and H_2 [4] • Bonding in homonuclear diatomic molecules of second period, bond orders, bond lengths and bond strengths, bonding in heteronuclear diatomic molecules, concepts of g and u symmetries of molecular orbitals, polarity and electronegativity, and photoelectron spectroscopy [6]
Text & Reference Books	1. D. A. McQuarrie, Quantum Chemistry, Viva Student ed., Viva, 2011. 2. P. Atkins, J. de Paula and J. Keeler, Atkins' Physical Chemistry, 11th ed., OUP, 2018. 3. J. Barrett, Structure and Bonding, Wiley-Royal Society of Chemistry, 2002. 4. T. Engel and P. Reid, Physical Chemistry, 3rd ed., Pearson, 2013. 5. R. J. Silbey, R. A. Alberty and M. G. Bawendi, Physical Chemistry, 4th ed., Wiley Student ed., 2006.

Course Name: Basic Concepts in Organic and Inorganic Chemistry I [3 1 0 3]	
Course Code: CHY 121	
Learning Outcomes	This course introduces basic concepts in organic and inorganic chemistry with the aim to provide a structured understanding of chemistry.
Syllabus	• Elements and periodicity: Classification of elements; concepts of atomic, ionic, and covalent radii; oxidation state, ionization energy, electronegativity, electron affinity, polarizability, inert pair effect, and lanthanoid contraction. [3] • Structure and bonding: Crystal lattices and unit cell; crystal packing and defects; structures of NaCl, CsCl, and Wurtzite; lattice enthalpy, Born-Haber cycle; structures of elemental B, C, Si, P, and S; Bonding in boron halides, PF5, SF6, interhalogens, and xenon flourides; Bent's rule, Berry pseudorotation; molecular orbital diagrams of selected triatomic molecules: HF2-, BeH2, and CO2. [9] • Oxidation and reduction: Reduction potential; electrochemical series; redox reactions; balancing of redox equations; factors affecting redox stability; Frost diagrams for redox reactions; Ellingham diagram and extraction of elements. [4] • Acids and bases: Arrhenius concept, solvent systems (in H2O, NH3, SO2, and HF), Brønsted concept, Lux-Flood concept, and Lewis concept; HSAB principle, superacids, relative strengths of acids; acid-base neutralisation curves and indicators. [4] • Aromaticity: Aromaticity, antiaromaticity, and homoaromaticity; aromatic ring currents; examples of nonbenzenoid aromatic and antiaromatic compounds. [3] • Acidity, basicity, pKa, steric inhibition of resonance, ortho effect, nucleophilicity, and electrophilicity dealing with organic molecules. [3] • Stereochemistry: Baeyer's strain theory, Pitzer strain (torsional strain) and conformational analysis (up to decalin), geometrical isomerism (E/Z), optical isomerism, projections, CIP rules (R/S nomenclature of acyclic and cyclic molecules); nomenclature – threo and erythro, syn and anti, endo and exo, and meso and d/l; Chirality – axial and planar chirality and helicity; topicity - homotopic, enantiotopic and diastereotopic atoms, groups and faces (including Pro-R, Pro-S, and Re/Si stereodescriptors); chirotopicity and stereogenicity. [9] • Reactive Intermediates: Structure, stability and reactivity of carbocations, carbanions, free radicals, carbenes, and nitrenes. [5]
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. G. L. Miessler and D. A. Tarr, Inorganic Chemistry, 3rd ed., Pearson, 2008. 3. J. E. House, Inorganic Chemistry, 3rd ed., Academic Press, 2019. 4. J. E. Huheey, E. A. Keiter, and R. L. Keiter, Inorganic Chemistry – Principles of Structure and Reactivity, 4th ed., Pearson Education, 2006. 5. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2nd ed., Oxford University Press, 2012. 6. J. McMurry, Organic Chemistry, 9th ed., Cengage Learning, 2015. 7. P. Sykes, A Guidebook to Mechanism in Organic Chemistry, 7th ed., Addison-Wesley, 2003. 8. D. Nasipuri, Stereochemistry of Organic Compounds-Principle and Applications, 4th Revised ed., New Academic Science, 2012.

Course Name: Basic Concepts in Organic and Inorganic Chemistry II [3 1 0 3]	
Course Code: CHY 211	
Learning Outcomes	This course is a continuation of CHY 121 and deals with the basic concepts in organic and inorganic chemistry with the aim to provide a structured understanding of chemistry.
Syllabus	• Nucleophilic Substitution at Saturated Carbons: SN1, SN2, SNi and SN2' with emphasis on stereochemical considerations, substrate structure, leaving group, nucleophiles and role of solvents. [3] • Elimination Reactions: Types (E1, E2 and E1cB), stereochemical considerations, and role of solvents; Saytzeff/Hofmann elimination, Bredt's rule; elimination vs substitution. [3] • Electrophilic Aromatic Substitution: Mechanism, orientation, and reactivity of benzene and substituted benzene derivatives (substituent effects); mechanistic aspects of special cases such as nitration of aniline, alkylation of benzene, sulfonation. [3] • Nucleophilic Aromatic Substitution. [1] • Reduction and Oxidation: Mechanism and selectivity in reduction of carbonyl compounds using NaBH4, LiAlH4 (including esters, amides and nitriles), and oxidation of alcohols using Jones, Collins, PCC, and PDC reagents. [4] • Synthesis of Drug Molecules: Naproxen, Ibuprofen, Aspirin and L-DOPA; examples love drugs and molecules of death. [3] • Synthesis and Applications of Organic Materials: Polymers (biodegradable polymers, conducting polymers, etc.); smart materials, OLEDs, intelligent gels, dyes, etc. [3] • Coordination Compounds: Geometries and isomerism of coordination compounds; crystal field theory, spectrochemical series, weak field and strong field ligands, spinel and inverse spinel structures; Jahn-Teller effect; thermodynamic stability and kinetic lability of coordination complexes; chelate and macrocyclic effect; optical activity of coordination complexes. [9] • Metals in Biology: Introduction to types of metalloenzymes with various metals (Mg, Mo, Mn, Fe, Co, Ni, Cu, and Zn); O2-transporting and storage proteins (hemocyanin, myoglobin, hemoglobin, and hemerythrin); bio-medical application of cis-platin. [5] • Catalysis: Concepts and applications of catalysis in homogeneous and heterogenous processes such as Haber-Bosch process, Fischer-Tropsch process, Wilkinson hydrogenation, Wacker oxidation, Monsanto process, hydroformylation, and Ziegler-Natta polymerization. [3] • Lanthanoids and Actinoids: Properties and reactivity trends; nuclear reactions of thorium and uranium; synthesis of trans-uranium elements; applications of radioisotopes. [3]
Text & Reference Books	1. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2nd ed., Oxford University Press, 2012. 2. J. McMurry, Organic Chemistry, 9th ed., Cengage Learning, 2015. 3. O. Snow, Love Drugs, Thoth Press, 2005. 4. R. H. Waring, G. B. Steventon and S. C. Mitchell Molecules of Death, Imperial College Press, 2007. 5. D. E. Newton, Chemistry of New Materials, Facts on File, 2007.

Course Name: Basic Concepts in Organic and Inorganic Chemistry II [3 1 0 3]	
Course Code: CHY 211	
	6. P. Atkins, T. Overton, J. Rourke, F. Armstrong, and M. Hagerman, Shriver and Atkins' Inorganic Chemistry, 5th ed, W. H. Freeman and Company New York, 2009. 7. G. L. Miessler and D. A. Tarr, Inorganic Chemistry, 3rd ed., Pearson, 2008. 8. J. E. House, Inorganic Chemistry, 3rd ed., Academic Press, 2019. 9. J. E. Huheey, E. A. Keiter, and R. L. Keiter, Inorganic Chemistry – Principles of Structure and Reactivity, 4th ed., Pearson Education, 2006. 10. W. Kaim and B. Schwederski, Bioinorganic Chemistry: Inorganic Elements in the Chemistry of Life, 2nd ed., Wiley, 2013.

Course Name: Physical Chemistry I [3 1 0 3]	
Course Code: CHY 221	
Learning Outcomes	▪ To introduce the formalisms for the microscopic description of states of matter, leading to an understanding of the fundamental intermolecular interactions governing them ▪ To provide an appreciation for the application of the ideas from thermodynamics for the description of solution state properties
Syllabus	• Gaseous State: Revision of gas laws, ideal gas equation of state, kinetic theory of gases, interpretation of gas pressure, Maxwell-Boltzmann distribution for velocities, speeds and energies of gas particles, average, most probable and root-mean-squared speeds, collision rate, collision flux, effusion, collision number, mean free path, transport properties, diffusion, Fick's laws, Einstein relation, thermal conductivity, viscosity, real gases, deviations from ideality, compressibility factor, van der Waals and virial equations of state, Boyle temperature, liquefaction of gases, critical constants, and law of corresponding states [10] • Intermolecular Interactions: Hard sphere potential, Lennard-Jones potential, ion-ion, ion-dipole, ion-induced dipole, dipole-dipole, dipole-induced dipole and induced dipole-induced dipole interactions, orientational averaging effects, Keesom interactions, Debye interactions, London interactions, hydrogen bonding, aromatic interactions, manifestation of intermolecular interactions in governing boiling points, states of matter, and heats of vaporization [8] • Review of Concepts in Thermodynamics: Concepts of temperature, enthalpy, entropy, Gibbs and Helmholtz energies, laws of thermodynamics, state and path functions, standard states, thermochemistry and Maxwell relations [1] • Physical Transformations of Pure Substances: Molar Gibbs energy, temperature and pressure dependence, Clausius-Clapeyron equation, phase equilibria of pure substances, application of Clausius-Clapeyron equation to solid-liquid, liquid-vapor and solid-vapor equilibria, phase rule, phase diagrams of one-component and two-component systems [4] • Thermodynamics of Mixtures: Partial molar quantities, partial molar Gibbs energy and chemical potential, thermodynamics of mixing, chemical potential of liquids, ideal dilute solutions, Henry's and Raoult's laws and their applications, fugacity and activity, liquid mixtures, excess functions and regular solutions [4]

Course Name: Physical Chemistry I [3 1 0 3]	
Course Code: CHY 221	
	• Colligative Properties: Elevation of boiling point, depression of freezing point, lowering of vapour pressure, osmosis, and solubility [1] • Phase Equilibria of Binary Systems: Vapor pressure diagrams, temperature-composition diagrams, liquid-liquid phase diagrams, liquid-solid phase diagrams, azeotropic mixtures, fractional distillation and steam distillation [2] • Chemical Equilibria: Responses to temperature and pressure, Le Chatelier's principle, and van't Hoff equation [1] • Electrochemistry: Properties of ions in solutions, ionic mobility and conductivity, Debye-Hückel theory, standard electrode potential, Nernst equation, electrochemical cells, redox reactions, electromotive force and free energy [2] • Chemical Kinetics: Chemical reactions of various orders, integration of rate equations, elementary reactions, opposing reactions, consecutive reactions, parallel reactions, steady state approximation, enzyme catalysis, and Arrhenius equation [3]
Text & Reference Books	1. P. Atkins, J. de Paula and J. Keeler, Atkins' Physical Chemistry, 11th ed., Oxford University Press, 2018. 2. T. Engel and P. Reid, Physical Chemistry, 3rd ed., Pearson, 2013. 3. R. J. Silbey, R. A. Alberty and M. G. Bawendi, Physical Chemistry, 4th ed., Wiley Student ed., 2006. 4. D. A. McQuarrie and J. D. Simon, Physical Chemistry: A Molecular Approach, Viva Student ed., Viva, 2019.

Chemistry Laboratory Courses

Course Name: Chemistry Laboratory I [0 0 3 1]	
Course Code: CHY 112	
Learning Outcomes	This laboratory course provides opportunities for hands-on laboratory experiences related to qualitative and quantitative analyses.
Syllabus	• Experiment 1 – Gravimetric Analysis: (a) Estimation of chloride anion in a water sample; (b) Estimation of nickel in a given sample as Ni(DMGH)2. • Experiment 2 – Colors of transition metal complexes: (a) Preparation and UV-vis analysis of coordination complexes of Co(II), Co(III), Ni(II), and Cu(II) with a series of ligands such as H2O, NH3, ethylenediamine, tartrate, SCN–, Cl–. • Experiment 3 – Preparation and analysis of [Zn(NH3)4][BF4]: (a) Synthesis of [NH4][BF4]; (b) Synthesis of [Zn(NH3)4][BF4]; (c) Analysis of the NH3 content in [Zn(NH3)4][BF4]. • Experiment 4 – Titrimetric Estimations Based on Acidimetry and Alkalimetry: (a) Standardisation of NaOH solution using N/20 oxalic acid solution; (b) Estimation of acetic acid concentration in commercial vinegar using standard NaOH solution as titrant; (c) Standardisation of HCl solution using N/20 oxalic acid solution, (d) Estimation of alkali content in commercial antacid tablet. • Experiment 5 – Redox-Titrimetric Estimations Based on Permanganometry: (a) Standardisation of potassium permanganate using sodium oxalate; (b) Preparation of K3[Fe(C2O4)3]·3H2O; (c) Estimation of the oxalate content of Potassium trisoxalatoferrate(III) trihydrate, (d) Photochemical reactions of Potassium tris-oxalatoferrate(III) trihydrate. • Experiment 6 – Redox-Titrimetric Estimations Based on Dichromatometry: (a) Preparation of N/20 potassium dichromate solution; (b) Estimation of iron and chromium in a mixture using a standard N/20 potassium dichromate solution as titrant. • Experiment 7 – Estimations Based on Iodimetry and Iodometry: (a) Preparation and standardisation of sodium thiosulfate solution; (b) Preparation of Cu(NH3)4SO4 and estimation of copper(II) using standard thiosulfate solution as titrant; (c) Solubility product of Ca(IO3)2. • Experiment 8 – Complexometric Estimations Based on EDTA: Quantitative estimation of calcium and magnesium in milk by EDTA complexometry - (a) Standardisation of EDTA solution using a standard zinc acetate solution; (b) Estimation of % amount of calcium and magnesium in a milk sample.
Text & Reference Books	1. G. H. Jeffery, J. Bassett, R. C. Denny, Vogel's Quantitative Chemical Analysis, 5th ed., ELBS and Longmans Green & Co Ltd, 1971. 2. A. J. Elias, General Chemistry Experiments, 3rd ed., Universities Press (India) Pvt Ltd, 2002. 3. J. Derek Woollins, Inorganic Experiments, 3rd ed., Wiley, 2010.

<table>
<tr><th colspan="2">Course Name: Chemistry Laboratory II [0 0 3 1]</th></tr>
<tr><th colspan="2">Course Code: CHY 212</th></tr>
<tr><td>Learning Outcomes</td><td>To learn the principles and applications of separation, isolation, and analytical techniques in organic chemistry.</td></tr>
<tr><td>Syllabus</td><td>

Basic Lab Techniques [6]

a) Thin layer chromatography (TLC) and calculation of Rf values.
b) Column Chromatography: separation of organic mixture.
c) Purification of organic compounds by crystallization.
d) Filtration techniques.
e) Determination of melting and boiling points.

Experiment No 1: Separation and quantification [6]

a) Separation of napthol, aspirin, and napthalene
b) Determination of purity by melting points and TLC.

Experiment No 2: Isolation of Natural Products [6]

a) Extraction of eugenol from cloves by steam distillation
b) Extraction of caffeine from tea leafs.

Experiment No 3: Organic preparations [6]

a) Preparation of paracetamol
b) Preparation of aspirin

Experiment No 4: conversion of nitrobenzene to aniline and its estimation [6]

a) Qualitative test for nitrobenzene
b) Reduction of nitro compound
c) Qualitative test for aniline
d) Estimation of aniline

Experiment No 5: Phenol and its erivatives [6]

a) Qualitative test for phenol
b) Nitration of phenol
c) synthesis of 7-hydroxy-4-methylcoumarin

Experiment No 6: Cannizarro Reaction [6]

a) Qualitative tests for benzaldehyde
b) Preparation of benzyl alcohol and benzoic acid from benzaldehyde
c) Qualitative tests for benzyl alcohol
d) Qualitative tests for benzoic acid

Experiment No 7: Claisen- Schmidt Reaction [3]

a) Preparation of dibenzalacetone (1,5-diphenylpenta-1,4-diene-3-one)
b) Qualitative test for bibenzalacetone

Experiment No 8: Beckmann Rearrangement [6]

a) Preparation of benzophenone oxime
b) Conversion of benzophenone oxime to benzanilide
c) Qualitative analysis of benzanilide

Experiment No 9: Preparation of ester and its estimation [6]

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Course Name: Chemistry Laboratory II [0 0 3 1]	
Course Code: CHY 212	
	○ a) Preparation methyl benzoate ○ b) Qualitative test for ethyl benzoate ○ c) Estimation of ester
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, - 5 ed., John Wiley & Sons, 1991.

Course Name: Chemistry Laboratory III [0 0 3 1]	
Course Code: CHY 222	
Learning Outcomes	Chemistry Laboratory III offers opportunities to familiarize the principles of physical chemistry through hands-on approaches. This laboratory is designed to have experiments related to the physical chemistry concepts taught in the theory course CHY221.
Syllabus	• Viscosity: ○ Determination of Viscosity of Pure Liquids ○ Effect of Salt on Viscosity of Liquids • Surface Tension: ○ Determination of the Surface Tension of a Liquid by Drop Number Method ○ Determination of Parachor Values • Chemical Kinetics ○ Determination of the Rate Constant of the Hydrolysis of Ester by Sodium Hydroxide at Different Temperature ○ Activation Energy • Refractometry: ○ Determination of Molar Refractions of Pure Liquids ○ Determination of Molar Refraction of Solids ○ Solvent-Solvent Interaction in Binary Solvent System • Conductivity Measurements: ○ Determination of the Degree of Ionization of Weak Electrolytes. ○ Titration of a Strong Acid and Weak Acid Against a Strong Base. ○ Titration of a Mixture of Acids Against a Strong Base. ○ Titration of a Mixture of Weak Acids Against a Strong Base. • Potentiometry: ○ Determination of Single Electrode Potentials (Cu and Zn). ○ Verification of Nernst Equation ○ Oxidation-Reduction Titration. • Distribution Law ○ Distribution Coefficient of Iodine Between an Organic Solvent and Water.

Course Name: Chemistry Laboratory III [0 0 3 1]	
Course Code: CHY 222	
	○ Determination of the Equilibrium Constant of the Reaction $KI + I_2$ KI_3 • Phase Diagrams-1: Phenol Water System: ○ Determine the Mutual Solubility Curve of Phenol and Water and Hence the Consolute Point. ○ Determine the Critical Solution Temperature of Phenol and Water in Presence of (i) Sodium Chloride (ii) Naphthalene and (iii) Succinic acid. • Phase Diagrams-2: Three Component System: ○ Construction of the Triangular Phase Diagram of Acetic Acid, Chloroform and Water ○ Construction of the Tie Line ○ Determination of the Composition of the Given Mixture • Solid Liquid Equilibrium: ○ Determination of Molal Depression Constant of Naphthalene ○ Determination of Molecular Weight of Solute
Text & Reference Books	1. M. Halpern and G. C. McBane, Experimental Physical Chemistry: A Laboratory Text Book, 3rd ed., W. H. Freeman, 2006 2. D. P. Shoemaker, G. W. Garland and J. W. Nibler, Experiments in Physical Chemistry, 5th ed., McGraw Hill, London.

Mathematics Foundation Courses

Course Name: Single Variable Calculus [3 1 0 3]	
Course Code: MAT 111	
Learning Outcomes	Under the BS-MS program, a few students join without mathematics background in their 10+2 standard. This course, on one hand, provides the necessary back ground in basic calculus to such students, on the other, it also exposes all the students to an abstract approach to calculus, which is necessary for more advanced courses on analysis.
Syllabus	• Properties of real numbers, the least upper bound and greatest lower bound properties (4 hours) • Limits of Sequences: Convergence and limit laws, limsup and liminf of sequences, some standard limits, Subsequences. (7 hours) • Series: absolute and conditional convergence of an infinite series, tests of convergence, examples. (5 hours) • Continuous functions on the real line: Formal definition, continuity and discontinuity of a function at a point; left and right continuity, examples of continuous and discontinuous functions, intermediate value theorem, extreme value theorem, monotonic functions, uniform continuity, limits at infinity.(8 hrs) • Differentiation of functions: Definition and basic properties, local maxima, local minima, and derivatives, monotone functions and derivatives, inverse functions and derivatives, Rolle's theorem, mean value theorem, Taylor's theorem. (8 hrs) • Riemann Integration: Partitions, upper and lower Riemann integrals, basic properties of the Riemann integral, Riemann integrability of continuous functions, monotone functions, and discontinuous functions, non-Riemann integrable functions, the fundamental theorem of calculus (8 hrs)
Text & Reference Books	1. T. M. Apostol, Calculus, vol. 1, 2nd ed., Wiley, 2007. 2. R. G. Bartle and D. R. Sherbert, Introduction to Real Analysis, 4th ed., Wiley, 2011. 3. S. Lang, A first course in Calculus, 5th ed., Springer India, 2006. 4. M. Spivak, Calculus, Publish or Perish, 2008. 5. W. Rudin, Principles of Mathematical Analysis, 3rd ed., McGraw Hill India, 1953.

Course Name: Introduction to Linear Algebra [3 1 0 3]	
Course Code: MAT 121	
Learning Outcomes	Basic linear algebra is foundation for every future mathematics course. The objective is to introduce linear algebra in a mathematically abstract form and relate it to matrix algebra.

Course Name: Introduction to Linear Algebra [3 1 0 3]	
Course Code: MAT 121	
Syllabus	• Matrices: Systems of linear equations, Row echelon form, Elementary matrices, The determinant of a matrix, Properties of determinants. (6) • Vector spaces: Definition and examples, Subspaces, Linear independence, Basis and dimension, Change of basis, Row space and column space (9) • Linear maps: Definition and examples, Matrix representations of linear maps, Similarity, Rank-Nullity Theorem. (7.5) • Inner product spaces: The scalar product in R^n, Inner product spaces, Orthonormal sets, The Gram-Schmidt orthogonalisation process. (7.5) • Eigenvalues and eigenvectors, Diagonalisable matrices, Cayley- Hamilton Theorem. (6 hours) • Hermitian Matrices. (4)
Text & Reference Books	1. S. Axler, Linear Algebra Done right, 3rd ed., Springer 2015 2. S. H. Friedberg, A. J. Insel, L.E. Spence, Linear Algebra, 4th ed., Pearson Education India. 3. L. N. Childs, A Concrete Introduction to Higher Algebra, Springer, 2009 4. S. Kumaresan, Linear Algebra: A Geometric Approach, PHI Learning, 2009. 5. K. Hoffman and R. Kunze, Linear Algebra, 2nd ed., Pearson Education, New Delhi, 2006 6. P. Halmos, Finite Dimensional Vector Spaces, Van Nostrand, Princeton, N. J. 1958

Course Name: Multivariable Calculus [3 1 0 3	
Course Code: MAT 211	
Learning Outcomes	This course is an extension to MAT 111. Limit, continuity, differentiation and integration in R^n are explained in a more problem solving manner, although abstract mathematical concepts are slowly introduced. The course also introduces some very basic topological properties of R^n.
Syllabus	• Differential calculus: Limits and continuity of functions of several variables; Differentiability, Partial derivatives, total derivative, composite functions, chain rule, partial derivatives of higher order, change of variables; inverse and implicit function theorems (without proof), unconstrained maxima and minima, Lagrange multipliers; Leibniz's formula, Taylor's formula, mean value theorems. (20) • Integral Calculus: Double integrals on rectangular regions, conditions of integrability, properties of integrable functions, repeated or iterated integrals, double integrals over finite regions, changing the order of integration; Fubini-Tonelli Theorem (without proof); triple integrals over any bounded domain, evaluation of multiple integral by change of variables; surface area, volume of a region, theorems of Green, Gauss, and Stokes (without proof). (20)

Course Name: Multivariable Calculus [3 1 0 3	
Course Code: MAT 211	
Text & Reference Books	1. T. M. Apostol, Calculus, vol. 2, 2nd ed., Wiley (India), 2007. 2. S. Lang, Calculus of several variables, 3rd ed., Springer, 1987. 3. V. Zorich, Mathematical Analysis I, Springer, 2004. 4. V. Zorich, Mathematical Analysis II, Springer, 2004. 5. M. Moskowitz, F. Paliogiannis, Funtions of several Real Variables, World Scientific Publishing, 2011.

Course Name: Introduction to Probability [3 1 0 3]	
Course Code: MAT 221	
Learning Outcomes	The aim of this problem oriented course is to give the students a broader perspective how the combinatorial probability and statistical methods can be used in all areas of sciences.
Syllabus	• Basic probability: Set operations, counting, finite sample spaces, axioms of mathematical probability, conditional probability, independence of events, Bayes' Rule, Bernoulli trials, Poisson trials, multinomial law, infinite sequence of Bernoulli trials.(10) • Random variables and probability distributions: Binomial distribution, geometric distribution, Poisson distribution, normal distribution, exponential distribution, Gamma distribution, Beta distribution; Cumulative and marginal distribution functions; Transformation of random variables in one and two dimensions. (15) • Mathematical expectations: Expectations for univariate and bivariate distributions, moments, variance, standard deviation, higher order moments, covariance, correlation, moment generating functions, characteristic functions. Central limit theorem, law of large numbers.(15)
Text & Reference Books	1. R. V. Hogg, J. McKean and A. T. Craig, Introduction to Mathematical Statistics, 7th ed., Pearson, 2012. 2. S. Ross, Introduction to Probability and Statistics for Engineers and Scientists, 3rd ed., Elsevier, 2004. 3. C. M. Grinstead and J. L. Snell, Introduction to Probability, 2nd ed., American Mathematical Society, 1997. 4. S. Ross, A first course in Probability, 8th ed., Prentice Hall, 2009. 5. K. L. Chung, Elementary Probability Theory, 4th ed., Springer, 2003. 6. P. G. Hoel, S.C. Port and C.J. Stone, Introduction to Probability Theory, 1st ed., Houghton Mifflin, 1972.

Physics Foundation Courses

<table>
<tr><th colspan="2">Course Name: Mechanics [3 1 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 111</th></tr>
<tr><td>Learning Outcomes</td><td>▪ Understand and express the fundamental principles of mechanics
▪ Undertake mathematical formulation of physical problems
▪ Solve equations of motion (EOM) with suitable initial and boundary conditions
▪ Comprehend relativistic concepts of space and time, reference frames.</td></tr>
<tr><td>Syllabus</td><td>• Newton's Laws [4]: Critical analysis of the Newton's laws, Concept of homogeneity and isotropy of space-time, symmetry, Concept of inertial, non-inertial reference frames, fictitious forces, Introduction to Galilean Relativity.
• Motion in one dimension [8]: Analytical solutions of EOMs, Conservation of momentum, Work energy theorem, Use of potential energy graphs to understand motion. Motion under gravity (rocket motion, block-pulley systems); Simple harmonic oscillator and damped oscillator.
• Motion in higher dimensions [3]: Position vector and its derivatives. EOM in Cartesian and Polar Coordinates;
• Force as the gradient of potential energy; Conservation of angular momentum for a point particle; Projectile motion, Motion under central force, The Kepler problem [7]
• Rigid bodies [4]: Centre of mass; Rotational inertia, Momentum and Energy,
• Conservation laws, Moment of Inertia-Examples with simple symmetric bodies. [5]
• Torque and work energy theorem. [3]
• Non-inertial frames [6]: Rotating reference frames and pseudo-forces
• Special Theory of Relativity: Measuring space-time in Galilean relativity; Michelson-Morley experiment, Postulates of special relativity, Lorentz transformation-Relativity of Simultaneity, Length contraction, Time dilation; Minkowski space-time diagram, Examples: Twin paradox, Doppler Effect. [8]</td></tr>
<tr><td>Text & Reference Books</td><td>1. D. Kleppner and R. Kolenkow, An introduction to Mechanics, McGraw-Hill Science/ Engineering/ Math, 1973.
REFERENCES:
1. Serway and Jewett, Physics for Scientists and Engineers, Brooks/Cole Publishers, 2004.
2. C. Knight, W. D. Ruderman, M. A. Helmholz, C. A. Moyer and B. J. Kittel, Berkeley Physics Course: Vol. I – Mechanics, McGraw-Hill, 1965.
3. R. Shankar, Fundamentals of Physics, Yale Press.</td></tr>
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<table>
<tr><th colspan="2">Course Name: Electromagnetism [3 1 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 121</th></tr>
<tr><td>Learning Outcomes</td><td>▪ Understand and express the fundamental laws and principles of Electricity and Magnetism.
▪ Describe concepts and phenomena of electromagnetic fields, and their mathematical formulation in free space and matter.
▪ Calculate physical quantities associated with electromagnetism.</td></tr>
<tr><td>Syllabus</td><td>• Electrostatics [10]: Electric field: Coulomb's law, Divergence and Curl of electrostatic fields, Gauss's law in differential and integral form and simple application Electric Potential: Electrostatic potential, Poisson's equation and Laplace equation, Potential due to a localized charge distribution, Electrostatic Boundary conditions Work and energy in electrostatics: Work done to move a charge, Electrostatic energy for point charge as well as continuous charge distribution, Simple examples Conductors: Basic Properties, Surface charges induced on a conductor, Force on a conductor. Capacitors: Definition of capacitance, Calculation of capacitance for parallel plates, concentric spherical shells, coaxial cylindrical tubes
• Special Techniques in electrostatics [6]: Potential due to an arbitrary charge distribution, Solution of Laplace's/Poisson's equations, uniqueness theorems and applications, Method of Images, Examples involving solution of boundary value problems
• Electric field in matter [4]: Multipole Expansion; Electrical field and potential due to a point dipole; Dipole in an electric field; Dielectrics, Polarization, Field of a polarized object, Electric displacement vector (D); Gauss's theorem in dielectric media.
• Electrostatic field energy; Computation of capacitance in simple cases (parallel plates); spherical and cylindrical capacitors containing dielectrics – uniform and non-uniform. [2]
• Magnetostatics [6]: Biot - Savart and Ampere's laws; Ampere's law in differential form; Magnetic vector potential, Magnetostatic boundary conditions, Multipole expansion of the vector potential; Determination of magnetic fields for simple cases. Energy in a magnetic field
• Magnetic field in matter [4]: Field of a Magnetized object; Auxiliary Field H, Ampere's law in Magnetized materials; Magnetic Susceptibility and Permeability.
• Electrodynamics [8]: Current electricity: Electromotive force. Ohm's law; Motional emf; Electromagnetic induction; Faraday's law; Self-inductance and mutual inductance; Impedance; LCR circuit; Maxwell's equations; Equation of continuity; Poynting's theorem;</td></tr>
<tr><td>Text & Reference Books</td><td>1. D. J. Griffths, Introduction to Electrodynamics, Prentice-Hall India, 2007.
Additional References
2. E. M. Purcell, Berkeley Physics course: Vol 2., Electricity and Magnetism, McGraw Hill.
3. Serway and Jewett, Physics for Scientists and Engineers, Brooks/Cole Publishers, 2004.</td></tr>
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<table>
<tr><th colspan="2">Course Name: Optics [3 1 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 211</th></tr>
<tr><td>Learning Outcomes</td><td>▪ Analyse optical systems using lens equations and matrix formalism
▪ Evaluate the effect of different aberrations on image formation
▪ Write expression for a travelling wave using wave properties such as wavelength, polarization and phase velocity
▪ Distinguish between polarization states and polarization conversion
▪ Analyse interference patterns and interferometers using the concept and conditions for interference.
▪ Analyse effect of aperture on wave propagation, diffraction and applications</td></tr>
<tr><td>Syllabus</td><td>• Geometrical Optics [3] Fermat’s Principle, Laws of reflection and refraction from Fermat’s principle,
• Refraction at a Single Spherical Surface, The thin lens, Thin lens equation,[3]
• Matrix method in paraxial optics, Thin lens combinations, Aberrations, Prisms, Optical Systems.[3]
• Wave Optics [4]: Wave Motion, One dimensional waves, Harmonic Waves, Phase Velocity, Group Velocity of a wave packet,
• Three-dimensional wave equation, Spherical waves, and cylindrical waves.[3]
• Polarisation: The nature of polarized light, Polarizers, Malus law, Dichroism, Birefringence, Scattering and Polarization, Polarization by reflection, Brewster angle, Retarders; full-wave plate, half-wave plate, quarter-wave plate, Circular Polarizers, Polarization of Polychromatic light [6]
• Maxwell’s equation, wave equation, Poynting Vector, Fresnel reflection coefficient, Total internal reflection, Optical fibre, single mode fibre, multimode fibre, evanescent wave. [5]
• Interference [3]: The superposition principle, phasors and the addition of waves, Condition for interference, Coherence,
• Two beam interference by division of wave-front; Fresnel’ Biprism, [2]
• Interference by division of amplitude; interference by a plane parallel film, Newton’s rings, Michelson interferometer, multiple beam interferometry; Fabry-Perot interferometer. [5]
• Diffraction: Fresnel diffraction: Fresnel Half-period zones, The zone-plate, Diffraction by a straight edge, The Fresnel propagation [6]
• Fraunhofer approximation, Fraunhofer diffraction and Fourier optics: Single slit diffraction, Diffraction by a circular aperture, Two-slit Fraunhofer diffraction, N-slit Fraunhofer diffraction, The diffraction grating, Oblique incidence, X-ray diffraction.[5]</td></tr>
<tr><td>Text & Reference Books</td><td>1. Ajoy Ghatak, Optics, Tata Mcgraw-Hill, 2009.
REFERENCES:
1. Eugune Hecht and A. R. Ganesan, Optics, AddisonWesley Longman, 2002.
2. Francis A. Jenkins and Harvey E. White, Fundamentals of Optics, McGraw- Hill Higher Education, 4th ed.
3. Frank S. Crawford, Waves: Berkeley Physics Course Vol. 3, Tata Mgraw Hill, 2008.</td></tr>
</table>

Course Name: Thermal & Statistical Physics [3 1 0 3]	
Course Code: PHY 221	
Learning Outcomes	▪ Apply concepts and laws of thermodynamics to describe physical processes and systems. ▪ Analyze the energy changes of physical/chemical systems using first law of thermodynamics. ▪ Apply concepts in probability and distribution functions to different physical systems and connect single particle quantum behaviour that of macroscopic thermodynamic systems. ▪ Evaluate intensive and extensive variables using statistical formulations for an ideal gas.
Syllabus	• Macroscopic and microscopic description of state; Thermal equilibrium and the Zeroth law; Concept of temperature; Temperature scales. [3] • Thermodynamic equilibrium; Thermodynamic variables; Equation of state; Relevant theorems in partial differential calculus; [3] • Thermodynamics of simple systems (hydrostatic system, stretched wire, surfaces, electrochemical cell, dielectric slab, paramagnetic rod); Intensive and extensive variables. [5] • Work, Heat and Internal energy; Thermodynamic Processes (reversible, irreversible, quasi-static, adiabatic, isothermal, etc); Work done in various processes; [4] • First law of thermodynamics, Specific heat capacity; Heat conduction and conductivity; Blackbody radiation; Kirchhoff's law; Stefan-Boltzmann law. [4] • The Second Law of thermodynamics; Gasoline Engine; Carnot cycle and Kelvin temperature scale, [4] • Clausius' theorem, Entropy change for simple processes; Physical interpretation of Entropy; Applications of Entropy principle. [4] • Thermodynamic functions (Enthalpy, Helmholtz free energy, Gibbs free energy, etc.);[4] • Conditions of equilibrium; Maxwell's relations, Chemical potential. [3] • Equilibrium between two phases; General equilibrium conditions; The Clausius-Clapeyron equation and phase diagrams; [3] • Stability conditions: Le-Chatelier's principle; Third law of thermodynamics. [3] • Concept of ensembles and Statistical postulates; Examples of probability distributions; Maxwell's distribution (Mean and variance); Canonical partition function of an ideal mono-atomic gas; [4] • Evaluate pressure, internal energy, and entropy of ideal gas; Equipartition of energy; Distribution of speeds (average speed, average square of speed) [4]
Text & Reference Books	1. M. W. Zemanski and R. H. Dittman, Heat and Thermodynamics, McGraw- Hill, 1997. REFERENCES: 2. F. Reif, Statistical Physics: Berkeley Physics Course Vol. 5, Tata McGraw-Hill, 2011. 3. Daniel V. Schroeder, An introduction to thermal Physics, Addison- Wesley, 2000. 4. S. J. Blundell and K. M. Blundell, Concepts in Thermal Physics, Oxford, 2006.

Physics Laboratory Courses

Course Name: Experiments in Mechanics [0 0 3 1]	
Course Code: PHY 112	
Learning Outcomes	▪ Apply laws of mechanics to describe real life systems ▪ Handle apparatus and Assemble simple experimental setup ▪ Record measurements and Perform data analysis ▪ Calculate physical parameters from experimental results and their deviation from theoretical predictions and Error Analysis
Syllabus	• Simple pendulum & variable g pendulum • Conservation of energy • Conservation of momentum & ballistic pendulum • Centripetal force • Symmetric compound bar pendulum • Projectile motion • Melde's string • Newton's laws of Motion • Moment bar • Sonometer
Text & Reference Books	Laboratory Notes and Reference Material

Course Name: Experiments in Optics, Electricity and Magnetism [0 0 3 1]	
Course Code: PHY 122	
Learning Outcomes	▪ Experimentally verify theoretical concepts in electromagnetism and optics ▪ Handle apparatus and Assemble simple experimental setup ▪ Record measurements and Perform data analysis ▪ Calculate physical parameters from experimental results and their deviation from theoretical predictions and Error Analysis ▪ Appreciate safety protocols and measures taken
Syllabus	• Magnetic field along the axis of a circular coil • Deflection magnetometer • Spot galvanometer- high resistance by leakage • Spectrometer: refractive index of prism and i-d curve • Spectrometer-Grating • Newton's rings

Course Name: Experiments in Optics, Electricity and Magnetism [0 0 3 1]	
Course Code: PHY 122	
	• Diffraction at single and double slits • Liquid lens • Reflection grating • Malu's law
Text & Reference Books	Laboratory Notes and Reference Material

Course Name: Experiments in Heat and Thermodynamics [0 0 3 1]	
Course Code: PHY 222	
Learning Outcomes	▪ Experimentally verify laws of Thermodynamics and Determine thermal properties of matter. ▪ Handle apparatus and Assemble simple experimental setup ▪ Record measurements and Perform data analysis ▪ Calculate physical parameters from experimental results and their deviation from theoretical predictions and Error Analysis
Syllabus	• Specific latent of steam • Thermal conductivity of rubber • Specific heat capacity of solid-method of mixtures • Joule's calorimeter-specific heat capacity of liquid • Thermal conductivity - Lee's disc method • Potentiometer and thermo emf • Latent heat of fusion of ice • P V Diagram • Stefan's Law • Newton's law of cooling
Text & Reference Books	Laboratory Notes and Reference Material

Interdisciplinary Courses

Course Name: Mathematical Tools I [2 1 0 2]	
Course Code: IDC 111	
Learning Outcomes	▪ Perform analysis of functions of several variables ▪ Use concepts of vector calculus in physical problems ▪ Perform operations with complex numbers
Syllabus	• Functions of several variables - partial differentiation. Cartesian, Spherical and Cylindrical coordinate systems: introduction and equivalence. Parametric representation of an equation. Introduction to Taylor's series with examples. [6] • Vector Calculus: Review of vector algebra: addition, subtraction and product of two vectors - polar and axial vectors with examples; triple and quadruple product. Concept of Scalar and Vector fields. Differentiation of a vector w.r.t. a scalar unit tangent vector and unit normal vector. Directional derivatives - gradient, divergence, curl and Laplacian operations and their meaning. Concept of line, surface and volume integrals. Statement of Gauss' and Stokes' theorems with physical examples. Gradient, divergence and curl in spherical polar and cylindrical coordinate systems. [15] • Complex numbers and functions: Arithmetic operation, conjugates, modulus, polar form, powers and roots; Derivatives. [4]
Text & Reference Books	1. E. Kreyszig, Advanced Engineering Mathematics, 8th ed. Wiley India Pvt Ltd, 2006. 2. Murray R. Spiegel, Schaum's Outlines Vector Analysis, Tata Mcgraw Hill 2009. 3. Murray R. Spiegel, Seymour Lipschutz, John Schiller, Dennis Spellman, Schaum's Outlines Complex Variables. Tata McGraw Hill Education; 2nd ed., 2017.

Course Name: Mathematical Tools II [3 1 0 3]	
Course Code: IDC 121	
Learning Outcomes	The aim of the second part of the interdisciplinary maths methods course is to making the students aware of various mathematical tools which are applied to other branches of sciences and engineering. This is a complete problem oriented course with lots of applications drawn from various fields.
Syllabus	• Solving techniques for first and second order linear ODEs: constant and variable coefficients [10] • Power series method, Legendre, Hermite, Bessel, Lauguerre, Chebyshev polynomials. [10] • Laplace transforms and application to ODEs. (6) • BVPs and Green's functions. (7) • Linear 2x2 systems of ODEs. (4)

Course Name: Mathematical Tools II [3 1 0 3]	
Course Code: IDC 121	
	• Application to other fields. (3)
Text & Reference Books	1. E. Kreyszig, Advanced Engineering Mathematics, 8th ed. Wiley India Pvt Ltd, 2006. 2. C. Edwards and D. Penny, Elementary Differential Equations with Boundary Value Problems, 5th ed. Prentice Hall 2007. 3. R. Bronson and G. Costa, Schaum's Outlines Differential Equations, 3rd ed. Mcgraw-hill 2009. 4. William E. Boyce, and Richard C. DiPrima, Elementary Differential Equations 9th ed., Wiley, 2008.

Course Name: Physical Principles in Biology [3 1 0 3]	
Course Code: IDC 211	
Learning Outcomes	Biological living organisms reach organizational complexity that far more exceeds the complexity of any inanimate objects or matter from which they are made of. The objective of the course is to introduce the students to the spatial (size) and temporal (time) scales that span the living organisms in order to understand the physical principles behind their complexity. The course will introduce students to the physical principles of biomolecules, their interactions/recognition, their census in time and scale, the techniques used to probe the physical properties that govern the functions of biomolecules and the linearity, non-linearity and stochasticity in biological systems.
Syllabus	• Physical biochemistry of the cell: Chemical forces translation and rotation, diffusion, directed movements, biomolecules as machines, work, power and energy, thermal, chemical and mechanical switching of biomolecules, Responses to light and environmental cues [8-9] • Physical principles of molecular structure: organization of biomolecules, molecular census in size and time, macromolecular assemblies, sizing up HIV, channels, transporters and motors [19] • Molecular recognition: principles of specificity in biological recognition, hormone-receptor interaction, antigen-antibody interaction, transient interactions, importance of transient interaction in biology.[5-6] • Linearity and non-linearity in biological systems : Definitions and example of linear and non-linear systems. Representing linear and nonlinear functions and applications. Stochasticity in Biological systems. [3-4]
Text & Reference Books	1. John Kuriyan, The Molecules of Life: Physical and Chemical Principles. 2. Rob Phillips et al., Physical Biology of the Cell. Garland Science. 3. Peter Atkins and Julio de Paula, Physical Chemistry for the Life Sciences. 4. Watson J. D. and Crick F. H. C., A Structure for Deoxyribose Nucleic Acid (1953), Nature, 171, 737-738. 5. Michael J. Rust. Orderly wheels of the cyanobacterial clock, PNAS, 09, 16760–16761 (Review), 2012.

Course Name: Physical Principles in Biology [3 1 0 3]	
Course Code: IDC 211	
	6. Erwin Schrödinger, The Physical Aspect of the Living Cell, Science book written for the lay reader by a physicist, 1944. 7. Kaern M., Elston T. C., Blake W. J., Collins J. J., Stochasticity in gene expression: from theories to phenotypes, Nat Rev Genet., 6:451-464. (Review), 2005.

Course Name: Principles of Spectroscopy [3 1 0 3]	
Course Code: IDC 221	
Learning Outcomes	To describe the fundamental principles governing various spectroscopic techniques and the relevant applications
Syllabus	• Fundamental Aspects of Spectroscopy: Electromagnetic radiation, absorption, emission, scattering, Einstein A and B coefficients, signal to noise ratio, resolving power, lasers, spectral lineshapes, Fourier transform spectroscopies, and pump-probe techniques [6] • Atomic Spectroscopy: Spectra of hydrogenic systems, coupling of orbital and spin angular momenta in many-electron systems, term symbols, fine and hyperfine structure, Zeeman and Stark effects [8] • Rotational Spectroscopy: Rigid rotor model for diatomics, rotational angular momentum, rotational energy levels, rotational constant, selection rules, microwave spectra of representative diatomics, structure determination, and isotope effects [5] • Infrared Spectroscopy: Harmonic oscillator model for diatomics, energy levels, selection rules, anharmonic effects, dissociation energies, and Morse oscillator [5] • Raman Spectroscopy: Light scattering, Raman effect, classical model of scattering, polarizability, Stokes and anti-Stokes lines, selection rules, mutual exclusion principle, structure determination using IR and Raman spectroscopies [2] • Electronic Spectroscopy of Molecules: Jablonski diagram, absorption, emission, Frank-Condon principle, Stokes shift, 0-0 band, fluorescence, phosphorescence, and quantum yields [4] • Photoelectron Spectroscopies: X-ray photoelectron spectroscopy, ultraviolet photoelectron spectroscopy, and Auger processes [2] • Spin Resonance Spectroscopies: Nuclear and electron spins, effect of applied external fields, nuclear magnetic resonance spectroscopy, electron spin resonance spectroscopy, illustrative examples and applications [3] • Mössbauer Spectroscopy: Principle and illustrative examples [1]
Text & Reference Books	1. T. Engel, Quantum Chemistry and Spectroscopy, 3rd ed., Pearson 2006. 2. J. M. Hollas, Modern Spectroscopy, 4th ed., Wiley, 2004. 3. C. N. Banwell and E. M. McCash, Fundamentals of Molecular Spectroscopy, 4th ed., Tata McGraw-Hill, 2017. 4. P. Atkins, J. de Paula and J. Keeler, Atkins' Physical Chemistry, 11th ed., Oxford University Press, 2018.

Course Name: Principles of Spectroscopy [3 1 0 3]	
Course Code: IDC 221	
	5. T. Engel and P. Reid, Physical Chemistry, 3rd ed., Pearson, 2013. 6. I. N. Levine, Physical Chemistry, 6th ed., Tata McGraw-Hill, 2011.

Course Name: Fundamentals of Programming [0 0 3 1]	
Course Code: IDC 112	
Learning Outcomes	▪ Write structured programs for accomplishing specific tasks in programming languages like C. ▪ Choose appropriate algorithms, libraries and Data Types. ▪ Understand the role of computation in solving problems. ▪ Test and debug programs
Syllabus	• Introduction to computer architectures and components • Programming Languages, Editors and Compilers. • Variables and types, operators and comparisons, compound types: control flow, loops, functions • Simple Programs-Sorting-Searching
Text & Reference Books	1. Byron S. Gottfried, Programming with C, Schaums Outlines, 2nd Ed, TataMcGraw-Hill, 2006. 2. R. G. Dromey, How to Solve it by Computer,Pearson Education, Fourth Reprint, 2007 3. Guttag John, Introduction to Computation and Programming Using Python: With Application to Understanding Data Second ed., MIT Press, 2016.ISBN:9780262529624. 4. H. P. Langtangen, A Primer on Scientific Programming with Python, Springer, 2016.

Course Name: Numeric Computing [0 0 3 1]	
Course Code: IDC 122	
Learning Outcomes	▪ Write structural programs for accomplishing specific tasks in programming languages like python. ▪ Develop object-oriented programme and design computational methods for scientific and data applications. ▪ Choose appropriate algorithms, libraries and Data Types. ▪ Understand the role of computation in solving problems. ▪ Introduction to python programming.
Syllabus	• Introduction to flow control functions, data types • Arrays: Arrays and Matrices, Multidimensional arrays, array and matrix operations, indexing, slicing, reshaping and resizing.

Course Name: Numeric Computing [0 0 3 1]	
Course Code: IDC 122	
	• Objects and Classes. • Computing eigenvalues and eigenvectors, norm and determinant, solving linear systems of equations, computing gradients.
Text & Reference Books	1. R. G. Dromey, How to solve it by computer, Pearson Education, 4th Reprint, 2007 2. Bjarne Stroustrup, The C++ Programming Language, 4th ed., Addison-Wesley2013. 3. Guttag John, Introduction to Computation and Programming Using Python: with Application to understanding Data 2nd ed., MIT Press, 2016. ISBN:9780262529624. 4. H. P Langtangen, A Primer on Scientific Programming with Python, Springer, 2016.

Course Name: Data Analysis and Visualisation [0 0 3 1]	
Course Code: IDC 212	
Learning Outcomes	▪ Write structured programs for accomplishing specific tasks in programming languages like C, C++ and Python. ▪ Develop object-oriented programs and design computational methods for scientific and data applications. ▪ Choose appropriate algorithms, libraries and Datatypes. ▪ Understand the role of computation in solving problems. ▪ Test and debug programs
Syllabus	• Introduction to data structures, classes, templates • Object oriented Programming • Understanding Program Efficiency • File input/output, Loading and storing data, data files. • Plotting and visualisation of scientific data,
Text & Reference Books	1. Byron S. Gottfried, Programming with C, Schaums Outlines, 2nd Ed, Tata McGraw-Hill, 2006. 2. John R. Hubbard, Programming with C++, Schaums Outlines, 2nd Ed, Tata McGraw-Hill, 2002. 3. R. G. Dromey, How to Solve it by Computer, Pearson Education, 4th Reprint, 2007. 4. Bjarne Stroustrup, The C++ Programming Language, 4th ed., Addison-Wesley 2013. 5. Guttag, John. Introduction to Computation and Programming Using Python: With Application to Understanding Data Second ed., MIT Press, 2016. ISBN: 9780262529624. 6. H. P. Langtangen, A Primer on Scientific Programming with Python, Springer, 2016.

Course Name: Scientific Computing [0 0 3 1]	
Course Code: IDC 212	
Learning Outcomes	▪ Write structured programs for accomplishing specific tasks in programming languages like C, C++ and Python. ▪ Develop object-oriented programs and design computational methods for scientific and data applications. ▪ Choose appropriate algorithms, libraries and Datatypes. ▪ Understand the role of computation in solving problems. ▪ Test and debug programs
Syllabus	• Special Functions, interpolation, optimisation and fit, random numbers, numerical integration, fast Fourier transforms, signal processing and image manipulations. • Numerical solution of differential equations • Applications to problems in natural sciences
Text & Reference Books	1. Byron S. Gottfried, Programming with C, Schaums Outlines, 2nd Ed, Tata McGraw-Hill, 2006. 2. John R. Hubbard, Programming with C++, Schaums Outlines, 2nd Ed, Tata McGraw-Hill, 2002. 3. R. G. Dromey, How to Solve it by Computer, Pearson Education, 4th Reprint, 2007. 4. Bjarne Stroustrup, The C++ Programming Language, 4th ed., Addison-Wesley 2013. 5. Guttag John, Introduction to Computation and Programming Using Python: With Application to Understanding Data 2nd ed., MIT Press, 2016. ISBN: 9780262529624. 6. H. P. Langtangen, A Primer on Scientific Programming with Python, Springer, 2016.

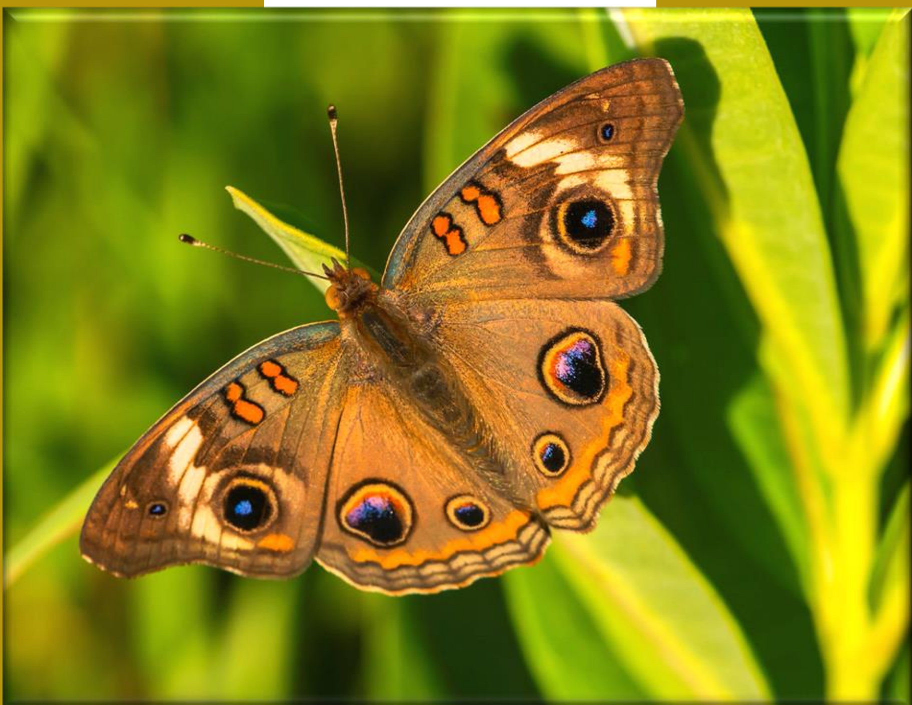
BIOLOGICAL SCIENCES

CURRICULUM FOR

BS-MS (SEM: 5 - 10)

MSc & IPHD (SEM: 1 - 4) AND PHD

CORE & ELECTIVE COURSES



BS-MS Biological Sciences (Semester 5 -10)

<table>
<tr><th>SEMESTER 5</th><th>SEMESTER 6</th><th>SEMESTER 7</th><th>SEMESTER 8</th><th>SEMESTER 9</th><th>SEMESTER 10</th></tr>
<tr><td>BIO 311
Advanced Microbiology
[3 0 0 3]</td><td>BIO 321
Structural Biology
[3 0 0 3]</td><td>BIO 411
Developmental Biology
[3 0 0 3]</td><td rowspan="6">Four electives
= 12 credits</td><td>1 elective
[1 credit]</td><td>Scientific grant writing
[1 credit]</td></tr>
<tr><td>BIO 312
Advanced Genetics and Genome Biology
[3 0 0 3]</td><td>BIO 322
Immunology
[3 0 0 3]</td><td>BIO 413
Neurobiology
[3 0 0 3]</td><td rowspan="5">Major Project Phase I
[15]</td><td rowspan="5">Major Project Phase II
[15]</td></tr>
<tr><td>BIO 313
Physiology
[3 0 0 3]</td><td>BIO 323
Cell Biology
[3 0 0 3]</td><td rowspan="3">Two electives
= 6 credits</td></tr>
<tr><td>BIO 314
Biochemistry
[3 0 0 3]</td><td>BIO 324
Molecular Biology
[3 0 0 3]</td></tr>
<tr><td>BIO 316
Biostatistics
[3 0 0 3]</td><td>BIO 326
Bioinformatics
[3 0 0 3]</td></tr>
<tr><td>BIO 315
Advanced Biology Lab I
[0 0 9 3]</td><td>BIO 325
Advanced Biology Lab II
[0 0 9 3]</td><td>BIO 412
Advanced Biology Lab III
[0 0 9 3]</td></tr>
<tr><td>Minor Course</td><td>Minor Course</td><td>Minor Course</td><td>Minor Project</td><td></td><td></td></tr>
<tr><td>21 credits</td><td>21 credits</td><td>18 credits</td><td>18 credits</td><td>16 credits</td><td>16 credits</td></tr>
</table>

*i*² Biological Sciences (Semester 5-10)

SEMESTER 5	SEMESTER 6	SEMESTER 7	SEMESTER 8	SEMESTER 9	SEMESTER 10
BIO 311 Advanced Microbiology [3 0 0 3]	BIO 321 Structural Biology [3 0 0 3]	BIO 411 Developmental Biology [3 0 0 3]	BIO 4208 Stem Cells & Regenerative Medicine [3 0 0 3]	Elective III [3 0 0 3]	I2B 522 Project [15]
BIO 312 Advanced Genetics & Genome Biology [3 0 0 3]	BIO 322 Immunology [3 0 0 3]	I2B 411 Systems Biology Theory [3 0 0 3]	I2B 421 Systems Biology Applications [2 0 0 2]	Elective IV [3 0 0 3]	
BIO 313 Physiology [3 0 0 3]	BIO 323 Cell Biology [3 0 0 3]	I2B 412 Microbiome & Vaccinology [2 0 0 2]	I2B 422 Bio-Imaging & Processing [2 0 0 2]	I2B 511 Project [15]	
BIO 314 Biochemistry [3 0 0 3]	BIO 324 Molecular Biology [3 0 0 3]	I2B 413 Synthetic Biology [3 0 0 3]	I2C 422 Biomaterials [3 0 0 3]		
BIO 315 Advanced Biology Lab - I [0 0 93]	BIO 325 Advanced Biology Lab- II [0 0 93]	I2B 414 Biological Spectroscopy & Microscopy [3 0 0 3]	I2B 521 Systems Biology & Imaging Lab [0 0 62]		
BIO 316 Biostatistics [3 0 0 3]	BIO 326 Bioinformatics [3 0 0 3]	I2B 415 Human Genetics, Gene Therapy & Personal Genomics [3 0 0 3]	I2C 521 Pharmacology & Pharmacokinetics [3 0 0 3]		
		Elective I [3 0 0 3]	Elective II [3 0 0 3]		
18 Credits	18 Credits	20 Credits	18 Credits	18 Credits	18 Credits

Master of Science in Biological Sciences (Semester 1-4)

<table>
<tr><th>Semester 1</th><th>Semester 2</th><th colspan="2">Semester 3</th><th colspan="2">Semester 4</th></tr>
<tr><td>MSB 311
Microbiology
[3 0 0 3]</td><td>MSB 321
Structural Biology
[2 0 0 2]</td><td colspan="2">MSB 411
Developmental Biology
[3 0 0 3]</td><td colspan="2">MSB 421
Bioinformatics
[2 0 0 2]</td></tr>
<tr><td>MSB 312
Genetics & Genome Biology
[3 0 0 3]</td><td>MSB 322
Immunology
[3 0 0 3]</td><td colspan="2">MSB 412
Biostatistics
[2 0 0 2]</td><td colspan="2">Elective V
(School/Open)
[3 0 0 3]</td></tr>
<tr><td>MSB 313
Physiology
[3 0 0 3]</td><td>MSB 323
Cell Biology
[3 0 0 3]</td><td colspan="2">MSB 413
Adv. Biology Lab – III
[0 0 9 3]</td><td rowspan="5">MSB 415
Project
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<tr><td rowspan="2">MSB 314
Biochemistry
[3 0 0 3]</td><td rowspan="2">MSB 324
Molecular Biology
[3 0 0 3]</td><td colspan="2">MSB 414
Seminar
[0 0 0 1]</td></tr>
<tr><td colspan="2">Elective II
(School)
[3 0 0 3]</td><td rowspan="3">MSB 415
Project
[0 0 0 9]
Project
(P-2)</td></tr>
<tr><td>MSB 315
Evolutionary Ecology
[3 0 0 3]</td><td>MSB 325
Adv. Biology Lab – II
[0 0 9 3]</td><td colspan="2">Elective III
(School/Open)
[3 0 0 3]</td></tr>
<tr><td>MSB 316
Adv. Biology Lab – I
[0 0 9 3]</td><td>Elective I
(School)
[3 0 0 3]</td><td>Elective IV*
(School)
[3 0 0 3]</td><td>MSB 215*
Project (P-1)
[0 0 0 3]</td></tr>
<tr><td>Core = 18</td><td>Core = 14
Elective = 3</td><td colspan="2">Core = 9
Elective = 6/9
Project = 0/3</td><td colspan="2">Core = 2
Elective = 3/6
Project = 9/12</td></tr>
<tr><td>Credits 18</td><td>17</td><td colspan="2">18</td><td colspan="2">14/17</td></tr>
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IPhD Biological Sciences (Semester 1- 6)

<table>
<tr><th>SEMESTER 1</th><th>SEMESTER 2</th><th>SEMESTER 3</th><th>SEMESTER 4</th></tr>
<tr><td>MSB 311
Advanced Microbiology
[3 0 0 3]</td><td>MSB 321
Structural Biology
[3 0 0 3]</td><td>MSB 411
Developmental Biology
[3 0 0 3]</td><td rowspan="2">2 Electives
[3 0 0 3]</td></tr>
<tr><td>MSB 312
Advanced Genetics & Genome Biology
[3 0 0 3]</td><td>MSB 322
Immunology
[3 0 0 3]</td><td rowspan="4">4 Electives
[3 0 0 3]</td></tr>
<tr><td>MSB 313
Physiology
[3 0 0 3]</td><td>MSB 323
Cell Biology
[3 0 0 3]</td><td rowspan="4">Research Project
[6]</td></tr>
<tr><td>MSB 314
Biochemistry
[3 0 0 3]</td><td>MSB 324
Molecular Biology
[3 0 0 3]</td></tr>
<tr><td>MSB 316
Biostatistics
[3 0 0 3]</td><td>MSB 326
Bioinformatics
[3 0 0 3]</td></tr>
<tr><td>MSB 315
Advanced Biology Lab - I
[0 0 9 3]</td><td>MSB 325
Advanced Biology Lab - II
[0 0 9 3]</td><td>MSB 412
Advanced Biology Lab - III
[0 0 9 3]</td></tr>
<tr><td>Credits = 18</td><td>Credits = 18</td><td>Credits = 18</td><td>Credits = 12</td></tr>
</table>

- *The semester 5 and 6 are designated for research*

List of Electives

Sl No:	List of Electives
1	Genome Stability
2	Advanced Developmental Biology
3	Evolutionary Ecology
4	Chronobiology
5	Cancer Biology
6	Host-Pathogen Interactions
7	Biological Data Analysis
8	Ecological Interactions
9	Stem Cells and Regenerative Medicine
10	Advances in Plant Biology
11	Cryo-Electron microscopy and 3D image processing for Life sciences
12	Biosafety and Regulation
13	Scientific Writing
14	Animal Behavior
15	Bacterial Genetics
16	Synthetic Biology
17	Drug discovery and development

CORE COURSES - SYLLABUS

<table>
<tr><th colspan="2">Course Name: Advanced Microbiology [3 0 0 3]</th></tr>
<tr><td colspan="2">Course Code: BIO 311 / MSB 311</td></tr>
<tr><td>Prerequisite</td><td>NA</td></tr>
<tr><td>Learning Outcomes</td><td>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.</td></tr>
<tr><td>Syllabus</td><td>• 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]
• 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]
• Microbial communication - quorum sensing and chemosensory response - bacterial chemotaxis, regulatory network of chemotaxis. [3]
• Microbial pathogenesis: types, mode of infection with examples of human and plant pathogens. Antimicrobial agents and their mode of action. [6]
• Applied microbiology: biodegradation, bioremediation, fermentation, recombinant protein production [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]</td></tr>
<tr><td>Text and Reference Books</td><td>1. Willey, Joanne M; Sherwood, Linda; Woolverton, Christopher J; Prescott Harley Klein’s Microbiology, McGraw-Hill, 7th ED., 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</td></tr>
</table>

<table>
<tr><th colspan="2">Course Name: Advanced Genetics and Genome Biology [3 0 0 3]</th></tr>
<tr><td colspan="2">Course Code: BIO 312 / BIO 612 / MSB 312</td></tr>
<tr><td>Prerequisite</td><td>NA</td></tr>
</table>

Course Name: Advanced Genetics and Genome Biology [3 0 0 3]	
Course Code: BIO 312 / BIO 612 / MSB 312	
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	• Model genomes, Genome organization and features. [1] • Genome variation: SNPs, RFLPs, structural variation, ploidy changes, extent of genome variation between individuals. [1] • Genomics and medicine: Sanger sequencing, next generation sequencing technologies, Human genome sequencing, Personalized medicine. [3-4] • Methods to study genomes: Vectors (Lambda vector, Bacterial Artificial Chromosome, Yeast Artificial Chromosome), PCR, microarrays, comparative genomic hybridization, pulse field gel analysis. [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] • Physical mapping: Restriction maps, Sequence Tag sites, Radiation hybrid maps, FISH, mapping contigs, shotgun sequencing. [2] • Co-relating genotype with phenotype: Mendelian traits, Quantitative traits, Genome wide association studies. [2] • Genome evolution: plasticity of genomes, genetic incompatibilities, gene duplication. [1]
Text and Reference Books	1. TA Brown, *Genomes* 4, Garland Science, 4th ed., Published May 24, 2017. 2. Tom Strachan, Andrew Read, *Human Molecular Genetics*, Garland Science, 5th ed., 20-Dec-2018. 3. Greg Gibson and Spencer V. Muse, *A Primer of Genome Science*, Sinauer Associates, 3rd ed., February 15, 2010.

Course Name: Physiology [3 0 0 3]	
Course Code: BIO 313 / MSB 313	
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.

Course Name: Physiology [3 0 0 3]	
Course Code: BIO 313 / MSB 313	
Syllabus	• 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] • 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] • 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] • 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] • 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] • 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] • 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 ed. 2. Eckert's Animal Physiology: Mechanisms and Adaptations. David Randall, Warren Burggen and Kathleen French: 5th ed.

Course Name: Biochemistry [3 0 0 3]	
Course Code: BIO 314 / MSB 314	
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".

Course Name: Biochemistry [3 0 0 3]	
Course Code: BIO 314 / MSB 314	
Syllabus	• 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] • 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] • 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] • 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] • 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] • 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] • 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] • 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] • 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] • 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] • Nucleic acid metabolism: purine and pyrimidine biosynthesis and catabolism of purines and pyrimidines. [3]

Course Name: Biochemistry [3 0 0 3]	
Course Code: BIO 314 / MSB 314	
	• One carbon metabolism: Importance of folate, SAM and Metcobalamine in folic acid pool of one carbon metabolism [1] • 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] • Interconvertibility of fuels: Relationship between glucose, fat and amino acid oxidation for energy generation. [1] • 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 ed., 2 December 2005' 2. Thomas Millar, Biochemistry Explained: A Practical Guide to Learning Biochemistry. CRC Press; 1ST ed., 30 May 2002. 3. Lubert Stryer et al., Biochemistry. W. H. Freeman; 6th ed., 14 July 2006 4. John E. McMurry and Tadgh Begley. The Organic Chemistry of Biological Pathways. WH Freeman; 2nd ed., 11 December 2015. 5. Laurence A Moran, Principles of Biochemistry. Pearson; 5TH ed,. 30 July 2013 6. David L. Nelson and Michael M. Cox, Lehninger Principles of Biochemistry WH Freeman; 7th ed. 2017.

Course Name: Biostatistics [3 0 0 3]	
Course Code: BIO 316	
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]

Course Name: Biostatistics [3 0 0 3]	
Course Code: BIO 316	
	• 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	1. Michael C. Whitlock and Dolph Schluter, The Analysis of Biological Data, Roberts And Company Publishers, 2015. 2. Steve McKillup, Statistics Explained: An Introductory Guide for Life Scientists, Cambridge University Press, 2006. 3. Calvin Dytham, Choosing and Using Statistics: A Biologist's Guide, Wiley-Blackwell, 2011.

Course Name: Structural Biology [3 0 0 3]	
Course Code: BIO 321	
Prerequisite	NA
Learning Outcomes	To introduce the Biology major/minor students the importance of Structural Biology in everyday research and to impart in them the knowledge to understand the principles of protein, nucleic acid, lipid and membrane structures. In addition, students will also learn tools to understand protein structures and their applications in structure-based drug design.
Syllabus	• Introduction to Structural Biology, Basics of proteins, conformation and analysis, Ramachandran Plot.[12] • Nucleic acid, lipids and membrane structures. [12] • Enzymes, Protein folding and degradation, membrane proteins, Virus structures. [10] • Tools for analysing protein structures to understand the molecular basis of their functions. Structure Based Drug Design.[5]
Text and Reference Books	1. Schulz G. E. and Schirmer R. H., Principles of protein structure, Springer-Verlag, 1979. 2. Branden C. and Tooze J., Introduction to protein structure, Garland Science, 2nd ed., 1999. 3. Liljas A., Liljas L., Piskur J., st Lindblom G., Nissen P. and Kjeldgaard M. (2009). Textbook of Structural Biology, 1st ed., World Scientific Publishing, 2009.

Course Name: Immunology [3 0 0 3]	
Course Code: BIO 322 / MSB 322	
Prerequisite	NA

Course Name: Immunology [3 0 0 3]	
Course Code: BIO 322 / MSB 322	
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). [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	1. Judith A. Owen, Jenni Punt, Sharon A. Stranford, Patricia P. Jones., Kuby Immunology, W.H. Freeman and Company, 2013. 2. Kenneth Murphy , Paul Travers , Mark Walport, Janeway's Immunobiology, Garland Science, Taylor & Francis Group, 2008.

Course Name: BIO 323 Cell Biology [3 0 0 3]	
Course Code: BIO 323 / MSB 323	
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

Course Name: BIO 323 Cell Biology [3 0 0 3]	
Course Code: BIO 323 / MSB 323	
	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	1. Cell Biology, Gerald Karp, (c2010). 2. Cell Cycle, Tim Hunt, Andrew Murray, (c1993). 3. Molecular Biology of the Cell, Bruce Alberts and co-authors, 6th ed., 2015.

Course Name: Molecular Biology [3 0 0 3]	
Course Code: BIO 324 / BIO 624 / MSB 324	
Prerequisite	NA

<table>
<tr><th colspan="2">Course Name: Molecular Biology [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: BIO 324 / BIO 624 / MSB 324</th></tr>
<tr><td>Learning Outcomes</td><td>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.</td></tr>
<tr><td>Syllabus</td><td>
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]
</td></tr>
<tr><td>Text and Reference Books</td><td>
Molecular Biology of the cell by Bruce Alberts et al. 6th ed.
DNA Repair and Mutagenesis (2nd ed.) Friedberg and others.
Mehta, A. and Haber J. E., sources of DNA double strand breaks and Models of Recombination DNA repair Cold Spring Harb Perspect Biol 6: a016428. 2014
Anand, R.P, Lovett, S.T. and Haber J.E. Break Induced DNA Replication. Cold Spring Harb Perspect Biol 5: a010397, 2013.
</td></tr>
</table>

Course Name: Bioinformatics [3013]	
Course Code: BIO 326 / BIO 626	
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	1. Bioinformatics, David Mount, CSHL, 2003 2. Bioinformatics & Functional Genomics, Jonathan Pevsner, Wiley 2015 3. M. Michael Gromiha, Protein Bioinformatics: From Sequence to Function, Elsevier, 2010

Course Name: Developmental Biology [3 0 0 3]	
Course Code: BIO 411 / BIO 611 / MSB 411	
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	1. Scott F Gilbert, Developmental Biology, Sinauer, 10th Ed, 2014 2. Lewis Wolpert and Cheryll Tickle, Principles of Development, OUP, 4th Ed, 2011 3. Other references would be provided during the lectures

Course Name: Neurobiology [3 0 0 3]	
Course Code: BIO 413 / BIO 613	
Prerequisite	NA

Course Name: Neurobiology [3 0 0 3]	
Course Code: BIO 413 / BIO 613	
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	• Organization of the nervous system [1] • Neuroanatomy [1] • Historical overview of neuroscience from Empedocles to Bernstein [1] • Electrical properties of the neuron: Equilibrium potential, The Nernst potential and Cable equations; Voltage gated ion channels; Resting and action Potentials [2]; • Goldman-Hodgkin-Katz equation, Hodgkin and Huxley model. Electrophysiological recording techniques: Patch-clamp and Voltage-clamp techniques [2]. • Energetics of the Nervous System [1]. • Synaptic transmission: Ligand gated ion channels; Electrical and chemical synapses. Synaptic plasticity, Short term potentiation, Long term potentiation [4]. • Learning and memory [1]. • 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. Mechano-transduction, 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]. • 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]. • Experimental methods to study neurobiology [1-3]. • Diseases of the nervous system [1-2].

Course Name: Neurobiology [3 0 0 3]	
Course Code: BIO 413 / BIO 613	
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. 5th. ed., November 2011. 2. Mark F. Bear, Barry W. Connors, Michael A. Paradiso, Neuroscience: Exploring the Brain, Lippincott Williams & Wilkins, 3rd ed., April 1995. 3. Eric R. Kandel, James H. Schwartz, and Thomas M. Jessell. Principles of Neural Science. 5th. ed., October 2012. 4. Arthur C. Guyton and John E. Hall. Textbook of Medical Physiology, 12th ed..

Course Name: Structural Biology [2 0 0 2]	
Course Code: MSB 321	
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	• Introduction to Structural Biology, Basics of proteins, conformation and analysis, Ramachandran Plot. [12] • Nucleic acid, lipids and membrane structures. [12] • Enzymes, Protein folding and degradation, membrane proteins. Virus Structures and Assembly. [10]
Text and Reference Books	1. Schulz GE and Schirmer RH, Principles of protein structure, Springer- Verlag. 2. Branden C and Tooze J, Introduction to protein structure, Garland Science. 3. Liljas A, Liljas L, Piskur J, st Lindblom G, Nissen P and Kjeldgaard M. (2009). Textbook of Structural Biology , 1st ed., World Scientific Publishing.

Course Name: Biostatistics [2 0 0 2]	
Course Code: MSB 412	
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.

Course Name: Biostatistics [2 0 0 2]	
Course Code: MSB 412	
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]
Text & Reference Books	1. Michael C. Whitlock and Dolph Schluter, The Analysis of Biological Data, Roberts And Company Publishers, 2015. 2. Steve McKillup, Statistics Explained: An Introductory Guide for Life Scientists, Cambridge University Press, 2006. 3. Calvin Dytham, Choosing and Using Statistics: A Biologist's Guide, Wiley-Blackwell, c2011.

Course Name: Bioinformatics [2 0 0 2]	
Course Code: MSB 421	
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. [1] • 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. [3]

Course Name: Bioinformatics [2 0 0 2]	
Course Code: MSB 421	
	• 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. [2] • 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] • 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. [2]
Text & Reference Books	1. Bioinformatics, David Mount, CSHL, 2003 2. Bioinformatics & Functional Genomics, Jonathan Pevsner, Wiley 2015 3. M. Michael Gromiha, Protein Bioinformatics: From Sequence to Function, Elsevier, 2010

Course Name: Evolutionary Ecology [3 0 0 3]	
Course Code: BIO 4102 / BIO 4202 / MSB 315	
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	• Recapitulation of fundamental concepts of evolution: Selection; Fitness; Adaptation; Types of selection; Evolution without selection. [1] • 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] • 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] • Historical biogeography: Biogeographic realms; Understanding geographic patterns of speciation using phylogenies; Vicariance, dispersal and sympatric speciation; Plate

<table>
<tr><th colspan="2">Course Name: Evolutionary Ecology [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: BIO 4102 / BIO 4202 / MSB 315</th></tr>
<tr><td></td><td>tectonics and its impact on diversification; Importance of dispersal for diversification; Geodispersal [2]
• 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]
• Phylogeography and Population genetics: Understanding history of populations using Haplotype Networks; HW Equilibrium; Population genetic structuring, Conservation genetics. [2-3]
• Phenotypic plasticity: Reaction norms; Polyphenisms; Adaptive plasticity; Reversible versus irreversible plasticity; Inducing environment versus adaptive environment; Genetic assimilation. [2]
• Sensory ecology: How senses are tuned to the environment; Sensory systems (vision, olfaction, acoustic and special senses). [8]
• Signaling and communication: Sign stimuli and releasing mechanisms; private channels and eavesdropping. Communication in animals and plants. [3]
• Life-history strategies: What are life-history strategies; Selection pressures on life-history strategies; Interesting case studies on life history evolution; Game theory. [3]</td></tr>
<tr><td>Text and Reference Books</td><td>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</td></tr>
</table>

THEMATIC COURSES

Course Name: Systems Biology - Theory [3 0 0 3]	
Course Code: I2B 411	
Prerequisite	MAT 111, 211
Learning Outcomes	Fast evolving multidisciplinary field that combines the power of mathematical & statistical models to decipher the functioning of biological systems. This is a multidisciplinary course, designed for applicants with a biological, biomedical, physical, computational or mathematical background. It equips students with the necessary skills to produce effective research in systems biology. After completing this course, students will have acquired an understanding of research topics is several areas of theoretical systems biology, which has wide-range of application in big-data analysis.
Syllabus	• Introduction to Systems Biology: introduction to biological physics, basic principles of biological systems, overview of experimental techniques. • Mathematics of Biological System: differential equations, deterministic ODE and PDE models, graph & network theory, linear, Boolean and Bayesian networks. • Networks structure & dynamics - mathematical graphs, random graphs, scale-free networks, clustering, network motifs, dynamic models, modularity. • Data formats & Simulations - types of biological data and their formats, Systems Biology Markup Language (SBML), SBML models, BioPAX, models and parameters for simulation of biological processes, stochastic simulation, Monte Carlo simulation. • Discrete, stochastic & spatial models - modelling of biological systems, classification of models, modelling process, formulation, and validation. • Variability, Robustness & Information - genetic & non-genetic variability, quantification of noise in biological systems, robustness mechanisms and scaling laws, adaptation and exploration strategies.
Text & Reference Books	1. Systems Biology, Edda Klipp, Christoph Wierling, Wolfram Liebermeister, Axel Kowald, Ralf Herwig, Hans Lehrach, 2nd ed., Wiley 2009 2. Mathematical Modeling in Systems Biology, Brian Ingalls, MIT Press 2013

Course Name: Microbiome & Vaccinology [2 0 0 2]	
Course Code: I2B 412	
Prerequisite	NA
Learning Outcomes	It is fascinating that human body harbors more microbial cells than the actual human cells. Microbiome of human is vast and diverse, and is strongly linked to human health and several diseases. The course aims to combine the microbiome of human, with emphasis on Indian population. Additionally, the course will provide on a very important overview on vaccinology, the theory and clinical applications of vaccines.
Syllabus	• Introduction to microbiome - overview, animal microbiome, microbiome & immune system. [1]

Course Name: Microbiome & Vaccinology [2 0 0 2]	
Course Code: I2B 412	
	• Human microbiome analysis - microbiota, gut microbiota, host diet, probiotics, ecosystem, evolutionary perspective, phylogeny & function. [4] • Methods to study microbiomes - culture-based methods, molecular methods: non-sequencing & sequencing-based, metabolic methods, metagenomics, metatranscriptomics, human microbiome project. [2] • Clinical relevance of microbiomes - microbiota in health and diseases, case studies. [2] • Introduction to Vaccinology - overview, historical perspective, disease prevention, therapeutic vaccines. [2] • Immunology of vaccines - chemical nature of antigens, antigen-presenting cells, cytokines, pathogen recognition, immune memory, mucosal immunity, pediatric & elderly immunology. [4] • Vaccine development - vaccine design: development pathway, antigens & epitopes, adjuvants, micro- and nanotechnology, recombinant vaccines, delivery technologies, formulation & manufacturing. [3] • Clinical trials - regulatory pathways, clinical evaluation, vaccine safety, vaccine recommendations. [2] • Health economics - overview, demand for health care services, health insurance, pharmaceutical manufacturers, public & private funding, cost-benefit analysis. [2] • Bio-manufacturing - overview, biopharmaceuticals, biotechnology-based therapeutics, production process, applications. [2]
Text & Reference Books	1. Haller, Dirk, The Gut Microbiome in Health and Disease, Springer, 2018 2. The Human Microbiome, Diet, and Health: Workshop Summary, National Academies Press 2013 3. Angela E. Douglas, Fundamentals of Microbiome Science: How Microbes Shape Animal Biology, Princeton University Press, 2018 4. Gregg N. Milligan, Alan D. T. Barrett, Vaccinology: An Essential Guide, Wiley-Blackwell, 2016 5. Giese, Matthias, Introduction to Molecular Vaccinology, Springer, 2016

Course Name: Synthetic Biology [3 0 0 3]	
Course Code: I2B 413	
Prerequisite	I2B 323, I2B 324
Learning Outcomes	This is yet another fast-evolving multidisciplinary field that combines the principles of biological systems with the power of engineering tools to develop practicable solutions for wide-range of applications, particularly in health sciences.

Course Name: Synthetic Biology [3 0 0 3]	
Course Code: I2B 413	
Syllabus	• Introduction to Synthetic biology – origin and concepts, quick overview of molecular biology, applications. [2] • Kinetics and dynamics of biological systems – biochemical networks, gene regulatory networks, signal transduction pathways. [6] • Biomechanics – introduction, cellular biomechanics, circulatory system, respiratory systems, ocular biomechanics, muscle & movement, skeletal biomechanics, locomotion. [7] • Genetic circuits & Feedback systems – development of synthetic modules, design & methods, expansion of genetic code. [3] • Bioengineering designs – prokaryotic & eukaryotic platforms – genes, genomes and proteins, engineering therapeutic pathways. [3] • Biosensors – enzyme-based electrochemical biosensors, optical technologies, transducer technologies, living biosensors. [7] • Tissue engineering – introduction, stem cells, extra-cellular matrix, mechanical surfaces, surface immobilization, biomaterials, examples of tissue engineering: skin, nerve, cardiac tissue regeneration. • Bionanotechnology – nanomaterials, biomolecules-nanoparticles interactions, applications in diagnostics & medicine [3] • Biomedical engineering – introduction, biomedical sensors, bio-signal processing, diagnostic devices, wearable sensors. [4]
Text & Reference Books	1. Daniel G. Gibson, J. Craig Venter; Clyde A. Hutchison III, J. Craig Venter Joseph D. Bronzino, Donald R. Peterson, The Biomedical Engineering Handbook, CRC Press, 2015 2. Biological and pharmaceutical nanomaterials; Nanotechnologies for the Life Sciences, Vol 2, Challa Kumar, Wiley-VCH, 2006. 3. Ajit Sadana, Engineering biosensors, kinetics and design applications, San Diego,Academic Press, 2002 4. Fredrick H. Silver: Biomaterials, Medical Devices & Tissue Engineering: An integrated approach. 5. C. Ross Ethier and Craig A. Simmons: Introductory Biomechanics: From Cells to Organisms. 2nd Edn., Cambridge University Press. 2009

Course Name: Biological Spectroscopy & Microscopy [3 0 0 3]	
Course Code: I2B 414	
Prerequisite	NA
Learning Outcomes	Essence of biology is in understanding how macromolecular machines function in a cell. Hence, sophisticated tools are required to investigate the structure and function. Spectroscopy and Microscopy are indispensable tools for research towards gaining insights into human health and disease. The course will cover theoretical basis of spectroscopy and microscopy for analyzing biological samples, various applications in biological research and clinic.

Course Name: Biological Spectroscopy & Microscopy [3 0 0 3]	
Course Code: I2B 414	
Syllabus	• Fundamentals of spectroscopy & microscopy - introduction, quantum mechanics, properties of particles and waves. [2] • Circular dichroism and optical rotary dispersion - concepts, analysis of nucleic acids and proteins, small molecule binding to DNA, protein folding, fluorescence polarization. [2] • Macromolecular vibration spectroscopy - fundamentals, infrared & near-infrared, Raman and Resonance Raman spectroscopy of biomolecules, structure determination, examples: enzyme-substrate complexes. [3] • Magnetic resonance - NMR, chemical shifts, spin-spin splitting, relaxation times, multidimensional NMR, MRI, electron spin resonance, applications in biology. [3] • X-ray crystallography - X-ray scattering, structure determination, neutron diffraction, nucleic acid & protein structure, enzyme catalysis, software tools. [2] • Light microscopy - light & color, lenses & geometrical optics, diffraction & interference, spatial resolution. [2] • Fluorescence spectroscopy & Microscopy - physical basis fluorescence, properties of fluorescent dyes, autofluorescence, fluorescent proteins, quenching, blinking & photobleaching. [2] • Mass spectrometry - introduction, mass analysis, problems in mass spectrometry, tandem mass spectrometry, ion detectors, ionization of samples, sample preparation & analysis, application in biology. [3] • Advanced microscopic methods for biology - overview, confocal microscopy, multiphoton microscopy, super-resolution imaging methods applied in biology. [3] • Optical traps - introduction to optical tweezers, applications in biology. [1] • Electron & cryo-electron microscopy - overview, TEM, SEM, image analysis, cryo-EM overview and development, Fourier transformations, sample preparation, data collection, image processing, single particle cryo-EM, 2D-crystallography. [3]
Text & Reference Books	1. Gordon G. Hammes, Spectroscopy for the Biological Sciences, Wiley 2005 2. James M. Thompson, Mass Spectrometry, CRC Press 2017 3. Douglas B Murphy, Fundamentals of Light Microscopy and Electronic Imaging, Wiley, 2001 4. Michael J. Dykstra, Biological Electron Microscopy: Theory, Techniques, And Troubleshooting, Springer 2003 5. David L. Spector, Robert D. Goldman, Basic Methods in Microscopy Protocols and Concepts from Cells: A Laboratory Manual, CSHL 2006

Course Name: Human Genetics, Gene Therapy & Personalized Medicine [3 0 0 3]	
Course Code: I2B 415	
Prerequisite	BIO 312

Course Name: Human Genetics, Gene Therapy & Personalized Medicine [3 0 0 3]	
Course Code: I2B 415	
Learning Outcomes	Genetics & genomics has revolutionized the field of medicine both in terms of diagnosis and treatment. The economical next-gen sequencing has made it possible to treat patients with more personalized treatment for various disorders including cancer through gene therapy. The course will cover brief introduction into genetics, human genome sequencing, various gene therapy approaches and personalized medicine.
Syllabus	• Human genome & variations - overview, organization & features of human genome, gene expression, mutation rates, nature of variation, evolution & population genetics. [3] • Human genetic disorders - Mendelian inheritance, chromosomal abnormalities, single-gene disorders, complex diseases, other genetic diseases, genetic testing. [3] • Genome-wide association studies - linkage analysis, common variants, haplotype map, linkage disequilibrium, genotyping technologies, study design, multi-locus analysis, meta-analysis, cancer genome. [6] • Gene therapy - concept & development, methods of gene therapy, genetic pharmacology. [6] • Types of gene therapy - somatic & germline gene therapy, in vivo gene therapy, DNA vaccines; [4] • Clinical applications of gene therapy - general considerations, clinical trials, therapeutic case studies, cancer gene therapy. [4] • Personalized medicine - concept of individualized therapy, genomic medicine, molecular diagnostics basis of personalized medicine, role of biomarkers, clinical genomics - childhood & adulthood treatments. [7] • Genome editing - targeted genome editing methodologies, genome editing in disease biology, case studies, bioethics. [4] • Statistics for GWAS - summary statistics, multiple testing, graphical models, Bayesian methods. [6] • Big data genomics - 1000 genomes project, cancer genome atlas, human microbiome project. [3]
Text & Reference Books	1. Jeanette McCarthy & Bryce Mendelsohn, Precision Medicine: A Guide to Genomics Clinical Practice, McGraw-Hil, 2016 2. Krishnarao Appasani, Genome Editing and Engineering: From TALENs, ZFNs and CRISPRs to Molecular Surgery, Cambridge University Press, 2018 3. Ricki Lewis, Human Genetics: Concepts and Applications, McGraw-Hill Co., c2012. 4. Tom Strachan and Andrew Read, Human Molecular Genetics, Garland Science, c2011 5. Mauro Giacca, Gene Therapy, Springer, 2010 6. Roland W Herzog and Sergei Zolotukhin, A Guide to Human Gene Therapy, World Scientific Publishing Company, 2010

Course Name: Systems Biology - Applications [2 0 0 2]	
Course Code: I2B 421	
Prerequisite	I2B 412 Systems Biology - Theory

Course Name: Systems Biology - Applications [2 0 0 2]	
Course Code: I2B 421	
Learning Outcomes	Application of theoretical knowledge & models to high-throughput data in Biology to predict the behavior of biological processes. This is both theoretical & practical course, designed for applicants with a biological, biomedical, physical, computational or mathematical background. It equips students apply the theoretical knowledge on actual research problem for empirical analyses and applications beyond bench.
Syllabus	• Transcriptional Networks - elements of transcriptional networks, dynamics and response, models of gene expression (basic, stochastic, and thermodynamic models), gene expression noise, network component analysis, dissecting transcriptional control networks. [6] • Biochemical Networks - structural modeling & reconstruction, reaction kinetics & thermodynamics, constraint-based flux optimization, metabolic control analysis. [6] • Feedback, Bistability & Memory - feedforward loops, feedback loops, network motifs, protein-protein interaction networks. [4] • Biological Oscillator - oscillations in biological systems: biochemical, gene expression, signal transduction, non-linear dynamics. [2] • Optimality in Biology - optimal gene-circuit design, optimal metabolic adaption, fitness landscape, pareto optimality, modularity, evolution and self-organization. [2] • Systems Medicine - introduction, modeling of diseases pathology, tumor biology, infection & immunity, metabolic diseases, stem cells, aging. [2]
Text & Reference Books	1. An Introduction to Systems Biology: Design Principles of Biological Circuits, Uri Alon, Chapman and Hall 2019 2. Systems Biology, Edda Klipp, Christoph Wierling, Wolfram Liebermeister, Axel Kowald, Ralf Herwig, Hans Lehrach, 2nd ed., Wiley 2009

Course Name: Bioimaging & Processing [2 0 0 2]	
Course Code: I2B 422	
Prerequisite	I2B 415 Biological Spectroscopy & Microscopy
Learning Outcomes	Imaging is essential to understand the functioning of organelles, macromolecules, etc., in a cell in health and diseases states. Thus, biological imaging has enabled faster and precise diagnosis in medicine. This theory combined with practical course enables students to learn various techniques used in imaging biological samples and their application in clinic. Further, students also gain knowledge about digital image processing.
Syllabus	• Foundations of bioimaging - overview of bioimaging technologies, need for bioimaging, cost & ease of bioimaging. [3] • Research-oriented imaging - applications of imaging in biological/clinical research, live cell imaging, data acquisition & processing. [6] • Biomedical imaging - overview, X-ray imaging, nuclear medicine, ultrasonic imaging, MRI. [6] • Biomarkers design for imaging - overview, developing biomarkers for disease diagnosis, genetics & proteomics-based markers, applications in cancer diagnosis. [3] • Functional imaging - brain imaging, fMRI, PET, data acquistion & analysis. [2]

Course Name: Bioimaging & Processing [2 0 0 2]	
Course Code: I2B 422	
	• Image processing algorithms and software - workflows & components of bioimaging, quantification of image data, segmentation in bioimaging, Matlab for bioimaging, image data storage and publishing. [6]
Text & Reference Books	1. Guy Cox, Optical Imaging Techniques in Cell Biology, 2nd ed., CRC Press, 2012 2. Rajagopal Vadivambal and Digvir S. Jayas , Bio-Imaging: Principles, Techniques, and Applications, CRC Press, 2018 3. Wheeler, Ann and Henriques, Ricardo, Standard and Super-Resolution Bioimaging Data Analysis A Primer, Wiley & Sons, 2017 4. Kota Miura, Bioimage Data Analysis, Wiley & Sons, 2016

Course Name: Biomaterials [3 0 0 3]	
Course Code: I2C 423	
Prerequisite	NA
Learning Outcomes	The course focuses on the study of biocompatible, biomimetic and nature-based materials as well as their diverse areas of application. The course provides an understanding of the characteristics of common biomaterials, its structure, properties and morphology. Students also learn the different interaction between biomaterials, proteins and cells.
Syllabus	• Concepts in material science: bulk properties of materials, surface properties and surface characterisation of materials, interpretation of phase diagram [10] • Classes of materials used in medicine: Polymers, silicone biomaterials, hydrogels, smart polymers, metals (basic structure and types of alloys, stress-strain behaviour, hardness, impact energy, fractured toughness, fatigue) [8] • Ceramics and glasses: characterising crystalline and non-crystalline materials, mechanical properties and processing methods: brittle fracture, static fatigue, thermal shock and viscous deformation, composites, surface immobilised biomolecules [6] • Biological response to biomaterials: biocompatibility and heme compatible, mechanism of foreign body response to implanted biomaterials. biodegradation of biomaterials. surface modification to control biological response [8] • Biomaterial application: biomaterial for joint versus blood vessel, biomaterial for soft and hard tissue replacement, cardiovascular, drug delivery system, biosensors, synthetic bioresorbable polymer scaffolds [8]
Text & Reference Books	1. Biomaterial Science by Buddy Ratner, Allan Hoffman, Frederick Schoen, Jack Lemons, Academic press, 2012 2. Biomaterials: The Intersection of Biology and Materials Science by J.S. Temenoff and A.G. Mikos, Pearson Prentice Hall, 2008. 3. Fundamentals of Biomaterials by Vasif Hasirci & Nesrin Hasirci, Springer, 2018

LABORATORY COURSES - SYLLABUS

Course Name: Advanced Biology Lab I (semester V)	
Course Code: BIO 315 / MSB 316	
Prerequisite	NA
Learning Outcomes	To provide a hands-on training of advanced Biological experimental methods.
Syllabus	• Microbiology: Microbial growth kinetics, bacterial motility assay; antibiotics susceptibility testing, Construction of bacterial gene deletions by homologous recombination, [24] • Genetics: Tetrad analysis in yeast, analysis of genomic data. [24] • 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]

Course Name: Advanced Biology Lab II (semester VI, for 2020 batch onwards)	
Course Code: BIO 325 / MSB 325	
Prerequisite	NA
Learning Outcomes	To provide a hands-on training of advanced Biological experimental methods.
Syllabus	• 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] • 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] • Molecular Biology: Molecular cloning, Site-directed Mutagenesis, qRT-PCR, In vitro transcription and translation [32]

Course Name: Advanced Biology Lab III (semester VII, 2020 batch onwards)	
Course Code: BIO 412 / MSB 413	
Prerequisite	NA
Learning Outcomes	To provide a hands-on training of advanced Biological experimental methods.
Syllabus	• Ecology and Animal behavior: Students will carry out 6 week-long studies which involves formulating hypotheses, study design, data collection, data analysis and report writing. – [48] • Developmental Biology: Making crosses in Drosophila, cell migration during oogenesis – [24] • Neurobiology experiments – [24]

Course Name: Systems Biology & Imaging Lab [0 0 6 2]	
Course Code: I2B 521	
Prerequisite	I2B 423 Systems Biology Applications, I2B 424 Bioimaging & Processing
Learning Outcomes	The practical course will introduce students to systems biology problems and analyzing large-scale 'omics datasets. In addition, hands-on-training will be provided on advanced microscopy and spectroscopy, data collection and analysis.
Layout	• Stochastic simulations. [4] • Modelling biological networks. [6] • Matlab and R packages. [6] • NMR spectroscopy. [8] • AFM imaging. [8] • Cryo-electron microscopy. [8]
Text & Reference Books	1. Methods' articles will be shared during the course.

ELECTIVE COURSES - SYLLABUS

Course Name: Research Methodology [1 0 0 1]	
Course Code: BIO 610	
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	• What is the purpose of research? [1] • Take examples of Newton and the inverse square law of gravitational force and of the calculus. [1] • Ethics, Plagiarism and Fraud [1] • Plagiarism and Fraud. Examples of Mark Spector, Mendel and Kepler [1] • Ethics of managing data and authorship [1] • Research Design [1] • Choice of Research Topic and design of experiments: [1] • Controls. Controls. Controls. [1]

Course Name: Genome Stability [3 0 0 3]	
Course Code: BIO 3201 / BIO 4216	
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	• Mechanisms of meiotic recombination and chromosome segregation: Chromosome pairing and synaptonemal complex assembly, Regulation of meiotic recombination pathways. [5] • DNA damage and recognition: sources and types of DNA damage, random and programmed double strand breaks, chromosome structural changes [4] • Cellular responses to DNA damage: signalling of DNA damage, choice of DNA repair and recombination pathways. [2] • DNA repair mechanisms: mismatch repair, Base excision repair, Nucleotide excision repair, non-homologous end joining, Homologous recombination, processing of Holliday junctions. [4]

Course Name: Genome Stability [3 0 0 3]	
Course Code: BIO 3201 / BIO 4216	
	• Genomic instability and human disease: cancer, birth defects, genomic disorders due to chromosome structural changes. [2] • Genome editing: targeted modification of the genome. [1] • Discussion of research papers [6]
Text and Reference Books	1. James Haber, Genome Stability, Garland Science, ed. 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 ed., February 23, 2006

Course Name: Advanced Topics in Developmental Biology [3 0 0 3]	
Course Code: BIO 4101 / BIO 4201	
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. • Maternal inheritance and maternal to zygotic transition during early development [3] • Cell migration and cell adhesion in development [3] • Cell shape in development [3] • Regulation of developmental gene expression [3] • Interpretation of morphogen gradients [3] • Asymmetry in the germ cells and in developing embryo [3]

Course Name: Advanced Topics in Developmental Biology [3 0 0 3]	
Course Code: BIO 4101 / BIO 4201	
	• Cell Polarity in development and changes in cell polarity [2] • Development and behavior [2] • 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

Course Name: Chronobiology [3 0 0 3]	
Course Code: BIO 4103 / BIO 4203	
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	• 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]. • 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]. • 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]. • Circadian photoreception: Input signals into the circadian clock, molecular pathway of circadian photoreception, light entrainment of circadian clock, extra-ocular photoreception [3]. • 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]. • Sleep for memory consolidation, sleep and synaptic plasticity, Sleep disorders. Evolution of sleep [4] • Circadian clock and metabolism: Central and peripheral circadian clocks, circadian disruptions and metabolic disorders, neuro-degenerative diseases, ageing and circadian clock [4]. • Evolution of the circadian timing system: Evolution of circadian clocks, fitness, adaptive significance of circadian clocks [3].

Course Name: Chronobiology [3 0 0 3]	
Course Code: BIO 4103 / BIO 4203	
Text and Reference Books	1. Jay C. Dunlap, Jennifer J. Loros, Patricia J. DeCoursey, Chronobiology: Biological time keeping, Sinauer Associates, Inc. Publishers, 1st ed., December 2009. 2. D.S. Saunders, Insect clocks, Elsevier science & Technology, 3rd ed., November 2002

Course Name: Cancer Biology [3 0 0 3]	
Course Code: BIO 4104 / BIO 4204	
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	• 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] • 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] • Oncogenes and their role in tumor development (ex: c-src, Ras, erbB2/neu, myc etc.) [6] • Tumor suppressor genes and their role in neoplasia (ex: p53, pRb, VHL, and APC etc.) [6] • 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] • Chronic inflammation and infectious agents and their role in cancer development (Colonic, liver and skin inflammation and tumor promotion) [3] • 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

Course Name: Host-Pathogen Interactions [3 0 0 3]	
Course Code: BIO 4105 / BIO 4205	
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	• Introduction to Host-pathogen interaction [2]. • Viral, Bacterial and parasite pathogens [3]. • Pathogen external interactions, Viral pathogen attachment and entry into the host cell [3]. • Virus replication cycle [3]. • Animal models [3]. • Experimental approaches to study Microbial pathogenesis: • Identification of virulence factors Genome-wide approaches to study host-pathogen interactions [4]. • Monitoring host response and immunity to pathogens [3] • Pathobiology of Infection: Survival strategies of viral, bacterial and parasite pathogens. Immune response to infectious diseases Mechanisms of pathogenesis, pathogens immune evasion mechanism [6] • 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 ed. (February 19, 2008) 3. Bruce Alberts et al., Essential Cell Biology; Richard Goldsby and Thomas J, &F/Garland, 4th ed., (2014) 4. Kindt, Kuby, Immunology, W. H. Freeman; 6th ed. (9 October 2006)

Course Name: Evolutionary Interactions [3 0 0 3]	
Course Code: BIO 4107 / BIO 4207	
Prerequisite	BIO 4102 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.

Course Name: Evolutionary Interactions [3 0 0 3]	
Course Code: BIO 4107 / BIO 4207	
Syllabus	• The central role of interactions in the ecology and evolution of organisms [1] • Coevolution: Coevolution of various types of interactions; Diffuse coevolution; Arms race [3] • Mutualism and Parasitism: When do mutualistic and parasitic interactions evolve? Continuum between mutualism and parasitism [4] • Competition and Facilitative interactions: Inter- and intra-specific competition: Spatial and temporal mechanisms of competition avoidance; Concept of niche and niche partitioning [6] • Host-endosymbiont interactions: Diversity of host-endosymbiont interactions in nature; Case studies of the widespread endosymbiont Wolbachia and its insect hosts [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] • Plant- pollinator interactions: Insect pollination as a key innovation; Specialisation and generalisation in plant-pollinator interactions; Obligate mutualisms [6] • 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

Course Name: Stem Cells and Regenerative Medicine [3 0 0 3]	
Course Code: BIO 4108 / BIO 4208	
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	• Introduction to Stem cells: Basics of stem cells and principles of stemness, Early mammalian development, Evolution of stem cells. [1.5] • 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]

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<tr><th colspan="2">Course Name: Stem Cells and Regenerative Medicine [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: BIO 4108 / BIO 4208</th></tr>
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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]
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]
Cancer stem cells: Concepts, identification, biology and potential applications of cancer stem cells. [3]
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]
Transplantation biology: Immunology of transplantation and graft rejection, mechanisms of homing of transplanted stem cells. [3]
Tissue engineering: Ex vivo expansion of stem cells, Ex vivo construction of tissues, scaffolds, bioreactors. [4.5]
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]
Methods in stem cells: In vitro and in vivo methods to assay stem cells. [6]

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<tr><td>Text and Reference Books</td><td>

Essentials of Stem Cell Biology by Robert Lanza Anthony Atala (Eds.): Academic Press. 3rd ed. 2013.
Stem Cells: An Insider's Guide by Dr. Paul Knoepfler: World Scietific publishing Co. Pvt. Ltd. 1st ed. 2013.
The science of stem cells by JMW Slack: Wiley Blackwell publishers. 1st ed. 2017.
Stem Cells, Tissue Engineering and Regenerative Medicine by David Warburton (Ed.) World Scietific publishing Co. Pvt. Ltd. 1st ed. 2014.
Stem Cells Handbook by Stewart Sell (Ed.). Springer 1st ed. 2013.
Stem Cells: A Short Course Rob Burgess. Wiley Blackwell publishers. 1st ed. 2016.
Principles of Tissue Engineering Robert Lanza Robert Langer Joseph Vacanti (Eds.). Academic Press 4th ed. 2013.
The Biomedical Engineering Handbook by Joseph D. Bronzino, Donald R. Peterson. CRC Press Taylor & Francis. 1st ed.. 2015.

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<tr><th colspan="2">Course Name: Advances in Plant Biology [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: BIO 4109 / BIO 4209</th></tr>
<tr><td>Prerequisite</td><td>NA</td></tr>
<tr><td>Learning Outcomes</td><td>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, whic610h continuously get exposed to fluctuating environmental conditions throughout their growth phase.</td></tr>
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<tr><th colspan="2">Course Name: Advances in Plant Biology [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: BIO 4109 / BIO 4209</th></tr>
<tr><td>Syllabus</td><td>Molecular genetic basis of morphological diversity in plants. [3]
Regulatory interactions between cell- fate determinants and cell cycle; cell fate, stem-cell behaviors, and cell polarity in plant morphogenesis. [9]
Cell biological tools to understand cellular behaviour in live plants and computational modelling to study morphodynamics. [9]
Cross talk and integration of hormone signalling pathways driving plant morphogenesis and physiology. [9]
Photosynthesis, hormone physiology, photorespiration and transpiration) stresses. [9]</td></tr>
<tr><td>Text and Reference Books</td><td>1. Leyser, O. and Dey, S. (2009) Mechanisms in Plant Development. John Wiley & Sons.</td></tr>
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<tr><th colspan="2">Course Name: Cryo-Electron microscopy and 3D image processing for Life sciences [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: BIO 4110 / BIO 4210</th></tr>
<tr><td>Prerequisite</td><td>Preferable: BIO321 course: Structural Biology (not compulsory).</td></tr>
<tr><td>Learning Outcomes</td><td>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.</td></tr>
<tr><td>Syllabus</td><td>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]
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]
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]
Cryo-EM map interpretation and data analysis, validation, molecular docking and Flexible Fitting in EM maps.[5-6]</td></tr>
</table>

Course Name: Cryo-Electron microscopy and 3D image processing for Life sciences [3 0 0 3]	
Course Code: BIO 4110 / BIO 4210	
Text and Reference Books	1. John J. Bozzola and Lonnie D. Russell. Electron Microscopy, 2nd ed., 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"

Course Name: Biosafety and Regulation [1 0 0 1]	
Course Code: BIO 4111 / BIO 4211	
Prerequisite	NA
Learning Outcomes	To introduce concepts related to safety in Biological laboratories and Biological waste management.
Syllabus	• 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] • 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.). Biosafety and Bioethics. Isha Books, Delhi, 2006 3. DBT, India Biosafety guidelines: http://dbtindia.gov.in/guidelines-biosafety

Course Name: Scientific Writing (1 Credit) [1 0 0 1]	
Course Code: BIO 4112 / BIO 4212	
Prerequisite	NA
Learning Outcomes	Researchers invariably need to communicate the results of their scientific research. This can be in the form of oral presentations, journal articles, reports, popular science articles, etc. The course will be designed to help students effectively communicate their research under such scenarios.

Course Name: Scientific Writing (1 Credit) [1 0 0 1]	
Course Code: BIO 4112 / BIO 4212	
Syllabus	• The course will be organized under the following modules • Writing manuscripts for journals [4] • Effective oral presentations (seminars, conferences, popular talks) [4] • Popular science writing [4]

Course Name: Animal Behaviour [3 0 0 3]	
Course Code: BIO 4113 / BIO 4213	
Prerequisite	BIO 4102 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	• The study of Animal Behaviour: a brief history [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] • Eusociality: Haplodiploid sex determination and evolution of extreme altruism; Eusociality in the absence of close relatedness [6] • 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] • Cooperation and conflict: Kinship and conflict with kin (parent-offspring conflict, sibling rivalry, kin recognition); Aggression; Alarm signals; Social learning [4] • Territoriality, Space and information usage: Habitat preferences; Costs and benefits of dispersal; Costs and benefits of migration; Territorial contests [3] • Learning, memory and cognition: Adaptive value of learning; Innate behaviours; Spatial orientation and navigation, Central place foragers [4] • Foraging behaviour: Optimal foraging theory and its criticisms; Game theory and feeding behaviour[3] • 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

Course Name: Drug discovery and development [3 0 0 3]	
Course Code: BIO 317	
Prerequisite	NA
Learning Outcomes	This course aims to provide students with an understanding of the process of drug / therapeutics design and discovery. It covers the basic principles of how drugs are designed using multi-disciplinary approach.
Syllabus	• Introduction to drug discovery - types of compounds (small molecules - biologics - antibody / drug conjugates, vaccines); different phases in development, approval, and life cycle management. (4) • Overview of discovery process: High throughput screening and profiling - phenotypic screening and target-based approach; target identification and validation; Assay development - target cloning, reporter assay, etc.; hit to lead generation- Approaches to Lead Optimization-Bio-isosteric replacement-conformation restriction, Drug metabolism and pharmacokinetics; animal models of disease- clinical trials. (8) • Receptors as targets of drug design: Pharmacological receptor types- molecular biology of receptors; receptor complexes and allosteric modulators; receptor binding assays; lead compound discovery of receptor agonists and antagonists. (4) • Enzymes as targets of drug design: enzyme kinetics; enzyme inhibition and activation; approaches to the rational design of enzyme inhibitors. (2) • Kinases as drug targets: kinase regression approach; current approved drugs targeting kinase families. (2) • Drug repurposing. (2) • Drug development for infectious diseases (malaria and tuberculosis) - antibiotics-host-targeted interventions (3). • Drug resistance - evolution and mechanism of drug resistance; overcoming drug resistance; antimicrobial resistance; mechanistic examples from cancer, tuberculosis, and malaria. (5) • Structure guided drug design. Target characterization and virtual screening of compounds - molecular docking - big data and machine learning (4). • Case studies and student seminars on current approaches to develop drugs against various disease models (cancer and infectious diseases). (5)
Text and Reference Books	1. Raymond G H and Duncan R. Drug Discovery and Development. Technology in Transition. 3rd Edition. May 16, 2021. 2. Kerns E H and Di L. Drug-Like Properties: Concepts, Structure Design and Methods: from ADME to Toxicity Optimization, Academic Press, Oxford, 2008.

CHEMICAL SCIENCES

CURRICULUM FOR

BS-MS (SEM: 5 - 10)

MSc & IPHD (SEM: 1 - 4) AND PHD

CORE & ELECTIVE COURSES

BS-MS Chemical Sciences (Semester 5 -10)

Semester 5	Semester 6	Semester 7	Semester 8	Semester 9	Semester 10
CHY 311 Coordination Chemistry [3 0 0 3]	CHY 321 Organometallic Chemistry [3 0 0 3]	CHY 411 Main Group Chemistry [3 0 0 3]	CHY 521 Instrumental methods for Structure Determination [3 0 0 3]	Elective III	Project [18]
CHY 312 Organic Chemistry - Reactions and mechanisms [3 0 0 3]	CHY 322 Solid-State Chemistry [3 0 0 3]	CHY 412 Advanced Organic Chemistry [3 0 0 3]	CHY 522 Physical Organic Chemistry [3 0 0 3]	Elective IV	
CHY 313 Quantum Chemistry [3 0 0 3]	CHY 323 Organic Chemistry-Synthetic methods [3 0 0 3]	CHY 413 Chemical and Statistical Thermodynamics [3 0 0 3]	Elective I	Project [12]	
CHY 314 Physical Chemistry II [3 0 0 3]	CHY 324 Theoretical Spectroscopy [3 0 0 3]	CHY 414 Chemical Kinetics and Dynamics [3 0 0 3]	Elective II		
CHY 315 Organic Chemistry Laboratory [0 0 9 3]	CHY 325 Inorganic Chemistry Laboratory [0 0 9 3]	CHY 415 Physical Chemistry Laboratory [0 0 9 3]	Minor Project		
Minor Course I	Minor Course II	Minor Course III			
Credits=18	Credits=18	Credits=18	Credits=18	Credits = 18	Credits = 18

i^2 Chemical Sciences (Semester 5-10)

Semester 5	Semester 6	Semester 7	Semester 8	Semester 9	Semester 10
CHY 311 Coordination Chemistry [3 0 0 3]	CHY 321 Organometallic Chemistry [3 0 0 3]	CHY 411 Main Group Chemistry [3 0 0 3]	CHY 521 Instrumental methods for Structure Determination [3 0 0 3]	I2C 523 Chemical Genomics [3 0 0 3]	Project [18]
CHY 312 Organic Chemistry - Reactions and mechanisms [3 0 0 3]	CHY 323 Organic Chemistry- Synthetic methods [3 0 0 3]	CHY 412 Advanced Organic Chemistry [3 0 0 3]	I2C 521 Pharmacology and Pharmacokinetics [3 0 0 3]	Elective II [3 0 0 3]	
CHY 313 Quantum Chemistry [3 0 0 3]	BIO 323 Molecular Biology [3 0 0 3]	CHY 414 Chemical Kinetics and Dynamics [3 0 0 3]	I2C 421 Soft Matter and Polymers [3 0 0 3]	Project [12]	
CHY 314 Physical Chemistry II [3 0 0 3]	BIO 324 Cell Biology [3 0 0 3]	I2C 411 Medicinal Chemistry [3 0 0 3]	I2C 422 Biomaterials [3 0 0 3]		
CHY 315 Organic Chemistry Laboratory [0 0 9 3]	CHY 325 Inorganic Chemistry Laboratory [0 0 9 3]	I2C 412 Enzymology and Biocatalysts [3 0 0 3]	I2C 522 Computational Chemical Biology [3 0 0 3]		
I2C 311 Biochemistry & Bioconjugation [3 0 0 3]	Elective I [3 0 0 3]	I2C 413 Biophysical Chemistry [3 0 0 3]	I2C 423 Chemical Biology Lab [0 0 9 3]		

Electives Semester 6

Biology-Based
I2B 421 Bioinformatics
BIO 322 Immunology

Chemistry-Based
CHY 42XX Solid-State Chemistry
CHY 42XX Drug Discovery Design and Development

Physics-Based
I2P Principles of Digital imaging [3 0 0 3]
I2P Sensor Technology [3 0 0 3]

Biology-Based
BIO 411 Developmental Biology [3 0 0 3]
BIO 413 Microbiome and Vaccinology [3 0 0 3]

Chemistry-Based
CHY 51XX Modern Organic Synthesis: Advances in Methods and Reagents [3 0 0 3]
CHY 51XX Supramolecular chemistry [3 0 0 3]

Master of Science in Chemical Sciences (Semester 1-4)

<table>
<tr><th>Semester 1</th><th>Semester 2</th><th colspan="2">Semester 3</th><th colspan="2">Semester 4</th></tr>
<tr><td>MSC 311
Coordination Chemistry
[3 0 0 3]</td><td>MSC 321
Organometallic Chemistry
[3 0 0 3]</td><td colspan="2">MSC 411
Main Group Chemistry
[3 0 0 3]</td><td colspan="2">MSC 422
Physical Organic Chemistry
[3 0 0 3]</td></tr>
<tr><td>MSC 312
Organic Chemistry – Reactions and mechanisms
[3 0 0 3]</td><td>MSC 323
Organic Chemistry – Synthetic methods
[3 0 0 3]</td><td colspan="2">MSC 413
Chemical and Statistical Thermodynamics
[3 0 0 3]</td><td colspan="2">Elective V
[3 0 0 3]</td></tr>
<tr><td>MSC 313
Quantum Chemistry
[3 0 0 3]</td><td>MSC 324
Theoretical Spectroscopy
[3 0 0 3]</td><td colspan="2">MSC 414
Chemical Kinetics and Dynamics
[3 0 0 3]</td><td rowspan="4">MSC 429
Project
[12]</td><td>Elective VI
[3 0 0 3]</td></tr>
<tr><td>MSC 314
Physical Chemistry II
[3 0 0 3]</td><td>MSC 421
Instrumental Methods for Structure determination
[3 0 0 3]</td><td>Elective III
[3 0 0 3]
OR</td><td>MSC 418
Project
[3 Credits]</td><td rowspan="3">MSC 428
Project
[9]
OR</td></tr>
<tr><td>MSC 315
Organic Chemistry Lab
[3 0 0 3]</td><td>MSC 325
Inorganic Chemistry Lab
[3 0 0 3]</td><td colspan="2">MSC 415
Physical Chemistry Lab
[3 0 0 3]</td></tr>
<tr><td>Elective I
Biosystems MSC #### / Mathematics for Chemistry MSC ####
[2 0 0 2]</td><td>Elective II
[3 0 0 3]</td><td colspan="2">Elective IV
[3 0 0 3]</td></tr>
<tr><td>17</td><td>17-18</td><td colspan="2">16-18</td><td colspan="2">16-18</td></tr>
</table>

IPHD Chemical Sciences (Semester 1-6)

Semester 1	Semester 2	Semester 3	Semester 4
MSC 311 Coordination Chemistry [3 0 0 3]	MSC 321 Organometallic Chemistry [3 0 0 3]	MSC 411 Main Group Chemistry [3 0 0 3]	MSC 521 Instrumental methods for Structure Determination [3 0 0 3]
MSC 312 Organic Chemistry - Reactions and mechanisms [3 0 0 3]	MSC 322 Solid-State Chemistry [3 0 0 3]	MSC 412 Advanced Organic Chemistry [3 0 0 3]	MSC 522 Physical Organic Chemistry [3 0 0 3]
MSC 313 Quantum Chemistry [3 0 0 3]	MSC 323 Organic Chemistry-Synthetic methods [3 0 0 3]	MSC 413 Chemical and Statistical Thermodynamics [3 0 0 3]	Elective I [3 0 0 3]
MSC 314 Physical Chemistry II [3 0 0 3]	MSC 324 Theoretical Spectroscopy [3 0 0 3]	MSC 414 Chemical Kinetics and Dynamics [3 0 0 3]	Minor Project [6]
MSC 315 Organic Chemistry Laboratory [0 0 9 3]	MSC 325 Inorganic Chemistry Laboratory [0 0 9 3]	MSC 415 Physical Chemistry Laboratory [0 0 9 3]	
Credits=15	Credits=15	Credits=15	Credits=15

- *Semester 5 and 6 are designated for research project.*
- *Total credits for IPHD = 60*

List of Electives

Sl No:	List of Electives	Remarks
1	Biosystems	Elective - 2 credits
2	Mathematics for Chemistry (2002)	Elective - 2 credits
3	Advanced Organic Chemistry (3003)	Elective for MS - 3 credits
4	Principles of Inorganic Chemistry	Elective for PhD - 3 credits
5	Principles of Organic Chemistry	Elective for PhD - 3 credits
6	Principles of Physical Chemistry	Elective for PhD - 3 credits
7	Advanced Material Chemistry	3 Credits
8	Modern Organic Synthesis: Advances in Methods and Reagents	3 Credits
9	Computational Chemistry	3 Credits
10	Fundamentals of Solution-State NMR Spectroscopy: Principles and Applications	3 Credits
11	Solid State Chemistry	3 Credits
12	Catalysis in Organic Synthesis	3 Credits
13	Chemistry of Natural Products and Polymers	3 Credits
14	Electrochemistry	3 Credits
15	Name Reactions and Rearrangements - Application in Organic Synthesis	2 Credits
16	Chemistry of Carbohydrates, Amino Acids and Peptides	2 Credits
17	Chemistry of Heterocyclic Compounds	2 Credits
18	Chemistry of Natural Products	2 Credits
19	Basics of Supramolecular Chemistry	2 Credits
20	Polymer Chemistry	2 Credits
21	Group Theory in Chemistry	2 Credits
22	Advanced Electrochemistry	2 Credits
23	Basics of Nanoscience	1 Credit
24	Frontiers in Inorganic Chemistry	3 Credits
25	Metals in Biology	2 Credits
26	Main Group Catalysis	2 Credits

CORE COURSES - SYLLABUS

Course Name: Coordination Chemistry [3 0 0 3]	
Course Code: CHY 311 / MSC 311	
Prerequisites	NA
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, 3rd ed., 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, 5th ed., W. H. Freeman and Company New York, 2009. 6. G. L. Miessler and D. A. Tarr, Inorganic Chemistry, 3rd ed., Pearson, 2008. 7. J. E. House, Inorganic Chemistry, 3rd ed., Academic Press, 2019. 8. B. Douglas, D. McDaniel, and J. Alexander, Concepts and Models of Inorganic Chemistry, 3rd ed., Wiley, 2001. 9. J. E. Huheey, E. A. Keiter, and R. L. Keiter, Inorganic Chemistry – Principles of Structure and Reactivity, 4th ed., Pearson Education, 2006.

Course Name: Coordination Chemistry [3 0 0 3]	
Course Code: CHY 311 / MSC 311	
	10. R. L. Dutta and A. Syamal; Elements of Magnetochemistry, 2nd ed., Affiliated East-West Press, 2004. 11. W. Kaim and B. Schwederski, Bioinorganic Chemistry: Inorganic Elements in the Chemistry of Life, 2nd ed., Wiley, 2013. 12. R. R. Crichton, Biological Inorganic Chemistry - An Introduction, Elsevier, 2008.

Course Name: Organic Chemistry - Reactions and Mechanisms [3 0 0 3]	
Course Code: CHY 312 / MSC 312	
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	• 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] • 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] • 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] • Conjugate additions to α, β-unsaturated systems; direct addition versus conjugate addition [2] • 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. 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, 5th ed., Springer, 2008. 2. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2nd ed., Oxford University Press, 2012.

Course Name: Organic Chemistry - Reactions and Mechanisms [3 0 0 3]	
Course Code: CHY 312 / MSC 312	
	3. R. Bruckner, Advanced Organic Chemistry, Reaction Mechanisms, 3rd ed., Springer, 2010. 4. W.S. Carruthers and I. Coldham, Modern Methods of Organic Synthesis, 4th ed., Cambridge University Press, 2004.

Course Name: Quantum Chemistry [3 0 0 3]	
Course Code: CHY 313 / MSC 313	
Prerequisites	CHY111 or equivalent
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 [14] • 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 [12]

Course Name: Quantum Chemistry [3 0 0 3]	
Course Code: CHY 313 / MSC 313	
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 ed., Viva, 2011. 6. F. L. Pilar, Elementary Quantum Chemistry, 2nd ed., Dover Publications, 2001.

Course Name: Physical Chemistry II [3 0 0 3]	
Course Code: CHY 314 / MSC 314	
Prerequisites	CHY 221 (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	• Fundamentals of Electrochemistry: Electrochemistry as interdisciplinary science, electrochemistry and battery technology, and electrochemical approaches to environmental problems [4] • 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] • 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] • 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]

Course Name: Physical Chemistry II [3 0 0 3]	
Course Code: CHY 314 / MSC 314	
	• Surfaces: Physisorption and chemisorption, Brunauer-Emmett-Teller (BET) equation, estimation of surface area, surface films of liquids, Freundlich adsorption isotherm, and Langmuir adsorption isotherm [5] • 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] • 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, 2nd ed., Wiley Student ed., 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, 11th ed., Oxford University Press, 2018. 4. G. W. Castellan, Physical Chemistry, 3rd ed., Narosa Publishing House, 2004. 5. F. L. Pilar, Elementary Quantum Chemistry, 2nd ed., Dover Publications, 2001.

Course Name: Organometallic Chemistry [3 0 0 3]	
Course Code: CHY 321 / MSC 321 / CHY 621	
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	• General Concepts: Types of ligands and their binding modes, metal–ligand frontier orbital interactions, valence electron counting, usefulness and limitations of $18e^-$ rule [5] • 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] • 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]

Course Name: Organometallic Chemistry [3 0 0 3]	
Course Code: CHY 321 / MSC 321 / CHY 621	
	• 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] • 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] • Metal–ligand Multiple Bonds: Fischer and Schrock type carbene complexes, carbyne complexes, and metal–heteroatom (O/N) multiple bonds [5] • 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, 6th ed, 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, 2nd ed., Universities Press, 2013. 4. G. L. Miessler and D. A. Tarr, Inorganic Chemistry, 3rd ed., Pearson, 2008. 5. B. Douglas, D. McDaniel, and J. Alexander, Concepts and Models of Inorganic Chemistry, 3d ed., Wiley, 2010.

Course Name: Solid-State Chemistry [3 0 0 3]	
Course Code: CHY 322 / CHY 3202 / CHY 622	
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.

Course Name: Solid-State Chemistry [3 0 0 3]	
Course Code: CHY 322 / CHY 3202 / CHY 622	
Syllabus	• Solid State Structure: Types of solids, symmetry in crystals, X-ray diffraction, common crystal structure motifs, quasicrystals [12] • 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] • Thermal Properties: Lattice vibrations - phonon spectrum; lattice heat capacity; thermal expansion; thermal conductivity [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] • 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] • Optical properties: Optical reflectance, plasmon frequency, Raman scattering in crystals, photoconduction, photo and electroluminescence, photovoltaic, and photoelectrochemical effects [3] • General Concepts in Materials Synthesis: Phase diagrams, preparation of pure materials, nucleation and crystal growth, crystal growth techniques, and zone refining [2] • 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, 2rd ed, Wiley, 2014. 2. C. N. R. Rao and J. Gopalakrishnan, New Directions in Solid State Chemistry, 2nd ed, 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.

Course Name: Organic Chemistry — Synthetic Methods [3 0 0 3]	
Course Code: CHY 323 / MSC 323	
Prerequisites	CHY 312
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.

Course Name: Organic Chemistry — Synthetic Methods [3 0 0 3]	
Course Code: CHY 323 / MSC 323	
Syllabus	• 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] • 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] • Synthetic aspects of Diels-Alder reaction, inverse Diels-Alder reaction, hetero Diels-Alder reaction and ene-reaction [5] • 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] • 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, 4th ed., Cambridge University Press, 2004. 2. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2nd ed., Oxford University Press, 2012. 3. H.O. House, Modern Synthetic Reactions, 2nd Revised ed., Benjamin-Cummings Publishing, 1972. 4. R. Bruckner, Advanced Organic Chemistry, Reaction Mechanisms, 3rd ed., 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, 5th ed., Springer, 2008. 6. D. Nasipuri, Stereochemistry of Organic Compounds-Principle and Applications, 4th Revised ed., New Academic Science, 2012. 7. E. L. Eliel, S. H. Wilen and L. N. Mander, Stereochemistry of Carbon Compounds, 1st ed., Wiley, 2010.

Course Name: Theoretical Spectroscopy [3 0 0 3]	
Course Code: CHY 324 / MSC 324 / CHY 624	
Prerequisites	CHY 313 (Quantum Chemistry) or equivalent
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	• 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] • 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] • 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] • 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 [6] • 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 [6]
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, 20040.

Course Name: Theoretical Spectroscopy [3 0 0 3]	
Course Code: CHY 324 / MSC 324 / CHY 624	
	5. M. H. Levitt, Spin Dynamics: Basics of Nuclear Magnetic Resonance, 2nd ed., Wiley, 2008.

Course Name: Main Group Chemistry [3 0 0 3]	
Course Code: CHY 411 / MSC 411 / CHY 614	
Prerequisites	NA
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	• Hydrogen: Preparation, properties and applications of dihydrogen; molecular, saline and metallic hydrides; hydrogen bonding [4] • 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] • 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] • 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] • 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] • 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] • 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] • Noble Gases: Occurrence and chemical properties, Bartlett discovery of reactivity of noble gases; synthesis, structure, and reactivity of fluorides and oxides of xenon [4]

Course Name: Main Group Chemistry [3 0 0 3]	
Course Code: CHY 411 / MSC 411 / CHY 614	
Text & Reference Books	1. P. Atkins, T. Overton, J. Rourke, F. Armstrong, and M. Hagerman, Shriver and Atkins' Inorganic Chemistry, 5th ed., W. H. Freeman and Company New York, 2009. 2. N. N. Greenwood, A. Earnshaw, Chemistry of the Elements, 2nd ed., Elsevier, 1997. 3. F. A. Cotton, G. Wilkinson, C. A. Murillo, and M. Bochmann, Advanced Inorganic Chemistry, 6th ed., Wiley. 4. A. J. Elias; The Chemistry of p-Block Elements: Synthesis, Reactions, and Applications, 2nd ed., Universities Press, 2019. 5. J. E. House, Inorganic Chemistry, 3rd ed., Academic Press, 2019.

Course Name: Advanced Organic Chemistry [3 0 0 3]	
Course Code: CHY 412 / CHY 4102 / CHY 615	
Prerequisites	CHY 312 & CHY 323
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	• 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] • Asymmetric Synthesis: Sharpless epoxidation and dihydroxylation; Jacobsen-Katsuki and Shi epoxidation; CBS reduction, Midland-alpine borane reduction, Noyori asymmetric reduction [9] • 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] • Natural Products: Structure, properties and reactions of mono- and di-saccharides, steroids, terpene and terpenoids, carotenoids, and alkaloids [8] • 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]

Course Name: Advanced Organic Chemistry [3 0 0 3]	
Course Code: CHY 412 / CHY 4102 / CHY 615	
Text & Reference Books	1. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2nd ed., Oxford University Press, 2012. 2. R. Bruckner, Advanced Organic Chemistry, Reaction Mechanisms, 3rd ed., Springer, 2010. 3. E. L. Eliel, S. H. Wilen and L. N. Mander, Stereochemistry of Carbon Compounds, 1st ed., Wiley, 2010. 4. D. Nasipuri, Stereochemistry of Organic Compounds-Principle and Applications, 4th Revised ed., New Academic Science, 2012. 5. W. S. Carruthers and I. Coldham, Modern Methods of Organic Synthesis, 4th ed., Cambridge University Press, 2004. 6. L. Kurti and B. Czako, Strategic Applications of Named Reactions in Organic Synthesis, 1st ed., 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, 5th ed., Springer, 2008. 8. John A. Joule and Keith Mills, Heterocyclic Chemistry, 5th ed., Wiley-Blackwell, 2013. 9. I. L. Finar, Organic Chemistry, Vol. 2: Stereochemistry and the Chemistry Natural Products, 5th ed., Pearson, 2002.

Course Name: Chemical and Statistical Thermodynamics [3 0 0 3]	
Course Code: CHY 413 / MSC 413 / CHY 616	
Prerequisites	CHY313 or equivalent
Learning Outcomes	To provide a molecular level interpretation of the bulk properties of chemical systems in terms of the concepts of probability theory
Syllabus	• 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 [6] • Ensembles and averages: Ergodic hypothesis, canonical ensemble, microcanonical ensemble, grand canonical ensemble, partition functions, equivalence of various ensembles, and fluctuations [9] • Atomic and molecular degrees of freedom: Translational, rotational, vibrational, electronic, and electronic and nuclear spin degrees of freedom, and equipartition theorem [4] • Chemical equilibria: Chemical equilibrium and thermodynamic properties, enthalpy, entropy, free energy, chemical potential, and equilibrium constants in terms of partition functions [4]

Course Name: Chemical and Statistical Thermodynamics [3 0 0 3]	
Course Code: CHY 413 / MSC 413 / CHY 616	
	• Quantum statistics: Review of Boltzmann distribution, Bose-Einstein and Fermi-Dirac statistics, and Bose-Einstein condensation [4] • Solids: Einstein and Debye models and heat capacities [3] • Gases: Intermolecular potentials, equations of state, non-interacting classical and quantum gases, equipartition theorem, and Gibbs paradox [4] • Stochastic processes: Brownian motion, Langevin equation, and random walk problem in one-dimension [3] • Non-equilibrium statistical mechanics: Linear response theory, fluctuation-dissipation theorem, time-correlation functions, and applications to transport phenomena [3]
Text & Reference Books	1. D. A. McQuarrie, Statistical Mechanics, Viva Student ed., 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 ed., 2018. 5. H. B. Callen, Thermodynamics and an Introduction to Thermostatistics, 2nd ed., Wiley, 2006.

Course Name: Chemical Kinetics and Dynamics [3 0 0 3]	
Course Code: CHY 414 / MSC 414	
Prerequisites	CHY221 and CHY 314 (physical chemistry I and II)
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	• 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 [7] • 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 [19]

Course Name: Chemical Kinetics and Dynamics [3 0 0 3]	
Course Code: CHY 414 / MSC 414	
	• 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 [5] • 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 [9]
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 ed., Viva, 2017. 5. J. I. Steinfeld, J.S. Francisco and W. L. Hase, Chemical Kinetics and Dynamics, 2nd ed., Prentice Hall, 1999.

Course Name: Instrumental Methods for Structure Determination [3 0 0 3]	
Course Code: CHY421 / MSC 421 / CHY 617	
Prerequisites	NA
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	• Infrared and UV Spectroscopy: Functional group characterization using IR technique; classification of UV absorption bands, examples of UV chromophores, Woodward rule. [3] • 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] • 13C-NMR: natural abundance, sensitivity, 13C chemical shifts and structure correlations, 13C satellites, and DEPT. [2] • 2D NMR: COSY, one-bond (HSQC) and multiple-bond (HMBC) 1H–13C correlations; defining molecular stereochemistry using the Nuclear Overhauser Effect (NOE); dynamic processes by NMR - restricted rotation (DMF, DMA, biphenyls, annulenes), ring inversion etc. [4]

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<tr><th colspan="2">Course Name: Instrumental Methods for Structure Determination [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: CHY421 / MSC 421 / CHY 617</th></tr>
<tr><td></td><td>
• 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]
• Structure elucidation of organic compounds using above techniques. [5]
• 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]
• 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]
• Mössbauer Spectroscopy: Introduction and analysis of spectral patterns of zero-field spectrum to determine oxidation state, spin state, and coordination geometry with examples. [3]
• X-ray Photoelectron Spectroscopy: Basic concepts and application to determine atomic charges, oxidation state, and catalyst surface structures; analysis of spectrum with examples. [3]
• X-ray Absorption Spectroscopy: Basic concepts and application to determine oxidation state, spin state, and coordination geometry; analysis of spectrum with examples. [3]
• Structure elucidation of inorganic compounds using above techniques. [2]
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<tr><td>Text & Reference Books</td><td>
1. R. M. Silverstein, F. X. Webster, D. J. Kiemle, and D. L. Bryce, Spectrometric Identification of Organic Compounds, 8th ed., Wiley, 2014.
2. W. Kemp, Organic spectroscopy, 2nd ed., Macmillan, 2019.
3. L. D. Field, S. Sternhelland, J.R. Kalmann, Organic Structures from Spectra, 5th ed., Wiley, 2012.
4. M. H. Levitt, Spin Dynamics, 2nd ed., Wiley, 2008.
5. S. Braun, H. O. Kalinowski and S. Berger, 150 and More Basic NMR Experiments, 2nd Revised ed., Wiley-VCH, 1998.
6. D. Neuhaus and M. Williamson, The Nuclear Overhauser Effect in Structural and Conformational Analysis, 2nd ed., Wiley-Blackwell, 2008.
7. D. L. Pavia, G. M. Lampman, G. S. Kriz, J. A. Vyvyan, Introduction to Spectroscopy 5th ed., Cengage, 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.
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Course Name: Physical Organic Chemistry [3 0 0 3]	
Course Code: CHY422 / MSC 422 / CHY 626	
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, ET, a, b, AN and DN, 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 sp3, sp2, 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, 2nd ed., Pearson, 1995. 2. T. H. Lowry and K. S. Richardson, Mechanism and Theory in Organic Chemistry, 3rd ed., Pearson, 1997. 3. P. Deslongchamps, Stereoelectronic 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, 1st ed., Wiley-Blackwell, 2007. 6. H. Maskill, The Physical Basis of Organic Chemistry, Oxford University Press, 1985.

Course Name: Instrumental Methods for Structure Determination [3 0 0 3]	
Course Code: CHY 521	
Prerequisites	NA
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	• Infrared and UV Spectroscopy: Functional group characterization using IR technique; classification of UV absorption bands, examples of UV chromophores, Woodward rule [3] • NMR Spectroscopy: 1H-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] • 13C-NMR: natural abundance, sensitivity, 13C chemical shifts and structure correlations, 13C satellites, and DEPT [2] • 2D NMR: COSY, one-bond (HSQC) and multiple-bond (HMBC) 1H–13C correlations; defining molecular stereochemistry using the Nuclear Overhauser Effect (NOE); dynamic processes by NMR - restricted rotation (DMF, DMA, biphenyls, annulenes), ring inversion etc [4] • 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] • Structure elucidation of organic compounds using above techniques [5] • 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] • 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] • Mössbauer Spectroscopy: Introduction and analysis of spectral patterns of zero-field spectrum to determine oxidation state, spin state, and coordination geometry with examples [3] • X-ray Photoelectron Spectroscopy: Basic concepts and application to determine atomic charges, oxidation state, and catalyst surface structures; analysis of spectrum with examples [3] • X-ray Absorption Spectroscopy: Basic concepts and application to determine oxidation state, spin state, and coordination geometry; analysis of spectrum with examples [3] • Structure elucidation of inorganic compounds using above techniques [2]

Course Name: Instrumental Methods for Structure Determination [3 0 0 3]	
Course Code: CHY 521	
Text & Reference Books	1. R. M. Silverstein, F. X. Webster, D. J. Kiemle, and D. L. Bryce, Spectrometric Identification of Organic Compounds, 8th ed., Wiley, 2014 2. W. Kemp, Organic spectroscopy, 2nd ed., Macmillan, 2019. 3. L. D. Field, S. Sternhelland, J.R. Kalmann, Organic Structures from Spectra, 5th ed., Wiley, 2012. 4. M. H. Levitt, Spin Dynamics, 2nd ed., Wiley, 2008. 5. S. Braun, H. O. Kalinowski and S. Berger, 150 and More Basic NMR Experiments, 2nd Revised ed., Wiley-VCH, 1998. 6. D. Neuhaus and M. Williamson, The Nuclear Overhauser Effect in Structural and Conformational Analysis, 2nd ed., Wiley-Blackwell, 2008. 7. D. L. Pavia, G. M. Lampman, G. S. Kriz, J. A. Vyvyan, Introduction to Spectroscopy 5th ed., Cengage, 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.

Course Name: Physical Organic Chemistry [3 0 0 3]	
Course Code: CHY 522	
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, ET, a, b, AN and DN, 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]

Course Name: Physical Organic Chemistry [3 0 0 3]	
Course Code: CHY 522	
	• 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 sp3, sp2, 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 (PET and CET) [2]
Text & Reference Books	1. N. S. Isaacs, Physical Organic Chemistry, 2nd ed., Pearson, 1995. 2. T. H. Lowry and K. S. Richardson, Mechanism and Theory in Organic Chemistry, 3rd ed., 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, 1st ed., Wiley-Blackwell, 2007. 6. H. Maskill, The Physical Basis of Organic Chemistry, Oxford University Press, 1985.

Thematic Subjects for *i*² Chemical Sciences

Course Name: Biochemistry & Bioconjugation [3 0 0 3]	
Course Code: I2C 311	
Prerequisite	NA
Learning Outcomes	To impart knowledge about the biochemical processes and bioconjugation techniques to unravel biological functions and dynamics of biomolecules (proteins, nucleic acids, polysaccharides, lipids etc.) and to equip the students for careers in pharmaceutical industry/Chemical biology research. The course consist of Biochemistry module from BIO 314 & Bioconjugation module given by chemistry department
Syllabus	• Introduction to bioconjugation: Protein chemistry, reactive groups, different functional groups targeting reactions, blocking of specific functional groups, buffer systems • Bioconjugate reagents: different cross linkers (zero, homo and hetero-biofunctional cross linkers etc.), cleavable cross linkers, fluorescent tags, biotinylation reagents, radio-labeling reagents, light activated reagents • Practical applications and techniques: PEGylation of proteins, microspheres, liposomes, dendrimers, immobilization of proteins, antibody-enzyme conjugate (ELISA), label transfer reagents, DNA probes and hybridization, bioorthogonal reagents (click chemistry), Solid-phase peptide synthesis, labelling of sugars, bioconjuagation by exploiting Cell's translational machinery (Auxotrophs)-Bioconjugation using posttranslational machinery (Formyl glycine generating enzymes) • Application of bioconjugates with examples
Text & Reference Books	1. Bioconjuagte Techniques, Greg T. Hermanson, 3rd ed., Academic Press, 2013. 2. Bioconjugation: Methods and Protocols, Sam Massa & Nick Devoogdt, Humana Press, 2019. 3. Kuriyan, Konforti & Wemmer, The molecules of life: Physical and chemical principles, 2012. 4. Walsh, Enzymatic reaction mechanisms, 1978

Course Name: Medicinal Chemistry [3 0 0 3]	
Course Code: I2C 411	
Prerequisite	Organic Chemistry — Reactions and Mechanisms, Organic Chemistry — Synthetic Methods (desirable)
Learning Outcomes	Describe the overall process of drug discovery, and the role played by medicinal chemistry in this process. Demonstrate an understanding of concepts such as drug metabolism, bioavailability and pharmacokinetics and the role of medicinal chemistry in improving these parameters.

<table>
<tr><th colspan="2">Course Name: Medicinal Chemistry [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: I2C 411</th></tr>
<tr><td>Syllabus</td><td>

Structure, energy and interactions in drug molecules [2]
Receptorology, Enzyme Inhibition, drug action and metabolism, chirality in drug design, The Lipinski's Rule in drug discovery [4]
Routes of administration, drug leads and pharmacokinetics (PK), ADME [3]
Structure-Activity Relationships (SAR): Structural modifications in drug design Oral bioavailability-Quantitative SAR-Receptor interactions, Receptor interaction theories [4]
Enzyme inhibitors: Stereochemistry, Enzymes-Enzyme mechanisms, Enzyme inhibition, Reversible enzyme inhibitors, Transition-State inhibitors, Irreversible enzyme inhibitors/inactivators, antibiotics-Enzyme inhibitors [6]
Case Studies, discovery of antibiotic [2]
Drug Metabolism-Discovery; Anticancer Types of drug metabolism-anticancer MMP inhibitors Prodrugs [3]
Physico-chemical properties: drug-likeness, design (diversity, scaffold-hopping), halogenes in biologically active organic substances [3]
Proteins: structures, protein-ligand interactions, sequence/structure homology, structure-based design, docking [6]
Synthesis of substances: Retrosynthetic analysis, diversity-oriented synthesis, scaffold-based synthesis using example benzodiazepines, piperidinones, indoles, purines, and benzofurans [5]
Biological evaluation of substances: Cell-free assays, whole cell assays , animal assays [4]

</td></tr>
<tr><td>Text & Reference Books</td><td>

The Organic Chemistry of Drug Design and Drug action. Richard B. Silverman, 2nd ed., Academic Press, 2004.
Medicinal Chemistry: Principles and Practice, F. D. King, 2nd ed., RSC, 2002.
Real World Drug Discovery: A Chemist’s Guide to Biotech and Pharmaceutical Research. Robert M. Rydzewski, Elsevier, 2008.
The Practice of Medicinal Chemistry, Camille-Georges Wermuth, 3rd ed., Academic Press, 2008.
Graham L. Patrick. An Introduction to Medicinal Chemistry, Oxford 6th ed., 2013.
John Saunders. Top Drugs, Top Synthetic Routes, Oxford University Press, 1st ed., 2012.

</td></tr>
</table>

Course Name: Enzymology and Biocatalysis [3 0 0 3]	
Course Code: I2C 412	
Prerequisite	Physical Chemistry I

Course Name: Enzymology and Biocatalysis [3 0 0 3]	
Course Code: I2C 412	
Learning Outcomes	The course provides understanding of the potential of biocatalysts for the molecular transformation of simple molecules. Advantages of biocatalysts and chemo-catalysts, as well as the complementation of these sub-disciplines of catalysis are given. The course should be able to equip the student to responsibly select the right biocatalyst, process conditions and reactions for required transformations.
Syllabus	• Introduction, general characteristics of enzymes, purification and structure of enzymes [3] • Mechanism of enzyme action: Activation energy, coupled reactions, active site and its importance, thermodynamics and equilibrium, enzyme activity, specific activity and units, enzyme turnover [4] • Case studies : Enzymes in organized system and enzymes in cells, EgsIsozyme, Ribozymes, Zymogens, Abzymes, Classification and nomenclature of enzymes [3] • Regulation and control of enzyme activity: reversible covalent modification, irreversible covalent modification, half-site reactivity, bifunctional enzymes, compartmentalization [4] • Enzyme Inhibition: Models and types of inhibition, kinetics and diagnostic plots multi-substrate enzymes, multisite and allosteric enzymes, models and examples [4] • Applications of enzymology: Clinical aspect of enzymology, enzyme technology, enzyme assay (types, continuous and discontinuous assays, optimization of enzyme assays, factors influencing catalytic efficiency and the mechanisms employed) [7] • Introduction to biocatalytic reactions: hydrolyses, oxidoreductase, Diels Alderase, epoxidase, cyclo-oxygenase, isomerases, lysasase, phosphorylase, glycosyl transferase [6] • Biocatalysis in biofuels: hydrolyse of cellulose, biocatalysis in the synthesis of pharmaceutical intermediates [9]
Text & Reference Books	1. Enzyme Biocatalysis: Principles and Applications, Andrés Illanes, Springer Netherlands, 2008. 2. Fundamentals of Enzymology: Cell and Molecular Biology of Catalytic Proteins, Nicholas C. Price & Stevens Lewis, OUP, 1999. 3. Modern Biocatalysis: Stereoselective and Environmentally Friendly Reactions, Wolf-Dieter Fessner & Thorleif Anthonsen, Wiley VCH, 2009. 4. Enzymology, T. Devasena OUP, 2010. 5. Applied Biocatalysis, 2nd ed., edited by Adrie J. J. Straathof and Patrick Adlecreutz., CRC press, 2000. 6. Biocatalysis, Fundamentals and Applications, A. S. Bommarius, Bettina R. Riebel Bommarius, Wiley-VCH, 2004. 7. Introduction to Biocatalysis using Enzymes and Microorganisms, Stanley M. Roberts, Nicholas J. Turner, Andrew J. Willets, Michael K. Turner, Cambridge University Press, 1995.

Course Name: Biophysical Chemistry [3 1 0 3]	
Course Code: I2C 413	
Prerequisite	Physical Chemistry 1 & II (desirable)
Learning Outcomes	The course emphasises the connections between molecular structure, interactions, and biological function. The course also introduces students to the methods used to visualize and analyze macromolecular structures and assemblies.
Syllabus	• **Basics of thermodynamics and Kinetics of biological process**: Chemical equilibria, thermodynamics of transport process (diffusion), redox reaction is biology (respiratory chain, light reaction in biology), electrochemical potential and membrane potential [4] • Electrophysiology: patch clamp method [2] • Enzyme kinetics: Cooperativity and Hill equation, inhibition of enzyme activity [2] • Protein folding: driving force, Levinthal paradox, energy landscape for protein folding, folding pathways [2] • Protein-protein interactions: Energetics of macromolecular interactions, role of water [2] • Nucleic acids: structure of DNA and RNA; folding of RNA, DNA-protein interaction, small molecule binding to DNA [2] **Methods**: • Optical spectroscopy, linear and circular dichorism and IR [2] • Fluorescence: fluorescence anisotropy, time resolved fluorescence, Foerster resonance energy transfer [4] • Light scattering, solution scattering, SAXs and small angle neutron scattering [4] • Imaging and Microscopy: Fluorescence(Wide-field, confocal scanning, Fluorescence lifetime imaging) microscopy techniques, fluorescence correlation spectroscopy, single molecule fluorescence microscopy, super resolution microscopy. [7] • Electron microscopy: Principle of electron microscopy, 3D electron microscopy, cryo-electron tomography and single particle cryo-EM [5] • Scanning probe microscopy: Scanning tunnelling, scanning force microscopy [2] • Atomic force Microscopy: Force spectroscopy with AFM optical and magnetic tweezers [2]
Text & Reference Books	1. Biophysical Chemistry by Dagmar Klostermeier & Markus G. Rudolph, CRC Press, 2020. 2. Charles Cantor, Paul Schimmel. Biophysical Chemistry Part 1, W. H. Freeman; 1980. 3. Charles Cantor, Paul Schimmel. Biophysical Chemistry Part 2, W. H. Freeman; 1980. 4. Charles Cantor, Paul Schimmel. Biophysical Chemistry Part 3, W. H. Freeman; 1980. 5. Alan Fersht. Enzyme Structure and Mechanism (1985), W H Freeman & Co (Sd), 1985. 6. David Eisenberg and Donald Crothers. Physical Chemistry with Applications to Life Sciences, The Benjamin / Cummings Publishing Company, 1979.

Course Name: Biophysical Chemistry [3 1 0 3]	
Course Code: I2C 413	
	7. Modern Biophysical Chemistry by Peter Jomo Wall, Second ed., Wiley-VCH, 2014.

Course Name: Soft Matter and Polymers [3003]	
Course Code: I2C 421	
Prerequisite	Physical Chemistry-1
Learning Outcomes	The course covers topics on the physical chemistry of soft matter, liquid crystals, surfactants, colloidal particles and polymers. The course will deepen the understanding of the structure, dynamics and properties of these materials in a concerted manner and introduce you to some of their technical applications.
Syllabus	• Introduction: Intermolecular interactions, structural organization, dynamics, Phase transition, order parameters, scaling laws, polydispersity, experimental techniques for investigating soft matter, thermodynamic and mechanical properties of soft matter, aggregation and assembly [8] • Liquid crystals: Introduction, anisotropy in liquid crystals, thermotropic and Lyotropic liquid crystals, birefringence in liquid crystals, thermotropic liquid crystal phases, various experimental technique to characterise the liquid crystal [6] • Applications of liquid crystals: LC displays, the twisted Nematic displays, spatial light modulators, LC temperature sensors [2] • Surfactants: Surface tension and surfactants, self-assembly and phase behaviour; membrane elasticity and curvature; Applications of surfactants (Detergent, detergent foams, Emulsifiers & emulsions, paints and inks, surfactants and gel electrophoresis, lung surfactants [6] **Polymers** • Polymer Introduction: polymer structure, LC polymers, Polymer solutions; Natural Polymers, organic chemistry and polymers, polymer synthesis, condensation & free radical polymerizations, polycarbonates and polyanhydrides, degradation, glassy and polymer melt phases, the mechanical properties of polymer [6] • Functional polymers, Responsive Polymers & Scaffolds; controlled drug delivery, nanostructured polymers, polymers at interfaces, polymer mechanics and rheology, self-assembly, polymers in energy [6] • Colloidal materials: Characteristics of colloidal systems, colloids in suspension, forces in collided dispersions, interparticle interactions, colloidal aggregations, colloidal crystals, granular materials, foams [6]
Text & Reference Books	1. Fundamentals of Soft matter Science by Linda S. Hirst (CRC press), 2019. 2. Polymer Chemistry by Malcolm P. Stevens, Oxford University Press, Inc, 1990. 3. Text book of polymer Science, Billmeyer, John Wiley and Sons 1984.

Course Name: Soft Matter and Polymers [3003]	
Course Code: I2C 421	
	4. Principles of Polymer Systems, Rodriguez, Hemisphere Publishing Corpn, 1982. 5. Introduction to Polymer Science and Technology, H. S. Kaufman and J. J. Falcetta, Wiley, 1977. 6. Polymer chemistry, Seymour and Carraher, Marcel Dekker, CBS Publishers, 2003. 7. Odian, George. Principles of Polymerization. 4th ed. Hoboken, N. J, 2004.

Course Name: Biomaterials [3 0 0 3]	
Course Code: I2C 422	
Prerequisite	Fundamental Chemistry courses and polymer & soft matter (desirable)
Learning Outcomes	The course focuses on the study of biocompatible, biomimetic and nature-based materials as well as their diverse areas of application. The course provides an understanding of the characteristics of common biomaterials, its structure, properties and morphology. Students also learn the different interaction between biomaterials, proteins and cells.
Syllabus	• Concepts in material science: bulk properties of materials, surface properties and surface characterisation of materials, interpretation of phase diagram [10] • Classes of materials used in medicine: Polymers, silicone biomaterials, hydrogels, smart polymers, metals (basic structure and types of alloys, stress-strain behaviour, hardness, impact energy, fractured toughness, fatigue) [8] • Ceramics and glasses: characterising crystalline and non-crystalline materials, mechanical properties and processing methods: brittle fracture, static fatigue, thermal shock and viscous deformation, composites, surface immobilised biomolecules [6] • Biological response to biomaterials: biocompatibility and heme compatible, mechanism of foreign body response to implanted biomaterials. biodegradation of biomaterials. surface modification to control biological response [8] • Biomaterial application: biomaterial for joint versus blood vessel, biomaterial for soft and hard tissue replacement, cardiovascular, drug delivery system, biosensors, synthetic bioresorbable polymer scaffolds [8]
Text & Reference Books	1. Biomaterial Science by Buddy Ratner, Allan Hoffman, Frederick Schoen, Jack Lemons, Academic press, 2012. 2. Biomaterials: The Intersection of Biology and Materials Science by J.S. Temenoff and A.G. Mikos, Pearson Prentice Hall, 2008. 3. Fundamentals of Biomaterials by Vasif Hasirci & Nesrin Hasirci, Springer, 2018.

Course Name: Experimental Chemical Biology [0 0 93]	
Course Code: I2C 423	
Prerequisite	NA
Learning Outcomes	To provide hands on training on the techniques involved in chemical biology and to equip the students for careers in pharmaceutical industry/chemical biology research.
Syllabus	• DNA Synthesis and DNA hybridization. [9] • Doubly labelled Peptide-nucleic acids as probes for the detection of DNA point mutation. [9] • Synthesis and Characterization of a covalent oligonucleotide-streptavidin conjugate and its applications in DNA directed immobilization. [9] • Solid Phase Synthesis of peptides: Bradykinin Analogs and the evaluation of calcium mobilization in PC-12 cells [9] • In silico Protein Ligand Design [9] • Lipidation of proteins and peptides: Farnesylation of the Ras proteins [18] • Insertion of lapidated peptides into model membranes [9] • Isolation of potato phosphorylase and enzymatic Synthesis of amylose [9] • Proteome analysis: identification of proteins isolated from yeast [9] • Lectins: determination of the sugar specificity of jacalin by a sugar-lectin binding assay [9] • Combinatorial synthesis and genetic algorithm [9] • Solid-phase synthesis of an antibiotic [9]
Text & Reference Books	1. Chemical Biology, A practical course. Herbert Waldmann, Petra Janning. Wiley-VCH, 2004.

Course Name: Pharmacology and Pharmacokinetics [3 0 0 3]	
Course Code: I2C 521	
Prerequisite	NA
Learning Outcomes	The course explores drug actions on living systems, their metabolism, and their toxic effects. The course focuses on the main principles of pharmacology: pharmacokinetics; drug metabolism and its transport and drug therapy

Course Name: Pharmacology and Pharmacokinetics [3 0 0 3]	
Course Code: I2C 521	
Syllabus	• General pharmacology and pharmacodynamics. a general understanding of how drugs work and how their actions may be modified [10] • Pharmacokinetics: variability in drug response, pharmaceutical aspects and drug development, how drugs are developed, formulated and the importance of additives in drugs [6] • Pharmacology of drugs used in anesthesia, intensive care and pain medicine, inhalational anaesthetic agents, intravenous anesthetic agents, local anesthetic drugs-pain, non-steroidal anti-inflammatory drugs, neuromuscular blocking agents [8] • Anticholinesterase drugs, anticholinergic drug, pharmacology of the autonomic nervous system, adrenoceptor blocking agents, anti-hypertensive drugs, anti-arrhythmic drugs, therapy of cardiac arrest, ischemia and failure, neuropharmacology, anti-emetic drugs, respiratory pharmacology and therapeutic gases, histamine and serotonin, diuretics, drugs and coagulation, obstetric pharmacology, endocrine pharmacology, gastrointestinal pharmacology, intravenous fluids, pharmacological basis of poisoning, chemotherapeutic drugs [16]
Text & Reference Books	1. A Pharmacology Primer: Theory, Application and Methods. Terry P. Kenakin, 3rd ed., Academic Press, 2009. 2. Golan, D., et. al., eds. Principles of Pharmacology: The Pathophysiologic Basis of Drug Therapy, Lippincott Williams & Wilkins, 2012. 3. Hardman, J. G., et. al., eds. Goodman and Gilman's The Pharmacological Basis of Therapeutics. McGraw Hill, 2011. 4. Molecular Biology in Medicinal Chemistry 1st ed., Theodor Dingermann, Dieter Steinhilber, Gerd Folkers, Wiley-VCH, 2004. 5. Pharmacokinetics Made Easy, Donald Birkett, McGraw-Hill, 2002. 6. Drug-like Properties: Concepts, Structure Design and Methods: from ADME to Toxicity Optimization, Li Di, Edward H Kesrns, 1st ed., Academic Press, 2008.

Course Name: Computational methods in Chemical Biology [3 0 0 3]	
Course Code: I2C 522	
Prerequisite	Quantum Chemistry
Learning Outcomes	The course applies computational methods to understand chemical and biochemical properties and processes. The course also emphasises on the required theory and application of atomistic simulations needed to model and understand systems of biological relevance (proteins, DNA, small molecule therapeutic drug properties)

Course Name: Computational methods in Chemical Biology [3 0 0 3]	
Course Code: I2C 522	
Syllabus	• Molecular structure and Stability: Proteins, peptide bond, post translational modifications, protein structure, protein-protein interactions, membrane protein and their lipid environment [5] • Folding and stability: energy landscape for protein folding, protein folding disease [3] • Nucleic acids: Structure of DNA and conformations, higher order DNA structures, DNA interactions with proteins [3] • RNA structure: secondary structure, tertiary structure, RNA folding [2] • Protein sequence composition and properties, secondary structure prediction [2] • Molecular modelling: Force fields, Energy minimisation, molecular mechanics and dynamics, Boundary conditions and solvation, integration of Newtonian equations, trajectory analysis, extraction of information from MD, enhanced configurational sampling, simulating rare events [10] • Applications: Fold recognition, homology modelling, simulated annealing, coarse-grained modelling [4] • Design of substances: Conformational analysis and basic cheminformatics; force-field, energy minimisation, 3Ds, pharmacophore identification, sub-structure search, similarity search, databases [5] • Computational Chemistry: structure, energies, conformational analysis of small molecules; studies of biomolecules and interactions between drug molecules and receptors, rational design, structure-based design, docking [6]
Text & Reference Books	1. Biophysical Chemistry by Dagmar Klostermeier & Markus G. Rudolph, CRC press, 2020. 2. Real World Drug Discovery: A Chemist's Guide to Biotech and Pharmaceutical Research. Robert M. Rydzewski, Elsevier, 2008. 3. Molecular dynamic simulation by J.M. Haile, Wiley, 1997. 4. Computational Tools for Chemical Biology, by Sonsoles Martín-Santamaría. RSC publishing, 2017.

Course Name: Chemical Genomics and Proteomics [3 0 0 3]	
Course Code: I2C 523	
Prerequisite	Biochemistry
Learning Outcomes	A comprehensive introduction to the origins and emerging frontiers of chemical biology. This course develops the fundamental chemistry of molecules in nature, a quantitative description of their interaction with themselves and each other and subsequent effects on biological function.

<table>
<tr><th colspan="2">Course Name: Chemical Genomics and Proteomics [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: I2C 523</th></tr>
<tr><td>Syllabus</td><td>• Protein design
• Molecular evolution
• Chemical genetics
• Metabolic engineering
• Methods in genomics and proteomics research.
• Biomolecules: lipids, carbohydrates, peptides and nucleic acids-
• Chemical methods to synthesize proteins and peptides-
• Chemical methods to synthesize DNA and RNA
• DNA recognition
• Protein-Protein interactions
• Ligands for protein surfaces
• Small molecule arrays</td></tr>
<tr><td>Text & Reference Books</td><td>1. Chemical Biology: From Small Molecules to Systems Biology and Drug Design, vol 1-3, Stuart L. Schreiber, Tarun M. Kapoor & Günther Wess, Wiley VCH, 2007.
2. Chemical Genomics and Proteomics, Ferenc Darvas, Andras Guttman, Gyorgy Dorman, 2nd ed., CRC press, 2016.
3. Essentials of Chemical Biology, Andrew Miller & Julian Tanner, Wiley, 2008.
4. Chemical genomics, Ferenc Darvas, Andras Guttman, Gyorgy Dorman, Marcel Dekker, 2004.</td></tr>
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LABORATORY COURSES - SYLLABUS

Course Name: Organic Chemistry Laboratory [0 0 93]	
Course Code: CHY 315 / MSC 315	
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	**Experiment No 1: Protection of Alcohol and Amine Groups** (9) a) Boc_2O protection of amine. b) Alcohol protection with tosyl chloride. **Experiment No 2: Michael Addition** (9) a) Hydrolysis of 2-amino-6-methylbenzothiazole b) Aza-Michael addition reaction **Experiment No 3: Wittig Reaction** (9) a) Preparation of ylide c) Synthesis of ethyl cinnamate **Experiment No 4: Reductive Amination** (9) a) Synthesis of imine. b) Reduction of imine. **Experiment No 5: Oxidation of Aromatic Amine** (9) Synthesis of 2,2'-(diazene-1,2-diyl) diphenol. **Experiment No 6: Bromination of Binaphthol** (9) Synthesis of (R)-6,6''-dibromo-2,2''-dihydroxy-1,1''-binaphthyl. **Experiment No 7: Acetylation of Glucose** (9) Acetylation of glucose **Experiment No 8: Ketalization of Mannitol** (9) Ketalization of mannitol **Experiment No 9: Pyrylium Tetrafluoroborate** (9) Coupling of aldehyde and acetophenone. **Experiment No 10: $KMNO_4$ Oxidation of Dimethyl Pyridine** (9) Synthesis of dipicolinic acid **Experiment No 11: Synthesis of Diazene** (18) a) Coupling of dicarbonate and hydrazine. b) Bromine mediated oxidation of hydrazine to diazene. **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

Course Name: Inorganic Chemistry Laboratory [0 0 93]	
Course Code: CHY 325 / MSC 325	
Prerequisites	
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	**Experiment 1** – Linkage isomers of nitro-pentammine-cobalt (III): (a) Synthesis of [Co(NH3)5Cl]Cl2, [Co(NH3)5ONO]Cl2 and [Co(NH3)5NO2]Cl2; (b) Characterisation by UV-vis and IR spectroscopic methods. **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. **Experiment 3** – Synthesis, optical, and electrochemical studies of metal-acetylacetonato complexes: M(acac)3 (M = Mn3+ and Fe3+) **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. **Experiment 5** – Electronic spectra of nickel(II) complexes: Preparation and UV-vis spectroscopic characterisation of (a) [Ni(bipy)3]SO4, (b) [Ni(en)3]Cl2.2H2O, (c) [Ni(NH3)6]Cl2, (d) [Ni(DMSO)6]Cl2. **Experiment 6** – Synthesis and study of an oxygen-binding cobalt complex: (a) Preparation of salenH2 ligand, (b) Preparation of Co(salen) and its reactivity towards oxygen. **Experiment 7** – Synthesis of zinc-porphyrin complex: (a) Preparation of 5,10,15,20-meso-tetra(p-tolyl) porphyrin (H2TTP) ligand, (b) Preparation of Zn(II)-tetra(p-tolyl)porphyrin (ZnTTP). **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, 3rd ed, Wiley, 2010.

Course Name: Physical Chemistry Laboratory [0 0 9 3]	
Course Code: CHY 415 / MSC 415	
Prerequisites	NA

Course Name: Physical Chemistry Laboratory [0 0 9 3]	
Course Code: CHY 415 / MSC 415	
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 [9] 2. Kinetics, Spectroscopy: Determination of Stoichiometry and Association/Binding Constant Using UV-Vis Spectroscopy [9] 3. Electrochemistry: Estimation of Diffusion Coefficient of Redox Species on Aqueous and Non-aqueous Medium [9] 4. Surface Chemistry: Validation of Freundlich and Langmuir Adsorption Isotherms [8] 5. Kinetics, Photochemistry: Kinetics-Inversion of Sucrose and Mutarotation of Glucose Using Polarimetry [9] 6. Spectroscopy: [9] 7. Construction of Jablonski Diagram of Polyaromatic Compounds 8. Estimation of Quantum Yield of Perylene and Pyrene Excimer Formation 9. Supramolecular Chemistry, Electrochemistry: Estimating the Critical Molar Concentration and Aggregation Number of Micelles [9] 10. Computational Chemistry: Theoretical Estimation of Vibrational Frequencies [9] 11. NMR Spectroscopy: [18] 12. To Identify the Amino Acids Using COSY Spectrum 13. 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. 14. Demonstration of the Application of the NMR Technique to Chemical Exchange Processes-Hydration of Pyruvic Acid 15. Simulating NMR Spectra Using Mathematica
Text & Reference Books	1. M. Halpern and G. C. McBane, Experimental Physical Chemistry: A Laboratory Text Book, 3rd ed., W. H. Freeman, 2006 2. D. P. Shoemaker, G. W. Garland and J. W. Nibler, Experiments in Physical Chemistry, 5th ed., McGraw Hill, London.

ELECTIVE COURSES – SYLLABUS

Course Name: Biosystems [2 0 0 2]	
Course Code: CHY 3101	
Prerequisites	NA
Learning Outcomes	This course covers structure and important functions of various biomolecules including DNA, proteins and carbohydrate.
Syllabus	• Buffers, pH, pKa of amino acids, D and L amino acid nomenclature. [1] • **Proteins:** protein sequencing, Primary (single letter amino acid codes), Ramachandran plot, Secondary structures, Tertiary (motifs and domains: some important motifs like Rossman fold, helix turn helix, 4 helix bundles, beta barrel), and Quaternary structure (Hemoglobin and Myoglobin). [2] • **Nucleic acids:** A, B and Z-DNA structures, Method of replication, sequencing of nucleic acids (chemical, dideoxy and fluorescence), Transcription, Translation, genetic code, genomes, genes, over expression of recombinant proteins, mutagenesis (random and site directed). Polymerase chain reaction (PCR). [5] • Carbohydrates and Glycoproteins, proteoglycans, Membranes and lipids, bacterial cell wall synthesis and mechanism of some important antibiotics like penicillin, antibiotic resistance. [4] • **Metabolism:** Photosynthesis, Calvin's cycle, Glycolysis, Krebs cycle, electron transport, cofactors. [5] • **Enzymes and their kinetics:** competitive, un-competitive, non-competitive and irreversible inhibition of enzymes. Effect of pH, temperature on enzyme activity. [5]
Text & Reference Books	1. D. Voet, J. G. Voet, and C. W. Pratt, Fundamentals of Biochemistry: Life at the Molecular Level, 5th Ed., Wiley, 2016. 2. J. M. Berg, L. Stryer, J. Tymoczko, and G. Gatto, Biochemistry: A Short Course, 4th Ed., W. H. Freeman, 2019.

Course Name: Mathematics for Chemistry [2 0 0 2]	
Course Code: CHY 3102	
Prerequisites	NA
Learning Outcomes	This course provides the overview of various essential parts mathematics as required for chemists.
Syllabus	• **Error Analysis**: Error, precision, accuracy, significant figures, mean, standard deviation, propagation of errors. [1] • **Vectors and Matrices:** Dot product, cross product, gradient, divergence, continuity equation, curl. Vector integration: Stokes' and Gauss' theorems, vector spaces. Matrices:

Course Name: Mathematics for Chemistry [2 0 0 2]	
Course Code: CHY 3102	
	coordinate transformation, Jacobian, system of linear equations, inverse of a matrix, Cramer's rule, Gaussian elimination and its variants, eigenvalues and eigenvectors. [7] • **Ordinary Differential Equations and Special Functions:** General and particular solutions of a differential equation. First order equations and their applications. Separation of variables, equations reducible to separable form. Exact differential equations, non-homogeneous differential equations, integrating factors. Second order linear differential equations: homogeneous with constant coefficients, characteristic equation, general solution, particular solution. Non-homogeneous linear second order equations, Sturm-Liouville theorem, Power series method of solution of differential equations, Special functions such as Legendre and Hermite polynomials, Beta, Gamma and error functions. Non-linear differential equations. [9] • **Fourier series and transform:** Basic theorems, convolution. Laplace transform and its properties, Applications of Fourier and Laplace transforms. [3] • **Numerical Methods:** Numerical differentiation and interpolation, Numerical quadrature, Newton-Cotes formulae, Simultaneous equations and matrix eigenvalues, Numerical solution of differential equations. [6]
Text & Reference Books	1. G. B. Arfken and H. J. Weber, Mathematical Methods for Physicists, 7th Ed., Elsevier, 2012. 2. M. L. Boas, Mathematical Methods in the Physical Sciences, 2nd Ed., Wiley, 2007). 3. E. Kreyszig, Advanced Engineering Mathematics, 9th Ed.,Wiley, 2007).

Course Name: Catalysis in Organic Synthesis [3 0 0 3]	
Course Code: CHY 4202	
Prerequisites	Organic chemistry knowledge at MSc level
Learning Outcomes	The course will walk through the recent advancements in catalytic reactions and organometallic reagents in organic synthesis, and this will allow the learners to have a better understanding of current trends in catalytic reactions.
Syllabus	• **Transfer Hydrogenation**: Introduction and development of Transfer Hydrogenation. Asymmetric Transfer Hydrogenation and Hydrogenation of Ketones. The selective applications of pincer complexes. (6) • **PCET**: Proton-Coupled Electron Transfer in Organic Synthesis: Fundamentals, application of PCET in coupling reactions, and opportunities (6) • **Reductive coupling**: Introduction to reductive cross-coupling reactions, synthetic application of various metal mediated reductive cross-coupling reactions. (4) • **Industrial Catalysis**: Catalysis on Industrial scale and Continuous-Flow chemistry (4) • **Catalytic Carbonylation and Decarbonylation Reaction**: Hydroformylation; carbonylation of aryl halides to form esters and amides; carbonylative coupling

Course Name: Catalysis in Organic Synthesis [3 0 0 3]	
Course Code: CHY 4202	
	reactions (carbonylative Heck reaction, carbonylative Stille Coupling Reactions), Tsuji-Wilkinson decarbonylation reaction. (6) • **Transition Metal - Catalyzed Coupling Reactions**: Fukuyama coupling, Nozaki-Hiyama-Kishi (NHK) reaction, Glaser Coupling, intramolecular Heck reaction. (3) • **Alkene and Alkyne Insertion Reactions**: Kulinkovich reaction, Pauson-Khand reaction, alkyne cobalt complex and Nicholas Reaction, Schwartz Hydrozirconation, hydroacylation of olefins, hydrocyanation of olefins, hydrosilylation of olefins. (5) • **Catalytic allylic substitution reaction**: Tsuji-Trost reactions. (1) • **Catalytic C–H Functionalization**: Fundamental aspects of C–H Functionalization, Fujiwara–Heck reaction, Catellani reaction, directed C–H Functionalization reactions. (5)
Text & Reference Books	1. Organic Synthesis Using Transition Metals, Roderick Bates, Wiley, 2012, 2nd ed.. 2. Organotransition metal chemistry: from bonding to catalysis, John F. Hartwig, University Science Books, 2010. 3. Industrial catalysis, Jens Hagen, Wiley, 2016, 3-rd ed..

Course Name: Chemistry of Natural Products and Polymers [3 0 0 3]	
Course Code: CHY 4203	
Prerequisites	MSc level knowledge in organic chemistry and fundamentals in polymers
Learning Outcomes	The course covers various aspects of natural products, like their source, structures, design and synthesis. It also emphasis on the biological importance and their impact on society. Second half of the course provides basic understanding about polymers, and their physical and chemical properties.
Syllabus	• **Introduction to natural products**: Classification, Isolation methods and Structure determination techniques. (2) • **Retrosynthetic analysis**: The basics of disconnection approach; One-group disconnections, Two-group disconnections; Transform based strategies; Structure & topological based strategies; Stereochemical strategies; Functional group based strategies. (6) • **Sustainable synthesis**: Atom economy, step economy and green chemistry protocols & environmental aspects in synthesis. Various synthetic approaches (linear, convergent, divergent, and etc.) (2) • **Chemistry of selected natural products**: Semi-synthesis and synthetic approaches to polyketides, macrolides, terpenes, steroids, alkaloids, penicillins and prostaglandins; case studies of drug molecules. (10) • **Introduction to polymers:** Basic concepts, monomers, repeat units, degree of polymerization, nomenclature of polymers, linear, branched and network polymers, concept of molecular mass, polydispersity, number average and weight average,

<table>
<tr><th colspan="2">Course Name: Chemistry of Natural Products and Polymers [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: CHY 4203</th></tr>
<tr><td></td><td>viscosity average molecular weight and their statistical equations, molecular weight distribution in linear polymers (step growth and chain polymers). (4)
• Measurement of molecular weight: Measurement of molecular weights, end group, viscosity, light scattering, osmotic and ultracentrifugation methods, (2)
• Techniques of polymerization: methods of polymerization, bulk polymerization, solution polymerization, emulsion polymerization, suspension polymerization, interfacial polymerization, melt polycondensation, solution polycondensation. (4)
• Step-growth and chain growth polymerization: Basics of step growth and chain growth polymerization, radical, cationic, anionic and condensation polymerization, copolymerization, reactivity ratios, thermodynamic aspects of polymerization, mechanism of living radical polymerizations: nitroxide mediated polymerization (NMP), metal-catalyzed living radical polymerization, Reversible Addition-Fragmentation chain Transfer (RAFT) radical polymerization, coordination polymerization, ring opening polymerization, click chemistry. (5)
• Polymer structure and properties: Types of stereo isomerism in polymers, properties of stereo regular polymers, Flory-Huggins theory of polymer solutions, nature, size and shape of macromolecules in solution, morphology and order in crystalline polymers, configurations of polymer chains, crystalline melting point Tm – _melting points of homogenous series, effect of chain flexibility and other steric factors, entropy and heat of fusion, the glass transition temperatureTg, relationship between Tm and Tg, Relation between Tg and other parameters, effects of molecular weight, diluents, chemical structure, chain topology, branching and cross-linking, DSC, DTA and TGA for polymer characterization, rheological properties.</td></tr>
<tr><td>Text & Reference Books</td><td>1. The Logic of Chemical Synthesis by E. J. Corey & X-M. Cheng.
2. Classics in Total Synthesis, Volumes I, II & III by K. C. Nicolau.
3. Organic Synthesis: The Disconnection Approach, Stuart Warren & Paul Wyatt.
4. Organic Chemistry by Clayden, Greeves, Warren and Wothers.
5. F. W. Billmeyer, Text Book of Polymer Science, 3rd ed., John Wiley & Sons, New York, 2003.
6. G. Odian, Principles of Polymerization, 4nd ed., John Wiley & Sons, New York, 2004.
7. 7. Sebastian Koltzenburg, Michael Maskos, Oskar Nuyken, Polymer Chemistry, Springer-Verlag GmbH Germany, 2015.</td></tr>
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<tr><th colspan="2">Course Name: Electrochemistry [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: CHY 4204</th></tr>
<tr><td>Prerequisites</td><td>CHY222 Physical Chemistry I & CHY314 Physical Chemistry II</td></tr>
<tr><td>Learning Outcomes</td><td>▪ To understand the basics of electrochemistry
▪ To apply such fundamental concepts in developing environmentally friendly energy storage devices</td></tr>
</table>

Course Name: Electrochemistry [3 0 0 3]	
Course Code: CHY 4204	
	▪ To motivate students in exploring cutting-edge research based on advanced electrochemistry
Syllabus	• **Introduction to basics of electrochemical processes (4h)** • General electrochemical concepts, redox reactions, Reference electrodes, galvanic and electrolytic cells • **Thermodynamics of electrochemical cells (4h)** • Electrode potentials, Half reactions and reduction potentials, Reversibility, Free energy and cell emf, Nernst Equation, Liquid junction potentials • **Kinetics of electrode reactions (6h)** • Homogenous kinetics, The Arrhenius Equation, Butler-Volmer model of electrode kinetics, The standard rate constant and the transfer coefficient, Microscopi theories of charge transfer, The Marcus theory, Tafel plot, multistep electrode reactions, charge transfer at electrode-solution interfaces, quantization of charge transfer, • **Mass transfer by migration and diffusion (4h)** • General Mass transfer equation, Migration, Diffusion, Fick's Laws of diffusion • **Electrochemical instrumentation and techniques (4h)** • Linear sweep voltammetry, cyclic voltammetry, chronopotentiometry, chronoamperometry, concepts of impedance • **Applied electrochemistry with focus on energy devices (3h)** • Electrical double layers, structure and dynamics of double layers, Faradaic and non-Faradaic charging mechanisms • **Electrochemical capacitors (4h)** • Generation and storing of charges, derivation of capacitance equations, evolution of capacitor technologies, materials development for supercapacitors, working principles and mechanism of operation, real life applications of supercapacitors. • **Batteries (4h)** • Redox reactions, cell emf, evolution of battery technologies, operation mechanism of a battery, advanced batteries – metal-ion and metal based rechargeable batteries
Text & Reference Books	1. A. J. Bard and L. R. Faulkner, Electrochemical Methods: Fundamentals and Applications, 2nd ed., Wiley Student ed. (2004). 2. P. Atkins, J. de Paula and J. Keeler, Atkins' Physical Chemistry, 11th ed., Oxford University Press (2018). 3. B. E. Conway, Electrochemical Capacitors: Scientific Fundamentals and Technological Applications, Kluwer Academic/Plenum Publishers, New York (1999).

Course Name: Advanced Materials Chemistry [3 0 0 3]	
Course Code: CHY 5101	
Prerequisites	CHY 322 (Solid State Chemistry)

Course Name: Advanced Materials Chemistry [3 0 0 3]	
Course Code: CHY 5101	
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	• **Overview of general chemical and physical principles:** of materials chemistry applied to synthesis, structure and properties of various inorganic & hybrid materials [8] • **Classification based on structure:** Various molecular solids, layered materials, 3D-materials, nanostructures materials with specific examples [4] • **Classification based on function:** Porous materials, optical materials, semiconductors, ionic conductors, superconductors, thermoelectric and magnetic materials [8] • **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] • **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. R. Rao (Editor), Achim Müller (Editor), Anthony K. Cheetham (Editor), 2004, Wiley-VCH. 5. Molecules Into Materials: Case Studies in Materials Chemistry - Mixed Valency, Magnetism and Superconductivity, 2007, World Scientific.

Course Name: Modern Organic Synthesis: Advances in Methods and Reagents [3 0 0 3]	
Course Code: CHY 5102 / CHY 6103	
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]

Course Name: Modern Organic Synthesis: Advances in Methods and Reagents [3 0 0 3]	
Course Code: CHY 5102 / CHY 6103	
	• **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 inorganic synthesis; (c) Modern electro organicsynthesis [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 ed., 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.

Course Name: Computational Chemistry [3 0 0 3]	
Course Code: CHY 5103	
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:** • 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] • 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] • Concept of hybridization, sp, sp^2, and sp^3 hybridizations [1] • 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] • Band theory of solids, tight-binding approximation, density of states, Kronig-Penney model, and Brillouin zone [2] • 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] • 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] • Moller-Plesset (MP) perturbation theory, MP0, MP1 and MP2 methods [2] • 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:** • Born-Oppenheimer approximation, potential energy surfaces, geometry optimization, single point energies, stationary points, gradients, Hessian, transition states, intrinsic reaction coordinates, and minimum energy path [3] • Normal modes of vibration, internal coordinates, mass-weighted coordinates, and normal mode analysis in diatomics and polyatomics [3] • Molecular mechanics, force fields, stretching, bending, torsions, non-bonded interactions, and illustrative examples [3] • Ion-ion, ion-dipole, dipole-dipole, dipole-induced dipole, induced dipole-induced dipole interactions, and quantum mechanical description of dispersion interactions [3]

Course Name: Computational Chemistry [3 0 0 3]	
Course Code: CHY 5103	
	• 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 ed., Viva, 2011. 5. A. Leach, Molecular Modelling: Principles and Applications, 2nd ed., Pearson, 2009.

Course Name: Fundamentals of Solution-State NMR Spectroscopy: Principles and Applications [3 0 0 3] (NKN course with IISER Pune & IISER Bhopal)	
Course Code: CHY 5104 / CHY 6101	
Prerequisites	CHY 313, CHY 324
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	• Pertinent introductory notes: Vector calculus - simple problems, Postulates of QM - simple examples with 1D box problem [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] • **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] • **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

Course Name: Fundamentals of Solution-State NMR Spectroscopy: Principles and Applications [3 0 0 3] (NKN course with IISER Pune & IISER Bhopal)	
Course Code: CHY 5104 / CHY 6101	
	Transfer (INEPT) - provide examples of ^{1}H to X nuclei, ^{13}C to ^{15}N, Spin-state selective coherence transfer [3] • **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) - 45º, 90º, 135º and its application to distinguish methyl, methylene and methine group [2] • **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] • **Introduction to 2D NMR:** Basic concepts in multidimensional NMR - “indirect” dimension, Homonuclear 2D experiments: COSY (regular, 60º, 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] • **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] • **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 ed., Viva, 2011. 5. A. Leach, Molecular Modelling: Principles and Applications, 2nd ed., Pearson, 2009.

Course Name: Principles of Inorganic Chemistry [3 0 0 3]	
Course Code: CHY 611	
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	• **Bonding models:** Bonding models in inorganic chemistry with appropriate examples. [1] • **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] • **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] • **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 organo metallic reactions. [9] • **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, 3rd ed., 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, 3rd ed., Pearson, 2008. 7. J. E. House, Inorganic Chemistry, 3rd ed., Academic Press, 2019. 8. B. Douglas, D. McDaniel, and J. Alexander, Concepts and Models of Inorganic Chemistry, 3rd ed., Wiley, 2001. 9. J. E. Huheey, E. A. Keiter, and R. L. Keiter, Inorganic Chemistry – Principles of Structure and Reactivity, 4th ed., 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, 2nd ed., Universities Press, 2013. 13. N. N. Greenwood, A. Earnshaw; Chemistry of the Elements, 2nd ed., Elsevier, 1997.

Course Name: Principles of Organic Chemistry [3 0 0 3]	
Course Code: CHY 612	
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 atun functionalized 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, NaBH4-CeCl3.7H2O 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, 4th Revised ed., New Academic Science, 2012. 2. 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, 5th ed., Springer, 2008. 3. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2th ed., 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, 2nd Revised ed., Benjamin-Cummings Publishing, 1972. 6. E. J. Corey and Xue–Min Cheng, The Logic of Chemical Synthesis, Revised ed., Wiley-Blackwell, 1995.

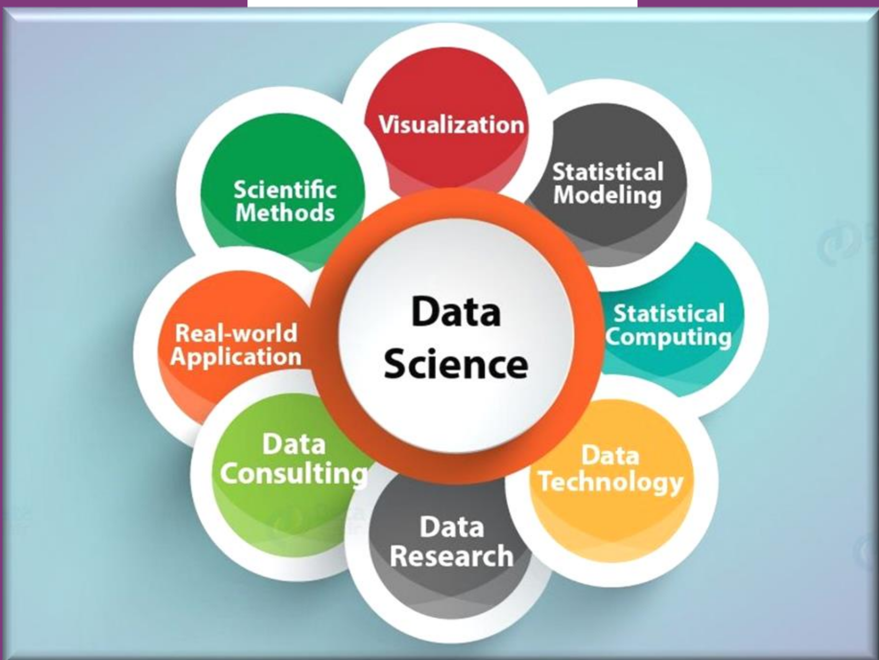
Course Name: Principles of Physical Chemistry [3 0 0 3]	
Course Code: CHY 613	
Prerequisites	NA
Learning Outcomes	To equip the entry-level graduate students with the essentials of various concepts in physical chemistry.
Syllabus	• Essentials of quantum chemistry: Review of postulates, exactly-solvable 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 ed., Viva (2019). 6. R. J. Silbey, R. A. Alberty and M. G. Bawendi, Physical Chemistry, 4th ed., Wiley Student ed., 2006.

DATA SCIENCES

CURRICULUM FOR

i[2] Data Sciences (SEM: 5-10)

CORE & ELECTIVE COURSES



*i*² Data Sciences (Semester 5 -10)

Semester 5	Semester 6	Semester 7	Semester 8	Semester 9	Semester 10
DSC 311 Mathematical Statistics [3 0 1 4]	DSC 321 Design and Analysis of Algorithms [3 0 0 3]	DSC 411 Statistical Modelling [3 0 0 3]	DSC 421 Big Data Analytics [2 0 3 3]	Electives I2D 52XX	Project [18]
DSC 312 Optimization Techniques [2 0 0 2]	DSC 322 Scientific Computing [3 0 3 4]	DSC 412 Parallel & Distributed Computing [3 0 0 3]	DSC 422 Humans and Data [1 0 0 1]	Electives I2D 52XX	
DSC 313 Discrete Mathematics [2 0 0 2]	DSC 323 Database Management System [3 0 0 3]	DSC 413 Data Warehousing & Business Intelligence [3 0 0 3]	DSC 423 Gambler's Ruin Problem [3 0 0 3]	Project [12]	
DSC 314 Data Structures [3 0 3 4]	DSC 324 Machine Learning-II [3 0 0 3]	DSC 414 Artificial Intelligence [3 0 0 3]	Elective I I2D 42XX/I2D 52XX		
DSC 315 Computer Organisation & Operating System [3 0 0 3]	DSC 325 Data Science Lab-II [1 0 3 2]	DSC 415 Data Analysis & Visualization [2 0 3 3]	Elective II I2D 42XX/I2D 52XX		
DSC 316 Machine Learning-I [3 0 0 3]	Open Elective-I I2D 32XX/	Open Elective-II I2D 41XX/I2D 51XX	Elective III I2D 42XX/I2D 52XX		
DSC 317 Data Science Lab-I [0 0 3 1]			Elective IV I2D 42XX/I2D 52XX		
Credits: 19	**Credits: 18**	**Credits: 18**	**Credits: 19**	**Credits: 18**	**Credits: 18**

List of Electives

Sl No:	List of Electives
1	Mathematical Modelling
2	Probabilistic Machine Learning
3	Statistical Simulation and Computation
4	Data Science for Finance
5	Machine Learning for Material Science
6	Particle Physics data processing
7	Data science in Chemistry
8	Computer Vision
9	Internet of Things and Cloud Computing
10	Big Data in Ecology and Environmental Sciences
11	Text Mining and Natural Language Processing
12	Clinical Data Analysis
13	Quantum information theory
14	Drug discovery and data science
15	Systems biology
16	Cryptography and data security
17	Open Electives
18	Advanced Genetics and Genomics
19	Bioinformatics
20	Computational Fluid Dynamics
21	Computational Chemical Biology
22	Modelling Materials

Credit Structure

Semester	Course	Credits	Total
1	Foundation Courses	19	76
2	Foundation Courses	19	
3	Foundation Courses	19	
4	Foundation Courses	19	
5	Core Courses	19	19
	Thematic	0	
	Electives	0	
6	Core Courses	15	18
	Thematic	0	
	Electives	3	
7	Core Courses	15	18
	Thematic	0	
	Electives	3	
8	Core Courses	7	19
	Electives	12	
9	Electives	6	18
	Project	12	
10	Project	18	18
5-10	General Courses (IP/Ethics/Languages/Music/Psychology)	5	5
Total		191	191

CORE COURSES - SYLLABUS

Course Name: Mathematical Statistics [3 0 1 4]	
Course Code: DSC 311	
Prerequisites	NA
Learning Outcomes	This course provides students with decision theory, estimation, confidence intervals, and hypothesis testing. Students will get hand-on experience in the lab component of the course which will be implemented either in Matlab or R.
Syllabus	• Sampling Distributions [9]: Populations and samples; distribution of samples; graphical repre-sentation 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. • Estimation of Parameters [9]: Method of maximum likelihood; applications to different popu-lations; point and interval estimation; method for finding confidence intervals; applications to normal populations; approximate confidence intervals. • Bivariate Samples [7]: Sample from a bivariate population; least square curve fitting; maxi-mum likelihood estimation; multivariate samples. • Testing of Hypotheses [15]: 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. Practicals: • Objects and functions, Arithmetical and Boolean operators, Importing and Exporting Data sets, Packages, Loops and Conditional statements, Measure of central tendency, basic plots. • Density, distribution function, quantile function and random generation for standard discrete and continuous distributions. Q-Q plots and P-P plots. Fitting distributions. Maximum Like-lihood estimation. Generating bivariate random sample. Test for mean, variance, proportion and independency.
Text & Reference Books	1. D. Freedman, R. Pisani and R. Purves, Statistics, Â W. W. Norton & Company, 4th ed., 2007. 2. R. V. Hogg, J. McKean and A. T. Craig, Introduction to Mathematical Statistics, Pearson Education India; 7th ed., 2013. 3. A. Mood, F. Graybill and D. Boes, Introduction to the Theory of Statistics, McGraw Hill Education; 3rd ed., 2017. 4. P. J. Bickel and K. A. Doksum, Mathematical Statistics: Basic Ideas and Selected Topics, Volume 1. 2nd ed., 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.

Course Name: Optimization Techniques [2 0 0 2]	
Course Code: DSC 312	
Prerequisites	NA
Learning Outcomes	▪ To apply optimization techniques. ▪ Understanding of linear and nonlinear techniques
Syllabus	Classification and general theory of optimization [1]; • Linear programming (LP): • Formulation and geometric ideas, simplex and revised simplex methods [5]- • Duality and sensitivity, interior-point methods for LP problems [5]- • Transportation- assignment-and integer programming problems [5] Nonlinear optimization: • Method of Lagrange multipliers [2]- • Karush-Kuhn-Tucker theory [2]- • Numerical methods for nonlinear optimization [2]- • Convex optimization, quadratic optimization [2]- • Dynamic programming [2].
Text & Reference Books	1. D. G. Luenberger and Y. Ye, Linear and Nonlinear Programming, 3rd ed., 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, 2nd ed., Wiley India, 2001. 4. M. S. Bazarra, H. D. Sherali and C. M. Shetty, Nonlinear Programming Theory and Algorithms, 3rd ed., Wiley India, 2006. 5. K. G. Murty, Linear Programming, Wiley, 1983.

Course Name: Discrete Mathematics [2 0 0 2]	
Course Code: DSC 313	
Prerequisites	Nil
Learning Outcomes	▪ Have knowledge of the concepts needed to test the logic of a program. ▪ Have an understanding in identifying structures on many levels. ▪ Be aware of a class of functions which transform a finite set into another finite set which relates to input and output functions in computer science. ▪ Be able to apply basic counting techniques to solve combinatorial problems ▪ Acquire ability to describe computer programs in a formal mathematical manner.

Course Name: Discrete Mathematics [2 0 0 2]	
Course Code: DSC 313	
Syllabus	• Logic: Propositions, negation, disjunction and conjunction, implication and equivalence,truth tables, predicates, quantifiers, rules of inference, methods of proof. [3] • Set theory: definition and simple proofs in set theory, Inductive definition of sets andproof by induction, inclusion and exclusion principle, relations, representation of relations by graphs, properties of relations, equivalence relations and partitions, partial orderings, linear and well-ordered sets. [7] • Functions: mappings, injection and surjections, composition of function, inverse functions, special functions, recursive function theory. [3] • Elementary combinatorics: Counting techniques, pigeonhole principle, recurrence relation, generating functions. [3] • Graph theory: Elements of graph theory, Euler graph, Hamiltonian path, trees, tree traversals, spanning trees. [5] • Algebra: groups, Lagrange's theorem, homomorphism theorem, rings and fields, structure of the ring Zn and the unit group Zn*, lattice. [5]
Text & Reference Books	1. Kenneth H. Rosen, Discrete Mathematics and Its Applications, 7th ed., Mcgraw-Hill, 2017. 2. Norman L. Biggs, Discrete Mathematics, Oxford University Press, 2nd ed., 2003. 3. P. B. Bhattacharya, S. K. Jain, S, R. Nagpaul, Basic Abstract Algebra, 2nd ed., Cambridge University Press, 2003

Course Name: Data Structures [3 0 3 4]	
Course Code: DSC 314 / 3104	
Prerequisites	NA
Learning Outcomes	▪ 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	• Introduction- Algorithm Analysis, Finding Complexity. Fundamental data structures - List-Sorted Lists, Double Linked Lists, Stack & Queue application. [10] • Binary Trees – Insertion and Deletion of nodes, Tree Traversals, Polish Notations, Red Black Trees, B-Trees, Heaps,Priority Queues.[10] • Sorting – Bubble, Selection, Insertion, Merge Sort, Quick Sort, Radix Sort, Heap sort. Searching. [10] • Graphs- Shortest path algorithms, Minimum Spanning Trees, BFS, DFS.[10]

Course Name: Data Structures [3 0 3 4]	
Course Code: DSC 314 / 3104	
Text & Reference Books	1. Clifford A Shaffer, Data Structures and Algorithm Analysis, ed., 3. 2 (Java Version), 2011. 2. Michael T. Goodrich, Roberto Tamassia, Michael H. Goldwasser. Data Structures And Algorithms In Java™ 6th ed., Wiley Publishers, 2014. 3. Mark Allen Weiss Data Structures And Algorithm Analysis In Java, 3rd ed., 2012. 4. Robert L. Kruse, Data Structures And Program Design In C++, Pearson Education, 2nd ed., 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. 7. Thomas H Cormen, Charles E Leiserson, Ronald L Rivest, Clifford Stein - Introduction to Algorithms, MIT Press, 3rd ed., 2010.

Course Name: Computer Organisation & Operating System [3 0 0 3]	
Course Code: DSC 315	
Prerequisites	NA
Learning Outcomes	▪ Understanding the fundamental concepts underlying modern computer organization and operating system. ▪ Understanding the memory organization and execution of programs ▪ Designing of an OS.
Syllabus	Part-I: Computer Organization • Computer abstraction and technology: Basic principles, hardware components, Measuring performance: evaluating, comparing and summarizing performance. Instructions: operations and operands of the computer hardware, representing instructions, making decision, supporting procedures, character manipulation, styles of addressing, starting a program. [5] • Computer Arithmetic: signed and unsigned numbers, addition and subtraction, logical operations, constructing an ALU, multiplication and division, floating point representation and arithmetic, Parallelism and computer arithmetic. [4] • The processor: building a data path, simple and multi-cycle implementations, microprogramming, exceptions, Pipelining, pipeline Data path and Control, Hazards in pipelined processors [4] • Memory hierarchy: caches, cache performance, virtual memory, common framework for memory hierarchies Input/output: I/O performance measures, types and characteristics of I/O devices, buses, interfaces in I/O devices, design of an I/O system, parallelism and I/O. Introduction to multicores and multiprocessors. [5] Part-II: Operating System

Course Name: Computer Organisation & Operating System [3 0 0 3]	
Course Code: DSC 315	
	• Operating system overview: Computer System Organization, Operating System structure, operations of OS, process management, memory management, storage management, protection and security, distributed systems. [2] • Processes: Process concept, Process scheduling, Operations on processes, Cooperating processes, inter-process communication [3] • Threads: Overview, Multi-threading models, threading issues, P threads, Windows XP threads[3] • CPU Scheduling: Basic concepts, scheduling criteria, scheduling algorithms, multiple-processor scheduling [3] • Process synchronization: The critical section problem, Peterson's solution, synchronization hardware, Semaphores, Monitors. Synchronization examples [2] • Deadlocks: Methods for handling deadlocks, Deadlock prevention, deadlock avoidance, Deadlock recovery [1] • Memory management: Swapping, Paging, Segmentation, Virtual memory, Demand paging, Page replacement [4] • I/O Systems: I/O hardware, Application I/O interface, Kernel I/O subsystem, transforming I/O requests to hardware operations[4]
Text & Reference Books	1. D. A. Pattersen and J. L. Hennesy, Computer Organisation and Design: The Hardware/ Software Interface, 4th ed., Morgan Kaufman, 2009. 2. V. P. Heuring and H. F. Jordan, Computer System Design and Architecture, Prentice Hall, 2003. 3. J.L. Hennessy & D.A Pattersen , Computer Architecture: A Quantitative Approach, 5th ed., Morgan Kaufman, 2011. 4. Carl Hamazher, ZvonkoVranesic and SafwatZaky, Computer Organization, 5th ed., McGraw Hill, 2002. 5. William Stallings,Operating systems: Internals & design principles, Pearson, 7th ed., 2014. 6. Andrew S. Tanenbaum, Modern Operating Systems, Pearson 4th ed., 2016. 7. Charles Crowley, Operating Systems - Design Oriented Approach, Mc. Graw Hill Education, 1st ed., 2017.

Course Name: Machine Learning-I [3 0 0 3]	
Course Code: DSC 316	
Prerequisites	NA
Learning Outcomes	▪ Understanding the theoretical foundations of important learning algorithms. ▪ Applications of learning algorithms. ▪ Evaluation of learning algorithms and model selection procedures.

Course Name: Machine Learning-I [3 0 0 3]	
Course Code: DSC 316	
Syllabus	• Review of linear algebra, optimization and probability: Matrices, Eigen values and vectors, gradient, hessian, least squares, optimization; random variables and distributions [6] • Definitions, goals and history of Machine Learning; Introduction, linear classification; Classification errors; Regression Techniques [9] • Supervised learning (generative/discriminative learning, parametric/non-parametric learning, neural networks, support vector machines); [10] • Unsupervised learning (clustering, dimensionality reduction, kernel methods); learning theory (bias/variance trade-offs; VC theory; large margins); [10] • Reinforcement learning and adaptive control. Applications of machine learning [5].
Text & Reference Books	1. Mitchell, Tom, Machine Learning. New York, N Y: McGraw-Hill, 1997. 2. Bishop C., M., Pattern Recognition and Machine Learning, Springer, 2006. 3. P. Langley, Elements of Machine Learning, Morgan Kaufmann, 1995. 4. Hastie, T., R. Tibshirani, and J. H. Friedman. The Elements of Statistical Learning: Data Mining, Inference and Prediction, 2nd ed., Springer, 2009. 5. MacKay, David. Information Theory, Inference, and Learning Algorithms. Cambridge, UK: Cambridge University Press, 2003.

Course Name: Data Science Lab-I [0 0 3 1]	
Course Code: DSC 317	
Prerequisites	NA
Learning Outcomes	▪ Extraction of information from data. ▪ Evaluation of algorithms and model selection procedures ▪ Hands-on experience in handling real world data.
Syllabus	• Introduction: What is Data Science?- Big Data and Data Science hype, Introduction to statistical packages (R /Python/ S-Plus / MATLAB / SAS). • Exploratory Data Analysis(EDA) and Statistical Inference: Populations and samples,-Statistical modelling, probability distributions, fitting a model, Exploratory data analysis tools (plots, graphs and summary statistics) of EDA, kernel density estimation; Basic estimation and testing; Random number generator and Monte Carlo samples, Least square Estimation, Inference, Model Checking, Multivariate data analysis - multivariate normal and inference .
Text & Reference Books	1. Cathy O'Neil and Rachel Schutt. Doing Data Science, Straight Talk From The Frontline, O'Reilly, 2014. 2. Joel Grus, Data Science from Scratch: First Principles with Python, O’Reilly Media, 2015.

Course Name: Data Science Lab-I [0 0 3 1]	
Course Code: DSC 317	
	3. Trevor Hastie, Robert Tibshirani and Jerome Friedman. Elements of Statistical Learning: Data Mining, Inference and Prediction, 2nd ed., Springer, 2009. 4. Mohammed J. Zaki and Wagner Miera Jr. Data Mining and Analysis: Fundamental Concepts and Algorithms. Cambridge University Press. 2014. 5. Jiawei Han, MichelineKamber and Jian Pei. Data Mining: Concepts and Techniques, 3rd ed., Elsevier, 2012. 6. T.W. Anderson, An Introduction to Multuvariate Statistical Analysis, 3rd ed., Wiley India, 2009.

Course Name: Design and Analysis of Algorithms [3 0 0 3]	
Course Code: DSC 321	
Prerequisites	NA
Learning Outcomes	▪ Understanding the basics of algorithms ▪ Complexity analysis of algorithms ▪ Approximation algorithms
Syllabus	• Prim's Algorithm – Locally Modifying Solutions to Build Better Solutions – Exchange Arguments [5] • Dijkstra's Algorithm – Kruskal's Algorithm – Knapsack – Huffman Coding [6] • Dynamic Programming: Reusing work across sub computations – Definition of DynamicProgramming – Optimal Rod Cut Problem - Optimal Matrix Chain Multiplication - Bellman-Ford Algorithm, Floyd-Warshall Algorithm – Longest Common Subsequence – Machine Scheduling Problem. [12] • Amortized Complexity Analysis – Aggregate Method, Accounting Method, Potential Method, Dynamic Tables – Balanced Trees. [8] • Intractable Problems: Polynomial Time – class P – Polynomial Time Verifiable Algorithms –class NP – NP completeness and reducibility – NP Hard Problems – NP completeness proofs – Approximation Algorithms.[9]
Text & Reference Books	1. Thomas H Cormen, Charles E Leiserson, Ronald L Rivest, Clifford Stein - Introduction to Algorithms, MIT Press, 3rd ed., 2010. 2. Jon Kleinberg, Eva Tardos, Algorithm Design, Pearson Addison, Wesley, 2013.

<table>
<tr><th colspan="2">Course Name: Scientific Computing [3 0 3 4]</th></tr>
<tr><th colspan="2">Course Code: DSC 322</th></tr>
<tr><td>Prerequisites</td><td>NA</td></tr>
<tr><td>Learning Outcomes</td><td>▪ Apply standard techniques to analyse key properties of numerical algorithms, such as stability and convergence.
▪ Understand and analyse common pitfalls in numerical computing such as ill-conditioning and instability.
▪ Perform data analysis efficiently.
▪ Derive and analyse numerical methods for constrained and unconstrained optimization problems.
▪ Introduce the basics of Monte Carlo methods</td></tr>
<tr><td>Syllabus</td><td>• Brief review of the sources of error and local analysis: Relative error, absolute error, and cancellation; Computer arithmetic; Truncation error; Error propagation and amplification; Condition number and ill-conditioned problems. [3]
• Numerical linear algebra: [18]
○ Direct solution methods for linear systems, Gaussian elimination and its variants; LU, QR,Singular value decomposition,
○ Iterative methods for a linear system, Stationary iterative methods- Jacobi, Gauss-Seidel, and successive overrelaxation methods. Non-stationary iterative methods- conjugate gradient (CG), convergence analysis; preconditioning.
○ Estimation and computation of eigenvalues- Gershgorin disc, power methods, the QR algorithm,
○ Chebyshev polynomials and Chebyshev semi-iterative methods;
• Nonlinear equations and optimization: [14]
○ Unconstrained Optimization: Optimality conditions, steepest descent method, Newton and quasi-Newton methods, General line search methods, Trust region methods, Least squares problems and methods.
○ Constrained Optimization: Optimality/KKT conditions, penalty and augmented Lagrangian for equality-constrained optimization, interior-point/barrier methods for inequality constrained optimization. SQP methods.
• Monte Carlo methods: Basic review of probability; Random number generators, Sampling, Error bars, Variance reduction. [5]</td></tr>
<tr><td>Text & Reference Books</td><td>1. L. N. Trefethen and D. Bau III, Numerical Linear Algebra, SIAM, 1997.
2. J. W. Demmel, Applied Numerical Linear Algebra, SIAM, 1997.
3. A. Greenbaum, Iterative Methods for Solving Linear Systems, SIAM, 1997.
4. G. H. Golub and C. F. van Loan, Matrix Computations, John Hopkins University Press, 1996.
5. H. C. Elman, D. J. Silvester and A. J. Wathen, Finite Elements and Fast Iterative Solvers, Oxford University Press, 1995.
6. J. Nocedal and S. J. Wright, Numerical Optimization, Springer, 2006.
7. D. P. O'Leary, Scientific Computing with Case Studies, SIAM, 2009.</td></tr>
</table>

Course Name: Database Management System [3 0 0 3]	
Course Code: DSC 323	
Prerequisites	NA
Learning Outcomes	▪ Understanding basic concepts of DBMS ▪ Understanding the E R model and relational model ▪ Applying normalization techniques ▪ Understanding query processing and query optimization.
Syllabus	• Database Modeling: Database System concepts and architecture, Data modeling using Entity Relationship (ER) model and Enhanced ER model, Specialization, Generalization.[4] • Database Indexing: Data Storage and indexing- Single level and multi-level indexing, Dynamic Multi level indexing using B Trees and B+ Trees[6] • Relational Databases: The Relational Model, Relational database design using ER to relational mapping Relational algebra, Relational calculus, Tuple Relational Calculus, Domain Relational Calculus, SQL[10] • Database Design: Database design theory and methodology, Functional dependencies and normalization of relations, Normal Forms, Properties of relational decomposition, Algorithms for relational database schema design[10] • Database Transactions: Transaction processing concepts, Schedules and serializability, Concurrency control, Two Phase Locking Techniques, Optimistic Concurrency Control, Database recovery concepts and techniques[8] • Database Security: Introduction to database security[2]
Text & Reference Books	1. RamezElmasri and Shamkant B. Navathe, Fundamentals of Database Systems, 5th ed., Pearson Education, 2008. 2. Raghu Ramakrishnan and Johannes Gehrke, Database Management Systems, 3rd ed., McGraw Hill, 2014. 3. Peter Rob and Carlos Coronel, Database System- Design, Implementation and Management, 7th ed., Cengage Learning, 2007.

Course Name: Machine Learning-II [3 0 0 3]	
Course Code: DSC 324	
Prerequisites	NA
Learning Outcomes	▪ Understanding Neural Network structures and learning. ▪ Understanding the deep learning algorithms for domains. ▪ Implementing deep learning algorithms to solve real-world problems

Course Name: Machine Learning-II [3 0 0 3]	
Course Code: DSC 324	
Syllabus	• Introduction: Biological Neuron, Idea of computational units, McCulloch–Pitts unit and Thresholding logic, Linear Perceptron, Perceptron Learning Algorithm, Linear separability. Convergence theorem for Perceptron Learning Algorithm.[2] • Feedforward Networks: Multilayer Perceptron, Gradient Descent, Backpropagation, Empirical Risk Minimization, regularization.[2] • Deep Neural Networks: Difficulty of training deep neural networks, Greedy layerwisetraining[3]. • Better Training of Neural Networks: Newer optimization methods for neural networks (Adagrad, adadelta, rmsprop, adam, NAG), second order methods for training, Saddle point problem in neural networks, Regularization methods (dropout, drop connect, batch normalization). [5] • Convolutional Neural Networks: Architectures, convolution / pooling layers , LeNet, AlexNet.[3] • Recurrent Neural Networks: Back propagation through time, Long Short Term Memory, Gated Recurrent Units, Bidirectional LSTMs, Bidirectional RNNs.[4] • Generative models: Restrictive Boltzmann Machines (RBMs), Introduction to MCMC and Gibbs Sampling, gradient computations in RBMs, Deep Boltzmann Machines.[5] • Deep Unsupervised Learning and Recent Trends: Autoencoders (standard, sparse, denoising, contractive, etc), VariationalAutoencoders, Adversarial Generative Adversarial Networks, Autoencoder and DBM , Multi- task Deep Learning, Multi-view Deep Learning. [6] • Applications of Deep Learning to Computer Vision: Image segmentation, object detection, automatic image captioning, Image generation with Generative adversarial networks, video to text with LSTM models. Attention models for computer vision tasks. [5] • Applications of Deep Learning to NLP: Introduction to NLP and Vector Space Model of Semantics Word Vector Representations: Continuous Skip-Gram Model, Continuous Bag-of-Words model (CBOW), Glove, Evaluations and Applications in word similarity, analogy reasoning[5]
Text & Reference Books	1. Ian Goodfellow and YoshuaBengio and Aaron Courville, Deep Learning, MIT Press, 2016. 2. Bishop, C. ,M., Pattern Recognition and Machine Learning, Springer, 2006. 3. Raúl Rojas, Neural Networks : A Systematic Introduction, Springer, 1996.

Course Name: Data Science Lab-II [1 0 3 2]	
Course Code: DSC 325	
Prerequisites	DSC 317
Learning Outcomes	▪ Understand the data science and data science process ▪ How various tools can be applied in data science process. ▪ Develop an appreciation for what is involved in learning from data. ▪ Understand how to extract the basic information from the data. ▪ Understand how to perform evaluation of algorithms and model selection.
Syllabus	• Data Science Process & Basic Machine Learning Algorithms: - Data Science Process, Linear Regression, k-Nearest Neighbours (k-NN), k-means, Naïve based algorithms. • Feature Generation and Feature Selection (Extracting Meaning From Data): Feature Generation (brainstorming, role of domain expertise, and place for imagination) and Feature Selection algorithms. • Recommendation Systems: Building a User-Facing Data Product: Algorithmic ingredients of a Recommendation Engine, Dimensionality Reduction,- Singular Value Decomposition, Principal Component Analysis • Data Visualization: Basic principles, ideas and tools for data visualization. • Issues: Discussions on privacy, security, ethics, A look back at Data Science, Next-generation data scientists.
Text & Reference Books	1. Cathy O'Neil and Rachel Schutt. Doing Data Science, Straight Talk From The Frontline, O'Reilly, 2014. 2. Data Science from Scratch: First Principles with Python, Joel Grus, O'Reilly Media, 2015. 3. Trevor Hastie, Robert Tibshirani and Jerome Friedman. Elements of Statistical Learning: Data Mining, Inference and Prediction, 2nd ed., Springer, 2009. 4. Mohammed J. ZakiandWagnerMiera Jr. Data Mining and Analysis: Fundamental Concepts and Algorithms. Cambridge University Press. 2014. 5. Jiawei Han, MichelineKamber and Jian Pei. Data Mining: Concepts and Techniques, 3rd ed., Elsevier, 2012. 6. T.W. Anderson, An Introduction to Multuvariate Statistical Analysis, 3rd ed., Wiley India, 2009.

Course Name: Statistical Modeling [3 0 0 3]	
Course Code: DSC 411	
Prerequisites	NA
Learning Outcomes	▪ Understanding the theoretical foundations of various statistical models ▪ Fitting of linear and nonlinear regression and time series models.

Course Name: Statistical Modeling [3 0 0 3]	
Course Code: DSC 411	
Syllabus	• Introduction to Economic Questions and Data, Review of Probability, Review of Statistics [6] • Linear regression with one regressor, Regression with multiple regressors, [8] • Non-linear regression functions [6], • Assessing studies based on linear regression (internal and external validity), Regression with a binary dependent variable, Panel Data Regression [10] • Introduction to Time-series regression and forecasting, Estimation of Dynamic Causal Effects, VAR, ARCH and GARCH models.[10]
Text & Reference Books	1. Douglas C Montgomery, Elizabeth A. Peck and G. Geoffrey Vining, Introduction to Linear Regression Analysis, Wiley 5th ed., 2013 2. Norman R. Draper, Harry Smith, Applied Regression Analysis, Wiley, 3rd ed., 2011. 3. Peter J Brockwell, Richard A Davis, Introduction to Time Series and Forecasting, Springer, 2nd ed., 2010.

Course Name: Parallel & Distributed Computing [3 0 0 3]	
Course Code: DSC 412	
Prerequisites	DSC 315
Learning Outcomes	▪ Understanding various programming languages for HPC applications. ▪ Gaining sufficient practical knowledge to utilize the performance analysis tools.
Syllabus	• Architectures – Multi-core and Many-core architectures, Accelerators (SIMD untis - Vectorization, GPUs), Goals of parallel systems. [4] • Applications – Scientific applications, Characteristics, requirements, regular grid applications, irregular applications, data dependence, parallelization process. [8] • Parallel Programming on Shared Memory – OpenMP, Execution Model, Shared and private data, Directives, Barriers, Sections, Run-Time library functions, scheduling strategies, Scalability study, OpenMP for accelerator programming. [10] • Parallel Programming on Distributed Memory – MPI, Collective operations, Non-Blocking, Collectives, Process topologies, Parallel I/O, Single sided communications. [8] • Performance Tools – Concepts, Event-Model execution, profiling, tracing, types of profiling, profiling tools – Scalasca, Score-P, MPI-P, EnergyAnalyzer, Tracing tools, Autotuning – Periscope Tuning Framework. [10]
Text & Reference Books	1. Ian Foster, Designing and Building Parallel Programs – Concepts and tools for Parallel Software Engineering, Pearson Publisher, 1st ed., 2019.

Course Name: Parallel & Distributed Computing [3 0 0 3]	
Course Code: DSC 412	
	2. Eric Stotzer and Christian Terboven, Using OpenMP—The Next Step: Affinity, Accelerators, Tasking, and SIMD (Scientific and Engineering Computation, Ruud van der Pas, 2017. 3. P Michael J. Quinn, Parallel computing theory and Practice, McGraw Hill, 2nd ed., 2017.

Course Name: Data ware Housing & Business Intelligence [3 0 0 3]	
Course Code: DSC 413	
Prerequisites	NA
Learning Outcomes	▪ Creating data warehouse and process raw data to make it suitable for various data mining algorithms. ▪ Discovering and measuring interesting patterns from different kinds of databases. ▪ Applying the techniques of clustering, classification, association finding, feature selection and visualization to real world data.
Syllabus	• Overview of Knowledge extraction, Data Warehousing concepts and Architecture, Online Analytical Processing (OLAP) – OLAP and Multidimensional Data Representation, Data cube technologies, Business Intelligence. [6] • Data Mining: - Data Mining Functionalities – Data Pre-processing – Data Cleaning – Data[4] • Integration and Transformation – Data Reduction – Data Discretization and Concept Hierarchy Generation. Association Rule Mining.[6] • Classification and Prediction:-Issues Regarding Classification and Prediction – Classification [4] • by Decision Tree. Introduction – Bayesian Classification – Rule Based Classification – Classification by Back propagation – Support Vector Machines – Associative Classification –Lazy Learners – Other Classification Methods.[10] • Cluster Analysis:- Types of Data in Cluster Analysis, Model-Based Clustering Methods, Hierarchical and Partitioning methods. Outlier Analysis. Applications and trends in Data Mining: Mining Text and Web data. [10]
Text & Reference Books	1. Alex Berson,Stephen J. Smith, "Data Warehousing, Data Mining, & OLAP", Tata Mcgraw- Hill, 2004. 2. Jiawei Han. Data Mining: Concepts and Techniques. Morgan Kaufmann Publishers 3. Anahory and Murray, Data warehousing in the real world, Pearson Education/Addison Wesley. 4. Berry Micheal and Gordon Linoff, Mastering Data Mining. John Wiley & Sons Inc. 5. Margaret H. Dunham Data Mining: Introductory and Advanced Topics. Prentice Hall

Course Name: Artificial Intelligence [3 0 0 3]	
Course Code: DSC 414	
Prerequisites	NA
Learning Outcomes	▪ Acquiring a thorough knowledge of fundamental concepts and techniques in artificial Intelligence. ▪ Learning simulation tools. ▪ Developing intelligent and expert systems.
Syllabus	• Introduction to Artificial Intelligence: Artificial Intelligence (AI),Major Branches of AI, Applications- Characteristics and Fundamental issues for AI problems, Steps to build Artificial intelligence (AI) systems,Intelligent systems,Characteristics of intelligent systems[3] • Search Techniques: Why Search, Applications of search, Tree and Graph, Search strategies,Complexity of Search[6] • Knowledge Representation: Knowledge, Characteristics of knowledge representation, Types of knowledge representation,Propositional Logic,Tautology and Contradiction,Predicate Logic, Production Systems, Semantic network, Frame systems, Scripts.[10] • Neural Networks:Introduction to Neural network,Structure of Neural network, Neural Network Architecture, Network Layers, Neural Network Learning, Back-Propagation Algorithm[10] • Intelligent agents:Introduction to Agents, Functions,Examples of Agents, Intelligent Agent classification, Features of intelligent agents, Structure of Agents, Intelligent Agents Models[2] • Fuzzy logic:Crisp logic, Fuzzy logic, Member ship function,Member ship function,Fuzzy logic Applications.[4] • Expert Systems:What is Expert system, Conventional systems vs. Expert systems,Basic Concepts, Human Expert Behaviors, Knowledge Types, Inferencing, Rules,Structure of Expert Systems, ES Components, Knowledge Engineer, Expert Systems Working, Problem Areas Addressed by Expert Systems, benefits-limitations- Applications of expert systems.[5]
Text & Reference Books	1. Stuart J Russell, Peter Norvig, Artificial Intelligence: A Modern approach, 3rd ed., 2015. 2. Elaine Rich and Kevin Knigh, Introduction to Artificial Intelligence, McGraw Hill, 3rd ed., 2017. 3. Michael Negnevitsley, Artificial Intelligence: A guide to Intelligent Systems, Addison Wesley, 3rd ed., 2017. 4. G.F. Luger, and W.A. Stubblefield, Artificial Intelligence: Structures and Strategies for Complex Problem Solving, Addison-Wesley Publishing Company, 2011. 5. C.S. Krishnamoorthy and S. Rajeev, Artificial Intelligence and Expert Systems for Engineers by CRC Press, 1996.

Course Name: Data Analysis & Visualization [2 0 3 3]	
Course Code: DSC 415	
Prerequisites	DSC 325
Learning Outcomes	▪ Familiarizing with data visualization tools such as Tableau, python ▪ Making reports and dash boards
Syllabus	• Creating static graphs, animated visualizations - loops, GIFs, and Videos. [6] • - Introduction to Visualization Toolkit (VTK) for 3D computer graphics, image processing, and visualization, visualization pipeline, isosurfaces, volume rendering, vector field visualization, applications to biological and medical data. [10] • - Visualization for deep learning. [2] • Data Visualization BI Tool: Tableau 9.x-Introduction to Data Visualization with Tableau, Exploring Data Visualization with Tableau. What is Data Visualization? Exporting Data and Working with Tableau. [4] • Building Data Visualization BI Project With Tableau 9.x, BI Reporting Understanding, Report and Dashboard Template Document, Tableau Design and Development Database Source Connection [4]
Text & Reference Books	1. Ossama Embark, Data Analysis and Visualization Using Python: Analyze Data to Create Visualizations for BI Systems, Apress, 2018. 2. Kieran Healy, Data visualization: A practical introduction, Princeton university press, 2019. 3. Tristan Guillevin, Getting Started with Tableau, Packet publishing, 2019. 4. Hansen, C.D., and Johnson, C.R., Visualization Handbook, Academic Press, 2004.

Course Name: Big Data Analytics [2 0 3 3]	
Course Code: DSC 421	
Prerequisites	DSC 413, 324
Learning Outcomes	▪ Working with big data processing tools and its analysis techniques ▪ Designing efficient algorithms for mining the data from large data set ▪ Designing an efficient recommendation system and tools for visualization. ▪ Learning Hadoop/ NoSQL databases and management.
Syllabus	• Evolution of Big data - Best Practices for Big data Analytics - Big data characteristics - Big Data Use Cases- Characteristics of Big Data Applications- Big Data Modelling- Hadoop Eco system. [5] • An Overview of Clustering - K-means clustering - Use Cases - Determining the Number of Clusters - Classification- Decision Trees - Decision Tree Algorithms - Evaluating a Decision Tree - Decision Trees in R - Bayes Theorem - Naive Bayes Classifier.[8]

Course Name: Big Data Analytics [2 0 3 3]	
Course Code: DSC 421	
	• Association Rules - Overview - Apriori Algorithm - Evaluation of Candidate Rules - Applications of Association Rules - Finding Association & similarity [4] Recommendation System: Collaborative Recommendation- Content Based Recommendation - Knowledge Based Recommendation- Hybrid Recommendation Approaches [5] • Introduction to Streams Concepts – Stream Data Model and Architecture - Sampling Data in a Stream – Filtering Streams – Counting Distinct Elements in a Stream –Real time Analytics Platform(RTAP) applications - Case Studies - Real Time Sentiment Analysis- Stock Market Predictions. [9] • NoSQL Databases - Schema less Models- Increasing Flexibility for Data Manipulation- Key Value Stores- Document Stores - Tabular Stores - Object Data Stores - Graph Databases– Big data for twitter - Big data for E-Commerce blogs [9]
Text & Reference Books	1. Jure Leskovec, Anand Rajaraman and Jeffrey David Ullman, "Mining of Massive Datasets", Cambridge University Press, 2012. 2. Tom White, Hadoop: The Definitive Guide, 4th ed., O'Reily Publications, 2015 3. David Loshin, "Big Data Analytics: From Strategic Planning to Enterprise Integration with Tools, Techniques, NoSQL, and Graph", 2013. 4. EMC Education Services, "Data Science and Big Data Analytics: Discovering, Analyzing, Visualizing and Presenting Data", Wiley publishers, 2015. 5. Bart Baesens, "Analytics in a Big Data World: The Essential Guide to Data Science and its Applications", Wiley Publishers, 2015. 6. DietmarJannach, Markus Zanker, Alexander Felfernig and Gerhard Friedrich "Recommender Systems: An Introduction", Cambridge University Press, 2010. 7. Kim H. Pries and Robert Dunnigan, "Big Data Analytics: A Practical Guide for Managers " CRC Press, 2015. 8. Jimmy Lin, Chris Dyer and Graeme Hirst, "Data-Intensive Text Processing with MapReduce", Synthesis Lectures on Human Language Technologies, Vol. 3, No. 1, Pages 1-177, Morgan Claypool publishers, 2010.

Course Name: Humans & Data [1 0 0 1]	
Course Code: DSC 422	
Prerequisites	NA
Learning Outcomes	▪ Demonstrate a clear understanding of debates on central ethical and legal issues in Big Data and be able to contribute to these debates ▪ Explain how various positions taken on these topics relate to deeper principles and problems in ethics. ▪ Be able to apply a framework of dealing with issues related to Big Data ▪ Perform their own evaluation and critique of the validity and soundness of arguments with care and clarity, both orally and in writing

Course Name: Humans & Data [1 0 0 1]	
Course Code: DSC 422	
Syllabus	• The course will be based on topical and immediately relevant case studies available in the public domain • Introduction to the ethics of big data ○ Case Study 1 – Who owns Data [1] ○ Case Study 2 – Transaction transparency [1] ○ Case Study 3 – Consent and Privacy [1] ○ Case Study 4 – Value/currency of big data transactions [1] • Issues with mass surveillance and privacy ○ Case Study 1 – Mass surveillance systems around the world [1] ○ Case Study 2 – Mass surveillance in India [1] ○ Case Study 3 – Use and misuse of mass surveillance data [1] • Corporate accountability ○ Case Study 1 –Individual data available with corporations [1] ○ Case Study 2 – Consents signed when using services [1] • Big data and the question of identity ○ Case Study 1 – Big data used to profile individuals [1] ○ Case Study 2 – Targeted advertising: pros and cons [1] ○ Case Study 3 – Big data in elections and mass movements [1] • Correlation and causation and its connection to data and knowledge ○ Case Study 1 – Difference between correlation and causation and big data [1] Responsible use of AI [1]
Text & Reference Books	1. Online material on various case studies like NSA and Edward Snowden, Uber and self-driving cars. Data collected by amazon through alexa and its uses. Cambridge analytica and its influence on elections. Privacy concerns and facebook datat etc.

Course Name: Gambler's Ruin problem [3 0 0 3]	
Course Code: DSC 423	
Prerequisites	NA
Learning Outcomes	▪ Understanding the basic concepts and types of stochastic processes ▪ Understanding finite and large sample properties of important stochastic processes.

Course Name: Gambler's Ruin problem [3 0 0 3]	
Course Code: DSC 423	
Syllabus	• Generating functions; Bivariate distributions and Conditional expectations.Introduction to stochastic processes - time and state space, classification of stochastic processes,stationary processes, processes with independent increments, Gaussian process, Martingales,Markov process, random walk and Wiener process (examples only). [14] • Markov chain, transition probabilities and stationary transition probabilities, transition probabilitymatrix, Chapman - Kolmogorov equation: classification of states, first passage time distribution,stationary distribution, irreducible Markov chain, aperiodic chain, ergodic theorem and Gamblersruin problem. [14] • Poisson Process: postulates of Poisson process, properties of Poisson process, inter-arrival time, pure birth process, birth and death process, pure death process. [12]
Text & Reference Books	1. Sheldon M. Ross, Stochastic Processes, 2nd ed., Wiley India, 2009. 2. S. Karlin and H. Taylor, A first course in Stochastic Process, 2nd ed., Academic Press, 1975. 3. Bhat, U.N. and Miller, G.K. Elements of Applied Stochastic Processes, 3rd ed., John Wiley, New York. 2002 4. Basu, A.K., Introduction to Stochastic Processes, Narosa Publishing, 2005. 5. Cinlar E., Introduction to Stochastic Processes, Prentice Hall, 2013. 6. Medhi J., Stochastic Processes, New Age International Publishers, New Delhi 2009. 7. Ross, S. M., Introduction to Probability Models, Elsevier, 2014.

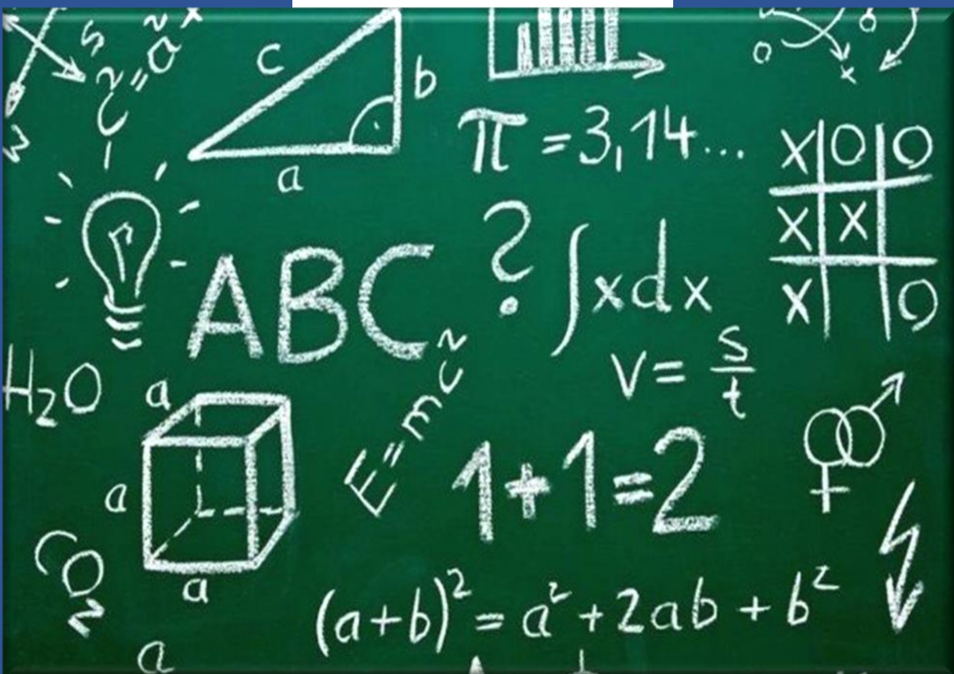
MATHEMATICAL SCIENCES

CURRICULUM FOR

BS-MS (SEM: 5 - 10)

MSc & IPHD (SEM: 1 - 4) AND PHD

CORE & ELECTIVE COURSES



BS-MS Mathematical Sciences (Semester 5 - 10)

Semester 5	Semester 6	Semester 7	Semester 8	Semester 9	Semester 10
MAT 311 Real Analysis [3 0 0 3]	MAT 321 Complex Analysis [3 0 0 3]	MAT 411 Measure Theory [3 0 0 3]	MAT 421 Functional Analysis [3 0 0 3]	MAT 511 Fourier Analysis [3 0 0 3]	Major Project Phase II [18]
MAT 312 Theory of Groups and Rings [3 0 0 3]	MAT 322 Fields, Modules and Algebras [3 0 0 3]	MAT 412 Commutative Algebra [3 0 0 3]	MAT 422 Algebraic Topology [3 0 0 3]	MAT 41XX/51XX Elective II [3 0 0 3]	
MAT 313 Linear Algebra [3 0 0 3]	MAT 323 General Topology [3 0 0 3]	MAT 413 Analysis on Manifolds [3 0 0 3]	MAT 423 Differential Geometry [3 0 0 3]	Major Project Phase I [12]	
MAT 314 Numerical Analysis [3 0 0 3]	MAT 324 Theory of ODE [3 0 0 3]	MAT 414 Partial Differential Equations [3 0 0 3]	MAT 424 Number Theory and Cryptography [3 0 0 3]		
MAT 315 Mathematical Statistics + Lab [3 0 1 4]	MAT 325 Probability Theory and Stochastic Processes [3 0 0 3]	DSC 314 Data Structures [3 0 3 4]	MAT 42XX/52XX Elective I [3 0 0 3]		
Minor Course I	Minor Course II	Minor Course III	Minor Project [6]		
Credits = 19	Credits = 18	Credits = 19	Credits = 21	Credits = 18	Credits = 18

i^2 Mathematical Sciences (Semester 5 - 10)

<table>
<tr><th>Semester 5</th><th>Semester 6</th><th>Semester 7</th><th>Semester 8</th><th>Semester 9</th><th>Semester 10</th></tr>
<tr><td>MAT 311
Real Analysis
[3 0 0 3]</td><td>MAT 321
Complex Analysis
[3 0 0 3]</td><td>MAT 411
Measure Theory
[3 0 0 3]</td><td>MAT 421
Functional Analysis
[3 0 0 3]</td><td>Elective IV</td><td rowspan="6">Project
[18]</td></tr>
<tr><td>MAT 312
Theory of Groups and Rings
[3 0 0 3]</td><td>MAT 323
General Topology
[3 0 0 3]</td><td>MAT 414
Partial Differential Equations
[3 0 0 3]</td><td>I2M 421
Variational Methods and Control Theory
[3 0 0 3]</td><td>Elective V</td></tr>
<tr><td>MAT 313
Linear Algebra
[3 0 0 3]</td><td>MAT 324
Theory of Ordinary Differential Equations
[3 0 0 3]</td><td>DSC 314
Data Structures
[3 0 3 4]</td><td>I2M 422
High Performance Computing
[3 0 0 3]</td><td rowspan="4">Project
[12]</td></tr>
<tr><td>MAT 314
Numerical Analysis
[3 0 0 3]</td><td>MAT 325
Probability Theory and Stochastic Processes
[3 0 0 3]</td><td>I2M 411
Applied Stochastic Analysis
[3 0 0 3]</td><td>I2M 423
Finite Element Methods
[3 0 0 3]</td></tr>
<tr><td>MAT 315
Mathematical Statistics
[3 0 1 4]</td><td>I2M 321
Scientific Computing
[3 0 3 4]</td><td>I2M 412
Numerical Solutions of Differential Equations
[3 0 0 3]</td><td>Elective II</td></tr>
<tr><td>I2D 315
Machine Learning
[3 0 0 3]</td><td>I2M 322
Mathematical Modelling
[3 0 0 3]</td><td>Elective I</td><td>Elective III</td></tr>
</table>

Master of Science in Mathematical Sciences (Semester 1-4)

<table>
<tr><th>Semester 1</th><th>Semester 2</th><th colspan="2">Semester 3</th><th colspan="2">Semester 4</th></tr>
<tr><td>MSM 311
Real Analysis
[3 0 0 3]</td><td>MSM 321
Complex Analysis
[3 0 0 3]</td><td colspan="2">MSM 411
Measure Theory
[3 0 0 3]</td><td colspan="2">MSM 421
Functional Analysis
[3 0 0 3]</td></tr>
<tr><td>MSM 312
Theory of Groups and Rings
[3 0 0 3]</td><td>MSM 322
Fields, Modules and Algebras
[3 0 0 3]</td><td colspan="2">MSM 413
Analysis on Manifolds
[3 0 0 3]</td><td colspan="2">MSM 423
Differential Geometry
[3 0 0 3]</td></tr>
<tr><td>MSM 313
Linear Algebra
[3 0 0 3]</td><td>MSM 323
General Topology
[3 0 0 3]</td><td colspan="2">MSM 414
Partial Differential Equations
[3 0 0 3]</td><td colspan="2">MAT ####
Dept. Elective/Open Elective/Modules
[3 0 0 3]</td></tr>
<tr><td>MSM 314
Numerical Analysis
[3 0 0 3]</td><td>MSM 324
Theory of Ordinary Differential Equations
[3 0 0 3]</td><td colspan="2">MAT ####
Department Electives/Modules
[3 0 0 3]</td><td rowspan="3">MSM 429
Project
[12]
OR</td><td>MAT ####
Dept. Elective/Open Elective/Modules
[3 0 0 3]</td></tr>
<tr><td rowspan="2">MSM 315
Mathematical Statistics + Lab
[3 0 1 4]</td><td>MSM 325
Probability Theory and Stochastic Processes
[3 0 0 3]</td><td colspan="2">MAT ####
Dept. Elective/Open Elective/Modules
[2 0 0 2]</td><td rowspan="2">MSM 428
Project
[9]</td></tr>
<tr><td>MAT ####
Department Electives/Modules
[3 0 0 3]</td><td>MAT ####:
Department Electives/Modules
[3 0 0 3]
OR</td><td>MSC 418:
Project
[3]</td></tr>
<tr><td>16</td><td>18</td><td colspan="2">17</td><td colspan="2">18</td></tr>
</table>

IPhD Mathematical Sciences (Semester 1- 4)

Semester 1	Semester 2	Semester 3	Semester 4
MSM 311 Real Analysis [3 0 0 3]	MSM 321 Complex Analysis [3 0 0 3]	MSM 411 Measure Theory [3 0 0 3]	MSM 421 Functional Analysis [3 0 0 3]
MSM 312 Theory of Groups and Rings mechanisms [3 0 0 3]	MSM 322 Fields, Modules and Algebras [3 0 0 3]	MSM 412 Commutative Algebra [3 0 0 3]	MSM 422 Algebraic Topology [3 0 0 3]
MSM 313 Linear Algebra [3 0 0 3]	MSM 323 General Topology [3 0 0 3]	MSM 413 Analysis on Manifolds [3 0 0 3]	MSM 423 Differential Geometry [3 0 0 3]
MSM 314 Numerical Analysis [3 0 0 3]	MSM 324 Theory of Ordinary Differential Equations [3 0 0 3]	MSM 414 Partial Differential Equations [3 0 0 3]	MSM 424 Number Theory and Cryptography [3 0 0 3]
MSM 315 Mathematical Statistics Lab [3 0 3 4]	MSM 325 Probability Theory and Stochastic Processes [3 0 0 3]	DSC 314 Data Structures [3 0 3 4]	Elective IV
MSM 3101 (or) MSM 3102 Elective I Discrete Math (or) Optimization Techniques [2 0 0 2]	Elective II	Elective III	Elective V
Credits = 18	Credits = 18	Credits = 19	Credits = 18

- *Semester 5 and 6 are designated for research project, which may continue into further doctoral thesis work.*

List of Electives

Sl No:	List of Electives
1	Representation Theory
2	Algebraic Number Theory
3	Homological Algebra
4	Topics in Number Theory
5	An Introduction to Stochastic Calculus and Its Applications
6	Introduction to Computational Fluid Dynamics
7	Wavelet Analysis
8	Hyperbolic Geometry
9	Category Theory
10	Topics in Matrix Analysis
11	Non-Negative Matrices and Applications
12	Algebraic Geometry Over Complex Numbers
13	Finite Frames
14	Control Theory

CORE COURSES - SYLLABUS

Course Name: Real Analysis [3 0 0 3]	
Course Code: MAT 311 / MSM 311	
Prerequisite	NA
Learning Outcomes	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	• Preliminaries: Zorn's lemma, Axiom of choice (1) • 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) • 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) • 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 ed., Addison Wesley, 1974. 2. R. G. Bartle and D. R. Sherbert, Introduction to Real Analysis, 4th ed., 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 ed., Wiley, 1976. 6. S. Lang, Undergraduate Analysis, 2nd ed., Springer, 1996. 7. W. Rudin, Principles of Mathematical Analysis, 3rd ed., McGraw-Hill, 1976. 8. T. Tao, Analysis I, Hindustan Book Agency, 2006. 9. H. L. Royden, Real Analysis, 3rd ed., PHI Learning, 2009.

Course Name: Theory of Groups and Rings [3 0 0 3]	
Course Code: MAT 312 / MSM 312	
Prerequisite	NA

Course Name: Theory of Groups and Rings [3 0 0 3]	
Course Code: MAT 312 / MSM 312	
Learning Outcomes	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	• Definition of group, examples of symmetric groups, cyclic groups, multiplicative group Z_n*, Dihedral groups, subgroups and normal subgroups, homomorphisms. (4.5) • Quotient groups, Noether Isomorphism Theorems, Theorems of Lagrange and Cauchy. (4.5) • Group actions, examples of group actions, Cayley's Theorems, Orbit Stabilizer theorem, Class Equation, Burnside's Counting lemma, Sylows theorems. (9) • Direct Products and Semi-Direct Products, Solvable groups, Nilpotent Groups (6) • Rings, Ideals, Ring homomorphisms, subrings, examples of rings, Prime ideals, maximal ideals, Integral domains. (4.5) • Noether Isomorphism theorems, Euclidean domains, PID's, UFD's, Gauss theorem, Eisenstein Criterion for Irreducibility, power series rings. (7.5) • Modules, definitions and examples, Fundamental theorem of finitely generated modules over a PID. (4)
Text & Reference Books	1. D. S. Dummit and R. Foote, Abstract Algebra, 3rd ed., WIley India, 2011. 2. Michael Artin, Algebra, Phi Learning Pvt. Ltd., New Delhi, 2011. 3. Serge Lang, Algeba, 3rd Revised ed., Springer International ed.

Course Name: Linear Algebra [3 0 0 3]	
Course Code: MAT 313 / MSM 313	
Prerequisite	NA
Learning Outcomes	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	• Vector spaces, subspaces, quotient spaces, basis, change of basis, linear functional, dual space, projection, eigenvalues and eigenvectors. (5) • Cayley Hamilton Theorem, invariant subspaces, simultaneous diagonalization, direct sum decomposition, invariant direct sum, the primary decomposition theorem. (9) • Nilpotent Operators, Jordan Canonical form. (6) • 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) • LU decomposition, QR factorization, Singular Value Decomposition, Orthogoanl matrices. (8)

Course Name: Linear Algebra [3 0 0 3]	
Course Code: MAT 313 / MSM 313	
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 ed., Pearson Education, New Delhi, 2006

Course Name: Numerical Analysis [3 0 0 3]	
Course Code: MAT 314 / MSM 314	
Prerequisite	NA
Learning Outcomes	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 component of this course will enable the students to have hand on experience in implementing numerical schemes.
Syllabus	• Roundoff Errors and Computer Arithmetic. (2) • Interpolation: Lagrange interpolation, divided differences, Hermite interpolation, splines. (5) • Numerical differentiation, Richardson extrapolation. (3) • Numerical integration: Trapezoidal, Simpson, Newton-Cotes, Gauss quadrature, Romberg integration. (6) • Solutions of linear algebraic equations: Direct methods, Gauss elimination, pivoting, matrix factorisations; Iterative methods: Matrix norms, Jacobi and Gauss-Siedel methods, relaxation methods. (8) • Computation of eigenvalues and eigenvectors: Power method, Householder's method, QR algorithm. (4) • Numerical solutions of nonlinear algebraic equations: Bisection, Secant and Newton's method, fixed-point iteration. (4) • 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 ed., 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 ed., Brookes/Cole, 2011. 4. S. D. Conte and C. deBoor, Elementary Numerical Analysis-an algorithmic approach, 3rd ed., McGraw Hill, 1980. 5. J. W. Dummel, Applied Numerical Linear Algebra, SIAM, 1997. 6. C. F. Gerald and P. O. Wheately, Applied Numerical Analysis, 5th ed., Addison Wesley, 1994. 7. G. H. Golub and C. F. vanLoan, Matrix Computations, John Hopkins University Press, 1996.

Course Name: Numerical Analysis [3 0 0 3]	
Course Code: MAT 314 / MSM 314	
	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.

Course Name: Mathematical Statistics [3 0 1 4]	
Course Code: MAT 315 / MSM 315	
Prerequisite	NA
Learning Outcomes	This is an introductory course on statistics. This course provides students with decision theory, estimation, confidence intervals, and hypothesis testing.
Syllabus	• 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, χ2 and F distributions. (9) • 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) • Bivariate Samples: Sample from a bivariate population; least square curve fitting; maximum likelihood estimation; multivariate samples. (7) • 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; χ2- test of goodness of fit. (15) **Practicals** • Objects and functions, Arithmetical and Boolean operators, Importing and Exporting Data sets, Packages, Loops and Conditional statements, Measure of central tendency, basic plots. • Density, distribution function, quantile function and random generation for standard discrete and continuous distributions. • Q-Q plots and P-P plots. Fitting distributions. • 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 ed., 2007. 2. R. V. Hogg, J. McKean and A. T. Craig, Introduction to Mathematical Statistics, Pearson Education India; 7th ed., 2013.

Course Name: Mathematical Statistics [3 0 1 4]	
Course Code: MAT 315 / MSM 315	
	3. A. Mood, F. Graybill and D. Boes, Introduction to the Theory of Statistics, McGraw Hill Education; 3rd ed., 2017. 4. P. J. Bickel and K. A. Doksum, Mathematical Statistics: Basic Ideas and Selected Topics, Vol.1, 2nd ed., 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. Alain F. Zuur, Elena N. Ieno, and Erik H. W. G. Meesters. A Beginner's Guide to R. Springer Science & Business Media, 2009.

Course Name: Complex Analysis [3 0 0 3]	
Course Code: MAT 321 / MSM 321	
Prerequisite	MAT311 Real Analysis
Learning Outcomes	Objective is to study 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	• Geometric representation of complex numbers, Analytic functions: limits, derivatives, Cauchy-Riemann equations, sufficient conditions, Cauchy Riemann equations in polar form, harmonic conjugate. (6) • Mapping by elementary functions: Linear functions, the function 1/z, linear fractional transformations, the logarithmic function and its branches, special fractional transformations. (6) • 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) • 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) • 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, 3rd ed., GSM, Vol. 40, AMS, 2006. 4. E. M. Stein and R. Shakarchi, Complex Analysis, Princeton University Press, 2003.

Course Name: Fields, Modules and Algebras [3 0 0 3]	
Course Code: MAT 322 / MSM 322	
Prerequisite	MAT312 Theory of Groups and Rings
Learning Outcomes	To learn the basics of field theory, finite fields, Fundamental Theorem of Galois Theory, Solvability of radicals and basics of Module theory
Syllabus	• 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. (20) • Noetherian rings and modules, Hilbert Basis Theorem. (4) • Elementary Algebraic geometry, Hilbert Nullstellensatz (9) • Introduction to Representation theory till and including Induced Representations. (7)
Text & Reference Books	1. D. S. Dummit and R. Foote, Abstract Algebra, 3rd ed., WIley India, 2011. 2. Michael Artin, Algebra, Phi Learning Pvt. Ltd., New Delhi, 2011. 3. Serge Lang, Algebra, 3rd Revised ed., Springer International ed.

Course Name: General Topology [3 0 0 3]	
Course Code: MAT 323 / MSM 323	
Prerequisite	MAT311 Real Analysis
Learning Outcomes	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	• 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) • 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) • Countability and Separation Axioms: The countability axioms, The separation axioms, The Urysohn lemma, The Tychonoff theorem, Completely regular spaces, one-point compactification. (6) • Homotopy, Fundamental Groups, examples and computations, Van Kampen Theorem, covering spaces. (10)
Text & Reference Books	1. J. R. Munkres, Topology, 2nd ed., Prentice Hall, 2000. 2. G. F. Simmons, Introduction to Topology and Modern Analysis, McGraw-Hill, 1963. 3. J. Dugundji, Topology, Prentice Hall, 1965.

Course Name: Theory of Ordinary Differential Equations [3 0 0 3]	
Course Code: MAT 324 / MSM 324	
Prerequisite	MAT311 Real Analysis, MAT313 Linear Algebra
Learning Outcomes	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	• 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) • 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) • 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) • Boundary value problems: Linear BVP, Green's function, Sturm-Liouville theory, comparison principle, eigen function 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 ed., 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 ed., Springer, 2006. 5. G. F. Simmons, Differential Equations with Applications and Historical Notes, 2nd ed., 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 ed., Wiley, 2004.

Course Name: Probability Theory and Stochastic Processes [3 0 0 3]	
Course Code: MAT 325 / MSM 325	
Prerequisite	NA
Learning Outcomes	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.

Course Name: Probability Theory and Stochastic Processes [3 0 0 3]	
Course Code: MAT 325 / MSM 325	
Syllabus	• Review of Probability: Events and probability; random variables; conditional probability; independence. (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) • Markov Chains: Chapman-Kolmogorov equations; classification of states; limiting probabilities; the Gambler's Ruin problem; birth and death chains; branching and queuing chains. (10) • 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) • 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, 11th ed., Elsevier, 2014. 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 ed., Oxford University Press, 2001. 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.

Course Name: Measure Theory [3 0 0 3]	
Course Code: MAT 411 / MSM 411	
Prerequisite	MAT311 Real Analysis
Learning Outcomes	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	• Outer measure, σ-algebra of measurable sets and its properties, Lebesgue measure and its properties, a non-measurable set, measurable function. (9) • 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)

Course Name: Measure Theory [3 0 0 3]	
Course Code: MAT 411 / MSM 411	
	• Differentiation and integration: Differentiation of monotone functions, functions of bounded variation, differentiation of an integral, absolute continuity. (9) • 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 ed., John Wiley and Sons, 1999. 4. P. R. Halmos, Measure Theory, Springer, 2009. 5. H. L. Royden, Real Analysis, 3rd ed., PHI Learning, 2009. 6. W. Rudin, Real and Complex Analysis, 3rd ed., 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.

Course Name: Commutative Algebra [3 0 0 3]	
Course Code: MAT 412 / MAT 6102	
Prerequisite	MAT312 Theory of Groups and Rings
Learning Outcomes	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	• Basic facts on Rings and Ideals: Nilradical Jacobson radical, operations on ideals, extensions and contractions. (3) • 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) • Rings and modules of fractions: Local properties, extended and contracted ideals in ring of fractions. (5) • Chain conditions: Noetherian ring, Arinian ring, Hilbert basis theorem, Primary decomposition, primary decomposition in Noetherian rings. (6) • Integral dependence and valuations: Integral dependence, going-up theorem, integrally closed integral domain, going-down theorem, valuation rings. (5) • Discrete valuation ring and Dedekind domains. (3) • Dimension Theory: Grades ring and modules, Hilbert function, dimension theory of Noetherian local rings, regular local rings. (8)

Course Name: Commutative Algebra [3 0 0 3]	
Course Code: MAT 412 / MAT 6102	
Text & Reference Books	1. M. F. Atiyah and I. G. Macdonald, Introduction to Commutative Algebra. 2. D. Eisenbud, Commutative Algebra with a view towards Algebraic Geometry. 3. H. Matsumura, Commutative Ring Theory.

Course Name: Analysis on Manifolds [3 0 0 3]	
Course Code: MAT 413 / MAT 6103 / MSM 413	
Prerequisite	MAT311 Real Analysis and MAT313 Linear Algebra
Learning Outcomes	To learn the basic theorems and techniques in analysis on Rn; 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	• Functions of several Variables: Differentiation, directional derivatives, chain rule, Inverse function theorem and implicit function theorem. (10) • Integration: Integration over a rectangle, surface and volume integrals, Fubini's theorem, Change of variables formula, Partitions of unity. (12) • Submanifolds in Rn, tangent spaces. (6) • 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.

Course Name: Partial Differential Equations [3 0 0 3]	
Course Code: MAT 414 / MAT 6104 / MSM 414	
Prerequisite	MAT314 Theory of Ordinary Differential Equations
Learning Outcomes	This course aims at developing theory of first order partial differential equations as well as three second order linear partial differential equations
Syllabus	• 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

Course Name: Partial Differential Equations [3 0 0 3]	
Course Code: MAT 414 / MAT 6104 / MSM 414	
	equation, solution by spherical means, non-homogeneous problem, energy methods. (30) • 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 ed., American Mathematical Society, 2010. 2. R. Mc Owen, Partial Differential Equations: Methods and Applications, 2nd ed., Pearson, 2002. 3. G. B. Folland, Introduction to Partial Differential Equations, 2nd ed., Princeton University Press, 1995. 4. F. John, Partial Differential Equations, 4th ed., Springer, 1981. 5. M. E. Taylor, Partial Differential Equations I, 2nd ed., Springer, 2010. 6. S. Kesavan, Topics in Functional Analysis and Applications, Wiley, 1989.

Course Name: Data Structures [3 0 3 4]	
Course Code: DSC 314 / 3104	
Prerequisite	NA
Learning Outcomes	• 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	• Introduction- Algorithm Analysis, Finding Complexity. Fundamental data structures - List- Sorted Lists, Double Linked Lists, Stack & Queue application. (10) • Binary Trees – Insertion and Deletion of nodes, Tree Traversals, Polish Notations, Red Black Trees, B-Trees, Heaps, Priority Queues. (10) • Sorting – Bubble, Selection, Insertion, Merge Sort, Quick Sort, Radix Sort, Heap sort. Searching. (10) • Graphs- Shortest path algorithms, Minimum Spanning Trees, BFS, DFS. (10)
Text & Reference Books	1. Clifford A Shaffer, Data Structures and Algorithm Analysis, ed. 3.2 (Java Version), 2011. 2. Michael T. Goodrich, Roberto Tamassia, Michael H. Goldwasser. Data Structures And Algorithms In Java™ 6th ed., Wiley Publishers, 2014. 3. Mark Allen Weiss Data Structures And Algorithm Analysis In Java, 3rd ed., 2012. 4. Robert L. Kruse, Data Structures And Program Design In C++, Pearson Education, 2nd ed., 2006. 5. Ellis Horowitz, Fundamentals of Data Structures in C++, University Press, 2015.

Course Name: Data Structures [3 0 3 4]	
Course Code: DSC 314 / 3104	
	6. Ajay Agarwal, Data Structure through C, A Complete Reference Guide, Cyber Tech Publications, 2005

Course Name: Functional Analysis [3 0 0 3]	
Course Code: MAT 421 / MSM 421	
Prerequisite	MAT321 Complex Analysis and MAT411 Measure Theory
Learning Outcomes	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	• 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) • Fundamental theorems: Hahn-Banach theorems, uniform boundedness principle, divergence of Fourier series, closed graph theorem, open mapping theorem and some applications. (8) • Dual spaces and adjoint of an operator: Duals of classical spaces, weak and weak* convergence, adjoint of an operator. (6) • 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) • Bounded operators on Hilbert spaces: Adjoint, normal, unitary, self-adjoint operators, compact operators. (5) • 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 ed. 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 – Vol. 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 ed.), 1999.

Course Name: Algebraic Topology [3 0 0 3]	
Course Code: MAT 422	
Prerequisite	MAT312 Theory of Groups and Rings and MAT325 General Topology
Learning Outcomes	▪ 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	• Homotopy. Homotopy equivalence. Relative homotopy, Paths. Fundamental group. Induced homomorphism, Fundamental group of a product, Fundamental group of the circle, Homotopy lifting property. (7) • Some basic category theory (upto Natural transformations and push forward), Van Kampen theorem. (6) • Existence of covering spaces, and classification of covering spaces. (3) • Deck Transformations and Group actions, simplicial homology, singular homology, Homotopy invariance. (9) • Relative and reduced homology, long exact sequence of a pair. (3) • Mayer-Vietoris, Applications of Mayer Vietoris, Homology with coefficients etc. (4.5) • Cohomology, cup-product, Poincare Duality. (7.5)
Text & Reference Books	1. Algebraic Topology, Allen Hatcher, Cambridge Univ Pr; 1st ed., 2005 2. Homology Theory An Introduction to Algebraic Topology, James W. Vick, Springer; 2nd ed. 1994. 3. An Introduction to Algebraic Topology, Joseph Rotman, Springer; 1st ed., 1998

Course Name: Differential Geometry [3 0 0 3]	
Course Code: MAT 423 / MAT 6203 / MSM 423	
Prerequisite	MAT413 Analysis on Manifolds
Learning Outcomes	▪ 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	• Gauss curvature, Gauss curvature formula in terms of first and second fundamental forms. Intrinsic property of the Gauss curvature. (6)

Course Name: Differential Geometry [3 0 0 3]	
Course Code: MAT 423 / MAT 6203 / MSM 423	
	• 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) • 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) • Sub-manifolds; Regular value theorem. Lie groups, examples; Submersion, Immersion and Embeddings. (6) • Smooth vector bundles, smooth sections, Dual bundles, existence of local sections. (5) • Tangent bundles; Smooth vector fields; Lie bracket of smooth vector fields; Co-tangent bundles; Differential 1-forms. (5) • Differential p-forms. Orientation. Exterior derivative. Closed and exact forms. Integration of a p-form on a p-dim sub manifold. Stokes theorem. (6)
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.

Course Name: Number Theory and Cryptography [3 0 0 3]	
Course Code: MAT 424	
Prerequisite	NA
Learning Outcomes	▪ 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	• 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) • 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)

Course Name: Number Theory and Cryptography [3 0 0 3]	
Course Code: MAT 424	
	• Quadratic residues, Legendre symbol, law of quadratic reciprocity, Jacobi symbol, binary quadratic forms. (9) • Pythagorean triples, Fermat's Last Theorem, Lagrange's theorem, continued fractions, best approximations, quadratic irrationals, Pell's equation. (7) • 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 ed., Wiley, 1991. 2. Neal Koblitz, A Course in Number Theory and Cryptography, 2nd ed., Springer, 1994. 3. Kenneth Ireland and Michael Rosen, A Classical Introduction to Modern Number Theory, 2nd ed., Springer, 1990. 4. M. H. Weissman, An Illustrated Theory of Numbers, American Mathematical Society 2017.

Course Name: Fourier Analysis [3 0 0 3]	
Course Code: MAT 511	
Prerequisite	MAT414 Partial Differential Equations and MAT421 Functional Analysis
Learning Outcomes	The course provides a rigorous introduction to Fourier series and Fourier transforms. It starts with the definition of Fourier series and proceeds to its convergence analysis and some applications, such as the Weyl's equidistribution theorem, heat equation on unit circle etc. The second half of the courses deals with the theory of Fourier transforms. As an application of Fourier series partial differential equations, initial value problems of heat and the wave equations are done.
Syllabus	**Fourier Series:** • Definitions, Examples, Uniqueness of Fourier series, Convolution. (5) • Good Kernel, Cesaro sum and Abel summability, application to Fourier series: The Poisson kernel and Dirichlet problem in the unit disc (5) • Convergence of Fourier series: Mean square convergence, Pointwise convergence, Reimann-Lebesgue Lemma, existence of continuous function with diverging Fourier series (3) • Some applications of Fourier series Weyl's equidistributiontheorem, A continuous nowhere differentiable function. Heat equation on unit circle. (4) **Fourier transform on R and R^d** • Fourier transform, approximate identity, Fourier inversion, Schwartz class function, Plancherel theorem, Weierstrass approximation theorem. (9) • Application to PDE: Time dependent heat equation on real line. Steady state heat equation on upper half plane. (6)

Course Name: Fourier Analysis [3 0 0 3]	
Course Code: MAT 511	
	• The Poisson summation formula: Theta and zeta functions, heat kernel, Poisson kernel (5) • The wave equation in Rd x R (3)
Text & Reference Books	1. E. M. Stein, R. Shakarchi, Fourier Analysis, An introduction. 2. G. B. Folland, Fourier Analysis and Its Applications. 3. Y. Katznelson, An introduction to Harmonic Analysis

Thematic Subjects for i^2 Mathematical Sciences

Course Name: Scientific Computing [3 0 3 4]	
Course Code: I2M 321	
Prerequisite	NA
Learning Outcomes	▪ Apply standard techniques to analyse key properties of numerical algorithms, such as stability and convergence. ▪ Understand and analyse common pitfalls in numerical computing such as ill-conditioning and instability. ▪ Perform data analysis efficiently. ▪ Derive and analyse numerical methods for constrained and unconstrained optimisation problems. ▪ Introduce the basics of Monte Carlo methods

Syllabus	• Brief review of the sources of error and local analysis: Relative error, absolute error, and cancellation; Computer arithmetic; Truncation error; Error propagation and amplification; Condition number and ill-conditioned problems. (3)
	• Numerical linear algebra: Direct solution methods for linear systems, Gaussian elimination and its variants; LU, QR, Singular value decomposition, Iterative methods for a linear system, Stationary iterative methods- Jacobi, Gauss-Seidel, and successive over-relaxation methods. Non-stationary iterative methods-conjugate gradient (CG), convergence analysis; preconditioning. Estimation and computation of Â eigenvalues-Gershgorin disc, power methods, the QR algorithm, Chebyshev polynomials and Chebyshev semi-iterative methods. (18)
	• Nonlinear equations and optimisation:
	  • Unconstrained Optimisation: Optimality conditions, steepest descent method, Newton and quasi-Newton methods, General line search methods, Trust region methods, Least squares problems and methods. (6)
	  • Constrained Optimisation: Optimality/KKT conditions, penalty and augmented Lagrangian for equality-constrained optimisation, interior-point/barrier methods for inequality constrained optimisation. SQP methods. (8)
	• Monte Carlo methods: Basic review of probability; Random number generators, Sampling, Error bars, Variance reduction. (5)

Text & Reference Books	1. L. N. Trefethen and D. Bau III, Numerical Linear Algebra, SIAM, 1997. 2. J. W. Demmel, Applied Numerical Linear Algebra, SIAM, 1997. 3. A. Greenbaum, Iterative Methods for Solving Linear Systems, SIAM, 1997. 4. G. H. Golub and C. F. van Loan, Matrix Computations, John Hopkins University Press, 1996. 5. H. C. Elman, D. J. Silvester and A. J. Wathen, Finite Elements and Fast Iterative Solvers, Oxford University Press, 1995.

Course Name: Scientific Computing [3 0 3 4]	
Course Code: I2M 321	
	6. J. Nocedal and S. J. Wright, Numerical Optimisation, Springer, 2006. 7. D. P. O'Leary, Scientific Computing with Case Studies, SIAM, 2009.

Course Name: Mathematical Modelling [3 0 0 3]	
Course Code: I2M 322	
Prerequisite	MAT 313 Linear Algebra
Learning Outcomes	▪ This course will introduce student to mathematical models of real world problems ▪ Emphasis is on the use of elementary functions to investigate and analyze applied problems and questions. ▪ Linear, exponential, logarithmic, and polynomial function models will be discussed with examples taken from physics, biology, chemistry, and other fields.
Syllabus	• Introduction- Modelling philosophy: Why model? What's a good model? Model validation. Simple and complex models, simulation vs. modelling, stochastic vs. deterministic. Example problems: Growth of a Yeast Culture, Spread of a Contagious Disease, Decay of Digoxin in the Bloodstream, Heating of a Cooled Object. (4) • Probabilistic models: Monte Carlo (Buffon's needle, profit vs. risk, Bernoulli trials, Poisson distributions), Markov Chain Applications to the inventory problem, the queuing problem, genetics, gambling, and the Internet and Google's Page Rank algorithm. (12) • The Modelling Process, Proportionality, and Geometric Similarity: Example from Model Fitting, Experimental Modelling, Simulation Modelling, Discrete Probabilistic Modelling, Optimization of Discrete Models. (8) • Modelling with a Differential Equation: Population Growth. Prescribing Drug Dosage, A Predator-Prey Model, A Competitive Hunter Model, Two competing species: deadly survival struggle between sheep and Rabbits. Introduction to phase plane, fixed points, stability, classification of linear systems, nonlinear limit cycles. Predator-prey oscillations, Lotka-Volterra equations. Application to epidemiology, Numerical Approximation Methods. (16)
Text & Reference Books	1. Giordano F. R., Fox W. P., and Horton S. B., A first course in mathematical modeling, Brooks/Cole, 2014. 2. Michael Y. Li, An Introduction to Mathematical Modeling of Infectious Diseases, Springer, 2018. 3. Stefan Heinz, Mathematical modeling, Springer, 2011.

Course Name: Applied Stochastic Analysis [3 0 0 3]	
Course Code: I2M 411	
Prerequisite	MAT 311 Real Analysis, MAT 325 Probability and Stochastic Processes
Learning Outcomes	This course will introduce the major topics in stochastic analysis from an applied mathematics perspective, and will be a continuation of the course on Probability & Stochastic Processes. The course will pay particular attention to the connection between stochastic processes and ODEs and PDEs, as well as to physical principles and applications.
Syllabus	• Review of Markov Chains (Discrete and Continuous time), Gaussian Processes and Stationary Processes; (3) • Brownian Motion; (7) • Stochastic Integration; (10) • Stochastic Differential Equations; (10) • Applications from finance and biology; (7) • Numerically solving SDEs (basic concepts). (3)
Text & Reference Books	1. G. A. Pavliotis, Stochastic Processes and Applications, Springer Verlag, 2014. 2. C. Gardiner, Stochastic Methods: A Handbook for the Natural and Social Sciences, 4th ed., Springer 2009. 3. B. Oksendal, Stochastic Differential Equations, 6th ed., Springer, 2014.

Course Name: Numerical Solutions of Differential Equations [3 0 0 3]	
Course Code: I2M 412 / MSM 4106 / MAT 6106	
Prerequisite	MAT 313 Linear Algebra, MAT 314 Numerical Analysis
Learning Outcomes	▪ Understand the key-ideas, concepts and definitions of the computational algorithms, sources of errors, convergence theorems. ▪ Implement a given algorithm in a programming language and test and validate codes to solve a given differential equation numerically. ▪ Choose the best numerical method to apply to solve a given differential equation and quantify the error in the numerical (approximate) solution. ▪ Analyse an algorithm's accuracy, efficiency and convergence properties.
Syllabus	• Numerical methods for initial value problems (IVPs): Euler forward and backward methods, stability analysis, error estimates. Higher order methods, Runge-Kutta methods, convergence, Multistep methods, Predictor corrector methods. Stiff ODEs: Implicit-explicit (IMEX) method. (10)

Course Name: Numerical Solutions of Differential Equations [3 0 0 3]	
Course Code: I2M 412 / MSM 4106 / MAT 6106	
	• Numerical methods for boundary value problems (BVPs): Shooting method, Finite difference schemes, consistency, truncation error, stability and convergence, Galerkin collocation method. (6) • Numerical methods for partial differential equation: Review of Poisson equation in one dimension, finite difference method for Poisson equation, stability and convergence, finite difference method for heat equation, Crank-Nicolson method, theta method, alternate direction implicit methods (ADI methods), CFL condition, stability and convergence, finite difference method for linear advection equation, method of lines, upwind scheme, CFL condition, stability and convergence. (14) • Practicals: Implementation of the above algorithms, demonstration of stability, truncation error and order of accuracy. (10) Optional topics: • Numerical methods for differential algebraic equations (DAEs), Keller-box method, numerical methods in polar coordinates.
Text & Reference Books	1. R. L. Burden and J. D. Faires, Numerical Analysis. 2. Endre Suli and David F. Mayers, An introduction to numerical analysis. 3. K. Atkinson, W. Han and D. Stewart, Numerical solution of ordinary differential equations. 4. K. W. Morton and D. F. Mayers, Numerical Solution of partial differential equations.

Course Name: Variational Methods and Control Theory [3 0 0 3]	
Course Code: I2M 421	
Prerequisite	MAT 324 Theory of Ordinary Differential Equations
Learning Outcomes	The larger aim of this course is to train students in an area of application-oriented mathematics that deals with the basic principles underlying the analysis and design of control systems.
Syllabus	• Calculus of variations; (6) • Introduction to classical control theory; (6) • Controllability, rank condition, Kalman decomposition, observability; (8) • Stability and Lyapunov theory, stabilisation; (6) • Optimal control problems, Pontryagin's maximum principle, Ekeland's principle; (8) • Dynamic programming principle. (6)
Text & Reference Books	1. J. Zabczyk, Birkhauser, Mathematical Control theory, An Introduction, 2007. 2. W. H. Flemming and R. W. Rishel, Deterministic and Stochastic Optimal Control, Springer 1982. 3. E. R. Pinch, Optimal Control and Calculus of Variations, Oxford University Press, 1993.

Course Name: High Performance Computing [3 0 0 3]	
Course Code: I2M 422	
Prerequisite	I2M 321 Scientific Computing
Learning Outcomes	▪ Explain how large-scale parallel systems are architectured and how massive parallelism are implemented in accelerator architectures. ▪ Write parallel programs for large-scale parallel systems, shared address space platforms, and heterogeneous platforms. ▪ Design efficient parallel algorithms and applications. ▪ Be conversant with performance analyse and modelling of parallel programs. ▪ Perform optimisation using well-established algorithms. ▪ Implement a range of numerical algorithms efficiently in a modern scientific computing programming language.
Syllabus	There will be four major aspects of the course: • Part I will start with current trends in high-end computing systems and environments, and continue with a practical short description on parallel programming with MPI, Open MP, and Pthreads. (12) • Part II will illustrate the modelling of problems from physics and engineering in terms of partial differential equations (PDEs), and their numerical discretization using finite difference, finite element, and spectral approximation. (12) • Part III will be on solvers: both iterative for the solution of sparse problems of part II, and direct for dense matrix problems. Algorithmic and practical implementation aspects will be covered. (9) • Finally in Part IV, various software tools will be surveyed and used. This will include PETSc, Sca/LAPACK, MATLAB, and some tools and techniques for scientific debugging and performance analysis. (7)
Text & Reference Books	1. Jack Dongarra, Ian Foster, Geoffrey Fox, William Gropp, Ken Kennedy, Linda Torczon, Andy White, The Sourcebook of Parallel Computing, Morgan Kaufmann Publishers, 2002.

Course Name: Finite Element Methods [3 0 0 3]	
Course Code: I2M 423 /MAT 6206 / MAT 5206	
Prerequisite	MAT 414 Partial Differential Equations
Learning Outcomes	This course provides a mathematical introduction to finite elements and how to apply it to basic partial differential equations (PDEs). At the end of the course the students would have gained familiarity with algorithms for numerically solve PDEs on complex domains, software tools implementing the FEM, and scope for learning how to solve multiphysics

Course Name: Finite Element Methods [3 0 0 3]	
Course Code: I2M 423 /MAT 6206 / MAT 5206	
	application problems. The course builds on elementary calculus, analysis and linear algebra and, of course, requires some acquaintance with partial differential equations. Numerical analysis would be helpful but is certainly not essential. Function Space material will be introduced in the course as needed.
Syllabus	• Examples of PDEs, introduction to Sobolev spaces, Weak (variational) formulation of elliptic boundary-value problems of second order, natural and essential boundary conditions, Ritz-Galerkin method, some standard finite elements. (8) • General finite element theory. V-ellipticity, Lax-Milgram, Cea's lemma, error estimates in the energy norm, examples of finite elements including standard continuous Lagrange elements and non-conforming finite elements. Finite element methods for time-dependent problems. (12). • Data Structures and Implementation: The mesh data structure, programming the finite element method: Linear Lagrange triangles, Lagrange triangles of arbitrary degree, numerical integration, assembling global matrices, and solution of the algebraic systems. (8). • Multi-physics applications - heat and mass transfer and fluid dynamics and chemical reactions, theory of elasticity, multiphase systems, static electric and magnetic fields and interaction with matter, electrodynamics, wave optics. Solving the Schrödinger equation in different potentials, Electrical transport in microsystems, sensors and allied devices.(12)
Text & Reference Books	1. C. Johnson, Numerical Solution of Partial Differential Equations by the Finite Element Method, Cambridge University Press, 1987. 2. S. C. Brenner and L. R. Scott, The Mathematical Theory of Finite Element Methods, Springer-Verlag, New York, 1994. 3. S. M. Muhsa, Computational Finite Element Methods in Nanotechnology, CRC Press 2013. 4. R. Pryor, Multiphysics Modeling Using COMSOL 4, Mercury Learning, 2012. 5. S. Ganesan, L. Tobiska, Finite Elements: Theory and Algorithms, Cambridge IISc Series, Cambridge Univesity press, 2016.

Course Name: Mathematical Biology [3 0 0 3]	
Course Code: I2M 4101 / I2B 4101	
Prerequisite	NA
Learning Outcomes	This course is an exploration in applications of mathematics to various biological, ecological, physiological, and medical problems. By the end of this course, students will be able to derive, interpret, solve, simulate, understand, discuss and critique discrete and differential equation models of biological systems. Lab component of the course will be Python based.

Course Name: Mathematical Biology [3 0 0 3]	
Course Code: I2M 4101 / I2B 4101	
Syllabus	• Introduction to discrete models. • Discrete models of breathing, tumour initiation • Nonlinear discrete equations - steady states, stability, bifurcations • Nonlinear Systems: The Nicholson-Bailey Model • Continuous Models; The Spruce Budworm Outbreak Model, The Chemostat/Phase Portraits; Models in Immunology, Tumour-Immune Interactions • Multiple Species Models; The SIR and STD models
Text & Reference Books	1. Leah Edelstein-Keshet, Mathematical Models in Biology, Magraw-Hill, 1988.

Course Name: Stochastic Modelling of Biological Processes [3 0 0 3]	
Course Code: I2M 5101 / I2B 5101	
Prerequisite	NA
Learning Outcomes	This course provides an introduction to stochastic methods for modelling biological systems, covering a number of applications, ranging in size from molecular dynamics simulations of small biomolecules to stochastic modelling of groups of animals.
Syllabus	• Stochastic simulation of chemical reactions in well-stirred systems: Gillespie algorithm, chemical master equation, analysis of simple systems, deterministic vs. stochastic modelling. • Review of stochastic differential equations; numerical methods, Fokker-Planck equation, first exit time, backward Kolmogorov equation, chemical Fokker-Planck equation. • Stochastic reaction-diffusion modelling: compartment-based (lattice-based) models, reaction-diffusion master equation, Brownian dynamics, diffusion-limited reactions. • Molecular dynamics: molecular mechanics, generalised Langevin equation. • Stochastic models of dispersal in biological systems: velocity-jump processes, bacterial chemotaxis, collective animal behaviour.
Text & Reference Books	1. R. Erban, S. J. Chapman and P. K. Maini, A practical guide to stochastic simulation of reaction-diffusion processes (2007) Available at http://arxiv.org/abs/0704,1908. 2. H. Berg, Random Walks in Biology, Princeton University Press, 1993. 3. D. T. Gillespie, Markov Processes, an Introduction for Physical Scientists, Gulf Professional Publishing, 1992. 4. P. Attard, Non-Equilibrium Thermodynamics and Statistical Mechanics, Oxford University Press, 2012. 5. A. Nitzan, Chemical Dynamics in Condensed Phases, Oxford University Press, 2006.

Course Name: Stochastic Modelling of Biological Processes [3 0 0 3]	
Course Code: I2M 5101 / I2B 5101	
	6. P. Krapivsky, S. Redner and E. Ben-Naim, A Kinetic View of Statistical Physics, Cambridge University Press, 2010. 7. D. Anderson, T. Kurtz, Stochastic Analysis of Biochemical Systems, Springer, 2015. 8. B. Leimkuhler, C. Matthews, Molecular Dynamics: with Deterministic and Stochastic Numerical Methods, Springer, 2015.

ELECTIVE COURSES – SYLLABUS

Course Name: Discrete Mathematics [2 0 0 2]	
Course Code: MAT 3101	
Prerequisite	NA
Learning Outcomes	▪ 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	• 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) • Introduction to Logic: Logic in Language, Predicate Logic, Logical operators, Logic Proposition and logical proofs (by logical arguments), Logical Puzzles, Logic of statements. (2) • 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) • 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) • 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) • Euler's polyhedron formula,The Five colour Theorem, Ramsey Theory, Ramsey number, Regular graphs, Ramanujan graphs, Cayley graphs. (4) • Counting paths in Regular graphs, The Ihara Zeta function of a Graph. (2)
Text & Reference Books	1. Harary F., Graph Theory, Narosa, 1969. 2. Sebastian M. Cioaba and M. Ram Murty, A first course in Graphy Theory and Combinatorics, Hindustan Book Agency, 2009. 3. Kenneth Rosen, Discrete Mathematics and Its Applications, McGraw Hill Higher Education, 2006. 4. Van Lint J. H., Wilson R. M., A course in combinatorics. 2nd ed., Cambridge University Press, Cambridge, 2001. 5. C. L. Liu, Elements of Discrete Mathematics, Tata McGraw-Hill, 2000.

Course Name: Optimization Techniques [2 0 0 2]	
Course Code: MAT 3102	
Prerequisite	NA
Learning Outcomes	▪ To learn various optimization techniques and their applications ▪ Understanding of linear and nonlinear techniques
Syllabus	• Classification and general theory of optimization. (1) • Linear programming (LP): Formulation and geometric ideas, simplex and revised simplex method. (5) • Duality and sensitivity, interior-point methods for LP problems. (5) • Transportation- assignment-and integer programming problems. (5) • Nonlinear optimization: Method of Lagrange multipliers. (2) • Karush-Kuhn-Tucker theory. (2) • Numerical methods for nonlinear optimization. (2) • Convex optimization, quadratic optimization. (2) • Dynamic programming. (2)
Text & Reference Books	1. D. G. Luenberger and Y. Ye, Linear and Nonlinear Programming, 3rd ed., 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, 2nd ed., Wiley India, 2001. 4. M. S. Bazarra, H. D. Sherali and C. M. Shetty, Nonlinear Programming Theory and Algorithms, 3rd ed., Wiley India, 2006. 5. K. G. Murty, Linear Programming, Wiley, 1983.

Course Name: Algebraic Geometry over complex numbers [3 0 0 3]	
Course Code: MAT 4106 / MAT 6106	
Prerequisite	MAT 321, MAT 323, MAT 423
Learning Outcomes	▪ The objective of this course is to make students familiar with the basic notions of Algebraic Geometry.
Syllabus	• Plane curves (conics, singularities, Bezout's theorem, hyperelliptic curves (4) • Sheaves and Geometry-Manifolds and varieties via sheaves, sheaves of modules (12) • Line bundles on projective space, sheaf cohomology. (12) • De Rham's cohomology of Manifolds, Kunneth's formula, Poincare duality, Fundamental class, Lefschetz Trace formula, Riemann surfaces (12)

Course Name: Algebraic Geometry over complex numbers [3 0 0 3]	
Course Code: MAT 4106 / MAT 6106	
Text & Reference Books	• A. Donu, Algebraic Geometry over Complex Numbers, Universitext, Springer NewYork 2012

Course Name: An Introduction to Stochastic Calculus and Its Applications [3 0 0 3]	
Course Code: MAT 4110	
Prerequisite	MAT 325, MAT 411
Learning Outcomes	Measure Theory and Integration. A course on Probability Theory will be an added advantage, however is not a mandatory requirement. Concepts from Probability Theory, as and when require will be presented in the course.
Syllabus	• Measure theory preliminaries, probability spaces, random variables, distributions, expectation, conditional probability, stochastic processes • Construction of Brownian motion. • Martingales in continuous time. • The integral calculus. • Stochastic differential equations. • Giranoy's theorem; Martingale representation. • The Feynman-Kac formula, Applications to resonance and PDE (contents will depend on the available time).
Text & Reference Books	1. B. Oksendal, Stochastic Differential Equations: An Introduction with Applications, 6th ed., Springer, 2014. 2. I. Karatzas and S. Shreve, Brownian Motion and Stochastic Calculus, 2nd ed., Springer, 2004. 3. J. M. Steele, Stochastic Calculus and Financial Applications, 1st ed., Springer, 2001. 4. L. C. Evans, An Introduction to Stochastic Differential Equations, 1st ed., American Mathematical Society, 2014.

Course Name: Topics in Number Theory [3 0 0 3]	
Course Code: MAT 4111	
Prerequisite	MAT 312, MAT 313, MAT 322
Learning Outcomes	This is an advanced course useful for students pursuing algebra and number theory.

Course Name: Topics in Number Theory [3 0 0 3]	
Course Code: MAT 4111	
Syllabus	• 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) • 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) • 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 S. Brown, Cohomology of Groups, Springer 1st ed. Corr. 2nd Printing, 1994. 4. Serge Lang, Algebra, Springer 3rd ed., 2005.

Course Name: Introduction to Computational Fluid Dynamics [3 0 0 3]	
Course Code: MAT 4112	
Prerequisite	Prerequisites will be developed as needed.
Learning Outcomes	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.

Course Name: Introduction to Computational Fluid Dynamics [3 0 0 3]	
Course Code: MAT 4112	
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, 1990. 4. 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.

Course Name: Wavelet Analysis [3 0 0 3]	
Course Code: MAT 4113	
Prerequisite	MAT 311: Real Analysis, MAT 313 Linear Algebra, MAT 322 Measure Theory
Learning Outcomes	To learn the techniques of wavelet transforms and Frames of various types
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.

Course Name: Wavelet Analysis [3 0 0 3]	
Course Code: MAT 4113	
	9. Wojtaszczyk P., A Mathematical introduction to Wavelets, Cambridge University Press, 1997. 10. Yves Meyer, Wavelets and Operators, Cambridge University Press, 2009

Course Name: Hyperbolic Geometry [3 0 0 3]	
Course Code: MAT 4114 / MAT 511B	
Prerequisite	MAT312 Abstract Algebra; MAT321 Complex Analysis; MAT325 General Topology.
Learning Outcomes	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, 59 – 115, 1997.. 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.

Course Name: Category Theory [3 0 0 3]	
Course Code: MAT 4115 / MAT 4215	
Prerequisite	NA
Learning Outcomes	Understanding of basics of Category theory and Functors

Course Name: Category Theory [3 0 0 3]	
Course Code: MAT 4115 / MAT 4215	
Syllabus	• Brief overview of foundations of set theory; Russell'paradox. Sets and classes. Examples from algebra, topology to motivate the definition of a category. Illustration of `universal property' appearing in various areas of mathematics. Categories, monomorphisms, epimorphisms, isomorphisms; subcategories; Standard examples of categories; Groupoids. Small and large categories • Functors, covariant and contravariant functors, full, faithful, forgetful functors, Homfunctor; Subfunctors. • Natural transformations, natural isomorphisms, equivalence of categories, Mac lane's theorem for equivalence of categories; Functor category. • Yoneda functor and Yoneda Lemma, representable functors; Adjoint functors Comma category; Universal morphisms; Product and co-product, limits and co-limits Initial, terminal and null objects, kernel and co-kernel; Examples from algebra. • Additive category and additive functors, abelian category, exact functors Cartesian diagrams, fibre products, relative category, base change. • Definition of presheaves and sheaves on a topological space; Category theoretic formulation of sheaves. Category of categories; 2-categories. Grothendieck topology; Pseudo functors; Definition of stack
Text & Reference Books	1. Saunders Mac Lane, Categories for the Working Mathematician. 2. Steve Awdey, Category Theory 3. Tom Leinster, Basic Category Theory 4. Jiri Adamek, Horst Herrlich, George E. Strecker, Abstract and Concrete Categories: The Joy of Cats 5. Masaki Kashiwara, Pierre Schapira, Categories and Sheaves

Course Name: Non-Negative Matrices and Applications [3 0 0 3]	
Course Code: MAT 4117 / MAT 4217	
Prerequisite	NA
Learning Outcomes	▪ This is a first course on the theory of nonnegative matrices; ▪ Grasp the basic theory of nonnegative matrices; ▪ Understand the theory of convex cones and matrices leaving a cone invariant;
Syllabus	• Review of basic notions from linear algebra and matrix analysis. Positive matrices, Perron's theorem. • Nonnegative matrices, irreducible matrices, Perron-Frobenius theorem • Primitive matrices, Wielandt's theorem. • Stochastic and doubly stochastic matrices, Birkhoff's theorem. • Theory of convex cones, matrices leaving a cone invariant, Krein-Rutman theorem.

Course Name: Non-Negative Matrices and Applications [3 0 0 3]	
Course Code: MAT 4117 / MAT 4217	
	• Introduction to completely positive matrices.
Text & Reference Books	1. A. Berman and R. J. Plemmons , Nonnegative Matrices in the Mathematical Sciences, Classics in Applied Mathematics, SIAM, 1994. 2. A. Berman and Naomi Shaked-Monderer, Completely Positive Matrices, World Scientific, 2003. 3. R. A. Horn and C. R. Johnson, Matrix Analysis, 2nd ed., Cambridge University Press, 2012. 4. H. Minc, Nonnegative Matrices, Wiley, 1988.

Course Name: Sobolev Spaces and Elliptic Boundary Value Problems [3 0 0 3]	
Course Code: MAT 4204 / MAT 6204	
Prerequisite	MAT414 Partial Differential Equations
Learning Outcomes	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	• 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) • 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) • 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 ed., American Mathematical Society, 2010. 2. R. A. Adams and J. J. F. Fournier, Sobolev Spaces, Academic Press, 2nd ed., 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 ed., Springer-Verlag, 1990. 7. P. G. Ciarlet, Lectures on Finite Element Method, TIFR Lecture Notes Series, Bombay, 1975.

Course Name: Sobolev Spaces and Elliptic Boundary Value Problems [3 0 0 3]	
Course Code: MAT 4204 / MAT 6204	
	8. J. T. Marti, Introduction to Finite Element Method and Finite Element Solution of Elliptic Boundary Value Problems, Academic Press, 1986.

Course Name: Topics in Matrix Analysis [3 0 0 3]	
Course Code: MAT 4116 / MAT 6116	
Prerequisite	NA
Learning Outcomes	▪ This is a second course in linear algebra/matrix analysis. Prerequisites for this course is a good course on linear algebra and matrices, going upto the Jordan form; ▪ Grasp topics that are useful for students who intend to take up research in this subject area;
Syllabus	• Review: Block diagonal form, nilpotent matrices and the Jordan canonical Form, vector and matrix norms, SVD & polar forms. • The Weyr characteristic and the Weyr normal form. • Invariant subspaces & block triangularization, simultaneous triagularization, the Motzkin-Taussky theorem. • The numerical range, basic properties, convexity of the numerical range. • Stable matrices & inertia: basics, Lyapunov's theorem, the Routh-Hurwitz theorem, M- & P- matrices. • The Kronecker & Schur products, the Schur product theorem & its generalizations, additive and multiplicative commutators.
Text & Reference Books	1. R. A. Horn and C. R. Johnson, Matrix Analysis, 2nd ed., Cambridge University Press, 2012. 2. R. A. Horn and C. R. Johnson, Topics in Matrix Analysis, Cambridge University Press, 1991. 3. K. C. O'Meara, J. Clark and C. I. Vinsonhaler, Advanced Topics in Linear Algebra: Weaving Matrix Problems through the Weyr Form, Oxford University Press, 2011.

Course Name: Finite Frames [3 0 0 3]	
Course Code: MAT 4118 / MSM / 4118 / MAT 511B	
Prerequisite	Linear Algebra, Real Analysis

Course Name: Finite Frames [3 0 0 3]	
Course Code: MAT 4118 / MSM / 4118 / MAT 511B	
Learning Outcomes	▪ Students with knowledge on Linear Algebra and REAL analysis will get a good understanding about Frame theory. ▪ Gives some background to understand certain challenging problems involving Finite Frames.
Syllabus	• Introduction to Finite Frame Theory-The Role of Decompositions and Expansions-Beyond Orthonormal Bases (2) • Frames in Finite-dimensional Inner Product Spaces-Basic facts-frame bounds-frame algorithm Frames in Cn-Discrete Fourier Transform-Pseudo inverse and singular value decomposition-Finite dimensional function spaces and HRT conjecture (10) • Eigenvalues of the frame operator -Structure of the synthesis matrix -Gramian Operator Reconstruction from Frame Coefficients-Exact Reconstruction-Conjugate Gradient Method Construction of Frames-Frames with Given Frame Operator-Redundancy-Equivalence of Frames Applications of Finite Frames (10) • Group Frames-Representations and *G*-Frames-Group Matrices and the Gramian of a *G*-Frame Characterisation of Tight *G*-Frames-Harmonic Frames-Heisenberg Frames (SIC–POVMs) Zauner's Conjecture (10) • Gabor Frames for C*N*-Gabor Frames as a Time-Frequency Analysis Tool-Gabor Analysis on Finite Abelian Groups-Harmonic Analysis on Finite Abelian Groups-Properties of Gabor Frames and of the Gabor Frame Operator-Linear Independence-Coherence
Text & Reference Books	6. Peter G. Casazza and Gitta Kutyniok(editors) Finite Frames- Theory and Applications, Applied and Numerical Harmonic Analysis, Birkhauser 2013 7. Ole Christensen, An introduction to Frames and Riesz Bases, Second Edition, Applied and Numerical Harmonic Analysis, Birkhauser 2016

Course Name: Control Theory [3 0 0 3]	
Course Code: MAT 4119 / MSM 4119 / MAT 511B	
Prerequisite	ODE, Linear Algebra
Learning Outcomes	Understanding of Optimal control theory questions, Understanding two important techniques in control theory: DPP and Pontryagin's principle and their uses.
Syllabus	• Introduction to Classical Control Theory problems and important examples [2 Hours] • Calculus of Variation and Optimization Problems [8 Hours] • Controllability, rank condition, Kalman decomposition, Observability [8 Hours] • Stability and Luyapunov Theory, Stabilization [6 Hours] • Optimal Control Problems, Dynamic programming principle [8 hours] • Maximum principle, Ekeland's Principle [3 hours] • Nonlinear Control systems (Introduction) [2 Hours]

Course Name: Control Theory [3 0 0 3]	
Course Code: MAT 4119 / MSM 4119 / MAT 511B	
	• Infinite dimensional control problems (Few glimpses of the important questions in control of linear PDE's) [3 Hours]
Text & Reference Books	1. Zabczyk J. "Mathematical Control theory, An Introduction" 2. Fattorini H. O. "Infinite Dimensional Optimization and Control Theory" 3. Evans L. C. "Lecture Notes on Control Theory" 4. Raymond J. P. "Infinite dimensional Optimal Control Problem: lecture notes" 5. Zuazua E. " Control of Evolutionary Equations" Lecture Notes

PHYSICAL SCIENCES

CURRICULUM FOR

BS-MS (SEM: 5 - 10)

MSc & IPHD (SEM: 1 - 4) AND PHD

CORE & ELECTIVE COURSES

BS-MS Physical Sciences (Semester 5 -10)

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Adv. Physics Lab III
[0 0 9 3]</td><td rowspan="2">Minor Project
[6]</td></tr>
<tr><td>Minor</td><td>Minor</td><td>Minor</td></tr>
<tr><td>18</td><td>18</td><td>18</td><td>18</td><td>18</td><td>18</td></tr>
</table>

i^2 Physical Sciences (Semesters 5 - 10)

Semester 5	Semester 6	Semester 7	Semester 8	Semester 9	Semester 10
PHY 311 Mathematical Methods in Physics [3 0 0 3]	PHY 321 Statistical Mechanics [3 0 0 3]	PHY 412 Condensed Matter Physics II [3 0 0 3]	I2P 422 Optoelectronic Devices [3 0 0 3]	Electives/ Modules	I2P 521 Project [18]
PHY 312 Classical Mechanics [3 0 0 3]	PHY 322 Condensed Matter Physics I [3 0 0 3]	I2P 411 Experimental Methods [3 0 0 3]	I2P 423 Device Technology [0 0 9 3]	Electives/ Modules	
PHY 313 Electronics [3 0 0 3]	I2P 321 Electrochemical Energy Systems [3 0 0 3]	I2P 412 Semiconductor Physics & Technology [3 0 0 3]	I2P 424 Thermal Transport and Thermoelectrics [3 0 0 3]	I2P 511 Project [12]	
PHY 314 Quantum Mechanics I [3 0 0 3]	I2C 421 Soft Matter & Polymers [3 0 0 3]	I2P 413 Fluid Mechanics & Transport Phenomena [3 0 0 3]	I2P 425 Finite Element Modelling [1 0 6 3]		
DSC 311 Mathematical Statistics [3 0 3 4]	I2P 421 Numerical Methods [3 0 0 3]	I2P 414 Modelling Materials [2 0 3 3]	I2P522 Machine Learning for Physical Sciences [2 0 3 3]		
Electives/ Modules	Electives/ Modules	Electives/ Modules	Electives/ Modules		

Master of Science in Physical Sciences (Semester 1-4)

<table>
<tr><th>Semester 1</th><th>Semester 2</th><th colspan="2">Semester 3</th><th colspan="2">Semester 4</th></tr>
<tr><td>MSP 311
Mathematical Methods in Physics
[3 0 0 3]</td><td>MSP 321
Statistical Mechanics
[3 0 0 3]</td><td>MSP 411
Nuclear Particle Physics
[3 0 0 3]
OR</td><td>MSP 412
Condensed Matter Physics II
[3 0 0 3]</td><td colspan="2">PHY/MSP/OE Elective
[3 0 0 3]</td></tr>
<tr><td>MSP 312
Classical Mechanics
[3 0 0 3]</td><td>MSP 322
Condensed Matter Physics I
[3 0 0 3]</td><td colspan="2">MSP 413
Quantum Mechanics- II
[3 0 0 3]</td><td colspan="2">PHY/MSP/OE Elective
[3 0 0 3]</td></tr>
<tr><td>MSP 313
Electronics
[3 0 0 3]</td><td>MSP 323
Electrodynamics and STR
[3 0 0 3]</td><td colspan="2">PHY/MSP/OE Elective
[3 0 0 3]</td><td rowspan="4">MSP 429
Project
[12]
OR</td><td>PHY/MSP/OE Elective
[3 0 0 3]</td></tr>
<tr><td>MSP 314
Quantum Mechanics I
[3 0 0 3]</td><td>MSP/OE Elective
[3 0 0 3]</td><td>PHY/MSP/OE Elective
[3 0 0 3]
OR</td><td>MSP 418
Project
[3]</td><td rowspan="3">MSP 428:
Project
[9]</td></tr>
<tr><td>MSP 315
Adv. Physics Lab I
[0 0 9 3]</td><td>MSP 325
Adv. Physics Lab II
[0 0 9 3]</td><td colspan="2">MSP 415
Adv. Physics Lab III
[0 0 9 3]</td></tr>
<tr><td>MSP 316
Seminar
[0 0 0 1]</td><td>MSP 326
Seminar
[0 0 0 1]</td><td colspan="2">MSP 416
Viva-Voce
[0 0 0 1]</td></tr>
<tr><td>16</td><td>16</td><td colspan="2">16</td><td colspan="2">18</td></tr>
</table>

IPhD Physical Sciences (Semester 1-6)

Semester 1	Semester 2	Semester 3	Semester 4	Semester 5	Semester 6
MSP 311 Mathematical Methods in Physics [3 0 0 3]	MSP 321 Statistical Mechanics [3 0 0 3]	MSP 411 Nuclear & Particle Physics [3 0 0 3]	MSP 42xx/52xx Elective – III [3 0 0 3]	MSP 510 Research Project [0 0 15]	MSP 520 Research Project [0 0 15]
MSP 312 Classical Mechanics [3 0 0 3]	MSP 322 Condensed Matter Physics I [3 0 0 3]	MSP 412 Condensed Matter Physics II [3 0 0 3]	MSP 42XX/52XX Elective-IV [3 0 0 3]		
MSP 313 Electronics [3 0 0 3]	MSP 323 Electrodynamics and STR [3 0 0 3]	MSP 413 Quantum Mechanics- II [3 0 0 3]	MSP 42XX/52XX Elective V [3 0 0 3]		
MSP 314 Quantum Mechanics I [3 0 0 3]	MSP 42XX Elective I [3 0 0 3]	MSP 41XX/51XX Elective II [3 0 0 3]	MSP 42XX/52XX Elective VI [3 0 0 3]		
MSP 315 Adv. Physics Lab I [0 0 9 3]	MSP 325 Adv. Physics Lab II [0 0 9 3]	MSP 415 Adv. Physics Lab III [0 0 9 3]	MSP 420 Research Project [0 0 0 6]		
Seminar [1 credit]	Seminar [1 credit]	Seminar [1 credit]			
Credits = 16	Credits = 16	Credits = 16	Credits = 18	Credits = 15	Credits = 15

Remark 1: *Minimum Credit requirement for SoP: 96 Credits for MS (Res)*

Remark 2: *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.*

List of Electives

Sl No:	List of Electives
1	Statistical Mechanics
2	Condensed Matter Physics I
3	Electrodynamics and STR
4	Digital Image Processing [3 0 0 3]
5	Data sciences for physical sciences [3 0 0 3]
6	Experimental Methods [3 0 0 3]
7	Material & Device Characterization Techniques [SoP Open Elective] [2 0 1 3]
8	Semiconductor Physics and Technology [3 0 0 3]
9	Lasers and Fiber Optic Communications [3 0 0 3]
10	Physics at Low Temperatures [3 0 0 3]
11	Nanoscale Physics [3 0 0 3]
12	Superconductivity[3 0 0 3]
13	Foundations of Quantum Mechanics [3 0 0 3]
14	Advanced Statistical Physics [3 0 0 3]
15	Fluid Dynamics [3 0 0 3]
16	General Relativity and Cosmology [3 0 0 3]
17	Quantum Many-body Theory [3 0 0 3]
18	Fluid Mechanics & Transport Phenomena [3 0 0 3]
19	Modelling Materials [3 0 0 3]
20	Quantum field theory II [3 0 0 3] [Grad level only]
21	Principles of Digital imaging [3 0 0 3]
22	Organic Semiconductors: Fundamentals and Applications [3 0 0 3]
23	Sensor Technology
24	Nonlinear Optics and Photonics [3 0 0 3]
25	Electronic Devices and Computer Interfacing [2103]
26	Astrophysics [3 0 0 3]
27	Numerical Simulation Techniques in Physics [3 0 0 3]
28	Introduction to Cosmology [3 0 0 3]
29	Particle Physics [3 0 0 3]

30	Nuclear Particle Physics [3 0 0 3]
31	Condensed Matter Physics II [3 0 0 3]
32	Computational Techniques and Programming Languages
33	Materials Growth and Processing Techniques [2013] [SoP Open Elective]
34	Theory of open quantum systems [3 0 0 3]
35	Quantum Field Theory I [3 0 0 3]
36	Probes in Condensed Matter Physics [3 0 0 3]
37	Quantum Transport [3 0 0 3]
38	Advanced Mathematical Methods in Physics [3 0 0 3]
39	Quantum Information Theory [3 0 0 3]
40	Nonlinear Dynamics [3 0 0 3]
41	Atomic and Molecular Physics
42	Computer Interfacing [1 0 3 2]
43	Energy Materials Laboratory [0 0 3 1]
44	Battery & Fuel Cell Laboratory [0 0 3 1]
45	Organic Photovoltaic Devices Laboratory [0 0 3 1]
46	Renewable Energy Systems [2 0 0 2]
47	Introduction to Programming [0 0 3 1]
48	Spintronics Fundamental and devices applications [3 0 0 3]
49	Statistical and data analysis methods in Physical Sciences [3 0 0 3]

CORE COURSES - SYLLABUS

Course Name: Mathematical Methods in Physics [3 0 0 3]	
Course Code: PHY 311 / MSP 311	
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	• 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. • 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. • Special functions and Applications [2]. • 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, 2nd ed., (Schaum's Outline Series).

Course Name: Classical Mechanics [3 0 0 3]	
Course Code: PHY 312 / MSP 312 / PHY 3120	
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.

<table>
<tr><th colspan="2">Course Name: Classical Mechanics [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 312 / MSP 312 / PHY 3120</th></tr>
<tr><td>Syllabus</td><td>

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.
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.
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.
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.
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).

</td></tr>
<tr><td>Text & Reference Books</td><td>

H. Goldstein, C. Poole and J. Safko, Classical Mechanics, 3rd ed., Addison Wesley, 2005.
L. D. Landau and E. M. Lifshitz, Mechanics, Vol. 1 of course of Theoretical Physics, Pergamon Press, 2000.

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<table>
<tr><th colspan="2">Course Name: Electronics [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 313 / MSP 313</th></tr>
<tr><td>Learning Outcomes</td><td>

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.

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<table>
<tr><th colspan="2">Course Name: Electronics [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 313 / MSP 313</th></tr>
<tr><td>Syllabus</td><td>
• 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).
• 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)
• 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)
• 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)
• 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)
</td></tr>
<tr><td>Text & Reference Books</td><td>
1. 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.
</td></tr>
</table>

<table>
<tr><th colspan="2">Course Name: Quantum Mechanics I [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 314 / MSP 314</th></tr>
<tr><td>Learning Outcomes</td><td>
▪ 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
</td></tr>
</table>

Course Name: Quantum Mechanics I [3 0 0 3]	
Course Code: PHY 314 / MSP 314	
Syllabus	• Quantum Origins: (3): Particle aspect of radiation, Wave aspect of particles, Quantum measurements • 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) • Non-commutating operators and observables, Operators, eigenvalues, eigenvectors, observables and expectation values Quantum amplitudes, probabilities and the Born rule. (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) • Postulates of Quantum mechanics: (3) Quantum Kinematics, Quantum measurements, Quantum Dynamics (Hamiltonian and Schrodinger equation) • 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; • Applications: (14) One dimensional motion, free particle, Particle in a box, Potential Barrier and Well, Infinite and finite square well potential (5) • Harmonic oscillator, Spin of an electron, (5) • 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 ed., 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.

Course Name: PHY321 Statistical Mechanics [3 0 0 3]	
Course Code: PHY 321 / MSP 321 / PHY 3210	
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

Course Name: PHY321 Statistical Mechanics [3 0 0 3]	
Course Code: PHY 321 / MSP 321 / PHY 3210	
	▪ 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	• 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) • 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) • 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) • 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) • 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) • 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) • 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.

Course Name: Condensed Matter Physics- I [3 0 0 3]	
Course Code: PHY 322 / MSP 322 / PHY 3220	
Learning Outcomes	▪ To provide an exposure to the basic principles and essential concepts in condensed matter physics.

Course Name: Condensed Matter Physics- I [3 0 0 3]	
Course Code: PHY 322 / MSP 322 / PHY 3220	
Syllabus	• Crystal structure: Bravais lattice, two and three dimensional lattices, primitive cells, symmetry, space group and point groups, classification of lattices by symmetry; [4] • 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] • 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] • Models: Nearly free electrons, Brillouin zones, tightly bound electrons, Wannier functions, tight binding model, electron-electron interactions, Hartree Fock equations, density functional theory; [8] • Mechanical properties: elasticity, liquid crystals, phonons, Einstein and Debye models, inelastic scattering from phonons; [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 ed., John Wiley, 2004. 4. A. J. Dekker, Solid state physics, Macmillan India, 2005.

Course Name: Electrodynamics and Special Theory of Relativity [3 0 0 3]	
Course Code: PHY 323 / MSP 323 / PHY 3240	
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	• 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. • Relativistic Mechanics [4]: Principle of least action, Energy and momentum, Transformation of distribution functions, Elastic collisions, Angular momentum. • 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. • 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

Course Name: Electrodynamics and Special Theory of Relativity [3 0 0 3]	
Course Code: PHY 323 / MSP 323 / PHY 3240	
	second pair of Maxwell's equations, Energy density and energy flux, The energy-momentum tensor of the electromagnetic field. • 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. • Electromagnetic waves [4]: The wave equation, Plane waves; Poynting Vector and Energy Carried by the plane wave. Polarisation. • 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.

Course Name: Nuclear and Particle Physics [3 0 0 3]	
Course Code: PHY 411 / MSP 411 / PHY 611	
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	• Introduction: Origin of nuclear physics - Becquerel's discovery of radioactivity, Rutherford scattering experiment. (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) • Nuclear interaction: properties of nuclear force, nucleon-nucleon potential, two-nucleon system - example with deuteron. (2) • Nuclear models: liquid drop model, Fermi gas model, shell model - infinite square well, harmonic oscillator, spin-orbit potential. (4) • Dynamic properties of nuclei: radioactive decay, alpha, beta and gamma decay, nuclear fission and fusion, chain reaction, nuclear reactions. (4)

Course Name: Nuclear and Particle Physics [3 0 0 3]	
Course Code: PHY 411 / MSP 411 / PHY 611	
	• Nuclear astrophysics: particle and nuclear interactions in the early universe, primordial nucleosynthesis, stellar nucleosynthesis. (2) • Detectors: ionization detectors, scintillation detectors, Cherenkov detectors, semiconductor detectors, calorimeters. (2) • Accelerators: electrostatic accelerators, cyclotron, linear accelerator, colliding beams. (2) • Classification of fundamental forces and elementary particles, quantum numbers - charge, spin, parity, isospin, strangeness, flavor. (6) • 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. A. Das and T. Ferbel, Introduction to nuclear and particle physics. 2. Kenneth S. Krane, Introductory nuclear physics. 3. B. R. Martin, Nuclear and particle physics: An introduction.

Course Name: Condensed Matter Physics II [3 0 0 3]	
Course Code: PHY 412 / MSP 412 / PHY 612	
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	• 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] • 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] • 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

Course Name: Condensed Matter Physics II [3 0 0 3]	
Course Code: PHY 412 / MSP 412 / PHY 612	
	and AC Josephson effects SQUIDs, High-T superconductivity: structure and transport properties.[3] • 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 ed., John Wiley, 2004. 4. A. J. Dekker, Solid state physics, Macmillan India, 2005.

Course Name: Quantum Mechanics II [3 0 0 3]	
Course Code: PHY 413 / MSP 413 / PHY 613	
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	• Angular Momentum: Angular Momentum algebra, Eigenvalues and Eigenstates of Angular Momentum, SU(2) Representations, Addition of Angular Momentum [6]. • Motion in Central Potential, Spherical waves, Resolution of a plane wave, Asymptotic properties of Radial wavefunctions, Coulomb potential, Accidental Degeneracy. [4] • Time-independent Perturbation Theory (nondegenerate case, degenerate case), and Applications (Fine structure of hydrogen, relativistic and spin-orbital effects, Zeeman effect, Stark effect) [6] • Variational Methods and Applications (Ground and Excited states of Helium); Semi-classical (WKB) approximation, Bohr-Sommerfeld quantization rule [4] • 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] • 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] • Identical particles, Permutation Symmetry, Symmetrization Postulate, Two electron system [2]

Course Name: Quantum Mechanics II [3 0 0 3]	
Course Code: PHY 413 / MSP 413 / PHY 613	
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.

Course Name: Computational Techniques and Programming Languages [3 0 0 3]	
Course Code: PHY 421 / PHY 621	
Prerequisites	None
Learning Outcomes	▪ How to do numerical computation using a Programming language. ▪ Finding root of an equation, numerical differentiation and integration. ▪ Solving some selected problems in classical and quantum physics numerically. ▪ Solving differential equations, linear algebra problems numerically. ▪ Solve some classical statistical mechanics problems using Monte Carlo simulation.
Syllabus	• Numerical Approach: Need for computational physics, Computers in Physics? Working Program, Testing the code, assessing the errors, Programming guidelines, Brief introduction to Matlab/Octave/Python/C.[4] • Ordinary Differential Equations: Methods: Euler Method, Runge-Kutta Methods, Verlet Method; Physical Problems: Projectile Motion, Nuclear decay, Pendulum with dissipation, Forced pendulum, Chaotic pendulum, Logistic map, Period doubling, Lorentz model, Kepler problem and planetary orbits, Perihelion precession of mercury, Three body problem and effect of Jupiter on Earth[6]; Iterative methods (Root Finding): Methods: Successive bisection, Newton Raphson, Secant Method; Physical Problems: Energy Eigenvalues of the square well potential, Kronig-Penny model.[6] • Methods of Integration: Methods: Midpoint rule, Trapezoidal Rule, simpson's rule, errors; Physical Problems: First-order, second-order corrections in Perturbation theory, Magnetic field produced by the current [6]; Partial Differential Equations: Methods: Finite difference method, Relaxation Method, Crank-Nicholson scheme, Shooting Method, Spectral Methods; Physical Problems: Solving Diffusion Equation, Wave Equation, Poisson equation.[6] • Stochastic Simulations: Random numbers, Pseudo Random number generators, Distributions, Methods of generating random numbers following non-uniform distributions; transformation method and relaxation method.[4] • Monte-Carlo integration - Physical Problems: RandomWalk and Diffusion, Cluster Growth Models, Percolation, Ising Model.[4]
Text & Reference Books	1. Paul Devries and Javier Hasbun, A First Course on Computational Physics, Jones & Bartlett Learning. 2. Nicholas Giordano and Hisao Nakanishi, Computational Physic, 2nd ed., Prentice-Hall. 3. Numerical Analysis, 2nd ed., Timothy Sauer, Pearson

Course Name: Atomic and Molecular Physics [3 0 0 3]	
Course Code: PHY 422 / PHY 4220 / PHY 6220	
Prerequisites	PHY 413: Quantum Mechanics II
Learning Outcomes	▪ Use Fine structure to analyse electronic spectrum ▪ Calculate transition probability between electronic states, spontaneous and stimulated emission and role of spontaneous emission decay to transition linewidth ▪ Use dipole approximation and selection rules for transition between different electronic levels ▪ Apply perturbations to calculate line splitting e.g. Zeeman effect, Stark effect ▪ Differentiate between energy level schemes for one- and two-electron atoms. ▪ Apply various methods to analyse two-electron systems ▪ Use Hartree-Fock method to study many electron systems and molecules ▪ Apply scattering theory to collisions e.g. atom-atom, atom-electron
Syllabus	• One electron atoms: Hydrogenic atoms, Fine structure, transition rates, Einstein coefficients (4) • Dipole approximation, selection rules and spectrum, line shape and line widths. (4) • The photoelectric effect, Zeeman and Stark effects, Lamb shift, Hyperfine structure; (4) • Two electron atoms: Para and Ortho states, Energy level scheme, ground state, excited state, doubly excited states. (4) • Many electron atoms: The central field approximation, Hartree-Fock method and self-consistent field. (4) • L-S coupling, j-j coupling, Zeeman effect, quadratic Stark effect, X-ray spectra. (3) • Molecules: Born-Oppenheimer separation for diatomic molecules, rotation and vibration of diatomic molecules (4) • Electronic structure, rotational and vibrational energy levels, the nuclear spin. (3) • Atomic collisions: Review of quantum mechanical scattering including partial waves and Born approximation, electron scattering, ionization, resonance phenomena, atom-atom collisions, long range interactions, elastic scattering of atoms at low velocities (4) • Interaction of light and matter: The electric field of moving charges, Dipole radiation, Thompson scattering, Synchrotron radiation, Bremsstrahlung. (2).
Text & Reference Books	1. B. H. Brandsen and C. J. Joachain, Physics of atoms and molecules, Longman, 1983. 2. J. J. Sakurai, Modern Quantum Mechanics, Addison-Wesley. 3. Cohen-Tannoudji and Diu-Laloe, Quantum Mechanics (2 volumes), Wiley. 4. L. D. Landau And E. M. Lifshitz, Classical Theory of Fields,Vol-2 of course of theoretical physics, Pergamon, 2000.

i^2 Physics Syllabus

Course Name: Electrochemical Energy Systems [3 0 0 3]	
Course Code: I2P 321	
Prerequisites	Thermal and Statistical Physics
Learning Outcomes	▪ Understand thermodynamics and electrochemistry of electrochemical energy systems. ▪ Apply electrochemical equations to model storage and transducer systems. ▪ Comprehend the relevance of various component of batteries, super capacitors and fuel cells. ▪ Appreciate existing problems in storage and converter systems and devise solutions, especially involving nanotechnology and smart materials. ▪ Comprehend basic electrochemical measurement methods and parameters in design and performance quantification.
Layout	• Various forms of electrochemical energy systems - batteries, super capacitors and fuel cells [3] • Basics of Chemical Kinetics and Rate Equations [2] • Electrochemical principles: voltage series, half-cell, Galvanic cell, Nernst equation, over voltage etc. [3] • Electrochemical double layer: Helmholtz, Gouy-Chapman model.[3] • Measurement methods (staionary, quasi-stationary) [3] • Potentiostatic and galvanostatic methods, RDE, cyclic voltammetry etc. [5] • Memory and converter systems: temporal development from historical to modern systems, [4] • Emphasis on metal ion batteries, but also different types including lead acid, nickel metal hydride, metal air, sodium sulfur and redox flow. [6] • Advanced battery materials, device structure and components (electrolytes, separators, additives and electrode-electrolyte interfaces). [4] • Application to Batteries, Accumulators, fuel cells. [3]
Text & Reference Books	1. D. Linden and T. B. Reddy, Handbook of Batteries, 3rd ed., Mc Graw Hill, New York, 2002. 2. A. J. Bard and L. R. Faulkner, Electrochemical Methods: Fundamentals and Applications, 2nd ed., Wiley, New York, 2000. 3. Hamann CH, Hamnett A, Vielstich W. Electrochemistry 2nd ed., Wiley. VCH: New York, 1998. 4. P. Kurzweil: Fuel Cell Technology, 1st ed. Springer-Verlag London, 2006.

Course Name: Mathematical Statistics [3 0 3 4]	
Course Code: DSC 311	
Prerequisites	None
Learning Outcomes	▪ Understand the basic of statistical distributions their classification and methods of analysis. ▪ Apply decision theory, estimation, confidence intervals, and hypothesis testing.
Layout	• 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, χ2 and F distributions. (9) • 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) • Bivariate Samples: Sample from a bivariate population; least square curve fitting; maximum likelihood estimation; multivariate samples. (7) • 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; χ2 - test of goodness of fit. (15) Practicals: • Objects and functions, Arithmetical and Boolean operators, Importing and Exporting Data sets, Packages, Loops and Conditional statements, Measure of central tendency, basic plots. • Density, distribution function, quantile function and random generation for standard discrete and continuous distributions. Q-Q plots and P-P plots. Fitting distributions. 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 ed., 2007. 2. R. V. Hogg, J. McKean and A. T. Craig, Introduction to Mathematical Statistics, Pearson Education India; 7th ed., 2013. 3. A. Mood, F. Graybill and D. Boes, Introduction to the Theory of Statistics, McGraw Hill Education; 3rd ed., 2017. 4. P. J. Bickel and K. A. Doksum, Mathematical Statistics: Basic Ideas and Selected Topics, Volume 1. 2nd ed., 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.

<table>
<tr><th colspan="2">Course Name: Experimental Methods [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: I2P 411</th></tr>
<tr><td>Prerequisites</td><td>None</td></tr>
<tr><td>Learning Outcomes</td><td>
▪ 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)
</td></tr>
<tr><td>Layout</td><td>
• 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]
• Fitting bare data by linearisation techniques, obtaining best fit; Introduce calibration curve of a sensor and its predictive value. Error Analysis [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]
• Diffraction: Crystal systems, X-ray diffraction, single crystal, powder XRD. Unit cell determination. electron diffraction, pattern analysis. [6]
• Scanning probe techniques: Atomic force microscopy and Scanning tunnelling microscopy [6]
• Spectroscopy: Infra red, Raman, x-ray and UV photoelectron spectroscopy.
• 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]
• 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]
</td></tr>
<tr><td>Text & Reference Books</td><td>
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.
</td></tr>
</table>

Course Name: Experimental Methods [3 0 0 3]	
Course Code: I2P 411	
	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 ed., June 2020.

Course Name: Fluid Mechanics and Transport Phenomena [3 0 0 3]	
Course Code: I2P 413	
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. ▪ Apply advanced tools for analysing and modelling momentum, energy and mass transport in fluid or solid media ▪ Identify relevance of macroscopic and microscopic balances and their applications ▪ Differentiate Newtonian vs non-Newtonian fluids - properties and models ▪ Model Mass, Momentum and Energy transport and their applications.
Layout	• Ideal Fluids (Continuity Equation, Euler's Equation) [6] • Hydrostatics and Potential Flow [5] • Viscous Fluids (Equations of Motion, Energy Dissipation) [8] • Thermal Conduction in Fluids (Equation of Heat Transfer) [7] • Thermal Conduction in an Incompressible Fluid [4] • Free Convection and Convective Instability of a Fluid at Rest [6]
Text & Reference Books	1. G. Falkovich, Fluid Mechanics, Cambridge University Press, 2011 2. Merle Potter and David Wiggert, Fluid Mechanics, Schaum Outline, Mc Graw Hill, 2008 3. G. Hauke, An Introduction to Fluid Mechanics and Transport Phenomena, Springer 2008 4. B. Lautrup, Physics of Continuous Matter, Institute of Physics Publishing Ltd, 2005 5. J. O. Wilkes, Fluid Mechanics for Chemical Engineers, 3rd ed., Mc Graw Hill, 2017 6. R. B. Bird, W.E. Stewart and E.N. Lightfoot, Transport Phenomena, 2nd ed., Wiley, India, 2005. 7. Duderstadt, J. J., and W. R. Martin. Transport Theory. Wiley, 1979. 8. F. P. Incropera and D.P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th ed., Wiley India, 2006. 9. W. M. Deen, Analysis of Transport Phenomena, Oxford University Press, 2nd ed., 2012.

Course Name: Modelling Materials [2 0 3 3]	
Course Code: I2P 414	
Prerequisites	Quantum Mechanics, Condensed Matter Physics I
Learning Outcomes	▪ Apply computational methods to model, comprehend and predict material properties and material design. ▪ Apply first-principles approaches, molecular dynamics simulations, stochastic methods for optimization and sampling. ▪ 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.

Course Name: Soft Matter and Polymers [3 0 0 3]	
Course Code: I2C 421	
Prerequisites	None
Learning Outcomes	▪ Understand the physics and chemistry of soft matters such as polymers, gels, colloids etc.

<table>
<tr><th colspan="2">Course Name: Soft Matter and Polymers [3 0 0 3]</th></tr>
<tr><td colspan="2">Course Code: I2C 421</td></tr>
<tr><td></td><td>▪ Quantify/mathematical formulation of mechanical (viscoelastic) properties and shear moduli
▪ Apply knowledge of soft matter into various electronic, mechanical, optical devices/processes.</td></tr>
<tr><td>Layout</td><td>• What is soft condensed matter. Forces, energies, and time scales in soft condensed matter. Intra- and intermolecular interactions, structural organisation, phase transitions, order parameters, scaling laws.
• Experimental techniques to investigate soft matter.
• Polymers: Chemistry and architecture, Synthesis and characterisation Copolymers and polymer blends, Poly-dispersity, Phase separation and segregation, Polymer solution, Liquid Crystalline polymers. Functional polymers.
• Gelation: Classes of gels: physical gels, chemical gels, Theory of Gelation.Hydrogels: Types of hydrogels, Application of hydrogels, formation of hydrogels, Processing of hydrogels
• Colloids: Types of colloids and their formation, Forces between colloidal particles. Assembly and phase behaviour, Charges and stabilisation, Kinetics,Defects in assembly, Approaches to control long range order.
• Soft matter in nature, nucleic acids, proteins, membranes.
• Applications of colloids in photonics and optoelectronics. Applications of soft materials in micro and nano technology.</td></tr>
<tr><td>Text & Reference Books</td><td>1. Richard. A. L. Jones, Soft Condensed Matter, Oxford University Press, 2002
2. Malcolm P. Stevens, Polymer Chemistry, Oxford University Press, Inc, 1990.
3. Fundamentals of Soft matter Science by Linda S. Hirst (CRC press)
4. Text book of polymer Science, Billmeyer, John Wiley ans Sons 1984.
5. Principles of Polymer Systems, Rodriguez, Hemisphere Publishing Corpn, 1982.
6. Introduction to Polymer Science and Technology, H. S. Kaufman and J. J. Falcetta,
7. Polymer chemistry, Seymour and Carraher, Marcel Dekker, 2003.
8. Odian, George. Principles of Polymerization. 4th ed. Hoboken, NJ:</td></tr>
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<table>
<tr><th colspan="2">Course Name: Numerical Methods [3 0 0 3]</th></tr>
<tr><td colspan="2">Course Code: I2P 421</td></tr>
<tr><td>Prerequisites</td><td>Programming courses in semesters 1-4</td></tr>
<tr><td>Learning Outcomes</td><td>▪ Perform numerical computation using a programming language.
▪ Find root of an equation, numerical differentiation and integration.
▪ Solve sSolve differential equations, linear algebra problems numerically.</td></tr>
</table>

Course Name: Numerical Methods [3 0 0 3]	
Course Code: I2P 421	
	▪ Obtain numerical solutions to problems in classical and quantum physics and classical statistical mechanics problems using Monte Carlo simulation.
Layout	• Binary numbers, floating point representation of real numbers, machine precision, rounding errors. [1.5] • Root finding: Bisection method, Newton method, Secant method, Brent method etc. Application to physics problems [4.5] • Interpolation: Lagrange interpolation, Newton's divided differences, Chebyshev Interpolation, Cubic splines [4.5] • Least squares: Fitting models to data, models with linear parameters, non-linear parameters. [3] • Differentiation and Integration: Finite difference formulae and rounding errors, Trapezoid rule, Simpson rule, Composite Newton-Cotes formulae for integration, Gaussian Quadrature [3] • Systems of Equations: Gaussian elimination, LU factorization, Pivoting, Non-linear system of equations. Use of linear algebra packages like LAPACK, Numpy, SciPy etc. [4.5] • ODE: Initial value problems, Euler method, Runge Kutta methods, Higher order equations, Boundary value problems by finite difference menthods, applications. PDE: Forward difference, Backward difference methods, Wave equation, Heat equation, Poisson equation. [6] • Monte Carlo technique: Pseudo-random numbers, random number sequences with uniform, normal distribution etc. Monte Carlo integration, random walks, Brownian motion, Monte Carlo simulation in statistical physics, Markov chain, importance sampling, Metropolis algorithm, application of Ising model. [10]
Text & Reference Books	1. Timothy Sauer, Numerical Analysis, Pearson 2. R. W. Hamming, Numerical methods for Scientists and Engineers, Dover 3. K. E. Atkinson, An Introduction to Numerical Analysis, 2nd ed., JohnWiley, 1989 4. Paul Devries and Javier Hasbun, A First Course on Computational Physics, John Willey & Sons 5. Nicholas Giordano and Hisao Nakanishi Computational Physics, 2nd ed., Prentice-Hall 6. Hans Petter Langtangen, A primer on scientific programming with Python, Springer 7. K. Binder and D.W. Heermann, Monte Carlo simulation in statistical physics, Springer

Course Name: Optoelectronic Devices [3 0 0 3]	
Course Code: I2P 422	
Prerequisites	Semiconductor Physics, Condensed Matter, Quantum Mechanics

Course Name: Optoelectronic Devices [3 0 0 3]	
Course Code: I2P 422	
Learning Outcomes	▪ Design PV architectures including, Inorganic, perovskite, hybrid materials. ▪ Understand light-matter interaction at device application level along with designing techniques to control and enhance it. ▪ Apply characterisation techniques and device parameters for optoelectronic devices. ▪ Design and fabrication of field-effect transistors, photodetectors and light-emitting diodes. Estimate device parameters like quantum efficiency, fill factor, ON/OFF ratio etc.
Layout	• Overview of optoelectronic properties and electronic structure of crystalline and amorphous semiconductors. Basics of Organic Semiconductors. [3] • Light–Semiconductor Materials Interaction, Electrons and Optics of Quantum Structures, Devices Based on Intraband Phototransitions in Quantum Structures and Silicon Optoelectronics. [6] • Photovoltaic Devices: Basic principle, Junctions, Generation and Recombination, nanocrystalline and thin film solar cells, 1st/2nd/3rd generation Solar Cells. Strategies for high efficiency. [6] • Optical transmitter circuits - LED and laser drive circuits- LED – power and efficiency - double hetero LED - LED structure - LED characteristics - Junction laser operating principles - Condition for laser action - Threshold current – Homojunction – Heterojunction - Double heterojunction lasers - Quantum well laser - Distributed feedback laser - laser modes, strip geometry- gain guided lasers- index guided lasers. [9] • Photo detectors - thermal detectors – photoconductors – detectors - photon devices – PMT photodiodes - photo transistors - noise characteristics - PIN diode - APD characteristics - APD design of detector arrays – CCD - Solar cells. [8] • Modulation of light – birefringence - electro optic effect - EO materials - Kerr modulators. [4]
Text & Reference Books	1. J. Wilson, Hawkes, Optoelectronics, an introduction, Prentice Hall; 3rd ed., January 1998. 2. Vladimir V. Mitin, Michael A. Stroscio, Mitra Dutta, Viatcheslav A. Kochelap, Introduction to Optical and Optoelectronic Properties of Nanostructures, Cambridge University Press. March 2019. 3. E. Fred Schubert, Light-Emitting Diodes, Cambridge University Press, 2nd ed., 2006. 4. Jenny Nelson, The Physics of Solar Cells, Imperial College, UK, May 2003. 5. Jasprit Singh, Electronic and Optoelectronic Properties of Semiconductor Structures, Cambridge University Press, 2003. 6. Mark Johnson, Photodetection and Measurement: Maximizing Performance in Optical Systems, McGraw-Hill Education; 1st ed., August 2003.

<table>
<tr><th colspan="2">Course Name: Device Technology [0 0 9 3]</th></tr>
<tr><th colspan="2">Course Code: I2P 423</th></tr>
<tr><td>Prerequisites</td><td>Material Characterisation, Condensed Matter I</td></tr>
<tr><td>Learning Outcomes</td><td>
▪ Understand manufacturing processes, testing and prototype development
▪ Appreciate multidisciplinary approach towards fabrication and the end-use of devices.
▪ Physical understanding of fabrication and characterisation technologies.
▪ Design and describe components and processes for a target component and its applications, and develop improvement processes.
▪ Fabricate an electrical/electronic/photonic device using standard device fabrication methods.
</td></tr>
<tr><td>Layout</td><td>
<u>PART A: (8 weeks)</u>
• Micro-fabrication techniques (photolithography, soft lithography)
• Deposition, growth and engineering of materials (physical and chemical routes)
• Thermal and e-beam evaporation, DC-RF magnetron sputtering, sol-gel method, spin and dip coating. Etching: Wet (chemical), dry (Ar ion plasma)
• Advanced nano-fabrication and characterisation techniques (electron-beam lithography, focused ion-beam etching and scanning probe microscopy)
• Electrical and Optical characterisation: DC/AC I-V, C-V methods, RF electronics. Reflection, transmission and emission spectroscopy.
• Fabrication and Characterisation of;
• Sensors: chemical and bio-sensors using electrical, optical, acoustic, magnetic etc.
• Mechanical Energy harvester: piezoelectric or magnetic material based micro-cantilever fabrication by PCB or 3D printing. Demonstration of electricity generation from vibration of cantilever.
• Photovoltaic Energy conversion: Fabrication of thin film solar cell using Physical vapour deposition and spin coating (organic) techniques. Determination of device efficiency, fill factor.
• Thin film transistor (FET) using organic materials and inorganic 2D materials. Deposition of gate dielectric layer. Top / bottom / ionic liquid gating and evaluating the device performance.
• Si photonic structures and wave guide using lithography and etching.
• Design and fabrication of a bio-mechanical devices using 3D printing or microfluidic channels for biosensor platform. FET based or SAW based biosensor device to monitor glucose/biomarkers.
• Fluorescent materials based sensor arrays and principle component analysis.
<u>PART B: (4 weeks)</u>
• One Mini Project — Building prototypes integrating devices. Examples:
</td></tr>
</table>

Course Name: Device Technology [0 0 9 3]	
Course Code: I2P 423	
	• Project 1: Robotics – Build an automated robot (e.g. driverless car using Raspberry Pi and sensor, GPS/GSM based animal tracker) • Project 2: Photovoltaic Device —Build a solar light by using the solar cell film and other electronics. • Project 3: Analysis of climatic changes or health of student community and analysis by using Python/MATLAB.
Text & Reference Books	1. Marc J. Madou, Fundamentals of Microfabrication and Nanotechnology, CRC Press 3rd ed., December 2011. 2. Stephen D. Senturia, Microsystem Design, Springer US,1st ed., 2001. 3. Sami Franssila, Introduction to Microfabrication, 2nd ed., John Wiley and Sons Ltd 2010. 4. Ampere A. Tseng,Nanofabrication: Fundamentals and Applications World Scientific, 2008. 5. Bharat Bhushan (editor), Springer Handbook of Nanotechnogy, Springer-Verlag Berlin Heidelberg 2010.

Course Name: Thermal Transport and Thermoelectrics [3 0 0 3]	
Course Code: I2P 424	
Prerequisites	Condensed Matter, Fluid Mechanics and Transport Phenomena
Learning Outcomes	▪ Develop quantitative understanding of fundamental physical processes that govern heat transfer. ▪ Formulate heat, mass and momentum transfer processes based on basic transport equations. ▪ Principles and technologies for converting heat into electricity. ▪ Thermoelectric energy conversion and thermoelectric materials, therm-ionic energy conversion. ▪ Appreciate applied solar thermal technologies, solar heat collection systems, solar thermo-photovoltaics and solar thermo-electrics.
Layout	• Introduction, review of heat transfers and laws of radiative heat transfer. Conduction, Radiation, Development and Use of Heat Transfer Correlations Thermoelectric Generators, Thermoelectric Coolers, Optimal Design. [5] • Thomson Effect, Exact Solution, and Compatibility Factor, Thermal and Electrical Contact Resistances for Micro and Macro Devices, Modeling of Thermoelectric Generators and Coolers with Heat Sinks, Applications [6] • Review of electronic band structure and phonon spectrum, Physics of Electrons, Density of States and Fermi Energy, Thermoelectric Transport Properties, Phonons, Low-Dimensional Nanostructures, Generic Model of Bulk Silicon and Nanostructures, Theoretical Model of Thermoelectric Transport Properties. [8]

Course Name: Thermal Transport and Thermoelectrics [3 0 0 3]	
Course Code: I2P 424	
	• Thermoelectric effects and current research in thermoelectric materials, Graded materials, TE leg geometry impact, Ballistic thermionic coolers and non-linear Peltier. [8] • Thermionics vs. Thermoelectrics, Thermionic power conversion, Thermionic engines: vacuum, solid-state, Schottky barrier and diode. [5] • Solar concentration and solar thermal technology and Applications of Solar thermal technologies, Selective surfaces, Methods for concentration: trough, tower, dish, EM wave calculation of surface properties. [6]
Text & Reference Books	1. R. B. Bird, W.E. Stewart and E.W. Lightfoot, Transport Phenomena, John Wiley, 2nd ed., 2006. 2. G. S. Nolas J. Sharp H. J. Goldsmid, Thermoelectrics Basic Principles and New Materials Developments, Springer-Verlag Berlin Heidelberg New York, 2001. 3. Goldsmid, H. J. Thermoelectric Refrigeration. New York, NY: Plenum Press, 1964. 4. Petros J. Axaopoulos (ed.) Solar Thermal Conversion. Active Solar Systems, Symmetria., 2011, ISBN: 9602663286. 5. L. S. Sissom, and D. R. Pitts, Elements of Transport Phenomena, Mc Graw Hill, New York, 1972. 6. R. W. Fahien, Elementary Transport Phenomena, Mc Graw-Hill, New York, 1983. 7. D. M. Rowe (ed.,) CRC Handbook of THERMOELECTRICS , CRC Press LLC 1998.

Course Name: Finite Element Modelling [1 0 6 3]	
Course Code: I2P 425	
Prerequisites	Numerical Solutions of ODE/PDE
Learning Outcomes	▪ Apply finite element modelling methods to solve partial differential equations and develop an understanding of the various solvers. ▪ Apply the numerical techniques to simulate physical systems. ▪ Finite element formulation of Boundary Value Problems. ▪ Understand the scope for applications and limitations in the fields of electronics, photonics, thermoelectrics, microfluidics etc. especially incorporating multi physics applications.
Layout	• Introduction to Finite Element Methods (FEM) to solve partial differential equations (PDE) Numerical methods (solvers) for solving stationary, transient and eigenvalue problems and other systems of linear equations. [3 L] • Introduction to Sobolev spaces, Weak (variational) formulation of elliptic boundary-value problems of second order, natural and essential boundary conditions, Ritz-Galerkin method, some standard finite elements. [4 L] • Simulating Electrical conduction, Optical reflection, transmission, absorption, meta-materials, thermal and fluid transport [1 L + 12 P]

Course Name: Finite Element Modelling [1 0 6 3]	
Course Code: I2P 425	
	• Multi-physics applications - heat and mass transfer and fluid dynamics and chemical reactions, theory of elasticity, multiphase systems, static electric and magnetic fields and interaction with matter, electrodynamics, wave optics [2 L + 24 P] • Micro and Nano Technology: Solving the Schrödinger equation in different potentials, Electrical transport in microsystems, sensors and allied devices. • Photonics: Optical Components, Fiber and Fiber Bragg grating. • Kinetics and Transport: Modelling Chemical Reactions, Microfluidic Systems.[2L+36P]
Text & Reference Books	1. S. M. Muhsa, Computational Finite Element Methods in Nanotechnology, CRC Press 2013. 2. Claes Johnson, Numerical Solution of Partial Differential Equations by the Finite Element Method, Cambridge University Press, 1987 3. S. C. Brenner and L. R. Scott, The Mathematical Theory of Finite Element Methods, Springer-Verlag, New York, 1994. 4. R. Pryor, Multiphysics Modeling Using COMSOL 4, Mercury Learning, 2012. 5. M. Tabatabaian, COMSOL for Engineers, Mercury Learning 2014. 6. J. Berthier, P. Silberzan, Microfluidics for Biotechnology, 2nd ed., ARTECH HOUSE, 2010. 7. S. Ganesan, L. Tobiska, Finite Elements: Theory and Algorithms, Cambridge IISc Series, Cambridge University Press, 2016.

Course Name: Computer Interfacing [1 0 3 2]	
Course Code: I2P 4201	
Prerequisites	None
Learning Outcomes	▪ Understand the basics of AD/DA conversion and data transfer. ▪ Interface instruments and devices using AD/DA data acquisition and control systems.
Layout	• Basics of Analog to Digital conversion and vice versa. Analog and Digital data acquisition and generation. Counters and Timers, real-time data acquisition and instrument control and acquisition speed. [4] • Real-time data acquisition and instrument control and acquisition speed. Practical aspects of interfacing external hardware with a computer. Serial and Parallel Interfacing. Virtual instrumentation using IEEE GPIB, RS232, USB interfaces. [4] • Interfacing external hardware platforms like Arduino and Raspberry Pi [4] • Practicals [30] • Softwares: Labview, Python, Arduino IDE, C++ etc (5 hrs)

Course Name: Computer Interfacing [1 0 3 2]	
Course Code: I2P 4201	
Text & Reference Books	1. C. E. Strangio, Digital Electronics: Fundamental Concepts and Applications, Prentice Hall, N. J., 1980. 2. S. Gupta and J. John, Virtual Instrumentation using LabVIEW, Tata McGraw-Hill Publishing Company Limited, 2010. 3. Jovitha Jerome, Virtual Instrumentation Using Labview, Prentice Hall of India, 2010. 4. Bruce Mihura, LabVIEW for Data Acquisition, Prentice Hall of India, 2013. 5. R Bitter, T Mohiuddin, M Nawrocki, LabVIEW: Advanced Programming Techniques, CRC Press, 2007.

Course Name: Energy Materials Laboratory [0 0 3 1]	
Course Code: I2P 4202	
Prerequisites	Electrochemical Energy Systems and Thermal Transport and Thermoelectrics (be registered for)
Learning Outcomes	▪ Characterise thermal and thermoelectric parameters of materials ▪ Synthesise materials and coatings for applications ▪ Understand practical methods of hydrogen generation and storage
Layout	• Measurement of various thermal transport (conduction/radiation) • Measurement of Specific Heat of Metals & Semiconductors • Synthesis of thermoelectric materials (Bi2Te3) by Solution methods, Powder metallurgy, • Characterising the Thermal Efficiency of Thermoelectric Modules • Design, modelling and simulation of solar concentrators • Synthesis and characterisation of electrode materials for Li ion battery applications • Experimental investigation of hydrogen storage properties of porous carbon materials • Investigation on the electrocatalytic properties of noble metal catalysts towards hydrogen generation • Photocatalytic hydrogen generation and quantification of hydrogen evolution • Synthesis and characterisation of porous carbon materials • Electrochemical synthesis and characterisation of metal nanowires
Text & Reference Books	1. R. B. Bird, W.E. Stewart and E.W. Lightfoot, Transport Phenomena, John Wiley, 2nd ed., 2006. 2. G. S. Nolas J. Sharp H. J. Goldsmid, Thermoelectrics Basic Principles and New Materials Developments Springer-Verlag Berlin Heidelberg New York, 2001.

Course Name: Battery and Fuel Cell Laboratory [0 0 3 1]	
Course Code: I2P 4203	
Prerequisites	Electrochemical Energy Systems (be registered for)
Learning Outcomes	▪ Apply potentiostatic and galvanostatic methods, RDE, Cyclic Voltammetry, Electrochemical Impedance Spectroscopy techniques to characterise electrochemical cells ▪ Fabricate and benchmark electrochemical storage devices.
Layout	• Fabrication of coin cell devices and charge/discharge characterization of Lithium ion battery electrodes • Electrochemical Impedance spectroscopy studies of Lithium ion battery electrodes • Fabrication and electrochemical characterization of carbon-based supercapacitor devices • Electrochemical characterization of Hydrogen fuel cell device • Fabrication electrochemical characterization of microbattery devices
Text & Reference Books	1. Allen J. Bard and Larry Faulkner, Electrochemical Methods: Fundamentals and Applications, 2nd ed., Wiley, Jan 2001.

Course Name: Organic Photovoltaic Devices Laboratory [0 0 3 1]	
Course Code: I2P 4204	
Prerequisites	Optoelectronic Devices (be registered for)
Learning Outcomes	▪ Fabricate and characterise organic semiconductor based photoactive and light emitting devices ▪ Comprehend the physics of organic molecule as semiconductors ▪ Analyse photophysics of organic semiconductors and optoelectronic devices.
Layout	• Fabrication and characterisation of Photodetectors. • Fabrication and characterisation of solar cells. • Fabrication and characterisation of light emitting diodes. • Fabrication and characterisation of field effect transistors. • Fabrication and characterisation of electrochromic devices. • Fabrication and characterisation of electrochemical transistors.

Course Name: Organic Photovoltaic Devices Laboratory [0 0 3 1]	
Course Code: I2P 4204	
Text & Reference Books	1. Von A. Gilbert und J. Baggott, Essentials of Molecular Photochemistry. Blackwell Scientific Publications, Oxford, 1991. 2. K. K. Rohatgi-Mukherjee, Fundamentals of Photochemistry, New Age International, 3rd ed., 1978. 3. Pope & Swenberg, Electronic Processes of Organic Crystals and Polymers, Oxford University press, 2nd ed., 1999. 4. H. Meier, Organic Semiconductors. Verlag Chemie GmbH, 1974. 5. Wolfgang Brutting, Physics Of Organic Semiconductors, John Wiley & Sons Canada; 1st ed., 2005. 6. Organic Electronics: Materials, Manufacturing, and Applications*1, Hagen Klauk, John wiley & Sons; 1st ed., 2006. 7. Von K. C. Kao und W. Hwang, Electrical transport in solids with particular Text & Reference Books to organic semiconductors Pergamon Press New york, 1984

Course Name: Principles of Digital Imaging [3 0 0 3]	
Course Code: I2P 5201	
Prerequisites	Familiarity with programming and Numerical Methods
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 discretisation and digitisation 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 and to establish the theory of a given imaging system.
Layout	• Introduction and overview of imaging - photography, microscopy and tomography; aspects and prospects in industry, and laboratory research; theories of matrix and its application in imaging (using MATLAB software); basics of signal processing and image processing; image artefacts; temporal, spatial and contrast resolution, numerical methods (12 lectures) • Forward model and inverse problems; Tomographic imaging with non-diffracting sources • Radon transform. Fourier slice 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)

Course Name: Principles of Digital Imaging [3 0 0 3]	
Course Code: I2P 5201	
	• 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) • Tomography in selective imaging modalities - X-ray, ultrasound, magnetic resonance imaging (MRI), positron emission tomography (PET), photoacoustic tomography (PAT), diffuse optical tomography (DOT) (4 lectures)
Text & Reference Books	1. Avinash C. Kak and Malcolm Slaney, Principles of Computerized Tomographic Imaging, IEEE Press, 1999. 2. A. K. Jain, Fundamentals of digital image processing, Prentice Hall. 3. Oppenheim Schafer, Discrete time signal processing, Pearson.

Course Name: Machine Learning for Physicists [2 0 3 3]	
Course Code: I2P 522	
Prerequisites	Introduction to Programming, Numerical Methods and Applied Statistics. Machine Learning I (advisable)
Learning Outcomes	▪ Understand the fundamental concepts/tools used in Machine Learning ▪ Discriminate pros and cons of various ML models/algorithms ▪ Apply ML toolkits on data analysis problems relevant to Physics e.g. image/pattern recognition, string/language analysis. ▪ Prepare data and train ML models. ▪ Assess the quality of machine learning systems.
Layout	• Introduction to the core concepts, theory and tools of machine learning as required by physicists addressing practical data analysis tasks. • Supervised learning: linear models for regression and classification • Nonlinear models; Neural networks, Structure, Training and Analysing Neural Networks. Convolutional Neural Networks, Auto-encoders, Principal Component Analysis • Unsupervised learning: dimensionality reduction for clustering. • Recurrent networks, time series and sentence analysis. • Implementation of ML in real applications, relevant to problems in physics. • Free software, libraries and publicly available data-sets will be used.
Text & Reference Books	1. Understanding Machine Learning: From Theory to Algorithms, Shai Ben-David and Shai Shalev-Shwartz, Cambridge University Press, NY 2014. 2. Pattern Recognition and Machine Learning, Christopher M. Bishop, Springer-Verlag Berlin, Heidelberg, 2006. 3. Deep Learning, Ian Goodfellow, Yoshua Bengio, Aaron Courville, The MIT Press, 2016.

LABORATORY COURSES - SYLLABUS

Course Name: Advanced Physics Experiments I [0 0 9 3]	
Course Code: PHY 315 / MSP 315	
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. Fabry-Perot interferometer 10. Michelson's interferometer 11. LCR circuit (series and parallel)- Frequency response and the value of unknown L 12. Transistor characteristics and transistor as an amplifier 13. Phase shift oscillators

Course Name: Advanced Physics Experiments II [0 0 9 3]	
Course Code: PHY 325 / MSP 325	
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

Course Name: Advanced Physics Experiments II [0 0 9 3]	
Course Code: PHY 325 / MSP 325	
	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

Advanced Physics Experiments III [0 0 9 3]	
Course Code: PHY 415	
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. Optical fiber communication 8. Atomic Force Microscope 9. Thin film deposition and characterisation 10. X - ray diffractometer 11. SQUID magnetometer

ELECTIVE COURSES – SYLLABUS

Course Name: Experimental Methods [3 0 0 3]	
Course Code: PHY 4110 / PHY 6110 / I2P 411	
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	• 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] • Fitting bare data by linearisation techniques, obtaining best fit; Introduce calibration curve of a sensor and its predictive value. Error Analysis [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] • Diffraction: Crystal systems, X-ray diffraction, single crystal, powder XRD. Unit cell determination. electron diffraction, pattern analysis. [6] • Scanning probe techniques: Atomic force and Scanning tunnelling microscopy [6] • Spectroscopy: Infra-red, Raman, x-ray and UV photoelectron spectroscopy. • 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] • 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]

Course Name: Experimental Methods [3 0 0 3]	
Course Code: PHY 4110 / PHY 6110 / I2P 411	
Text & Reference Books	1. R. A. Dunlap, Experimental Physics - Modern Methods, Oxford University Press, 1988. 2. J. H. 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 Vol. 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 ed., June 2020.

Course Name: Semiconductor Physics and Technology [3 0 0 3]	
Course Code: PHY 4120 / PHY 6120 / I2P 412	
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	• Review of Bulk semiconductor physics: crystals, compound semiconductors, band-structure, density of states, doping and carrier concentration, Fermi statistics. [4] • Electrical Transport in Bulk Semiconductors: Drude model, Boltzmann transport; equations in electric and magnetic field; moments of transport equation, continuity equation, diffusion, drift, thermal gradient etc. [6] • Semiconductor Junctions: Schottky and heterojunctions, role of interfaces, band bending concept, self-consistent band bending equations (Poisson - Schrodinger etc). Band bending near surfaces and interfaces. Forward and reverse biased diodes. Special diodes: pin, tunnel diodes etc. [7] • 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 and Electroluminescence. [7]

Course Name: Semiconductor Physics and Technology [3 0 0 3]	
Course Code: PHY 4120 / PHY 6120 / I2P 412	
	• Quantum Heterostructures & Reduced dimensional systems: 3D, 2D, 1D electron gas and quantum dot systems; engineering heterostructures and superlattices; optical properties of reduced dimensional systems; Quantum confined Stark effect. [6] • Screening in 3D and 2D electron systems: Lattice polarisation; screened Coulomb potential, remote doping and mobility. [3] • Photovoltaic Devices: photoconductors, photodiodes, Light Emitting Diodes, Laser Diodes; Quantum cascade lasers etc. [3]
Text & Reference Books	1 S M Sze and M Lee, Semiconductor Devices: Physics and Technology, Wiley India, 3rd ed, 2007 2 Seeger, K., Semiconductor Physics, Springer-Verlag, 1990. 3 M Fox, Optical Properties of Solids, Oxford University Press. 4 J. H. Davies, Physics of Low-Dimesnional Semiconductors, Cambridge, 1997. 5 N. W. Ashcroft and D. Mermin, Solid State Physics, Brooks/Cole, 1976. 6 R. F. Pierret, Semiconductor Device Fundamentals, Pearson India, 2006

Course Name: Fluid Mechanics &Transport Phenomena (i2P) [3 0 0 3]	
Course Code: PHY 4130 / PHY 6130 / I2P 413	
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	• Ideal Fluids (The Equation of Continuity, Euler's Equation) • Hydrostatics and Potential Flow • Viscous Fluids (The Equations of Motion, Energy Dissipation) • Thermal Conduction in Fluids (Equation of Heat Transfer) • Thermal Conduction in an Incompressible Fluid • 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. 4. F. P. Incropera and D. P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th ed., Wiley India, 2006. 5. Landau and Lifshitz, Fluid Mechanics, Pergamon Press

Course Name: Modelling Materials [2 0 3 3]	
Course Code: PHY 4140 / PHY 6140 / I2P 414	
Prerequisites	Quantum Mechanics, Condensed Matter Physics I
Learning Outcomes	▪ Apply computational methods to model, comprehend and predict material properties and material design. ▪ Apply first-principles approaches, molecular dynamics simulations, stochastic methods for optimization and sampling. ▪ Hands-on training using open-source software packages provide experience with simulations of classical force fields, electronic-structure approaches, molecular dynamics, and Monte Carlo.
Syllabus	• 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, C. A: 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.

Course Name: Nonlinear Optics and Photonics [3 0 0 3]	
Course Code: PHY 4204 / PHY 6204	
Prerequisites	Mathematical Methods in Physics

Course Name: Nonlinear Optics and Photonics [3 0 0 3]	
Course Code: PHY 4204 / PHY 6204	
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	• Light-matter interaction, Polarization, Nonlinear Polarization, Wave Equation with driving polarization • 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 • 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 • Introduction to four-wave mixing, third harmonic generation, Phase matching techniques, Stimulated Raman Scattering, Stimulated Brillouin scattering, Electromagnetically Induced Transparency, • Applications of nonlinear optics, slow-light, microwave photonics, Ultra-fast communication and signal processing • Project:
Text & Reference Books	1. Nonlinear Optics by Robert W. Boyd, Academic Press. 2. Nonlinear Fibre Optics by Govind P Agarawal, Academic Press.

Course Name: Electronic Devices and Computer Interfacing [2 0 1 3]	
Course Code: PHY 4205 / PHY 6205	
Prerequisites	Basics of Programming, Electronics
Learning Outcomes	▪ Hands on experience in interfacing data acquisition and control systems

Course Name: Electronic Devices and Computer Interfacing [2 0 1 3]	
Course Code: PHY 4205 / PHY 6205	
Syllabus	• Heterojunctions, Special purpose diodes: Zener, Varactor diode, Tunnel diode, Diac, Triac, LED, PV cell, Photodetectors, SCR, UJT, IGBT. • Oscillator design and applications. • 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. • 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 • Softwares: Labview, Python, Arduino IDE, C++ etc • Project: Interfacing project to be conceived and executed by each student, using any one of the software.
Text & Reference Books	1 J. A. Strong, Basic Digital Electronics, Springer. 2 C. E. Strangio, Digital Electronics: Fundamental Concepts and Applications, Prentice Hall. 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.

Course Name: Astrophysics [3 0 0 3]	
Course Code: PHY 4206 / PHY 6206	
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.

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<tr><th colspan="2">Course Name: Astrophysics [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 4206 / PHY 6206</th></tr>
<tr><td>Syllabus</td><td>Overview of the universe. Astronomical scales, Coordinates, Magnitudes. Telescopes and Observations in various EM bands.
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.
Interstellar medium, Jeans instability.
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.</td></tr>
<tr><td>Text & Reference Books</td><td>1 Arnab Rai Choudhuri, Astrophysics for Physicists.
2 Frank Shu, The Physical Universe.
3 G. B. Rybicki and A.P. Lightman, Radiative Processes in Astrophysics.</td></tr>
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<tr><th colspan="2">Course Name: Quantum Information Theory [3 1 03]</th></tr>
<tr><th colspan="2">Course Code: PHY 4207</th></tr>
<tr><td>Prerequisites</td><td>PHY 314: Quantum Mechanics 1</td></tr>
<tr><td>Learning Outcomes</td><td>Understanding and appreciating the essential differences between classical and quantum information theory
Get closely acquainted with the qubit which is the basic unit of quantum information processing
Learning about the circuit model of quantum computing and other such approaches to quantum information processing
Studying a few basic quantum algorithms that can be run on quantum information processors to solve certain classes of problems exponentially faster than any known classical algorithm</td></tr>
<tr><td>Syllabus</td><td>Introduction to probabilities: Events, Boolean lattice of events, The axioms of probability, Laws of large numbers [2]
Review of Classical Information Theory: Quantifying information, sequences, Shannon entropy, typical sequences theorem, Shannon’s noiseless coding theorem, properties of Shannon entropy, relative entropy, conditional entropy, mutual information, sub-additivity [4]
Review of quantum mechanics: Axioms of quantum mechanics, state space, linear operators, density matrices [2]
Qubits and multiple quantum systems: The single qubit state space, the Bloch ball, representations of one qubit states, Unitary transformations on single qubit states, bipartite quantum systems, tensor product Hilbert spaces and operators on them, quantum entanglement, partial trace operation, two qubit systems [5]</td></tr>
</table>

Course Name: Quantum Information Theory [3 1 03]	
Course Code: PHY 4207	
	• Bell's inequalities and quantum teleportation: Bell states, Pauli representation of Bell states, CHSH-Bell inequality, Tsirilson bound, superdense coding and quantum teleportation. [2] • Quantum measurements with introduction to open quantum dynamics: Measurement models, the Stern-Gerlach case, VonNeumman measurements, Positive Operator Valued Measures (POVM), implementing POVMs, Connecting quantum measurements to open quantum dynamics, Kraus representation theorem, Qubit operations [3] • Quantum circuit model: Simple circuits, universal quantum gates, measurements and operators in circuits, circuit identities [4] • Quantum algorithms: Deutsch Josza algorithm, the quantum Fourier transform, the quantum period finding algorithm and Shor's algorithm [5] • Physical Implementations: Trapped ion and trapped atom implementation, superconducting qubits, semiconducting quantum dot based qubits, NMR quantum information processing, measurement based quantum computing [2] • Formal aspects of quantum information theory: VonNeumman entropy, the quantum relative entropy, conditional entropy and mutual information. The strong sub-additivity of VonNeumman entropy [2]
Text & Reference Books	1 M. A. Nielsen and I. L. Chuang, Quantum Computation and Quantum Information, Cambridge University Press, 2010.

Course Name: Quantum Information Theory [3 0 0 3]	
Course Code: PHY 4217 / PHY 6217	
Prerequisites	Quantum Mechanics 1
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	• Probabilities (3 hours): Review of probabilities, betting odds and the Dutch book. The probability simplex. • Classical Information theory (2 hours): Shannon entropy and Shannon's theorems. • Bits and Qubits (2 hours): The quantum two level system and its Hilbert space. • Quantum states (4 hours): Mixed quantum states and the density matrix. Quantum super-position, multipartite states and entanglement. • Quantum measurements (3 hours): The measurement super operator, generalized measurements and POVMs

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<tr><th colspan="2">Course Name: Quantum Information Theory [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 4217 / PHY 6217</th></tr>
<tr><td></td><td>
• Quantum dynamics, open and dosed dynamics (3 hours): Unitary evolution, Super operators and dynamical maps
• The circuit model (5 hours): The circuit model of quantum computation, operations on qubits, distinguishability of states.
• Quantum entropy and quantum correlations (4 hours): Quantum versions of the fundamental theorems in information theory, non-classical correlations, discord etc.
• Elements of quantum computing (5 hours): Quantum algorithms, possible implementations
</td></tr>
<tr><td>Text & Reference Books</td><td>
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.
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<tr><th colspan="2">Course Name: Nonlinear Dynamics [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 4218 / PHY 6218</th></tr>
<tr><td>Prerequisites</td><td>Mathematical Methods in Physics</td></tr>
<tr><td>Learning Outcomes</td><td>
▪ 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.
</td></tr>
<tr><td>Syllabus</td><td>
• 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.
• 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.
• 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.
• Fractals: Self similarity - Self-similarity in Henon attractor - Properties of fractals - Examples of fractals • Fractal dimension.
• Soliton: Linear and nonlinear waves - cotiidial and solitary waves - John Scott Russel's observation of solitary wave - Korteweg-de vries equation and solitons.
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Course Name: Nonlinear Dynamics [3 0 0 3]	
Course Code: PHY 4218 / PHY 6218	
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. O. 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.

Course Name: Digital Image Processing [3 0 0 3]	
Course Code: PHY 5101 / PHY 6101 / I2P 5101	
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	• 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). • 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,

Course Name: Digital Image Processing [3 0 0 3]	
Course Code: PHY 5101 / PHY 6101 / I2P 5101	
	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). 4. Alan V Oppenheim, Ronal W Schafer, and John R Buck, Discrete-time Signal Processing, Prentice Hall, 1999. 5. Rudra Pratap, Getting Started with MATLAB, Oxford University Press, 2010.

Course Name: Lasers and Fiber Optic Communications [3 0 0 3]	
Course Code: PHY 5121 / PHY 6121	
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	• 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). • Optical communications: data sampling and Nyquist criteria, analog to digital conversion, analog • 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

Course Name: Lasers and Fiber Optic Communications [3 0 0 3]	
Course Code: PHY 5121 / PHY 6121	
	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. • Final Project
Text & Reference Books	1. Lasers by Siegman, Anthony E. (1986), University Science Books. 2. Govind P. Agrawal, Fiber-Optic Communication Systems, Wiley Interscience.

Course Name: Physics at Low temperatures [3 0 0 3]	
Course Code: PHY 5122 / PHY 6122	
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	• Quantum fluids: Physical properties of Helium. Superfluidity in 4He: experimental findings, two fluid model, Bose-Einstein Condensation, macroscopic quantum state, vortex flow, critical velocities and second sound. • Normal and superfluid 3He, Quantum states of pairs of coupled quasi particles - Spin triplet pairing – macroscopic quantum effects, mixture of 3He and 4He, phase diagram, properties of this mixture, topological defects in superfluid 4He and superfluid 3He and salient properties of quantum solids. • Solids at low temperatures: Electrical transport, thermal, mechanical and magnetic properties, Kondo effect, Superconductivity and heavy fermion materials. • 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. • 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.

Course Name: Physics at Low temperatures [3 0 0 3]	
Course Code: PHY 5122 / PHY 6122	
Text & Reference Books	1. Guy K White and Phillips J Meeson, Experimental Techniques in Low-Temperature Physics, 4th ed., 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 ed., 1990. 4. James F. Annett, Superconductivity, Superfluids and Condensates, Oxford Master Series in Physics, Oxford University Press, 1st ed., 2004. 5. A. C. Rose-Innes and E. H. Rhoderick, Low Temperature Laboratory Techniques, English University Press, 1973. <u>Reference Books:</u> 1. Frank Pobell, Matter and Methods at Low Temperatures, 3rd revised and expanded ed, Springer, 2007. 2. V. E. Mclintock, D. H. Meredith and J.K. Wigmore, Matter at Low Temperatures, Blackie, Glassglow, 1984. 3. Christian Enns and Siegfried Hunklinger, Low Temperature Physics, Springer Verlag, 2005. 4. Anthony Kent, Experimental Low Temperature Physics, Macmillan Physical Science Series, AIP, 1993. 5. D. S. Betts, Introduction to Millikelvin Technology, Cambridge University Press, 1989. 6. O. V. Lounasmaa, Experimental Principles and Methods below 1 K, Academic Press, 1974. 7. Robert Coleman Richardson and Eric N. Smith, Experimental Techniques in Condensed Matter Physics at Low Temperatures, Advanced Books Classics, 1998 8. J. W. Ekin, Experimental Techniques in Low Temperature Measurements, Oxford University Press, 2006. 9. P. M. Chaikin and T. C. Lubensky, Principles of Condensed Matter Physics, Cambridge University Press, 2000.

Course Name: Nanoscale Physics [3 0 0 3]	
Course Code: PHY 5123 / PHY 6123	
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	• Overview of nanoscience- historical perspective, nanotechnology in nature. Basic physical principles of quantum confinement • Size matters: effect on structural, physical and chemical properties Nanomagnetism Nanophotonics. Electronic structure of semiconductor nanoparticles, size dependent

Course Name: Nanoscale Physics [3 0 0 3]	
Course Code: PHY 5123 / PHY 6123	
	optical properties: photoluminescence, absorption spectra, excitons and plasmons, vibrational and thermal properties of nanosystems; zone folding. Raman characterization. • Synthesis of nanomaterials: Bottom up and top down approaches - Physical and chemical methods. • Story of carbon nanoscience: Fullerenes, carbon nanotubes, graphene and beyond graphene - physics and applications. • Nanotools: Scanning probe techniques - tools for characterization, manipulation and constructions of the nanoscale structures and devices. • Applications of nanomaterials, nanoscale devices.
Text & Reference Books	1. Homyak et al., Introduction to Nanoscience & Nanotechnology, CRC Press, 2009 2. Chris Binns, Introduction to Nanoscience & Nanotechnology, Wiley, 2010. 3. Physical Properties of Carbon Nanotubes, Imperial College Press.

Course Name: Superconductivity [3 0 0 3]	
Course Code: PHY 5124 / PHY 6124	
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	• A historical overview: Superconductivity in Hg, cuprates, MgB2 and Fe pnictides. • Basic properties of metals in normal state: Resistivity, electronic and phonon specific heats, thermal conductivity, magnetic susceptibility and Hall effect. • Phenomenon of superconductivity: Zero resistance, persistent currents, superconducting transition temperature Tc, isotope effect, perfect diamagnetism and Meissner effect, penetration depth and critical field. • Thermodynamics of superconducting transition: First-order and second-order transition, specific heat above and below Tc, thermal conductivity. • Phenomenological theory of superconductivity: Free energy, order parameter, Ginzburg-Landau equations, predictions of Ginzburg Landau equations, flux-quantization, penetration depth. • 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.

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<tr><th colspan="2">Course Name: Superconductivity [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 5124 / PHY 6124</th></tr>
<tr><td></td><td>• Tunneling and the energy gap: Tunneling phenomenon, energy-level diagram, Josephson effect, quantum interference.
• Type-I and Type-II superconductivity: Type-I and type-II superconductors, intermediate states, mixed states.
• Experimental methods for probing the nature of the superconducting state: Superconducting quantum interference device and point-contact spectroscopy.
• Basics of High-Tc superconductivity.</td></tr>
<tr><td>Text & Reference Books</td><td>1. C. Kittel, Introduction to Solid State Physics 7th ed., John Wiley & Sons, Inc., Singapore, 1995.
2. A. C. Rose-Innes and E. H. Rhoderick, Introduction to Superconductivity, 2nd ed., Pergammon, Oxford, 1978.
3. M. Tinkham, Introduction to Superconductivity, 2nd ed., 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 ed., Academic Press, 2007.
6. D.R. Tilley and J. Tilley, Superfluidity and Superconductivity, IoP Publishing, Bristol, 3rd ed., 1990.
7. James F Annett, Superconductivity, Superfluids and Condensates, Oxford Master Series in Physics, Oxford University Press, 1st ed., 2004.
8. A. C. Rose-Innes and E. H. Rhoderick, Low Temperature Laboratory Techniques, English University Press, 1973.</td></tr>
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<tr><th colspan="2">Course Name: Foundations of Quantum Mechanics [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 5125 / PHY 6125</th></tr>
<tr><td>Prerequisites</td><td>PHY 314: Quantum Mechanics I</td></tr>
<tr><td>Learning Outcomes</td><td>▪ 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</td></tr>
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Course Name: Foundations of Quantum Mechanics [3 0 0 3]	
Course Code: PHY 5125 / PHY 6125	
Syllabus	• Review [3]: Mach-Zehnder interferometer; Stern-Gerlach experiment; Linear Algebra • Introduction [4]: Postulate of Quantum Theory; Einstein-Podolsky-Rosen paradox • 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) • Bell's Nonlocality [4]: Proof of Bell's theorem; Quantum entanglement; Quantum violation of Bell inequality; Study of different sets of correlations • Application of Bell's theorem [4]: Device independent (DI) randomness certification; Quantum cryptography protocols (BB84 and E91); DI cryptography • Kochen-Specker contextuality [4]: State independent / dependent contextuality proof; Generalized contextuality of Spekkens • Application of Kochen-Specker contextuality [3]: Some basic topics in graph theory; Binary Constraint System Games, Parity-oblivious multiplexing task • Reality of quantum wavefunction [4]: Pusey-Barrett-Rudolph theorem; Maroney's theorem • Quantum Measurement Problem [3]: Wigner's friend paradox and its extended version • Indefinite causal order [4]: Oreshkov-Costa-Brukner game; Quantum switch
Text & Reference Books	1. Asher Peres, Quantum Theory: Concepts and Methods (Fundamental Theories of Physics) 2. Travis Norsen, Foundations of Quantum Mechanics: An Exploration of the Physical Meaning of Quantum Theory. 3. Nicolas Brunner, Daniel Cavalcanti, Stefano Pironio, Valerio Scarani, and Stephanie Wehner, Bell nonlocality, Rev. Mod. Phys. 86, 419, 2014. 4. N. David Mermin, Hidden variables and the two theorems of John Bell, Rev. Mod. Phys. 65, 803, 1993. 5. Class notes and few relevant research papers.

Course Name: Advanced Statistical Physics [3 0 0 3]	
Course Code: PHY 5126 / PHY 6126	
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.

Course Name: Advanced Statistical Physics [3 0 0 3]	
Course Code: PHY 5126 / PHY 6126	
	▪ Use Renormalization group techniques to identify relevant couplings, determine their flow under scaling, and find the critical exponents.
Syllabus	• 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. • 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. • Collective excitations: Continuous symmetry breaking and Goldstone modes, Mermin-Wagner theorem, spin-waves in ferromagnets. • Exact solution of Ising model in one and two dimensions, Relation between transfer matrix method and path integrals in quantum mechanics. • Landau-Ginzburg theory: Mean-field approach. Saddle-point approximation, Breakdown of mean-field and Ginzburg criterion. • 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.

Course Name: Fluid Dynamics [3 0 0 3]	
Course Code: PHY 5127 / PHY 6127	
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.

Course Name: Fluid Dynamics [3 0 0 3]	
Course Code: PHY 5127 / PHY 6127	
Syllabus	• Foundations of fluid dynamics: Hydrodynamic variables, symmetries and conservation laws, local equilibrium, constitutive relations, entropy principle. [3] • Nonrelativistic fluid dynamics: Dynamical equations of Ideal fluids, constructing constitutive relations and equations of viscous fluids (Navier-Stokes equation, equation of heat transfer). [4] • Multi-component fluids (Mixture of fluids): Equations of motion, coefficients of mass transfer and thermal diffusion, kinetic coefficients and Onsager reciprocal relations. [6] • 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] • 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.

Course Name: General Relativity and Cosmology [3 0 0 3]	
Course Code: PHY 5128 / PHY 6128	
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	• Covariance of Physical Laws Special (1 Relativity (2 lectures) • The Equivalence Principle (2 lectures) • Space and Spacetime Curvature Tensors in Curved Spacetime (4 lect) The Geodesic equation (4 lectures) • Curvature and Einstein Field Equations (2 lect) Geodesic Deviation Equation Geometry (4 lectures)Outside of a Spherical Star Tests of caslativity (2 lectures) • Gravitational Radiation • Black Holes (3 lectures)

Course Name: General Relativity and Cosmology [3 0 0 3]	
Course Code: PHY 5128 / PHY 6128	
	• Cosmology (3 lectures)
Text & Reference Books	1. James Hartle, Gravity- An introduction to Einstein's general relativity, Addison-Wesley. 2. S. Weinberg, Gravitation and Cosmology, Wiley, 1972. 3. J. V. Narlikar, Introduction to General Relativity, Cambridge. 4. L. D. Landau and E. M. Lifshitz, Classical Theory of Fields, Butterworth-Heinemann.

Course Name: Quantum Many-body Theory [3 0 0 3]	
Course Code: PHY 5129 / PHY 6129	
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. • 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.

Course Name: Principles of Digital Imaging [3 0 0 3]	
Course Code: PHY 5201 / PHY 6201 / I2P 5201	
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	• 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) • 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) • 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) • Tomography in selective imaging modalities - X-ray, ultrasound, magnetic • Resonance imaging (MRI), positron emission tomography (PET), photoacoustic tomography (PAT), diffuse optical tomography (DOT) (4 lectures)
Text & Reference Books	1. Avinash C. Kak and Malcolm Slaney, Principle of computerised tomographic imaging, IEEE Press. 2. A. K. lain, Fundamentals of digital image processing, Prentice Hall. 3. Oppenheim Schafer, Discrete time signal processing, Pearson.

Course Name: Organic Semiconductors: Fundamentals and Applications [3 0 0 3]	
Course Code: PHY 5202 / PHY 6202 / I2P 5202	
Prerequisites	Condensed matter physics-I

<table>
<tr><th colspan="2">Course Name: Organic Semiconductors: Fundamentals and Applications [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 5202 / PHY 6202 / I2P 5202</th></tr>
<tr><td>Learning Outcomes</td><td>
▪ 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
</td></tr>
<tr><td>Syllabus</td><td>
PART I
• 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]
• 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]
• Excitons : Wannier Exciton, Charge-transfer Exciton Frenkel Exciton, Exciton Diffusion, Excitonic Energy Transfer. [2 Lectures]
• ConductionMn Organic Solids: Conductivity: carrier concentration versus mobility, Carrier generation, Hopping transport, Mobility measurements, Traps. [2 Lectures]
• Photovoltaics and Photodetectors: Photovoltaic Devices: Organic Heterojunction Photovoltaic Cells, Organic/Nanorod hybrid Photovoltaics, Gratzel Cells (Dye sensitized solar 1 cells),Photodetector Devices [5 Lectures]
• Organic Light Emitting Devices: Basic OLED Properties, Charged Carrier Transport, Organic LEDs, Quantum Dot LEDs. [8 Lectures]
• Lasing Action in Organic Semiconductors: Lasing Process, Optically Pumped Organic Lasers, Electrical Pumping of Organic Lasers. [2 Lectures]
• Organic Thin Film Transistors: OFETs: Materials, Contacts, Applications, And Nanotube Transistors. [2 Lectures]
• Device Fabrication Technology: Growth Techniques: Evaporation, Langmuir-Blodgett, Chemical Vapor Phase Deposition, Ink-Jet Printing, Self-Assembly. [3 Lectures]
PART II
• Project: Literature review on a certain relevant topic. [10 Lectures]
</td></tr>
<tr><td>Text & Reference Books</td><td>
1. Gilbert & Baggott, Essentials of Molecular Photochemistry, CRC Press, 1991.
2. K. K. Rohatgi-Mukherjee, Fundamentals of Photochemistry, NewAge International, 1978.
3. Pope & Swenberg, Electronic Processes of Organic Crystals and Polymers, Oxford University press, 2nd ed., 1999.
4. H. Meier, Organic Semiconductors, Verlag Chemie GmbH, 1974.
5. Wolfgang Brutting, Physics of Organic Semiconductors, John Wiley & Sons Canada; 1 ed., 2005.
6. Organic Electronics: Materials, Manufacturing, and Applications, Hagen Klauk, John Wiley & Sons; 1st ed., 2006,
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<table>
<tr><th colspan="2">Course Name: Organic Semiconductors: Fundamentals and Applications [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 5202 / PHY 6202 / I2P 5202</th></tr>
<tr><td></td><td>7. Electrical transport in solids: with particular reference to organic semiconductors, Kao, Pergamon Press; 1st ed., 1981.</td></tr>
</table>

<table>
<tr><th colspan="2">Course Name: Sensor Technology [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 5203 / PHY 6203 / I2P 5203</th></tr>
<tr><td>Prerequisites</td><td>Condensed Matter Physics - I, Electronics</td></tr>
<tr><td>Learning Outcomes</td><td>▪ 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.</td></tr>
<tr><td>Syllabus</td><td>• 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.
• 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.
• 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.
• Application of ceramic sensors
• MEMS based sensor, Nanotechnology in Sensor applications, recent developments in this area.</td></tr>
<tr><td>Text & Reference Books</td><td>1. Handbook of Modem Sensors: Physics, design and applications, 3rd ed.
2. Jacob Fraden, ISBN 0-387-00750-4, Publisher: Springer-Verlag, Inc. 2004.
3. Jon S. Wilson, Sensor Technology Handbook, ISBN: 978-0-7506-7729-5, Elsivier.
4. Wen Wang, Advances in Chemical Sensors, ISBN 978-953-307-792-5, 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.</td></tr>
</table>

<table>
<tr><th colspan="2">Course Name: Numerical Simulation techniques in Physics [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 5207 / PHY 6207</th></tr>
<tr><td>Prerequisites</td><td>Condensed Matter Physics-II</td></tr>
</table>

Course Name: Numerical Simulation techniques in Physics [3 0 0 3]	
Course Code: PHY 5207 / PHY 6207	
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	• 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. • Parallel programming; Introduction to parallel programming using OpenMP and MPI. • 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). • Molecular dynamics simulations: Basic concepts, algorithms, application to various model systems. • 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, 6th ed. 2. Bjame Stroustrup, The C++ Programming Language, 4th 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.

Course Name: Introduction to Cosmology [3 0 0 3]	
Course Code: PHY 5208 / PHY 6208	
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.

Course Name: Introduction to Cosmology [3 0 0 3]	
Course Code: PHY 5208 / PHY 6208	
Syllabus	• Historical overview and expansion of the Universe (3 hours): Ptolemaic Universe – Copernican Revolution – Expanding Universe -Measurement of motion – Redshift – Hubble's law – Cosmological principle • 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 • 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 • Cosmological distances (3 hours): Proper distance – Angular diameter distance - Luminosity distance – Horizon distance • Nucleosynthesis (4.5 hours): Thermal history of the early Universe - Equilibrium process - Neutron free-out - Deuterium bottleneck – Formation of light elements • Inflation (4.5 hours): Problems with Big Bang Theory – Horizon Problem – Flatness Problem –Accelerated expansion in early Universe – Solving Horizon and Flatness problem • 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 • Precession measurement of CMB (3 hours): Satellite experiment – Ground–based measurements – Balloon-bourne measurement • 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. Steven Weinberg, Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity, John Wiley & Sons Inc., 1st ed., July 1972. 2. Barbara Rayden, Introduction to Cosmology, Addison-Wesley, 1st ed., October 2002. 3. J. V. Narlikar, An Introduction to Cosmology, Cambridge University Press, 3rd ed., February 2002.

Course Name: Particle Physics [3 0 0 3]	
Course Code: PHY 5209 / PHY 6209	
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

Course Name: Particle Physics [3 0 0 3]	
Course Code: PHY 5209 / PHY 6209	
	▪ Explain spontaneous symmetry breaking and analyze various interaction terms of a Lagrangian
Syllabus	• Review of particle physics [3] • Symmetries, groups and quarks: Abelian and non-Abelian Lie groups, finite symmetry groups; baryon, meson and quark hypothesis. [10] • Recap of relativistic kinematics. [2] • 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] • Calculation of the 2 -> 2 scattering cross sections in QED. [3] • Local and global symmetries, spontaneous symmetry breaking, Higgs mechanism, GSW model, weak interactions. [9]
Text & Reference Books	1. Palash B. Pal, An Introductory course of particle physics, 2. David Griffiths, Introduction to Elementary Particles. 3. Halzen and Martin, Quarks and Leptons: An introductory course in modern particle physics,

Course Name: Theory of Open Quantum Systems [3 0 0 3]	
Course Code: PHY 5212 / PHY 6212	
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	• 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 • 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

<table>
<tr><th colspan="2">Course Name: Theory of Open Quantum Systems [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 5212 / PHY 6212</th></tr>
<tr><td></td><td>

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
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
Stochastic Dynamics in Hilbert Space [6 Lectures]
a. Dynamical semigroups and piecewise deterministic processes
b. Stochastic representation of continuous measurements
c. Example: Photodetection
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

</td></tr>
<tr><td>Text & Reference Books</td><td>1. Francesco Petruccione, The Theory of Open Quantum Systems, Heinz-Peter Breuer, Oxford University Press, 2007.</td></tr>
</table>

<table>
<tr><th colspan="2">Course Name: Quantum Field Theory I [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 5213 / PHY 6213</th></tr>
<tr><td>Prerequisites</td><td>Quantum Mechanics-2, ED & STR</td></tr>
<tr><td>Learning Outcomes</td><td>

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.

</td></tr>
</table>

Course Name: Quantum Field Theory I [3 0 0 3]	
Course Code: PHY 5213 / PHY 6213	
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.

Course Name: Probes in Condensed Matter Physics [3 0 0 3]	
Course Code: Course Code: PHY 5214 / PHY 6214	
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	• Scattering probes: X-ray diffraction, neutron scattering, scanning electron microscopy, transmission electron microscopy, Raman scattering, electron paramagnetic resonance, nuclear magnetic resonance, nuclear quadrupole resonance. • Spectroscopic probes: Fourier-transform infrared spectroscopy, Mossbauer spectroscopy, positron annihilation technique. • Thermal properties measurement probes: specific heat, thermal conductivity, thermal expansion, differential scanning calorimetry (DSC), thermogravimetric analysis (TGA) • Transport properties measurement probes: ac and dc conductivity, Hall effect, magnetoresistance, magnetic susceptibility, dc and ac magnetization. • Optical probes: Optical conductivity

Course Name: Probes in Condensed Matter Physics [3 0 0 3]	
Course Code: Course Code: PHY 5214 / PHY 6214	
Text & Reference Books	1. B. D. Cullity, Elements of X-ray Diffraction. 2. Stephen Blundell, Magnetism in Condensed Matter. 3. D. B. Williams and C. B. Carter, Transmission Electron Microscopy. 4. S. Amelinckx et al., Handbook of Microscopy, Applications in Materials Science, Solid-State Physics and Chemistry. 5. R. E. Hummel, Electronic properties of materials. 6. S. W. Lovesey, Theory of neutron scattering in condensed matter. 7. T. H. K. Barron and G. K. White, Heat Capacity and Thermal Expansion at Low Temperatures. 8. R. F. Bunshah, Techniques of Metals Research.

Course Name: Quantum Transport [3 0 0 3]	
Course Code: PHY 5215 / PHY 6215	
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	• Review of transport in 3D, Drude theory of electrical conduction, Sommerfield theory, Density of states. Magnetotransport in 3D, conductivity & Resistivity tensors. • Transport regimes & quantization effects: Classical diffusive, quantum diffusive & Quantum Ballistic transport regimes. • Micro and Nanoscale device fabrication, Photo-lithography, e-beam lithography • Two-dimensional systems: Quantum well heterostructures, remote doping, band bending, surface states, Schottky & Ohmic contacts, Graphene and other 2D layered systems. • 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 • Electron-electron interactions and weak localization, quantum interference effects in disordered systems. Aharanov Bohm effect in metals and semiconductors. • 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,

Course Name: Quantum Transport [3 0 0 3]	
Course Code: PHY 5215 / PHY 6215	
	• 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 • 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, • 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. S datta, Electronic transport in mesoscopic systems. 2. Nazarov & Blanter, Quantum Transport. 3. Ferry, Goodnick & Bird, Transport in nanostructures.

Course Name: Advanced Mathematical Methods in Physics [3 0 0 3]	
Course Code: PHY 5216 / PHY 6216	
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	• Topology [4.5]: Topological Spaces, Metric Spaces, Basis, Closure, Connected and Compact Spaces, Continuous functions, Homeomorphisms and Topological Invariants, Separability • Homotopy [4.5]: Paths and Loops, Homotopy, Fundamental Group, Higher Homotopy Groups, Applications in Physics • 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 • 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

Course Name: Advanced Mathematical Methods in Physics [3 0 0 3]	
Course Code: PHY 5216 / PHY 6216	
	• Group Representations [3]: Definition of representation, Invariant subspaces, Reducibility of representations, Equivalence of Representations, Unitary, orthogonal, contragradient, adjoint and complex conjugate representations. • 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. • 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. Mukhi and Mukund, Lectures on Advanced Mathematical Methods for Physicists. 2. M Nakahara, Geometry, Topology and Physics.

Course Name: Spintronics Fundamental and device applications [3 0 0 3]	
Course Code: PHY 5131 / PHY 6131	
Prerequisites	Quantum Mechanics, Condensed Matter - I
Learning Outcomes	▪ The course in physics and technological applications of spintronics introduces the fundamental concepts on spin electronics, different magnetic materials, quantum mechanics of spins, and different interactions of spins. The course covers introduction to spin and spin electronics, spin relaxation behaviour, spin dependent transport, spin-transfer torque, spin injections, spintronic materials, and device applications. ▪ As the motivation of the course is to provide an understanding of fundamentals of spinelectronics, spin relaxation, spin transport, and advances in spin electronic technology and futuristic advanced spintronics materials. ▪ This will be very much useful to the students studying in BS-MS with Physics major, Master of Science in Physics and PhD in Physics with the background knowledge on Solid State Physics.
Syllabus	• **Introduction:** History and overview of spin electronics, Fundamental of magnetism, Quantum Mechanics of spin [6] • **Spin interaction:** Spin-orbit interaction, Exchange interaction, Spin relaxation mechanisms, The spin Galvanic effect [4] • **Spin Transport:** Fundamentals of electron transport, Spin-dependent transport, Spin dependent tunnelling, Andreev Reflection at ferromagnet and superconductor interfaces, Spin injection, Spin current, and Spin hall effect. [8] • **Magnetic switching and oscillation:** Giant magnetoresistance (GMR), Spin-transfer torques (STT), Electric switching of magnetization and domain wall motion, Magnetodynamics [6] • **Spintronic Applications:** Fundamental of spintronic device applications, Silicon based spin electronic devices, Spin photoelectronic devices, Magnetic-field sensors, Quantum Computing with spins.[6]

Course Name: Spintronics Fundamental and device applications [3 0 0 3]	
Course Code: PHY 5131 / PHY 6131	
	• **Spintronic materials:** Materials for spin electronics, Deposition techniques, Different nanostructures for spin electronics, micro and nanofabrication techniques for spintronic materials. [8]
Text & Reference Books	1. Magnetism and Magnetic Materials," by J. M. D. Coey (2009) 2. "Nanomagnetism and Spintronics", by Teruya Shinjo (2013) 3. "Introduction to Spintronics (2nd Ed.)," by Supriyo Bandyopadhyay, Marc Cahay (2015) 4. Recent research papers and review articles on topics of current interest

Course Name: Statistical and data analysis methods in Physical Sciences [3 0 0 3]	
Course Code: PHY 5132 / PHY 6132	
Prerequisites	Numerical computing skills in Python, For lab sessions: Laptop with anaconda installation will be required.
Learning Outcomes	▪ Learning techniques and computing tools necessary to undertake research in physical sciences and data driven fields applications. ▪ Critical thinking and solving problems materials. ▪ Understand how to analyse observational data and make physical inferences to the science problem at hand.
Syllabus	• The course work will focus on understanding the basic concepts of data analysis methods and techniques, and its application to various astronomical (or other physical science) datasets involving hands-on projects in python • Introduction [1]: Probability and Statistics, Context of data science in 20th century. • Probability [3]: Axioms of probability, Conditional probability, Bayes theorem, Independent events, Random variables - discrete and continuous distributions, Quantile function, Central limit theorem. • Probability Distribution functions [2]: Different univariate probability distributions, moments, multivariate distributions and Lab [2]. • Data smoothing- density estimation [1]: Concept of density estimation, histograms, Kernel density estimators. Lab [2] • Statistical Inference [3]: Concepts of statistical inference, techniques of point estimation - method of least squares, maximum likelihood method, confidence intervals, hypothesis testing techniques, Resampling methods, Model selection and goodness of fit, Bayesian statistical inference. Lab [2] • Regression [3]: Concept of regression, Least-squares linear regression, model validation and selection. Lab [2] • Multivariate analysis [4]: Concepts of multivariate analysis, hypotheses tests, relationship among the variables - linear regression, principal component analysis, outliers, multivariate visualisation. Lab [2]

<table>
<tr><th colspan="2">Course Name: Statistical and data analysis methods in Physical Sciences [3 0 0 3]</th></tr>
<tr><th colspan="2">Course Code: PHY 5132 / PHY 6132</th></tr>
<tr><td></td><td>Clustering and classification [3]: Concept of clustering and classification, K-means and mixture models and supervised multivariate normal clusters. Lab [2]
Time series analysis [3]: Concept of time series analysis, analysis of evenly spaced data, autocorrelation, cross-correlation, dynamic time warping machine learning technique. Lab [2]</td></tr>
<tr><td>Text & Reference Books</td><td>Modern Statistical Methods for Astronomy by Eric D Feigelson and G. Jogesh Babu
Principles of Data Analysis by Prasenjit Saha
Statistical Methods for Astronomical Data Analysis by Asis Kumar Chattopadhyay and Tanuka Chattopadhyay
Python for Astronomers, An introduction to Scientific Computing by Imad Pasha and Chris Ago stino
Advances in Machine Learning and Data mining for Astronomy Edited by Michael J Way, Jeffrey D. Scargle, Kamal M. Ali and Ashok N.Srivastava.</td></tr>
</table>

OPEN ELECTIVES

Course Name: Material & device characterization techniques [2 0 1 3]	
Course Code: PHY 4111 / PHY 6111	
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	• Microscopy & Optical techniques: Optical Microscopy, Confocal Optical Microscopy, X-ray, Neutron diffraction, TEM, SEM, XPS, EDAX/EDS, Raman, PL, Ellipsometry, AFM & STM. • 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. • 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, 2nd ed., Yang Leng, Wiley- VCH 2013 .

Course Name: Materials Growth and Processing Techniques [2 0 1 3]	
Course Code: PHY 4211 / PHY 6211	
Prerequisites	None
Learning Outcomes	▪ Develop thorough understanding of growth techniques of materials, with 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.

Course Name: Materials Growth and Processing Techniques [2 0 1 3]	
Course Code: PHY 4211 / PHY 6211	
Syllabus	• 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. • Self-assembly, Langmuir-Blodgett (LB) films, clusters, colloids, Templated synthesis, anodic oxidation of alumina films, porous silicon, and pulsed electrochemical deposition. • 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. • 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. R. A. Laudise, The Growth of Single Crystals, Prentice-Hall publishing 2. M. Ohring, Materials Science of Thin Films, Academic, New York, 1992.

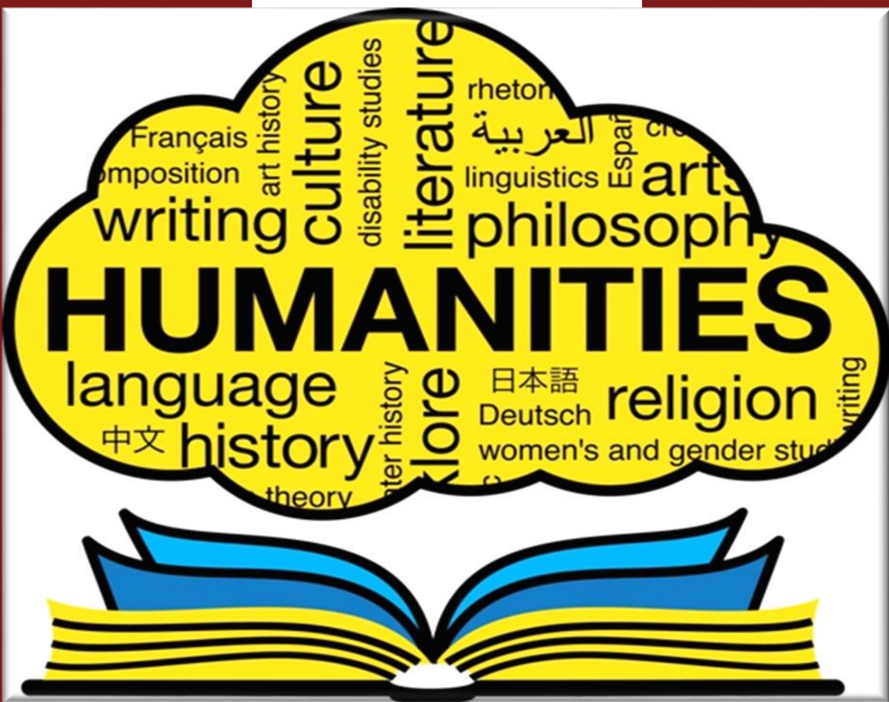
HUMANITIES

CURRICULUM FOR

BS-MS (SEM: 1 - 10)

MSc & IPHD (1 - 4)

CORE AND ELECTIVE COURSES



HUMANITIES SYLLABUS

<table>
<tr><th colspan="2">Course Name: Introduction to Economics [1 0 0 1]</th></tr>
<tr><th colspan="2">Course Code: HUM 211</th></tr>
<tr><td>Prerequisites</td><td>NA</td></tr>
<tr><td>Learning Outcomes</td><td>To familiarize the students with basic economic concepts and introduce them to the tools to analyze and evaluate public policies, poverty and welfare questions, and other applied topics.</td></tr>
<tr><td>Syllabus</td><td>• INTRODUCTION
◦ What is Economics? Scarcity, choice and economic systems
• MARKET: CONSUMPTION
◦ Supply and demand;
◦ Market equilibrium and the price mechanism.
◦ Shifts in the demand and supply curve and the impact on market equilibrium.
◦ Examples and Applications
• MARKET IN ACTION
◦ Elasticity of demand
◦ Consumer choice; Consumer theory with indifference curves
◦ Examples and Applications
• MARKET: PRODUCTION
◦ Production and cost; how firms make decisions: profit maximization
• MARKET STRUCTURE
◦ Perfect competition& Monopoly (representation of Market)
• MARKET FAILURE
◦ Micro economics and Public Policy: Externalities and Public Good; Poverty, Inequality and Welfare State
• MACRO ECONOMICS
◦ Introducing macroeconomics: The Big picture</td></tr>
<tr><td>Text & Reference Books</td><td>1. Mankiw, N. Gregory, Principles of Economics, 6th ed., South-Western College Publishers, 2012.
2. Paul A Samuelson & William Nordhaus, Microeconomics, McGraw Hill Education, New York, 2013.</td></tr>
</table>

Course Name: Introduction to Sociology [1 0 0 1]	
Course Code: HUM 221	
Prerequisites	NA
Learning Outcomes	▪ To improve the ability to cogently discuss and analyze social issues, institutions, relations and practices. ▪ To Identify the main methods of collecting data in sociological research and determine which is most appropriate for specific kinds of research questions.

Syllabus	• Introduction: what is sociology? Micro and macro sociology
	• Basic sociological Questions and concepts
	• Sociological Perspectives and methods
	• Social stratification and Class
	• Social deviance/Crime
	• Key elements of sociology
	  • Politics and social order
	  • Education and mass media
	  • Sociology of body and health
	  • Nation and Globalization
	• Social Problems
	• Sociology in India and South Asia

Text & Reference Books	1. Giddens, Anthony and Sutton Philip, Sociology, 8th ed., Wiley India Private Limited, New Delhi, 2017. 2. Beteille Andre, Sociology: Essays on Approach and Method, Oxford India, New Delhi, 2002. 3. T. K. Oommen, Knowledge and Society: Situating Sociology and Social Anthropology, Oxford University Press, New Delhi, 2007.

Course Name: Planning and Economic Development [3 0 0 3]	
Course Code: HUM 311 / HUM 321	
Prerequisites	Nil
Learning Outcomes	▪ To provide basic skills to discuss economic issues and suggest implications and least cost scientific solutions given the economic/ social situation in context. ▪ To identify very elementary local development realities and enable the students to link them with the larger planning process
Syllabus	• Growth and Development debate • Many facets of Development in Economics and Human Development • Strategies of Economic Development and Structural Change: Population Growth, Resource Constraint and Economic Development • Growth and Distribution: Poverty and inequality

Course Name: Planning and Economic Development [3 0 0 3]	
Course Code: HUM 311 / HUM 321	
	• Planning for Economic development: Changing contours of state and market in India • Strategies, planning techniques and Models in Indian plans • Discussion on Industry, Public Sector and Technology • International Trade and Development (external sector) • Economic Reforms • Political Economy of Development • Grassroots and the Globe: Poor and the Informal Economy
Text & Reference Books	1. Debraj Ray, Development Economics, Latest ed., Oxford University Press, New Delhi, 1998.(Min. Twelfth Impression 2007 2. Kaushik Basu (ed.), India's Emerging Economy: Performance and Prospects in the 1990s and Beyond, Oxford University Press, New Delhi, 2004. 3. Amartya Sen, Development as Freedom, Oxford University Press, New Delhi, 2000 4. Uma Kapila (ed.), Indian Economy since Independence, Academic Foundations, New Delhi, 2017.

Course Name: Introduction to Science, Technology and Society [3 0 0 3]	
Course Code: HUM 312 / HUM 322	
Prerequisites	NA
Learning Outcomes	▪ To help students gain a general understanding on the role that societal factors play in driving discovery, spread and use of scientific knowledge and technology and the subsequent impact these have on societies. ▪ To emphasize the dynamic nature of the relations between wider cultural practices on one hand and scientific practices on the other

Syllabus	• Module 1: Knowledge: Evolution of Science through the ages (6 hours)
	  • How did science and scientific thinking evolve?
	  • The role of early civilizations (Mesopotamia, Indus Valley, Early India, Egypt, China, Arabia, Medieval Europe) in the growth of science.
	  • Why did scientific renaissance and growth of modern science occur in Europe and not anywhere else?
	• Module 2: Experimentation: Indigenous knowledge and science (5 hours)
	  • Tacit Vs. codified knowledge.
	  • Discourses of Indigenous knowledge and modern science' relation?
	  • Attempts to modernise Indigenous science - Issues of codification and professionalization.
	  • Analysis of Power and politics of knowledge production (case of Indian medical knowledge and ecological knowledge).
	• Module 2a: Perspectives on Science and society (7 hours)

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Logical Positivism (The Vienna Circle).
Falsifiability (Karl Popper).
Functionalism (Robert Merton).
Kuhnian revolution; Strong program.
Actor Network Theory.

Module 2b: Technology and Society Relation (6 hours)

Is society in charge of technology or does technology control society?
How can we address challenges in resolving conflicts between technological, environmental, and social worlds?

Module 2c: Science, Technology and Economy (6 hours)

Are economically developed nations scientifically advanced?
Influence of science and technology on economic growth and vice versa?
Knowledge as public good and “market failure’.
Do innovations and property rights have a key role?

Module 3: Challenges: Inequalities and democratization (10 hours)

How gender influences technologies and the social organization of scientific and technical workspaces?
Women in science and the feminist critique of science
What is the role of civil society in scientific development?
Democratisation of science and public.
Good practices in the science communication and public engagements in popularising science.

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<tr><td>Text & Reference Books</td><td>

Sergio Sismondo, An Introduction to Science and Technology Studies, 2nd ed., Wiley-Blackwell, Chichester, 2010.
Arun Bala, The Dialogue of Civilizations in the Birth of Modern Science. New York: Palgrave MacMillan, 2006.
Alvares, C. A. Science, Development and Violence: The Twilight of Modernity, Oxford: Oxford University Press, 1992.
Bruno Latour, Science in Action: How to Follow Scientists and Engineers Through Society? Cambridge, M A: Harvard University Press, 1987.
David Hardiman and Projit Bihari Mukharji (eds.), Medical Marginality in South Asia: Situating Subaltern Therapeutics, London and New York: Routledge, 2012.
Dharampal, Indian Science and Technology in the Eighteenth Century: Some contemporary European accounts, Goa, Other India Press, 1971.

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OTHER HUMANITIES COURSES

* Institute may offer some of the humanities courses from the list below from time to time.

Course Name: Introduction to Psychology	
Syllabus	Psychological Science- Assumptions, schools, methods of doing psychology research, The relationship between brain, body and mental functioning, Sensation, perception and making sense of the world, Consciousness, Life span development and motor and language development, Nature and nurture controversy, The learning process and some important explanations of how we learn, Meaning of motivation and explanations, Theories of emotions and expression and regulation of emotions, basic cognitive processes, Language development, why we remember and why we forget- some explanations, Different kinds of intelligence, explanations of creativity, Differences among individuals and explanations for personality differences, Application of psychology to everyday life- enhancing health and well-being, performance, social relations, and sensitivity to environ- mental, social and cultural contexts.

Course Name: Theories of Personality	
Syllabus	Personality: Meaning & Assessment. Psychoanalytic & Neo-Psychoanalytic Approach; Behavioural Approach; Cognitive Approach; Social- Cognitive Approach; Humanistic Approach; The Traits Approach; Models of healthy personality: the notion of the mature person, the self-actualizing personality etc. Personality disorders; Psychotherapeutic techniques and Yoga & Meditation; Indian perspective on personality; Personality in Sociocultural context.

Course Name: Environment, Development and Society	
Syllabus	Students will be exposed to contemporary themes and debates on connection between environment, development, and society; industrialization and risk society; challenge of sustainable development; perception of the environment, dependence for livelihood, identity, and power on natural resources; social ecology; what is the role of religion in determining our world view and relation with the environment?; recognition of indigenous knowledge; rise of environmental movements, development projects and recent conflict over natural resources; understanding major environmental disasters and industrial accidents; global climate change negotiations; gender and environment. Importance of Environment science in modern society

Course Name: Introduction to Logic	
Syllabus	In this course, students are introduced to fundamentals of informal logic and verbal analysis, material and formal fallacies of reasoning often found ordinary discourse, deductive and Inductive reasoning, validity and sound- ness, formal rules and principles of the deductive system of Aristotelian logic, traditional square of opposition; propositional calculus; first order predicate calculus; the modern square of opposition and the problem of existential import; identity and definite descriptions; methods for formulating natural language arguments in symbolic forms and techniques for checking their validity; various meta-logical theorems and their proofs.

Course Name: Introduction to Philosophy	
Syllabus	What makes philosophical thinking radically critical? Investigation of the nature of knowledge about the world and justification of knowledge claims. Metaphysical understanding of the Absolute and Mind-Body relation. The nature of ethical and aesthetic beliefs and attitudes as part of understanding the nature of values. The discussion of the above is- sues will be influenced by three philosophical orientation perspectives: Anglo-American Analytic, Continental Phenomenological and Classical Indian. Indian School of Philosophy: Introduction and general characteristics of Indian Philosophy; Classification; Swami Vivekanda and Vedanta Philosophy; The significance of Upanishad and Vedas.

Course Name: Philosophy of Mind	
Syllabus	An appreciation of how the fundamental mental concepts are essentially amenable to philosophical sense over and above their usual psychological understanding and analysis. To explain why our mental conceptual scheme does not easily admit of their reduction to physical conceptual scheme. To reflect on whether mentally endowed human person differ, ontologically, from the rest of nature; Yoga and Meditation: The Philosophical and Psychological characteristics.

Course Name: Philosophy of Science	
Syllabus	Science is regarded as the most significant cognitive enterprise of the modern society. In view of this, the course addresses the question what sets science apart from other epistemic activities. Further It concentrates on debates on the nature of scientific methods, logical reconstruction of scientific explanation, the relation between theories and laws on the one hand, and empirical evidence on the other, the nature of the justification and the notion of truth involved in scientific knowledge, and the societal influence on scientific practice.

Course Name: Communication Skills	
Syllabus	Introduction to major grammatical models. Phonological and syntactical structure of present- day English. Language of science and technology. Aspects of style. Some common errors. Technical presentations design and delivery. Audio Visuals in communication. Collecting materials for research. Organization of research paper/dissertation.

Course Name: International Economics	
Syllabus	Basic concepts of national income accounting, money, and balance of payments; output and exchange-rate determination under fixed and flexible exchange-rate regimes; fiscal and monetary policies in an open economy; international capital movements and their impacts; Case Studies: East Asian crisis, global financial crisis; theories of international trade including factor-proportions and economies of scale; the international trading regime and its implications for developing countries.

Course Name: Industrial Economics	
Syllabus	Basic concepts: Plants, firm and industry. Market structure. Economics of scale and optimum firm size. Pricing under alternative market structures. Market power and concentration. Integration, diversification and merger. Behavioural and managerial theories of the firm, growth of the firm. Industrial productivity and its measurement. Industrial location. Input- out- put analysis. Project appraisal and capital budgeting. Industrialisation and economic development. Problems of industrialisation in India. Role of public and private sectors. Growth of small-scale industries and their problems. Government regulation of industry. Balanced regional development.

Course Name: Applied Game Theory	
Syllabus	This module introduces students in economics and other social sciences to game theory, a theory of interactive decision-making. This module provides students with the basic solution concepts for different types of non- cooperative games, including static and dynamic games under complete and incomplete information. The basic solution concepts that this module covers are Nash equilibrium, subgame perfect equilibrium, Bayesian equilibrium, and perfect Bayesian equilibrium. This module emphasizes the applications of game theory to economics, such as duopolies, bargaining, and auctions.

Academic Office

IISER Thiruvananthapuram, Maruthamala P.O., Vithura,

Thiruvananthapuram, Kerala, India - 695 551

Phone: 0471 277 8017

Email: acad[at]iisertvm.ac.in

www.iisertvm.ac.in

Designed and Compiled by: A. Muthukumaran

Indian Institute of Science Education and Research Thiruvananthapuram
Maruthamala P.O., Vithura
Thiruvananthapuram - 695551
Kerala, India