INDIAN INSTITUTE OF SCIENCE EDUCATION AND RESEARCH

THIRUVANANTHAPURAM

COURSE CATALOGUE

BS-MS & i² BS-MS

Batch 2023 & 2024

IISER THIRUVANANTHAPURAM

2024 - 25

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Contents

About the Booklet

IISER Thiruvananthapuram offers the following undergraduate, graduate and post-graduate level programs. Each has its own course structure and requirements for completion. The Schools offer an array of courses that students may opt to pursue. This catalogue enlists all the courses offered by various schools at IISER Thiruvananthapuram in a particular academic year.

1. BS MS Dual Degree program in Basic Sciences and i2 Sciences
2. Master of Sciences program
3. Integrated Ph.D program
4. Ph. D program

Primarily there are two types of courses:

a) CORE Courses
b) Elective Courses (within the department and Across the institute)

- *The booklet lists the courses starting with the Foundation Courses (Semesters 1-2) and Pre-Major Courses (Semester-3) which are all CORE courses.*
- *Later School/Discipline wise list of courses is provided along with detailed syllabi.*
- *Curriculum tables for each program relevant to each School are provided to offer glimpses of requisite CORE and Elective courses for each program.*

Each course carries a unique Course Code and Course Name. The Course Code may be understood as follows:

- The CORE courses of the BSMS program are numbered in the format: XYZ LSC (LTPC)
- The CORE courses of the MSc program 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)

XYZ	:	Subject code for CORE and Elective courses
MSQ	:	Prefix MS followed by Programme code (B-Biology, C-Chemistry, M-Mathematics, P-Physics)
L	:	Number denoting Level of the course (1, 2, 3, 4, 5, 6, 7)
SC (SCD)	:	Numbers unique to a Course
m (mn)	:	Module position – Applicable only to 1 and 2 credit modules *a* : Module spans 1st one-third of the semester (13 lectures) *b* : Module spans 2nd one-third of the semester (13 lectures) *c* : Module spans 3rd one-third of the semester (13 lectures) *ab* : Module spans 1st two-thirds of the semester (26 lectures) *bc* : Module spans 2nd two-thirds of the semester (26 lectures)
L	:	Number of Lecture hours per week
T	:	Number of Tutorial hours per week
P	:	Number of Practical (laboratory) hours week
C	:	Number of Credits

Subject Codes (XYZ)

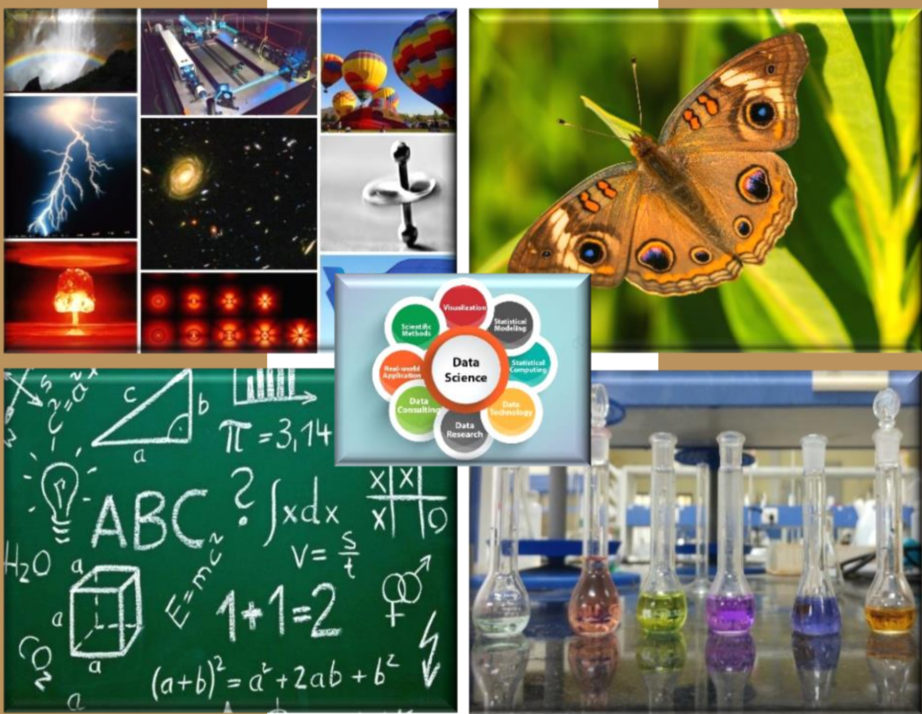
BIO: Biological Sciences
MAT: Mathematical Sciences
IDC: Interdisciplinary Studies
DSC: Data Sciences
EES: Earth Environment Sustainability Sciences
I2M: i^2 Mathematical Studies

CHY: Chemical Sciences
PHY: Physical Sciences
HUM: Humanities
I2B: i^2 Biological Sciences
I2C: i^2 Chemical Sciences
I2P: i^2 Physical Sciences

FOUNDATION & PRE-MAJOR COURSES

CURRICULUM FOR BS-MS (SEM: 1 - 3)

*i*² Sciences (SEM: 1 - 3)



Foundation & Pre-Major Courses

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<tr><td>Total Credits</td><td>21</td><td>23</td><td>23</td><td>20/21</td></tr>
</table>

Courses offered in Semester 3	Combination of 3 subjects (A B C) with 2 courses in each subject from those listed below.	
BIO 211 [3104] Principles of Life III: Organismal biology	CHY 211 [3104] Atomic Structure and Chemical Bonding	DSC 211 [3003] Introduction to Artificial Intelligence
BIO 212 [3003] Principles of Life IV: Microbiology	CHY 212 [3003] Basic Organic and Inorganic Chemistry II	DSC 212 [3104] Mathematical Foundations to Data Science
EESS 201 [3104] Introduction to earth and climate sciences	MAT 201 [3104] Calculus and Matrices II	PHY 211 [3104] Thermal & Statistical Physics
EESS 202 [3003] Introduction to environmental and sustainability sciences	MAT 202 [3003] Introduction to Probability	PHY 212 [3003] Optics

Allowed combinations of Subjects A B & C

Subject A	Subject B	Subject C	Combination
BIO	CHY	EES	**BCE**
BIO	CHY	MAT	**BCM**
BIO	DSC	MAT	**BDM**
BIO	EES	MAT	**BEM**
BIO	MAT	PHY	**BMP**
CHY	DSC	MAT	**CDM**
CHY	EES	MAT	**CEM**
CHY	MAT	PHY	**CMP**
DSC	MAT	PHY	**DMP**
EES	MAT	PHY	**EMP**

Biology Courses

BIO 111: Principles of Life I: Biomolecules, Genetics and Evolution [2 1 0 3]	
Learning Outcomes	The course will introduce students to the framework of biological systems. On completion of the course, students will ▪ gain an understanding of the basics of what life is, scales of biological organization, the chemical basis of life, and inheritance of traits. ▪ understand the fundamentals of biological evolution, how evolution has shaped phenotypic diversity & behaviour and how evolution is a unifying theme in biology.
Syllabus	Overview of Biology: • What is life? Importance of studying biology; Scales in biology; Disciplines of biology; Origins of life. [4] Biomolecules: • Chemical composition of life - elements and the importance of water [1] • Carbohydrates - mono-, oligo- and polysaccharides, their presence in biological systems. Isomers, enantiomers, epimers, cyclization. Derivatives of carbohydrates and their importance. [2] • Introduction to proteins - amino acids, classes (based on chemical nature and essential nature). [2] • Lipids - fatty acids structure and nomenclature. Types • (phospholipids, glycolipids, sphingolipids) and their importance. [2] • Nucleic acids - Introduction to nucleic acid bases and nucleotides. Structure and function of DNA and RNA, physicochemical properties of these informational macromolecules. [3] • Patterns and uniqueness of biomolecules: chemical nature, physical dimensions, the importance of understanding why biomolecules are specified for their respective functions. [1] Genetics: • Introduction to genetics-concept of gene and allele [2] • Mendelian genetics - Mendel's law and examples, Monohybrid and di-hybrid cross, recessive and dominant mutation [3] • Non-Mendelian genetics - incomplete dominance, semidominance, and introduction to epigenetics [3] • Genetic interactions (epistasis and synthetic lethality) [1] Evolutionary Biology • Basics of evolution - History of evolutionary thinking; 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) [9] • Species concepts and speciation [3] • Phylogenetics - Basics of phylogenetics; Understanding evolutionary history through phylogenies [3] • Human behaviour - an evolutionary perspective. [1]
Text & Reference Books	1. Nelson and Cox, Lehninger Principles of Biochemistry. WH Freeman 7th Edition. 2. Voet, Voet and Pratt, Biochemistry, Wiley, 4th Edition. 3. Anthony J. F. Griffiths et al., An Introduction to Genetic Analysis, W. H. Freeman, 7th ed., 2000. 4. Snustad and Simmons, Principles of Genetics 7th Edition. 5. Douglas J. Futuyma and Mark Kirkpatrick. Evolution. Oxford University Press 4th Edition 6. Barton et al., Evolution Cold Spring Harbor Laboratory Press 1st Edition 2007

BIO 111: Principles of Life I: Biomolecules, Genetics and Evolution [2 1 0 3]	
	7. Stephen C. Stearns and Rolf F. Hoekstra. Evolution: An Introduction Oxford University Press 2nd Edition

BIO 112: Biology Lab I [0 0 3 1]	
Learning Outcomes	This course teaches the students to apply scientific methods and provides basic training for sampling, experimental design, making scientific observations, record keeping and hypothesis testing. After this course, a student should be able to practically understand the structure of a cell, chemical nature of biomolecules and principles of flow of genetic information.
Syllabus	Life under a microscope: • Plant and animal cells under a microscope [6] • Isolation of microorganisms [9] • Biological solutions preparation and quantification of biomolecules (proteins, lipids, carbohydrates, DNA) [6] • Mutation frequencies, fluctuation tests [6] • Analyse data from crosses: theoretical problem solving • Sampling, hypothesis testing [9]

BIO 121: Principles of Life II: Biophysics, Cell and Molecular Biology [2 1 0 3]	
Learning Outcomes	On completion of this course, students will be able to understand the biophysical, cellular and molecular basis of life. The course lays the foundation for advanced biology courses by encompassing the basic and essential topics.
Syllabus	Biophysics: • Stabilizing interactions in biological macromolecules - hydrogen bonds, ionic interactions, salt bridges, hydrophobic interactions, van der Waals forces. [2] • Principles of biophysical chemistry - bioenergetics and laws of thermodynamics, reaction kinetics. [4] • Protein Structure and Function – physicochemical properties of amino acids. Basics of Ramachandran plot. Primary, secondary, tertiary and quaternary structure. [8] Cell Biology: • Structure of prokaryotic and eukaryotic cells. [2] • Cell membrane - structure and composition of the cell Membrane, membrane Proteins, transport across the cell membrane. [3] • Structure and function of intracellular organelles – cytoplasm, cytoskeletal elements, mitochondria, ribosomes, endoplasmic reticulum, lysosomes, Golgi complex, peroxisomes, vacuoles. [4] • Cell division and cell cycle - mitosis, meiosis, cell cycle regulation. [4] Molecular Biology: • Central dogma of molecular biology – replication, transcription and translation. [5] • Concept of gene regulation – operon concept, positive and negative regulation. [3] • DNA repair and mutagenesis – major DNA repair pathways, mutation assays. [3] • Genome composition and organization – AT & GC content, chromatin organization. [3]

BIO 121: Principles of Life II: Biophysics, Cell and Molecular Biology [2 1 0 3]	
	• Methods in molecular biology - PCR and cloning [1]
Text & Reference Books	1. Watson et. al., Molecular Biology of the Gene, Pearson, 7th Edition 2013 2. Jocelyn E. Krebs et al., Lewin's Gene Jones & Bartlett Learning; 11th edition (December 31, 2012) 3. Gerald Karp, Cell Biology, WILEY (Feb. 4th, 2013) 4. Wayne M. Becker et al., World of the Cell; Benjamin Cummings; 7th edition (February 19, 2008) 5. David L. Nelson, and Michael M. Cox et al., Lehninger principles of biochemistry, W. H. Freeman, 7th ed., 2017. 6. Bruce Alberts et al., Essential Cell Biology; Richard Goldsby and Thomas J, &F/Garland, 4th Edition, (2014) 7. Alberts, Bruce.; Molecular Biology of the Cell, Garland Science; 5th edition (2 January 2008). 8. Branden C and Tooze J, Introduction to protein structure, Garland Science

BIO 122: Biology Lab II [0 0 3 1]	
Learning Outcomes	▪ This course will provide basic hands-on learning of biological experimental methods involving various biomolecules. ▪ After this course, the students should be able to practically understand the fundamental processes and stages of cell division, linking it with distribution of genetic material in somatic and germ cells.
Syllabus	• Determination of pKa and pI of amino acids/proteins [3] • Enzyme assays [3] • Genomic DNA isolation [6] • PCR [6] • Plasmid DNA isolation [6] • SDS-PAGE [6] • Mitosis [3] • Meiosis [3]

BIO 211: Principles of Life III: Organismal biology [3 1 0 4]	
Prerequisites	NA
Learning Outcomes	On completion of this course, students should be able to ▪ appreciate the importance of interactions between organisms and their environment ▪ understand what factors control populations of organisms ▪ understand the importance of biodiversity and its conservation ▪ understand the evolutionary basis of animal behaviour ▪ appreciate the importance of studying plants and its unique life cycle ▪ understand the growth, development, and physiology of plants ▪ learn how the gained knowledge of plant biology facilitates improvements in agriculture
Syllabus	Ecology

BIO 211: Principles of Life III: Organismal biology [3 1 0 4]	
	• Diversity of Life (both plants and animals). [4] • Populations, Communities and Ecosystems [3] • Life history strategies [3] Animal Biology [5] • Eco-physiology • Comparative, environmental and evolutionary physiology • Problems of scale and size • Physiological effects of temperature • Coping with the aquatic, terrestrial, and extreme environments Behaviour [5] • Proximate and Ultimate explanations in Biology • Darwinian selection and the study of behaviour • Discovering the causes, development and control of behaviour • Evolution of key behaviours for Survival, Feeding, Reproduction, and Parental care Plant Biology • Why study plants? Unique aspects of the plant life cycle. [2] • Plant- water relations: Water potential and its components. [1] • Transpiration, root pressure, guttation, xylem-phloem interactions, and water transport in the soil-plant-air continuum. [1] • Photosynthesis: Light-dependent and independent phases, electron transport. [2] • C3, C4, and CAM pathways of Co2 fixation. [2] • Plant growth and development, floral development and reproductive physiology. [5] • Phytohormones: Auxin, cytokinin, gibberellic acid, brassinosteroids, ethylene, abscisic acid, salicylic acid, and jasmonic acid: its roles in plant development. [3] • Plant breeding and genetic improvements in agriculture. [4]
Text & Reference Books	1. John Alcock. Animal Behaviour: an evolutionary approach.Sinauer Associates, 2009. 2. Patrick J. Butler, J. Anne Brown, D. George Stephenson, and John R. Speakman, Animal Physiology: An environmental perspective. Oxford University Press. 3. Willmer Pat, and Stone G, Environmental Physiology of Animals. Wiley-Blackwell, 2009 4. Davies NB, Krebs JR, and West SA, An Introduction to Behavioural Ecology, 4th Edition, Wiley-Blackwell 5. Plant Biology by Alison Smith, George Coupland, Liam Dolan, Nicholas Harberd, Jonathan Jones, Cathie Martin, Robert Sablowski, and Abigail Amey, Garland Science, Taylor and Francis group 6. BIOS Instant Notes in Plant Biology, A.J. Lack & D.E. Evans, BIOS Scientific Publishers Limited, 2001 7. Teaching Tools in Plant Biology, published by "The Plant Cell" Oxford Academic Publishers. 8. Genetics, Agriculture, and Biotechnology by Walter Suza and Donald Lee Iowa State University Digital Press Ames, Iowa 9. Plant breeding- Classical to Modern by PM. Priyadarshan Springer publications 11. Other individual review articles and updated research advances will be cited during the lecture.

BIO 212: Principles of Life IV: Microbiology [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	On completion of this course, Students should be able to ▪ Understand the basics of Microbiology and structures and functions of prokaryotic cells as whole entities and in terms of their subcellular process ▪ Understand the biology of bacteria, viruses and other pathogens related to infectious diseases in humans.
Syllabus	• History of Microbiology: Discovery of microbes, important milestones, microbial diversity. [4] • Prokaryotic cell structure and function: Prokaryotic cell membrane, cell wall nucleoid and plasmids. [6] • Microbial physiology: microbial nutrition: growth requirements, culture media, growth kinetics, growth curve, autotrophic and heterotrophic metabolisms, microbial growth control: physical and chemical methods. [6] • Microbial pathogenesis: microbial diseases, types, mode of infection with examples of human pathogens, antimicrobial agents and their mode of action. [9] • Applied microbiology: biodegradation, bioremediation, fermentation, recombinant protein production. [6] • Viruses and prions: Introduction - development of virology, general characteristics - virus structure, reproduction, cultivation and pathogenesis. [9]
Text & Reference Books	Text Books: 1. Willey, Joanne M; Sherwood, Linda; Woolverton, Christopher J; Prescott Harley Klein's Microbiology, McGraw-Hill, 7th Edition, 2008 Reference Books: 1. Bacterial Physiology: A Molecular Approach / edited by Walid El-Sharoud, Springerlink 2. Irving, Will, Ala'Aldeen, Dlawer, Boswell Tim; Medical Microbiology, New York : Taylor and Francis Group, 2005.

Chemistry Courses

CHY 111: Basic Organic and Inorganic Chemistry [2 1 0 3]	
Learning Outcomes	This course introduces basic concepts in organic and inorganic chemistry with the aim to provide a structured understanding of chemistry.
Syllabus	• Chemical Bonding: Molecular orbital theory, bonding in homo-diatomic molecules – H2, N2, O2 and F2, concept of bond order, bond length and bond strength, bonding in heteronuclear diatomic molecules – CO, NO, HCl, and ICl, concepts of g and u symmetries of molecular orbitals. Bonding in triatomic molecules – HF2–, BeH2, O3, and CO2. [7] • Acids and bases: Brønsted concept, Lewis concept; Non-aqueous solvents, HSAB principle, super acids, relative strengths of acids. [3] • Oxidation and reduction: Reduction potential; electrochemical series; redox reactions; balancing of redox equations; factors affecting redox stability; Frost diagrams for redox reactions. [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 [2] • Stereochemistry: Baeyer's strain theory, Pitzer 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 - Pro-R, Pro-S, and Re/Si stereodescriptors; chirotopicity and stereogenicity. [9]
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, 3ed, Pearson, 2008. 3. J. E. House, Inorganic Chemistry, 3ed, Academic Press, 2019. 4. J. E. Huheey, E. A. Keiter, and R. L. Keiter, Inorganic Chemistry – Principles of Structure and Reactivity, 4 ed, Pearson Education, 2006. 5. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2ed., Oxford University Press, 2012. 6. J. McMurry, Organic Chemistry, 9ed., Cengage Learning, 2015. 7. P. Sykes, A Guidebook to Mechanism in Organic Chemistry, 7ed., Addison-Wesley, 2003. 8. D. Nasipuri, Stereochemistry of Organic Compounds-Principle and Applications, 4 Revised ed., New Academic Science, 2012.

CHY 112: Chemistry Lab I [0 0 3 1]	
Learning Outcomes	This laboratory course provides opportunities for hands-on laboratory experiences related to qualitative and quantitative analyses.

CHY 112: Chemistry Lab I [0 0 3 1]	
Syllabus	Basic Lab Techniques [3] 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 [3] a) Separation of naphthol, aspirin, and naphthalene b) Determination of purity by melting points and TLC. Experiment No 2: Isolation of Natural Products [3] a) Extraction of eugenol from cloves by steam distillation Experiment No 3: conversion of nitrobenzene to aniline and its estimation [3] a) Qualitative test for nitrobenzene b) Reduction of nitro compound c) Qualitative test for aniline d) Estimation of aniline Experiment 4: Titrimetric Estimations Based on Acid-Base Chemistry: [3] (a) Standardisation of HCl solution using standard NaOH solution, (b) Estimation of alkali content in commercial antacid tablet. Experiment 5: Redox-Titrimetric Estimations Based on Permanganometry: [6] (a) Standardisation of potassium permanganate using sodium oxalate; (b) Preparation of Potassium trisoxalatoferrate(III) trihydrate (c) Estimation of the oxalate content of Potassium trisoxalatoferrate(III) trihydrate. Experiment 6: Estimations Based on Iodimetry and Iodometry: [3] (a) Preparation and standardisation of sodium thiosulfate solution; (b) Preparation of $Cu(NH_3)_4SO_4$ and estimation of copper(II) using standard thiosulfate solution as titrant; (c) Solubility product of $Ca(IO_3)_2$. Experiment 7: Complexometric Estimations Based on EDTA: Quantitative estimation of calcium and magnesium in milk by EDTA complexometry. [3] (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. 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. 2. G. H. Jeffery, J. Bassett, R. C. Denny, Vogel's Quantitative Chemical Analysis, 5ed, ELBS and Longmans Green & Co Ltd, 1971. 3. A. J. Elias, General Chemistry Experiments, 3ed, Universities Press (India) Pvt Ltd, 2002. 4. J. Derek Woollins, Inorganic Experiments, 3ed, Wiley, 2010.

CHY 121: Physical Chemistry [3 1 0 4]	
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.

CHY 121: Physical Chemistry [3 1 0 4]	
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, 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] Thermodynamics: Concepts of temperature, enthalpy, entropy, Gibbs and Helmholtz energies, laws of thermodynamics, state and path functions, standard states, thermochemistry and Maxwell relations [5] Physical Transformations of Pure Substances: 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 [7] 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. Colligative Properties: Elevation of boiling point, depression of freezing point, lowering of vapour pressure, osmosis, and solubility [10] 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 [6]
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 Edition (2006). 4. D. A. McQuarrie and J. D. Simon, Physical Chemistry: A Molecular Approach, Viva Student Edition, Viva (2019).

CHY 122: Chemistry Lab II [0 0 3 1]	
Learning Outcomes	Chemistry Laboratory II 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 CHY121.
Syllabus	1. Viscosity: [3] a) Determination of Viscosity of Pure Liquids b) Effect of Salt on Viscosity of Liquids 2. Chemical Kinetics: [3] a) Determination of the Rate Constant of the Hydrolysis of Ester by Sodium Hydroxide at different Temperature b) Activation Energy 3. Refractometry: [3] a) Determination of Molar Refractions of Pure Liquids b) Determination of Molar Refraction of Solids c) Solvent-Solvent Interaction in Binary Solvent System 4. Conductivity Measurements: [3]

CHY 122: Chemistry Lab II [0 0 3 1]	
	a) Determination of the Degree of Ionization of Weak Electrolytes. b) Titration of a Strong Acid and Weak Acid Against a Strong Base. 5. Potentiometry: [3] a) Determination of Single Electrode Potentials (Cu and Zn). b) Verification of Nernst Equation and Oxidation-Reduction Titration. 6. Distribution Law: [3] a) Distribution Coefficient of Iodine Between an Organic Solvent and Water. b) Determination of the Equilibrium Constant of the Reaction KI + I2 → KI3 7. Phase Diagrams: [3] Phenol Water System: a) Determine the Mutual Solubility Curve of Phenol and Water and Hence the Consolute Point. b) Determine the Critical Solution Temperature of Phenol and Water in Presence of (i) Sodium Chloride/Naphthalene/Succinic acid. 8. Solid Liquid Equilibrium: [3] a) Determination of Molal Depression Constant of Naphthalene b) Determination of Molecular Weight of Solute
Text & Reference Books	1. M. Halpern and G. C. McBane, Experimental Physical Chemistry: A Laboratory Text Book, 3rd Edition, W. H. Freeman, 2006 2. D. P. Shoemaker, G. W. Garland and J. W. Nibler, Experiments in Physical Chemistry, 5th Edition, McGraw Hill, London.

CHY 211: Atomic Structure and Chemical Bonding [3 1 0 4]	
Prerequisites	NA
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, and concept of quantum numbers [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 [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: • Valence bond and molecular orbital descriptions of bonding, linear combination of atomic orbitals (LCAO) approach, hybridization, bonding in (H2)+ and H2 [6] • Bonding in homonuclear diatomic molecules of second period, bond orders, bond lengths and bond strengths, bonding in heteronuclear diatomic molecules, and concepts of g and u symmetries of molecular orbitals [4]

CHY 211: Atomic Structure and Chemical Bonding [3 1 0 4]	
	• Photoelectron spectroscopy: Principle and application to simple spectra of diatomic molecules. [4] • HMO theory, π conjugation, delocalization energy. Application of HMO theory to simple conjugated systems and aromaticity. [4]
Text & Reference Books	1. D. A. McQuarrie, Quantum Chemistry, Viva Student Edition, 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 Edition (2006).

CHY 212: Basic Organic and Inorganic Chemistry II [3 0 0 3]	
Prerequisites	NA
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; Neighbouring group participation. [7] • Elimination Reactions: Types (E1, E2 and E1cB), stereochemical considerations, and role of solvents; Saytzeff/Hofmann elimination, Bredt's rule; elimination vs substitution. syn-eliminations. [6] • 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. [4] • Nucleophilic Aromatic Substitution. [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; biomedical application of cis-platin. [5] • Homogeneous and Heterogeneous Catalysis: Basic concepts and applications in Haber-Bosch process, Fischer-Tropsch process, and Ziegler-Natta polymerization. [4] • Lanthanoids and Actinoids: Properties and reactivity trends; nuclear reactions of thorium and uranium; synthesis of trans-uranium elements; applications of radioisotopes. [2]
Text & Reference Books	1. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2ed., Oxford University Press, 2012. 2. J. McMurry, Organic Chemistry, 9ed., Cengage Learning, 2015. 3. O. Snow, Love Drugs, Thoth Press, 2005.

CHY 212: Basic Organic and Inorganic Chemistry II [3 0 0 3]	
	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. 6. 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. 7. G. L. Miessler and D. A. Tarr, Inorganic Chemistry, 3ed, Pearson, 2008. 8. J. E. House, Inorganic Chemistry, 3ed, Academic Press, 2019. 9. J. E. Huheey, E. A. Keiter, and R. L. Keiter, Inorganic Chemistry – Principles of Structure and Reactivity, 4ed, Pearson Education, 2006. 10. W. Kaim and B. Schwederski, Bioinorganic Chemistry: Inorganic Elements in the Chemistry of Life, 2ed, Wiley, 2013.

Data Sciences Courses

DSC 211: Introduction to Artificial Intelligence I [3 0 0 3]	
Prerequisite	NA
Learning Outcomes	On completion of this course, students should be able to ▪ Gain detailed knowledge on expert systems ▪ Obtain a broad overview of the field ▪ Identify the scope of Machine Learning in the broader field of Artificial Intelligence ▪ Implement advanced dimensionality reduction and clustering approaches on tabular datasets
Syllabus	• Introduction to knowledge-based intelligent systems: A brief history of AI, broad applications of AI; Goal of developing intelligent machines; Turing Test [1] • Rule-based expert systems: Goal of expert systems; What is knowledge? Riles as knowledge representation technique; Structure and Characteristics of an expert systems and participants in its development; Forward and Backward chaining; Advantages and Disadvantages; Practical examples of expert systems [2] • Uncertainty management in expert systems: What is uncertainty and how it can be modelled in an expert system? Revision of basic Probability Theory until Bayes Theorem; Bayesian reasoning; Bias of the Bayesian method; Certainty factors theory and evidential reasoning; Comparison of Bayesian reasoning and certainty factors; Case study [3] • Fuzzy expert systems: Introduction to fuzzy thinking? Fuzzy sets; Linguistic variables and hedges; Operations of fuzzy; Fuzzy rules; Fuzzy inference; Building a fuzzy expert system; Real-life application of fuzzy expert system [3] • Frame-based expert systems: Introduction to a frame; Frames as a knowledge representation technique; Inheritance in frame-based systems; Methods and demons; Interaction of frames and rules; Real-life application of fuzzy expert system [2] • Hybrid intelligent systems, Knowledge Engineering and Data Mining: Fuzzy evolutionary systems, applicability of expert systems, case studies, when to use what type of Expert system (3) • Evolutionary computation: Can evolution be intelligent? Components of modelling natural evolution; Genetic algorithms; Why genetic algorithms work; Evolution strategies; Genetic programming with demonstration [4] • Brief introduction to machine learning: Purpose of machine learning models; Beginner-level introduction to supervised-unsupervised approaches and classification-regression approaches; linear and logistic regression; Loss functions; Insights on convexity of loss functions, using gradient descent to learn parameters for a linear and logistic regression with a coding component. [6] • Detailed exploration of clustering algorithms: Fundamental clustering algorithms k-Means, fuzzy C-Means, DBSCAN, OPTICS, Agglomerative clustering; Brief revision of the concepts of Eigenvectors and Eigenvalues; Advanced clustering algorithms and related concepts such as Spectral Clustering; Self-Organizing Maps, CURE clustering, Particle Swarm Optimization, modularity in graphs; Performance measures for clustering such as Silhouette Score, Dunn Index, Davies-Bouldin index; Parameter learning and elbow method; Coding component to demonstrate the algorithms. [8] • Detailed exploration of dimensionality reduction: Principal component Analysis, Multi-Dimensional Scaling, Principal Co-ordinate analysis, Isometric Map, Stochastic Neighborhood Embedding, t-Stochastic Neighborhood Embedding, Uniform Manifold Approximation and Projection; Coding component to demonstrate the algorithms [8]

DSC 211: Introduction to Artificial Intelligence I [3 0 0 3]	
Text & Reference Books	1. Michael Negnevitsky, Artificial Intelligence: A Guide to Intelligent Systems, Addison-Wesley, ISBN 0 321 20466 2 2. Xu, D., Tian, Y. A Comprehensive Survey of Clustering Algorithms. Ann. Data. Sci. 2, 165–193 (2015). https://doi.org/10.1007/s40745-015-0040-1 3. Zhang, C., Huang, W., Niu, T. et al. Review of Clustering Technology and Its Application in Coordinating Vehicle Subsystems. Automot. Innov. 6, 89–115 (2023). https://doi.org/10.1007/s42154-022-00205-0 4. Newman, Mark E. J. "Modularity and community structure in networks." Proceedings of the National Academy of Sciences of the United States of America 103 23 (2006): 8577-82 5. Maaten, Laurens van der and Geoffrey E. Hinton. "Visualizing Data using t-SNE." Journal of Machine Learning Research 9 (2008): 2579-2605. 6. McInnes, Leland and John Healy. "UMAP: Uniform Manifold Approximation and Projection for Dimension Reduction." ArXiv abs/1802.03426 (2018) 7. Zha, Hongyuan and Zhenyue Zhang. "Isometric Embedding and Continuum ISOMAP." International Conference on Machine Learning (2003). 8. Hout, Michael C. et al. "Multidimensional scaling." Wiley interdisciplinary reviews. Cognitive science 4 1 (2013): 93-103.

DSC 212: Mathematical Foundations for Data Science [3 1 0 4]	
Prerequisite	NA
Learning Outcomes	On completion of this course, Students should be able to ▪ Acquire knowledge of basic mathematics that is necessary to understand advanced Data Science Courses ▪ Acquire knowledge on how and where mathematics is connected to Data Science
Syllabus	• Module 1: Linear Algebra [22] • Vector spaces: Definition and examples, Subspaces, Linear independence, Basis and dimension, Change of basis, Row space, and column space [6] • Linear maps: Definition and examples, Matrix representations of linear maps, Similarity, Rank-nullity Theorem [8] • Inner product spaces: The scalar product in R^n, Inner product spaces, Orthonormal sets, The Gram-Schmidt orthogonalization process [8] • Module 2: Discrete Mathematics [18] • Revision: Set theory and functions [4] • Basic graph theory: Elements of graph theory, Euler graph, Hamiltonian path, trees, tree traversals, spanning trees [7] • Intermediate concepts in graph theory: Brief coverage of coloring problem, Concepts of Cliques and Independent sets, Concept of planarity, Concept of Flows and Cut, Graph adjacency matrix [7]
Text & Reference Books	1. S. Kumaresan, Linear Algebra: A Geometric Approach, Prentice Hall India Learning Private Limited, 2000 2. Sheldon Axler, Linear Algebra Done Right, Springer, https://doi.org/10.1007/978-3-031-41026-0

DSC 212: Mathematical Foundations for Data Science [3 1 0 4]	
	3. Bondy and Murty, Graph Theory, Springer 2008, https://doi.org/10.1007/978-1-84628-970-5 4. West, D.B. (2001) Introduction to Graph Theory. 2nd Edition, Prentice-Hall, Inc., Upper Saddle River, 82-83

Earth Environmental & Sustainability Sciences Courses

EESS 201: Introduction to earth and climate sciences [3 1 0 4]	
Prerequisites	NA
Learning Outcomes	On completion of this course, students should be able to ▪ Understand Earth's Climate components ▪ Describe the layers of Earth, Atmosphere, Ocean ▪ Interpret and express radiative balance and vertical structure of atmosphere ▪ Conceptualize feedback in the climate system. ▪ Understand the Earth systems and geological events
Syllabus	• Solar System and the Planet Earth: Origin of the Earth's atmosphere, Sun, Earth and the atmosphere, Sun-Earth relationship, seasons-solstices and equinoxes. [2] • Components of Climate system: Lithosphere, Cryosphere, Biosphere, Hydrosphere, Atmosphere. [1] • Structure of the Earth: Layers, Lithosphere, Asthenosphere, Crust, Mantle, Core, Composition and structure of oceanic and continental crust. [2] • Plate Tectonics, volcanoes and mountain building: Convergent boundaries, Subduction, Divergent boundaries, Mid ocean ridges, Magma, movement within the Earth, Earth's magnetic field, volcanism and plate tectonics, Continental drift, Earthquakes; mountain building. [3] • Minerals: Composition, crystal structure, physical properties, classification and identification [1] • Rocks: Igneous Rocks, Sedimentary Rocks, Metamorphic Rocks, Composition, texture, classification, identification, formation, agents of change, Weathering, soil mineralogy, soil erosion. [1] • Activity-1 • Geological time: Relative ages and the principles of stratigraphy, Construction of the relative geologic time scale, Radioactivity and the absolute time scale, Numerical dating, stable isotope techniques, carbon dating. [3] • The Ocean: Structure of Ocean, Oceanic lithosphere, Continental margins, Ocean circulation, thermohaline circulation, waves, eddies, currents and tides, emergent and submergent coast, light, density, salinity, and temperature in the ocean. [3] • The Earth's atmosphere: The Atmosphere: vertical structure, density, pressure, thermal structure and composition. [3] • Activity-2 • Atmospheric Radiation: Heat transfer in the atmosphere - conduction, convection, radiation, laws of blackbody radiation, radiative equilibrium temperature, radiation balance, energy budget [3] • Activity-3 • Atmospheric Dynamics: Forces acting on the Earth Atmosphere, Coriolis force and centrifugal forces, hydrostatic equilibrium [3] • Global cycles: Hydrological Cycle and groundwater. [1] • Climate Change: Global CO_2 concentration and Keeling curve, Greenhouse effect, Radiative forcing global warming and climate change, Ozone hole, Montreal Protocol, Brief summary of Intergovernmental Panel on Climate Change (IPCC) reports, The Human Impacts on the Climate system. [5]

EESS 201: Introduction to earth and climate sciences [3 1 0 4]	
	• The Earth System: Coupled Ocean-Atmosphere-Land processes in the Earth's Climate System modeling, El Nino Southern Oscillation (ENSO), Indian Summer Monsoon, Indian-Ocean Dipole. [5]
Text and Reference Books	1. Essentials of meteorology, Donald Ahrens 2. Meteorology Today: An introduction to Weather, Climate and the Environment, C. Donald Ahrens, Robert Henson 3. First course in atmospheric Science, Lutgen and Tarbuk 4. Essentials of Geology Lutgen and Tarbuk 5. Introduction to Earth Science: Laura Leser 6. Introducing Oceanography: Thomas and Bowers 7. Bonan, G. (2015). Ecological climatology: concepts and applications. Cambridge University Press.

EESS 202: Introduction to environmental and sustainability sciences [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	On completion of this course, students should be able to ▪ Understand the importance of the environment and ecosystems ▪ Describe the biogeochemical cycling in the environment ▪ Identify the causes and aftermaths of environmental pollution ▪ Understand sustainability, waste management, and environmental policy ▪ Describe the application of GIS in environmental studies
Syllabus	• Earth's environment: Definition, scope, and importance of environment and ecosystems, components of Earth's environment, hydrosphere, lithosphere, atmosphere, and biosphere [3] • Hydrosphere: Ocean, terrestrial aquatic systems, the composition of freshwater and seawater, nutrients, and the biology of aquatic systems. [3] • Carbon in the environment: Carbon cycle, photosynthesis, terrestrial and marine primary production, phytoplankton, inorganic and organic carbon, reservoirs, flux and net change, carbon sequestration, solubility, and biological pump. [3] • Nitrogen in the environment: Nitrogen cycle, forms of nitrogen in the environment, N2 fixation, diazotrophs, nitrification, denitrification, nitrogen assimilation processes. [3] • Biodiversity: Conservation and utilization of biodiversity, biomes, landscapes, and ecosystems, problems, and issues in biodiversity and forestry. [3] • Environmental pollution: Causes, effects, and preventive measures of water, soil, noise, and air pollution, Fossil fuel and biomass burning, air quality, health impacts, greenhouse effect, smoke, fog, and acid rain. [3] • Environmental pollution: Keeling plot, Suess effect, Bjerrum plot, Ocean acidification, Aquatic pollution, Haber–Bosch process, green revolution, Phosphorus eutrophication, harmful algal blooms, agricultural practices, and environmental footprints. [3] • Waste management: Toxic chemical waste, acute and chronic toxicity, persistent organic pollutants in the environment, microplastics, Waste management: Solid, hazardous and e-waste management, waste treatment and segregation, 3Rs of the waste management program [3] • Environment policy: Environmental policy and its relevance in the Indian and global contexts. [3]

EESS 202: Introduction to environmental and sustainability sciences [3 0 0 3]	
	• Sustainability and sustainable development: Ecosystem activity: Producers, Consumers, Decomposers; Case studies of environmental pollution episodes and successful interventions; Composting methods, Carbon footprint and carbon credits; life cycle assessment. [6] • Energy and water: management and conversion: Renewable and non-renewable energy sources, Fossil fuels and biofuels, Clean and green energy, Water resource conservation, rainwater harvesting methods, water treatment, water purification methods, Water footprint of consumer products. [3] • Geoinformatics and remote sensing in environmental sciences: Geographic Information System (GIS), Satellite remote sensing, Applications of GIS and remote sensing in environmental sciences. [3]
Text and Reference Books	1. Introducing oceanography; David N. Thomas and David G. Bowers 2. The Global Carbon Cycle and Climate Change; David E. Reichle (2020), ISBN: 978-0-12-820244-9 3. Processes in microbial ecology; David L. Kirchman (2012), ISBN 978–0–19–958693–6 (Hbk.), 978–0–19–958692–9 (Pbk.) 4. The algal bowl; David W. Schindler & John R. Vallentine 5. Sustainability: A Comprehensive Foundation, Edited by Tom Theis and Jonathan Tomkin (https://cnx.org/contents/F0Hv_Zza@45.1:HdWd2hN5@2/Foreword) 6. Textbook Of Remote Sensing And Geographical Information Systems, 4th Edition by M. Anji Reddy.

Mathematics Courses

MAT 111: Introduction to Proofs [2 1 0 3]	
Learning Outcomes	Understanding basic concepts of mathematical logic, Using sets for solving problems and using the properties of set operations, Working with relations and functions and investigating their properties, Using induction to prove simple statements, Introducing concepts from elementary groups.
Syllabus	• Propositional logic, Predicates and quantifiers, Proofs and methods of proofs [6] • Sets, Set operations, Functions, Relations and their properties, Representing relations, Equivalence relations, Countable and uncountable sets, Product of sets (finite and infinite), Real numbers, Subsets of R, intervals, bounded and unbounded subsets [10] • Mathematical induction, Strong induction and well-ordering, Recursive Induction and structural induction [4] • Set of bijections from a set to itself, Symmetric groups and examples, Cayley's theorem, order of elements of a symmetric group [7]
Text & Reference Books	1. Ajith Kumar, B K Sharma and S Kumaresan. A Foundation Course in Mathematics, Narosa, 2018. 2. Kenneth Rosen. Discrete Mathematics and Its Applications, Seventh Edition, McGraw Hill Education, 2017 3. Donald Knuth, Oren Patashnik, and Ronald Graham. Concrete Mathematics, AddisonWesley Professional, 1994

MAT 121: Matrices and Calculus [3 1 0 4]	
Learning Outcomes	The aim of this course is to introduce students to the calculus of functions of a single variable and matrices. Key concepts of differential and integral calculus and linear systems of equations are introduced along with applications.
Syllabus	• Vectors in R^2 and R^3, R^n as a vector space, Subspaces [2] • System of linear equations, Row reduced echelon forms, Rank of a matrix. [2] • Consistent and inconsistent systems, Solution(s) (or its lack, thereof) of linear systems. [2] • Determinant of a matrix and its properties. [2] • Eigenvalues and eigenvectors of a matrix, Cayley-Hamilton theorem. [2] • Real sequences and subsequences, Limit of a sequence (intuitive definition and verification through examples), Monotone sequences and bounded sequences [3] • Series and limits of series, Absolute convergence, Conditional convergence. [2] • Tests of convergence: Comparison test, Root test, Ratio test. Examples of some standard convergent and divergent series [4] • Real-valued functions: Examples of standard functions, periodic functions, inverse functions, composition of functions. [2] • Continuous functions, Limits, Boundedness of continuous functions in closed and bounded intervals, Intermediate value theorem and its applications. [3] • Differentiation: Tangents and slopes, rate of change and derivative, Differentiability and Continuity, Rules of differentiation. [4] • Mean value theorem, Rolle's theorem and applications. Taylor's theorem and Taylor's series, Maclaurin Series [4]

MAT 121: Matrices and Calculus [3 1 0 4]	
	• Applications of differentiation in curve sketching: critical points, finding the extremum values using derivatives, second derivative test, monotone functions [4] • Anti-derivatives, Fundamental theorems 1 and 2 of calculus [4]
Text & Reference Books	1. T M Apostol, Calculus, Volume I, 2nd. Edition, Wiley, India, 2007 2. R. Bartle and D. Sherbert, Introduction to Real Analysis, Fourth Edition, Wiley India 3. G. Strang, Linear Algebra and Its Applications, 4th Edition, Brooks/Cole, 2006 4. James Stewart, Calculus: Early Transcendentals, Eighth Edition, Cengage Learning, 2014 5. Ross L. Finney and George B Thomas, Calculus and Analytic Geometry, 9th Edition, Addison Wesley Publishing Company.

MAT 201: Calculus and Matrices II [3 1 0 4]	
Prerequisites	MAT101
Learning Outcomes	▪ Understanding the basic concepts of matrix theory, including matrix operations, kernel and range spaces, basis and dimension, and the rank-nullity theorem. ▪ Students will develop proficiency in multivariable calculus, mastering topics such as limits and continuity of functions, partial derivatives, directional derivatives, and integration in two variables.
Syllabus	• Matrix as a linear operator.Kernel and Range space of a matrix.Linear dependence and linear independence of vectors, Basis and dimension,Rank-Nullity theorem.Change of basis of vector spaces. [12] • Limits and continuity of functions of several variables, Directional derivatives, Partial derivatives and total derivatives. [8] • Partial derivatives of higher order, Composition of functions and change of variable. [5] • Maxima and minima, Lagrange multipliers.Mean value theorems in several variables. [6] • Double integrals on rectangular regions,Repeated or iterated integrals, Double integrals over bounded domains,Changing the order of integration, Fubini-Tonelli theorem. [9]
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. Kenneth Hoffman and Ray Kunze, Linear Algebra, Second Edition, Prentice Hall Inc, 1971. 6. G. Strang, Linear Algebra and Its Applications, 4th Edition, Brooks/Cole, 2006 7. S. Kumaresan, Linear Algebra: A Geometric Approach, PHI Learning, 2009. 8. S. Axler, Linear Algebra Done right, 3rd ed., Springer 2015

MAT 202: Introduction to Probability [3 0 0 3]	
Prerequisites	NA

MAT 202: Introduction to Probability [3 0 0 3]	
Learning Outcomes	This is a first course on basics of probability theory beginning with combinatorial probability. The outcome is to make students familiar with more on problem solving and give them a broader perspective on how l probability can be used in various areas of science.

Syllabus	• Basic probability: Set operations, counting, finite sample spaces, axioms of mathematical probability [3]
	• Conditional probability, independence of events, Bayes' Rule, Bernoulli trials, Poisson trials, infinite sequence of Bernoulli trials [7]
	• Random variables and probability distributions:
	  ○ Binomial distribution, geometric distribution [2]
	  ○ Poisson distribution, normal distribution [3]
	  ○ Exponential distribution, Gamma Distribution, Beta distribution; [2]
	• Bivariate and multivariate probability distributions, marginal and conditional probability distributions, independent random variables, i.i.d. sequence of random variables [6]
	• Transformation of random variables in one and two dimensions [3]
	• Mathematical expectations: Expectations for univariate and bivariate distributions [2]
	• moments, variance, standard deviation [2]
	• higher order moments, covariance correlation, moment generating functions, characteristic functions [4]
	• Law of large numbers, Central limit theorem [6]

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. D. D. Wackerly, W. Mendenhall III and R. L. Scheaffer, Mathematical Statistics with Applications, 7th Edition, Brooks/COle Engage Learning, 2008. 6. P. G. Hoel, S.C. Port and C.J. Stone, Introduction to Probability Theory, 1st ed., Houghton Mifflin, 1972

Physics Courses

PHY 111: Mechanics [2 1 0 3]	
Learning Outcomes	▪ 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
Syllabus	Newton's Laws [2]: • Critical analysis of the Newton's laws • Concept of homogeneity and isotropy of space-time - symmetry. • Concept of inertial and non-inertial reference frames, fictitious forces, Galilean transformation. Motion in One dimension [4]: • Forces and Equations of Motion, • Conservation of Momentum, Work Energy theorem, • Analytical solutions of EOMs, • Motion under gravity, Simple harmonic oscillator and damped oscillator. Motion in higher dimensions [4]: • Position vector and its derivatives, • EOM in Cartesian and Polar Coordinates Angular Momentum and Fixed Axis Rotation [8] • Angular momentum, Torque, • Work–Energy Theorem and Rotational Motion, • Motion under central force, Centre of mass, Kepler's laws. Rigid Body Motion [6] • Angular Momentum, Moment of Inertia - simple symmetric bodies. • EOM of rotating bodies. Introduction to Special Theory of Relativity [2]
Text & Reference Books	1. D. Kleppner and R. Kolenkow, An introduction to Mechanics, McGraw-Hill Science/ Engineering/ Math, second reprint 2008 2. Serway and Jewett, Physics for Scientists and Engineers, 7th edn, Brooks/Cole Publishers 2008. 3. C. Knight, W. D. Ruderman, M. A. Helmholz, C. A. Moyer and B. J. Kittel, Berkeley Physics Course, Vol1, Mechanics, McGraw Hill 2017 4. R. Shankar, Fundamentals of Physics, Yale Press 2019

PHY 112: Physics Lab I [0 0 3 1]	
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

PHY 112: Physics Lab I [0 0 3 1]	
Syllabus	1. Simple pendulum & variable g pendulum 2. Conservation of energy 3. Conservation of momentum & ballistic pendulum 4. Centripetal force 5. Symmetric compound bar pendulum 6. Projectile motion 7. Melde's string 8. Newton's laws of Motion 9. Moment bar 10.Sonometer
Text & Reference Books	Laboratory Notes and Reference Material

PHY 121: Electromagnetism [3 1 0 4]	
Learning Outcomes	▪ 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.
Syllabus	• Electrostatics: 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 [4] • Work and energy in electrostatics: Work done to move a charge, Electrostatic energy for point charge as well as continuous charge distribution, Simple examples [2] • 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. [2] • Special Techniques to solve the potential due to a given charge configuration. Solution by the method of separation of variables in Cartesian; Examples involving solution of boundary value problems such as a conducting sphere in uniform electric field; Potential due to an arbitrary charge distribution; Solving the potential for point charge configuration in a system of grounded conducting planes using method of images. [6] • Multipole Expansion; Electrical field and potential due to a point dipole [2] • Electric field in matter: Dielectrics, Polarization, Field of a polarized object, Electric displacement vector (D); Gauss's theorem in dielectric media; Boundary value problem with linear dielectrics; [6] • Electrostatic field energy; Computation of capacitance in simple cases (parallel plates); spherical and cylindrical capacitors containing dielectrics – uniform and non-uniform. [6] • Magnetostatics: Biot - Savart and Ampere's laws; Ampere's law in differential form; Magnetic vector potential, Magnetostatic boundary conditions [4] • Multipole expansion of the vector potential: Determination of magnetic fields for simple cases. Energy in a magnetic field, Magnetic field in matter [4]

PHY 121: Electromagnetism [3 1 0 4]	
	• Electrodynamics: Current electricity: Electromotive force. Ohm's law; Motional emf; Electromagnetic induction; Faraday's law; Self-inductance and mutual inductance; Maxwell's equations. [4]
Text & Reference Books	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.

PHY 122: Physics Lab II - Experiments in Optics, Electricity and Magnetism [0 0 3 1]	
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	1. Magnetic field along the axis of a circular coil 2. Deflection magnetometer 3. Spot galvanometer- high resistance by leakage 4. Spectrometer: refractive index of prism and i-d curve 5. Spectrometer-Grating 6. Newton's rings 7. Diffraction at slits-single and double 8. Liquid lens 9. Reflection grating 10. Malu's law
Text & Reference Books	Laboratory Notes and Reference Material

PHY 211: Thermal & Statistical Physics [3 1 0 4]	
Prerequisites	NA
Learning Outcomes	▪ 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

PHY 211: Thermal & Statistical Physics [3 1 0 4]	
Syllabus	• 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]
Text & Reference Books	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.

PHY 212: Optics [3 0 0 3]	
Prerequisites	NA
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.

PHY 212: Optics [3 0 0 3]	
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 ClausiusClapeyron 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 monoatomic 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.

Skill Enhancement Courses (SEC)

IDC 111: Mathematical Tools I [3 1 0 4]	
Learning Outcomes	▪ Perform analysis of functions of single variable ▪ Perform analysis of functions of several variables ▪ Use concepts of vector calculus in physical problems ▪ Use complex numbers to describe physical systems or parameters
Syllabus	• Introduction to Limit and Continuity with examples [3] • Introduction to Differentiation. Introduction to Taylor's series with examples [3] • Functions of several variables - partial differentiation [3] • Cartesian, Spherical and Cylindrical coordinate systems: introduction and equivalence. Parametric representation of an equation [4] Vector Calculus: • Review of vector algebra: addition, subtraction and product of two vectors - polar and axial vectors with examples; triple and quadruple product. [4] • Concept of Scalar and Vector fields. Differentiation of a vector w.r.t. a scalar unit tangent vector and unit normal vector. [4] • Directional derivatives - gradient, divergence, curl and Laplacian operations and their meaning. [6] • 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. [9] • Complex numbers and functions: Arithmetic operation, conjugates, modulus, polar form [3]
Text & Reference Books	1. Frank Ayres, Elliott Mendelson, Schaum's Outlines Series Theory and Problems of Differential and Integral Calculus, Tata McGraw Hill, 3Ed 2. Murray R. Spiegel, Schaum's Outlines Vector Analysis, Tata Mcgraw Hill, 2Ed 3. Murray R. Spiegel, Seymour Lipschutz, John Schiller, Dennis Spellman, Schaum's Outlines Complex Variables, Tata McGraw Hill Education; 2Ed 4. George B. Thomas, Ross L. Finney, Maurice D. Weir, Calculus and Analytic Geometry, Addison-Wesley Publishing Company Inc, 9Ed.

IDC 112: Introduction to programming in C/C++ [0 0 3 1]	
Learning Outcomes	▪ Gain the basic skills in working with a Linux computer. ▪ Gain familiarity with the tools and techniques of creating a computer program. ▪ Gain familiarity with the basic C/C++ language features. ▪ Write a complete structured program in C/C++ to perform specific tasks. ▪ Develop ideas to design computer algorithms to solve simple problems.
Syllabus	• Introduction to computer architecture and components. • Introduction Linux OS and Linux Command Line Interface • Mechanics of creating, compiling, running a C/C++ program. The 'Hello World' program in C/C++. Program structure, simple statements, formatting style of source code. • Variables and keywords, Built-in data types, numeric literals or various data types, automatic type conversions, arithmetic operators, expressions.

IDC 112: Introduction to programming in C/C++ [0 0 3 1]	
	• Strings, arrays, dynamic arrays, concept of automatic, static and dynamic storage. • Loops and relational expressions. • Branching statements and logical operators. • Pointers and its relation to arrays. References. • Functions, function prototypes, different ways of passing arguments to functions, array arguments • File input/output. • Examples: Basic to intermediate level exercises utilizing the concepts in all the lab sessions.
Text & Reference Books	1. Stephen Prata, C++ Primer plus (6th Ed), Addison-Wesley 2. Stephen Prata, C Primer plus (6th Ed), Addison-Wesley 3. Kernighan and Ritchie, C Programming language, Prentice Hall

IDC 121: Mathematical Tools II [2 1 0 3]	
Learning Outcomes	The aim of the second part of the interdisciplinary mathematical methods course is to make the students aware of various tools to solve differential equations with applications in other branches of sciences and engineering. This is a problem-oriented course with lots of applications.
Syllabus	• Solving techniques for first and second order linear ODEs: constant and variable coefficients [12] • Power series method; Legendre and Hermite polynomials. [5] • Laplace transforms and application to ODEs. [5] • Fourier transforms [5]
Text & Reference Books	1. William E. Boyce, and Richard C. DiPrima, Elementary Differential Equations 9th ed., Wiley, 2008. 2. E. Kreyszig, Advanced Engineering Mathematics, 8th ed. Wiley India Pvt Ltd, 2006. 3. C. Edwards and D. Penny, Elementary Differential Equations with Boundary Value Problems, 5th ed. Prentice Hall 2007. 4. R. Bronson and G. Costa, Schaum's Outlines Differential Equations, 3rd ed. Mcgraw-hill 2009. 5. Dennis G. Zill, Warren S Wright, Differential Equations with Boundary value problems,Edition 8, Cengage Learning 2012.

IDC 122: Numerical computing using C/C++ [0 0 3 1]	
Learning Outcomes	▪ Understand sources of systematic errors in numerical computations. ▪ Learn about methods of numerical solutions to simple mathematical problems. ▪ Ability to implement a numerical algorithm in C/C++ programming language. ▪ Learn how to represent simple physical/mathematical objects using Classes in C++.
Syllabus	• Binary numbers, computer representation of real numbers, machine precision, rounding errors. • Numerical differentiation, finite difference formulas, rounding errors • Numerical integration, Trapezoid rule, Simpson's rule, composite Newton-Cotes formulas. • Finding the root of an equation of a single variable. Bisection method, Newton's method, secant method.

IDC 122: Numerical computing using C/C++ [0 0 3 1]	
	• Least squares, fitting a model to data. • Introduction to Class in C++: Basic notions of procedural and object-oriented programming, the concept of a Class, how to define and implement a Class, Class data members, Class methods, Private & Public member, Creating and using Class objects. • Examples: Create and use a 'Vector' class to mimic physical vectors in 3D space. Create and use a 'Complex' class to mimic mathematical complex numbers. • Example science problems.
Text & Reference Books	1. Timothy Sauer, Numerical Analysis, Pearson 2. Stephen Prata, C++ Primer plus (6th Ed), Addison-Wesley 3. Siddhartha Rao, C++ in One Hour a Day, SAMS

IDC 212: Programming in Python [0 0 3 1]	
Learning Outcomes	▪ Understand the nature of Python language, how it differs from C/C++. ▪ Learn about the fundamental data types in Python. ▪ Learn to write a complete Python program performing simple manipulations on various data types. ▪ Get introduced to various Python modules. ▪ Get introduced to scientific oriented programming using 'NumPy'.
Syllabus	• Introduction: What is Python? Why Python? Why is it called an interpreted language? Differences with C/C++. • Official Python website, download and installation instructions. • The "Hello World" program in Python. Different ways of running a Python • script. • Concept of variables, objects, and references. Python's built-in data types: Numbers, Strings, Lists, Tuples, Sets, Dictionaries. Concept of Sequence data • type. • More on numeric types: Integers, Floats, Complex number, Decimal, Fraction, Boolean. Random numbers of different distributions. • Python control structures: if-else statements. Looping statements: for, while loops. List comprehension. Python Functions. Exception handling. • File handling, Formatting of output texts. • Introduction to 'NumPy': What is NumPy, Why use NumPy? Why is it faster? NumPy 'ndarray': axes, shape, size, dtype. NumPy array creation, printing. Basic operations, universal functions. Array indexing, slicing, iterating. Array shape manipulation. Array Copies and Views. • Linear algebra with 'NumPy'. Use NumPy arrays to create vectors and matrices. Matrix-vector, matrix-matrix multiplications. Use NumPy built-in functions to find matrix norm, determinant, inverse, decompositions, eigenvalues and eigenfunctions. • Example science problems
Text & Reference Books	1. Mark Summerfield, Programming in Python 3, Addison-Wesley 2. Mark Lutz, Learning Python, O'Reilly 3. https://www.python.org/ 4. https://numpy.org/ 5. https://scipy.org/

IDC 222: Scientific Computing and Data Visualization [0 0 3 1]	
Learning Outcomes	▪ Learn different types of data structures represented by various C++ standard template library (STL) containers. ▪ Learn how to use the C++ STL containers to handle and process numerical data. ▪ Learn how to use SciPy to handle special mathematical functions, perform some of the routine numerical tasks with functions. ▪ Learn how to produce various graphics for visualization of numerical data using Python matplotlib. ▪ Learn how to apply numerical computing and data visualization techniques for specific scientific problems.
Syllabus	• Introduction to C++ standard template library (STL): Container Classes, Iterators, STL algorithms. • Data structures in STL containers: Usage of STL 'Vector', 'Array', 'Deque', 'List', 'Set', 'Multiset', 'Map', 'Multimap'. • Introduction to SciPy. Use SciPy to compute Special functions, do numerical integrations, find the root of a function, optimize a function. • String manipulation using Python. • Data plotting and visualization with Matplotlib. Anatomy of a matplotlib Figure. Figure, Axes, Artist, Color, Styles, Labels, Annotation. • Matplotlib Pyplot: Point plot, Line plot of 2D data, customizations. Histogram, Surface plot of 3D data, Contour plot. Plotting numpy arrays as images. • Introduction Seaborn: Statistical data visualization. • Application to specific scientific problems.
Text & Reference Books	1. Stephen Prata, C++ Primer plus (6th Ed), Addison-Wesley 2. Mark Summerfield, Programming in Python 3, Addison-Wesley 3. https://matplotlib.org/ 4. https://numpy.org/ 5. https://scipy.org/

Ability Enhancement Courses (AEC)

HUM 111: Communication Skills I [1 0 0 1]	
Learning Outcomes	▪ Understand the origin, nature and functions of language, its structural universals, its use in varied contexts in science and society, and its evolution into a marker of personal, social, and cultural identity. ▪ Comprehend the nature and role of communication including media. ▪ Expand writing skills through controlled and guided activities. ▪ Identify common errors in writing and rectify them. ▪ Develop coherence, cohesion and competence in communication.
Syllabus	• Need for a Universal Language [1] • Relevance of communication from the perspective of Science, Scientists and Society [1] • Communication as a tool to promote Art, Literature and Music [1] • Communication modules: how does it work and structure based on basic theories [1] • Developments in communication: emergence of social media, AI, and the issue of rights [1] • Varied kinds of communication: Verbal, Non-Verbal, Visual [1] • Different aspects of Verbal Communication a) Reading: its psychology and practice [1] b) Writing: the different perspectives of it from the angle of media and research [1] c) Listening and its psychological and social impacts and outcomes [1] • Functional Grammar [4]
Text & Reference Books	1. NCERT Vocational training modules on Communication 2. Remedial English Grammar for Foreign Students by F.T. Wood 3. Boy from the Hills by Ruskin Bond 4. Communication Studies: The Essential Resource (Essentials), Andrew Beck, Peter Bennett, Peter Wall

HUM 121: Communication Skills II [1 0 0 1]	
Learning Outcomes	▪ Comprehend the nature and role of communication including media ▪ Expand writing skills through controlled and guided activities ▪ Identify common errors in writing and rectify them ▪ Develop coherence, cohesion and competence in communication
Syllabus	• Communication as a social science rather than a tool for interaction [2] • Interdisciplinary nature of communication: theories pertaining to sociology and psychology - Relevance to science communication [2] • Understanding media and putting it to good use [2] • Subaltern voices: Communication's role in exploring gender, ecology, rights, science. [2] • Functional grammar e.g. tenses and construction of sentences etc., common errors, deeper understanding of tenses, concepts like dangling modifiers, etc. [5]
Text & Reference Books	1. Introduction to Communication Studies (Studies in Culture and Communication) 2. Remedial English Grammar by F.T. Woods

HUM 121: Communication Skills II [1 0 0 1]	
	3. NCERT Vocational training modules on Communication 4. Communication Studies: The Essential Resource (Essentials) by Andrew Beck, Peter Bennett, Peter Wall

HUM 211: Introduction to Economics [1 0 0 1]	
Prerequisites	NA
Learning Outcomes	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.
Syllabus	• Introduction ○ What is Economics? Scarcity, choice and economic systems [1] • Market: Consumption ○ Supply and demand; [1] ○ Market equilibrium and the price mechanism. [1] ○ Shifts in the demand and supply curve and the impact on market equilibrium. [1] ○ Examples and Applications • Market in Action ○ Elasticity of demand [1] ○ Consumer choice; Consumer theory with indifference curves [1] ○ Examples and Applications [1] • Market: Production ○ Production and cost; how firms make decisions: profit maximization [1] • Market Structure ○ Perfect competition& Monopoly (representation of Market) [1] • Market Failure ○ Micro economics and Public Policy: Externalities and Public Good; Poverty, Inequality and Welfare State [2] • Macro Economics ○ Introducing macroeconomics: The Big picture [1]
Text & Reference Books	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.

HUM 221: Introduction to Sociology [1 0 0 1]	
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.

HUM 221: Introduction to Sociology [1 0 0 1]	

Syllabus	• Introduction: what is sociology? Micro and macro sociology [1]
	• Basic sociological Questions and concepts [1]
	• Sociological Perspectives and methods [2]
	• Social stratification and Class [2]
	• Social deviance/Crime [2]
	• Key elements of sociology [3]
	  ○ Politics and social order
	  ○ Education and mass media
	  ○ Sociology of body and health
	  ○ Nation and Globalization
	• Social Problems [1]
	• Sociology in India and South Asia [1]

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

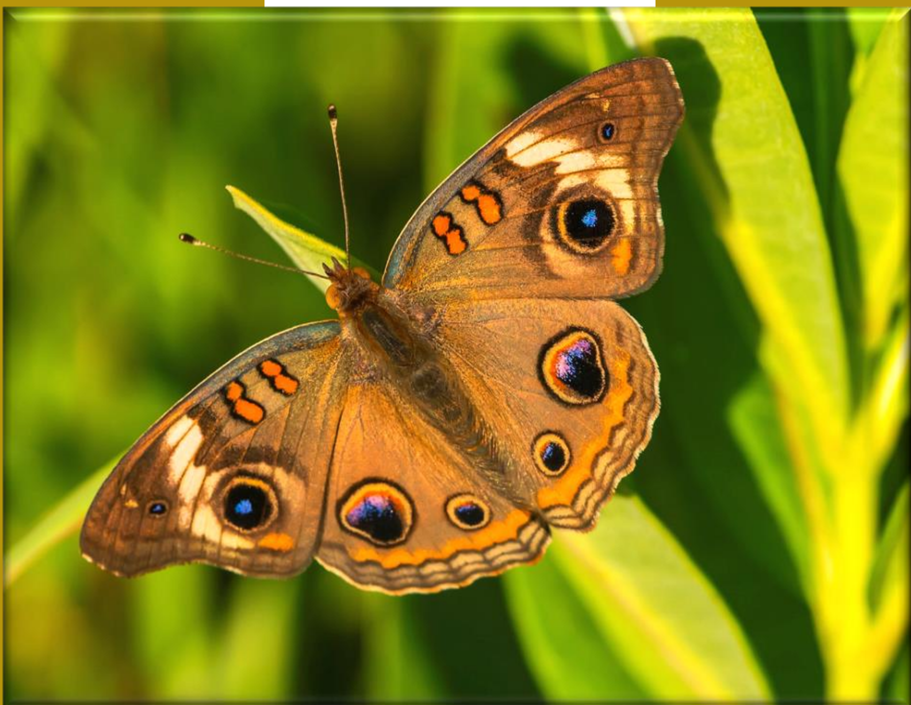
BIOLOGICAL SCIENCES

CURRICULUM FOR

BS-MS (SEM: 4 - 10)

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

CORE & ELECTIVE COURSES



BS-MS Courses

Semester 4	Semester 5	Semester 6	Semester 7	Semester 8
BIO 312 [3003] Advanced Genetics & Genome Biology	BIO 321 [3003] Structural Biology	BIO 426 [3003] Bioinformatics	BIO 416 [3003] Biostatistics	BIO 512 [3003] Neurobiology
BIO 313 [3003] Physiology	BIO 322 [3003] Immunology	BIO 412 [0093] Advanced Biology Lab III	BIO 511 [3003] Developmental Biology	DSE 7
BIO 314 [3003] Biochemistry	BIO 323 [3003] Cell Biology	DSE 1	DSE 4	GE V
BIO 324 [3003] Molecular Biology	BIO 327 [3003] Ecology & Evolution	DSE 2	DSE 5	Project (12)
BIO 315 [0093] Advanced Biology Lab I	BIO 325 [0093] Advanced Biology Lab II	DSE 3	DSE 6	
GE I	GE II	GE III	GE IV	
IDC 221	AEC/SEC (2)	AEC/SEC (2)	AEC/SEC (2)	
HUM 221				

I2B Courses

Semester 4	Semester 5	Semester 6	Semester 7	Semester 8
BIO 312 [3003] Advanced Genetics & Genome Biology	BIO 321 [3003] Structural Biology	BIO 426 [3003] Bioinformatics	BIO 511 [3003] Developmental Biology	BIO 4208 [3003] Stem Cells & Regenerative Medicine
BIO 313 [3003] Physiology	BIO 322 [3003] Immunology	I2B 411 [3003] Systems Biology Theory	I2B 421 [3003] Systems Biology Applications	DSE III
BIO 314 [3003] Biochemistry	BIO 323 [3003] Cell Biology	I2B 412 [3003] Microbiome & Vaccinology	I2B 422 [3003] Bio-Imaging & Processing	DSE IV
BIO 324 [3003] Molecular Biology	BIO 416 [3003] Biostatistics	I2B 413 [3003] Synthetic Biology	I2C 422 [3003] Biomaterials	Project (12)
BIO 315 [0093] Advanced Biology Lab I	BIO 325 [0093] Advanced Biology Lab II	I2B 414 [3003] Biomolecular Spectroscopy & Mass spectrometry	I2B 521 [0093] Systems Biology & Imaging Lab	
DSE I	DSE II	I2B 415 [3003] Human Genetics, Gene Therapy & Personal Genomics	I2C 521 [3003] Pharmacology & Pharmacokinetics	
IDC 221	AEC/SEC (2)	AEC/SEC (2)	AEC/SEC (2)	
HUM 221				

Minor Courses (General Electives)

Semester	Code	Title
IV	BIO 3001	Advanced Genetics & Genome Biology
	BIO 3002	Physiology
	BIO 3003	Biochemistry
	BIO 3004	Molecular Biology
V	BIO 3005	Structural Biology
	BIO 3006	Immunology
	BIO 3007	Cell Biology
	BIO 3008	Ecology & Evolution
VI	BIO 4001	Biostatistics
	BIO 4002	Biomolecular Spectroscopy & Mass spectrometry
	BIO 4003	Cryo-Electron microscopy and 3D image processing for Life sciences
VII	BIO 4004	Bioinformatics
	BIO 4005	Bio-imaging and Processing
	BIO 4006	Drug discovery and development
	BIO 5001	Developmental Biology
VIII	BIO 5002	Neurobiology
	BIO 4007	Synthetic Biology
	BIO 4008	Stem Cells and Regenerative Medicine

* One of the listed courses will be offered per semester.

Department Specific Elective Courses

Code	Title
BIO 3011	Genome Stability
BIO 3012	Bacterial Genetics
BIO 4011	Chronobiology
BIO 4012	Host-Pathogen Interactions
BIO 4013	Evolutionary Ecology
BIO 4015	Advances in Plant Biology
BIO 4016	Laboratory Animal Science
BIO 4017	Biosafety and Regulation (1 credit)
BIO 4018	Microbiome and Vaccinology
BIO 4019	Systems Biology Theory
BIO 4020	Human Genetics, Gene Therapy & Personal Genomics
BIO 4021	Systems Biology Applications
BIO 4022	Biological Data Analysis Using Python
BIO 4023	Bacterial Communication and Pathogenesis
BIO 4024	Population Genetics
BIO 5011	Advanced Developmental Biology
BIO 5012	Animal Behaviour
BIO 5013	Cancer Biology
BIO 5014	Scientific Writing (1 credit)

BS-MS Courses

BIO 312: Advanced Genetics and Genome Biology [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	This course provides an overview of genome organization, genome variation and methods used to analyze genomes. Recent advances in genome sequencing, genome wide association studies and advanced genetic analysis are also covered. The course will also introduce students to the emerging field of personal genomics and its relevance to human health.
Syllabus	• 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 & Reference Books	1. TA Brown, Genomes 4, Garland Science, 4th edition, Published May 24, 2017. 2. Tom Strachan, Andrew Read, Human Molecular Genetics, Garland Science, 5th edition, 20-Dec-2018. 3. Greg Gibson and Spencer V. Muse, A Primer of Genome Science, Sinauer Associates, Third Edition, February 15, 2010.

BIO 313: Physiology [3 0 0 3]	
Prerequisites	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 ▪ appreciate the conservation of some of the fundamental functions of life ▪ 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.

BIO 313: Physiology [3 0 0 3]	
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 & Reference Books	1. Animal Physiology by Richard W Hill, Gordon A Wyse and Margaret Anderson: Sinauer Associates. 4th Edition. 2. Eckert's Animal Physiology: Mechanisms and Adaptations. David Randall, Warren Burggen and Kathleen French: 5th edition.

BIO 314: Biochemistry [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	Life matter (unicellular or multicellular) is built using simple precursor molecules present in the biosphere. This course aims to understand the chemistry of life, how all biomolecules that comprise life matter is synthesized starting from simpler molecules by anabolic pathways, how these biomolecules are interconverted to each other by crossover metabolic pathways and ultimately the complex biomolecules are degraded back to simpler molecules by various catabolic pathways, generating bioenergy for the life to tick. At the completion of the course, the students can appreciate that "Life is a redox reaction".
Syllabus	• 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]

BIO 314: Biochemistry [3 0 0 3]	
	• Principles of bioenergetics: Equilibrium constants, free energy changes, coupled reactions: Concepts and misconcepts. Role of ATP in bioenergetics, ATP as energy transducing agent and nature's dehydrating agent in metabolism. [2] • 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] • 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 & Reference Books	1. Rodney F Boyer, Concepts in Biochemistry. John Wiley & Sons; 3rd Edition edition (2 December 2005)

BIO 314: Biochemistry [3 0 0 3]	
	2. Thomas Millar, Biochemistry Explained: A Practical Guide to Learning Biochemistry. CRC Press; 1 edition (30 May 2002) 3. Lubert Stryer et al., Biochemistry. W. H. Freeman; 6th Edition edition (14 July 2006) 4. John E. McMurry and Tadgh Begley. The Organic Chemistry of Biological Pathways. WH Freeman; 2nd edition (11 December 2015) 5. Laurence A Moran, Principles of Biochemistry. Pearson; 5th edition (30 July 2013) 6. David L. Nelson and Michael M. Cox, Lehninger Principles of Biochemistry WH Freeman; 7th ed. 2017 edition (1 January 2017)

BIO 321: Structural Biology [3 0 0 3]	
Prerequisites	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. [10] • Tools for analysing protein structures to understand the molecular basis of their functions. Structure Based Drug Design.[5]
Text & 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.

BIO 322: Immunology [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	To introduce students, the basic and advanced concepts in Immunology, and emphasize the importance of immunology in health and disease. The course will provide in-depth knowledge on functioning of immune systems, with specific emphasis to humans. Further, the clinical and therapeutic aspects of immunology will be covered.
Syllabus	• Introduction, Organization of the immune system (lymphoid tissues and organs). [3] • Immune cell development (hematopoiesis, T and B cell development). [6] • Innate and adaptive immunity (including cellular and humoral responses). [4]

BIO 322: Immunology [3 0 0 3]	
	• 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 & 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.

BIO 323: Cell Biology [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	The course will provide in-depth understanding of the fundamental cellular processes that regulate and coordinate growth, division and death of eukaryotic cells and their underlying molecular pathways. Functional links of the processes with human diseases will be touched upon. The course also will introduce advanced methodologies including various microscopy tools employed in modern cell biology research.
Syllabus	• Methods used in cell biology: microscopy, cell sorting, fractionation of cellular components, radioisotopes and antibodies as tools to study cellular functions. All light microscopy platforms (while light and fluorescence) covering basic principles and applications. Fluorescence activated cell sorting and radio-isotope/antibody based cellular biochemistry will include isotope based cellular and molecular fractionation and different immunoblot platforms. [4-5] • Cell membrane: organization and composition of the cell membrane, structural property of the membrane micro-domains. Details of compositions of the membranes of intracellular organelles and plasma membrane and their properties; and the structural properties of the micro-domains (lipid rafts etc.) of membranes. Understanding of the functional link of the compositional diversity of the cell membrane (plasma membrane and intracellular membrane) to cellular processes pertaining to the organelles and plasma membranes. [2-3] • Membrane transport- endocytosis and exocytosis Vesicular transport system and intracellular trafficking, protein targeting. In depth understanding of the molecular pathways pertaining to intra-cellular trafficking/transport and their mechanistic insights in model organisms from unicellular yeast to animal cells, cellular methods/tools/approaches to study these processes. [4-5] • Organelle biogenesis: Understanding the biogenesis of subcellular structures such as mitochondria, centrosome, kinetochore in cells across eukaryotic kingdom, similarity/diversities in their composition, structural organization and functions. [2-3] • Components of the cytoskeleton and their regulations: organization and function of actin, intermediate filaments, microtubules and motor proteins, integrins, cadherins. Compositions and cellular/molecular properties of different types of cytoskeletal elements, studies on the involvement of actin and microtubule cytoskeleton in intra-cellular trafficking, chromosome organization and cell motility. Functions of actin and microtubule-based motor proteins in

BIO 323: Cell Biology [3 0 0 3]	
	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 & 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 Edition, 2015.

BIO 324: Molecular Biology [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	This course is designed to introduce the concepts of gene expression and regulation starting from basic concepts of transcription, translation, replication and DNA repair. Basics of post-transcriptional, post-translational regulation and epigenetics are also discussed. The course also covers basic molecular biology techniques.
Syllabus	• Nucleic acid: building blocks, nucleotide analogs as drugs [1] • DNA STRUCTURE- base pairing and stabilizing forces, different forms of DNA. minor and major groves, supercoiling, organization into chromosomes, nucleosomes, heterochromatin, euchromatin, genes and organization, unique genes, operons, gene families, repetitive DNA, genome organization, transposons. [2] • Replication: basic processes in bacteria and eukaryotes, telomeres and telomerase [3] • DNA damage and repair: ionic radiation induced damage, chemical mutagens, different repair mechanisms, recombination, mechanisms of bacterial DNA repair, SOS response, measuring mutations, mutator strains. [3] • Basic steps in gene expression and regulation, transcriptional and post-transcriptional regulation of gene expression [3] • Bacterial translation: introduction to codon, tRNA mediated decoding, aminoacylation of tRNA and classes of aminoacyl-tRNA synthetase, basic subunits of ribosome, steps and factors involve in bacterial translation. [3] • Eukaryotic translation: Basic steps of translation and factors involved in translation. GTPases in translation [3] • Molecular aspects of RNA processing, transcription- Basic steps in transcription, splicing, transport across the nuclear membrane, recognition by translational apparatus, IRES [5]

BIO 324: Molecular Biology [3 0 0 3]	
	• Epigenetics: DNA methylation in prokaryotes and eukaryotes, epigenetic gene regulation by DNA methylation in plants and mammals. Methods to detect epigenetic modifications [3] • Protein-nucleic acid interactions - nucleic acid recognition by proteins binding motifs - techniques to study protein-nucleic acid interactions. [3] • Non-coding RNA: Biogenesis and its function. Function and use of Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR). [3] • Recombinant DNA technology and molecular cloning, purification of recombinant protein. [4]
Text & Reference Books	1. Molecular Biology of the cell by Bruce Alberts et al. 6th edition 2. DNA Repair and Mutagenesis (2nd Edition) Friedberg and others. 3. Mehta, A. and Haber J. E. (2014) sources of DNA double strand breaks and Models of Recombination DNA repair Cold Spring Harb Perspect Biol 6: a016428. 4. Anand, R.P, Lovett, S.T. and Haber J.E. (2013) Break Induced DNA Replication. Cold Spring Harb Perspect Biol 5: a010397.

BIO 327: Ecology and Evolution [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	By the end of the course, the student is expected to master an intermediate level of understanding of fundamental concepts in ecology and evolution.
Syllabus	• The four fundamental forces in evolution: mutation, selection, genetic drift and migration; Stochastic and deterministic forces in evolution; the role of chance in evolution. [2] • The concept of fitness; adaptation and maladaptation; the zero-force evolutionary law. [2] • The importance of trade-offs in evolution; fitness trade-offs; generalists and specialists. [2] • The utility of fitness landscapes in understanding evolution; Sewall Wright's adaptive landscapes; the shifting balance theory. [2] • The modern evolutionary synthesis (MS) and its extensions; the key tenets of the Extended Evolutionary Synthesis (EES). [3] • Phenotypic plasticity, reaction norms; polyphenisms; adaptive plasticity; reversible versus irreversible plasticity; genetic accommodation; genetic assimilation; genes-as-leaders vs. genes-as-followers in evolution. [4] • Microevolution versus macroevolution; the seven major transitions in evolution; levels of selection; multilevel selection; revisiting the environment's role in shaping evolutionary change (the ecological context of evolution). [5] • The study of ecology and its evolutionary backdrop [2] • Physical conditions and the availability of resources [2] • Biomes and Ecosystems [1] • The flux of energy and matter through ecosystems. [1] • Patterns of species richness [1] • Interspecific competition [3] • Mutualistic interactions. [3] • Applied issues in ecology: Habitat conversion, degradation, fragmentation. [2]

BIO 327: Ecology and Evolution [3 0 0 3]	
	• Global change and Conservation biology: Invasive species, over-exploitation, In-situ and ex-situ conservation, island biogeography. [3] • Biodiversity and biogeography of India. [2]
Text & Reference Books	1. Nicholas J. Gotelli, A primer of Ecology Oxford University Press, 4th Edition 2. Begon et al., Ecology: From Individuals to Ecosystem Wiley-Blackwell, 4th Edition 2005 3. Manuel C Molles, Ecology: Concepts and Applications Mc Graw Hill 7th Edition 2 4. Barton, N. H., D. Briggs, J. Eisen, D. B. Goldstein, and N. H. Patel. 2007. Evolution. Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y. 5. Bell, G. 2008. Selection: the mechanism of evolution. 2nd ed. Oxford University Press, Oxford. 6. Townsend CR, Begon M, Harper JL, Essentials of Ecology, Third Edition. Blackwell Publishing, 2008. 7. DeWitt, T. J., and S. M. Scheiner. 2003. Phenotypic plasticity: functional and conceptual approaches. Oxford University Press, New York; Oxford. 8. McShea, D. W., and R. N. Brandon. 2010. Biology's first law: the tendency for diversity and complexity to increase in evolutionary systems. The University of Chicago Press, Chicago. 9. Pigliucci, M., and G. B. Müller (eds). 2010. Evolution, the Extended Synthesis. The MIT Press. 10. Maynard Smith, J., and E. Szathmáry. 1995. The major transitions in evolution. W.H. Freeman, Oxford.

BIO 416: Biostatistics [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	This is an essential and important course for a student of biology, as statistics is critical to conclude any biological results. The course will cover basic of statistics, standard and advanced statistical tests that are routinely used in interpreting biological data and in health sciences. Students will also be trained to use R statistical package.
Syllabus	• Introduction to statistics for biologists: importance of statistics, hypothesis testing, overview of statistical tests, variables. [2] • Summarizing and visualizing data: types of data, summarizing data, displaying data, descriptive statistics, tools for graphical display. [2] • Probability & distributions: basic probability, laws of probability, types of distributions, statistics of distributions, probability distributions. [3] • Methods of sampling: populations and samples, sampling & non-sampling errors, various methods of sampling, experimental design. [2] • Hypothesis testing: need for statistical testing, acceptable errors, P-values. [2] • Parametric & non-parametric tests: concept of parametric & non-parametric statistics, tests for differences. [7] • ANOVA: one-way ANOVA, Two-way ANOVA, Three-way ANOVA, Multiway ANOVA, Nested ANOVA, ANCOVA. [4] • Correlation & regression: scatter plot, correlation coefficient, partial correlation coefficient, linear regression, non-linearity, non-linearity. [4] • Survival analysis: censoring, survival times, summarizing and presentation. [2]

BIO 416: Biostatistics [3 0 3 3]	
	• R for biostatistics: introduction, performing common statistical tests in R, visualizing data in R, exporting data and analysis. [6]
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.

BIO 426: Bioinformatics [3 0 0 3]	
Prerequisites	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

BIO 426: Bioinformatics [3 0 0 3]	
	3. M. Michael Gromiha, Protein Bioinformatics: From Sequence to Function, Elsevier, 2010

BIO 511: Developmental Biology [3 0 0 3]	
Prerequisites	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 signalling 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: Sea urchin, 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 signalling. [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 signalling 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 & 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

BIO 512: Neurobiology [3 0 0 3]	
Prerequisites	NA
○ Learning Outcomes	On completion of this course, Students should be able to ▪ Understand the structure of mammalian nervous system ▪ Understand the various modes of communication in nervous system ▪ Understand the principles of complex brain functions such as memory ▪ Familiarize themselves with the current techniques and experimental methods employed in Neuroscience
Syllabus	• Introduction to Neurobiology- History of neurobiology, overview of the field of Neurobiology [2] • Anatomy and organization of the nervous system- CNS and PNS, major structures, coverings of the brain, sympathetic and parasympathetic nervous system [4] • Sensation processing- General principles, afferent and efferent nerve fibres, role of spinal cord [3] • Types of cells in brains- neurons, microglia, astrocytes, oligodendrocytes, Blood brain barrier, functional interdependence of various cell types [4] • Electrical properties of the neuron- Types of cellular transport in the neurons, ionic balance, Equilibrium potential, Resting membrane potential, Nernst Potential, GHK equation, Various types of ion channels in neurons, Action potential [6] • Neural communication- Synaptic transmission, Summation, Electrical and chemical synapses, Synaptic vesicles-filling and release mechanisms, Post synaptic receptors, Neurotransmitters and recycling [5] • Brain plasticity - Synaptic plasticity, Short term potentiation, Long term potentiation, Structural plasticity [5] • Complex brain functions- Learning- Sensitization, Habituation; Memory- Types (non-associative & associative) and process of memory; Cellular and molecular mechanisms, brain structures involved in these processes [5] • Experimental methods to study neurobiology-General plans of experimental design, Imaging-based methods- microscopy, circuit tracing, fMRI, Electrophysiological methods-Voltage Clamp, Patch Clamp, Intracellular Recording, Field Potentials and Extracellular Recording, In-vivo methods such as amperometry, optogenetics , Behavioural methods [6]
Text & Reference Books	1. John G. Nicholls, A. Robert Martin, David A. Brown, Mathew E. Diamond, David A. Weisblat, and Paul A. Fuchs, From neuron to brain, Sinauer Associates, Inc. Fifth edition, November 2011. 2. Mark F. Bear, Barry W. Connors, Michael A. Paradiso, Neuroscience: Exploring the Brain, Lippincott Williams & Wilkins, Third Edition, April 1995. 3. Eric R. Kandel, James H. Schwartz, and Thomas M. Jessell. Principles of Neural Science. Fifth Edition, October 2012. 4. Arthur C. Guyton and John E. Hall. Textbook of Medical Physiology, Twelfth Edition.

I2B Courses

I2B 411: Systems Biology [3 0 0 3]	
Prerequisites	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 in several areas of theoretical systems biology, which has wide-range of applications in big-data analysis.
Syllabus	• Introduction to Systems Biology: Reductionist and holistic approach to studying biology, Basic principles of biology, introduction to mathematical models [2] • Modelling biochemical systems: Model scope, adequateness, and properties, classification of models: network-based models, agent-based models and statistical models [2] • Topology-based modelling: mathematical graphs, graph and network theory, application in network topology-based analysis [4] • Constraint-based modelling: linear algebra and linear programming, application in constraint-based modelling, Flux balance analysis (FBA) and related algorithms [5] • Kinetic modelling: ordinary differential equations (ODE), partial differential equations (PDE), deterministic ODE and PDE models, application in kinetic modelling [6] • Discrete, stochastic and spatial models: stochastic simulation and Monte Carlo simulation [3] • Network structure, dynamics and function: random graphs, scale-free networks, clustering, network motifs, dynamic models, modularity [3] • Gene Expression Models: Boolean and Bayesian networks, Application in gene regulatory networks [3] • Biological data for Systems Biology: Types of biological data, Overview of experimental techniques [2] • Data formats and standards: Data formats, the MIRIAM (Minimum Information Required in The Annotation of Models) standards, Systems Biology Markup Language (SBML) and SBML models, Biological Pathway Exchange (BioPAX), Models and parameters for simulation of biological processes and Simulation experiment markup language (SED-ML) [3] • Variability, Robustness and information: genetic & non-genetic variability, quantification of noise in biological systems, robustness mechanisms [3] • Optimality and Evolution: scaling laws, adaptation, exploration strategies. [1]
Text & Reference Books	1. Systems Biology, Edda Klipp, Christoph Wierling, Wolfram Liebermeister, Axel Kowald, Ralf Herwig, Hans Lehrach, 2nd Edition, Wiley 2009 2. Mathematical Modeling in Systems Biology, Brian Ingalls, MIT Press 2013

I2B 412: Microbiome & Vaccinology [3 0 0 3]	
Prerequisites	NA

I2B 412: Microbiome & Vaccinology [3 0 0 3]	
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] • Human microbiome analysis - microbiota, gut microbiota, host diet, probiotics, ecosystem, evolutionary perspective, phylogeny & function. [6] • Methods to study microbiomes - culture-based methods, molecular methods: non-sequencing & sequencing-based, metabolic methods, metagenomics, metatranscriptomics, human microbiome project. [6] • Clinical relevance of microbiomes - microbiota in health and diseases, case studies. [3] • Introduction to Vaccinology - overview, historical perspective, disease prevention, therapeutic vaccines. [2] • Types of vaccines – subunit, vector-based, nano-particle, mRNA and DNA vaccines. [6] • Immunology of vaccines - chemical nature of antigens, antigen-presenting cells, cytokines, pathogen recognition, immune memory, mucosal immunity, pediatric & elderly immunology. [6] • Vaccine development - vaccine design: development pathway, antigens & epitopes, adjuvants, micro- and nanotechnology, recombinant vaccines, delivery technologies, formulation & manufacturing. [6] • Clinical trials - regulatory pathways, clinical evaluation, vaccine safety, vaccine recommendations. [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

I2B 413: Synthetic Biology [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	Understand the principles and concepts of synthetic biology. Apply molecular biology techniques for DNA manipulation and genetic engineering, enzyme engineering and metabolic engineering. The knowledge to design and construct basic synthetic biological systems. Communicate effectively about synthetic biology concepts and research. Comprehend the ethical, social, and environmental implications of synthetic biology.
Syllabus	• Definition, history, a quick overview of molecular biology, editing tools in the context of the central dogma, basic concepts from control theory; Biomimicry and August-Krogh Principle [2]

I2B 413: Synthetic Biology [3 0 0 3]	
	• Gene synthesis methods and applications: Standard Biological Parts and BioBricks; Parts assembly and characterization; Registry of Standard Biological Parts; Optogenetics [2] • Design Principles in Synthetic Biology: Modeling and simulation approaches; Bioinformatics and DNA sequence analysis; Synthetic Gene Networks • Transcriptional regulation and promoters in prokaryotic and eukaryotic systems; Designing genetic circuits and Boolean logic gates; Orthogonality, genetic code expansion; Compartmentalization; in vitro translation. [4] • Kinetics and dynamics of biological systems – control theory; biochemical networks, gene regulatory networks, signal transduction pathways; introduction to cytoscape [3] • Metabolic Engineering; thermodynamic concepts; basic principles of metabolism, types of cofactors; Metabolic modelling and optimization. [3] • Enzyme engineering: a quick overview of enzymes and types; creating new-to-nature enzymes; directed evolution; ancestral sequence reconstruction; Chemical weapons and detoxification; plastic degrading enzymes; use of artificial amino acids using engineered tRNA synthetases. [4] • Genome Engineering and CRISPR-Cas Systems; CRISPR-Cas9 technology and applications; Genome editing and engineering; MAGE (Multiplexed automated genome engineering; PACE (Phage assisted continuous evolution). [4] • Biosecurity, Ethics, and Regulations in Synthetic Biology; Containment strategies, Safety considerations; Ethical and legal implications of synthetic biology; Applications of Synthetic Biology, Patentability, Entrepreneurship in India, Promising startups in synthetic biology. [4] • Biosensors – enzyme-based electrochemical biosensors, optical technologies, transducer technologies, living biosensors. [2] • Synthetic biology in medicine and healthcare; CAR-T cell, gene therapy, nanomaterials, biomolecules-nanoparticles interactions, applications in diagnostics & medicine; introduction, biomedical sensors, bio-signal processing, diagnostic devices, wearable sensors. [3] • Tissue engineering – introduction, stem cells, extra-cellular matrix, mechanical surfaces, surface immobilization, biomaterials, examples of tissue engineering: skin, nerve, cardiac tissue regeneration. [2] • Synthetic biology for environment and food security: Improving plant productivity Conventional breeding versus GMO's; Synthetic biology approaches to nitrogen fixation; De-extinction efforts. [3] • Case Studies and Research Papers; Analysis of seminal research papers in synthetic biology; Group discussions and presentations; Project Work; Course Review [4]
Text & Reference Books	1. D. Del Vecchio and R. M. Murray, Biomolecular Feedback Systems. 2. Justin Bois and Michel Elowitz, Design Principles of Genetic Circuits; http://be150.caltech.edu/2020/index.html 3. U. Alon, An Introduction to Systems Biology: Design Principles of Biological Circuits, 2nd Ed., CRC Press, 2020

I2B 414: Biomolecular Spectroscopy & Mass spectrometry [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	In this course, students will understand the fundamental principles and techniques of biomolecular spectroscopy and Mass spectrometry. At the end of the course, they will be able to apply their

I2B 414: Biomolecular Spectroscopy & Mass spectrometry [3 0 0 3]	
	knowledge to analyze spectroscopy and spectrometry data related to biomolecular structures, dynamics, and interactions. Students will develop the skills to interpret experimental data, draw meaningful conclusions, and critically evaluate scientific literature.
Syllabus	• Fundamentals of spectroscopy: Wave-particle duality of light, Fundamentals of molecular orbital theory, Quantum mechanical nature of matter, Electromagnetic spectrum, light-matter interaction, Jablonski diagram [6] • Behavior of biomolecules: Time scales of biological processes, size scales in biology, macromolecular composition of a cell, metals/cofactors/prosthetic groups in biology, biomolecular interaction [6] • Electronic spectra: Absorption spectra, UV spectra of proteins, Nucleic acid spectra, Fluorescence, and phosphorescence, monitoring RecBCD activity using fluorescence, FRET, energy transfer in biological applications [6] • Circular dichroism, optical rotatory dispersion, fluorescence polarization: Polarization of light, CD-ORD spectroscopy of proteins and DNA, small molecule binding to DNA, binding of zinc finger proteins to DNA, Studying integration of HIV genome into the host using anisotropy, Rotational correlation time of lipoic acid in alpha-ketoglutarate dehydrogenase. [3] • Vibration Spectroscopy: Infrared and Raman spectroscopy basics; vibrational modes, spectroscopic instrumentation, data interpretation, and case studies highlighting the use of vibration spectroscopy in studying biomolecules. [2] • Nuclear magnetic resonance and Electron spin resonance spectroscopy: Fundamentals of NMR and ESR, Chemical shifts, Spin-Spin splitting, Relaxation times, Multidimensional NMR, Protein-DNA interaction and protein folding using NMR, Studying lactose permease structure using ESR. [6] • Mass photometry: Principle, data interpretation, instrumentation, applications [2] • Mass Spectrometry: Introduction, mass analysis, problems in mass spectrometry, tandem mass spectrometry, ion detectors, ionization of samples, sample preparation & analysis, application in biology, native mass spectrometry. [8]
Text & Reference Books	1. Spectroscopy for the biological sciences, Gordon G. Hammes, John Wiley and Sons, Inc. 2005. ISBN-10 0-471-71344-9 2. Principles of Physical Biochemistry, van Holde, Kersal E.; Johnson, W. Curtis; Ho, P. Shing), 2005, ISBN-10:0130464279 3. Protein sequencing and Identification using Tandem Mass spectrometry, Michael Kinter and Nicholas E. Sherman, John Wiley and Sons, Inc. 2000. ISBN 0-471-32249-0

I2B 415: Human Genetics, Gene Therapy & Personalized Medicine [3 0 0 3]	
Prerequisites	BIO312
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.

I2B 415: Human Genetics, Gene Therapy & Personalized Medicine [3 0 0 3]	
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 Roland W Herzog and Sergei Zolotukhin, A Guide to Human Gene Therapy, World Scientific Publishing Company, 2010

I2B 421: Systems Biology - Applications [3 0 0 3]	
Prerequisites	I2B412 Systems Biology - Theory
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]

I2B 421: Systems Biology - Applications [3 0 0 3]	
	• Application of machine learning in systems biology. [3] • Feedback, Bistability & Memory - feedforward loops, feedback loops, network motifs, protein-protein interaction networks. [4] • Evolutionary game theory. [3] • Biological Oscillator - oscillations in biological systems: biochemical, gene expression, signal transduction, non-linear dynamics. [5] • Optimality in Biology - optimal gene-circuit design, optimal metabolic adaption, fitness landscape, pareto optimality, modularity, evolution and self-organization. [3] • 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 Edition, Wiley 2009

I2B 422: Bio-Imaging & Processing [3 0 0 3]	
Prerequisites	I2B 414 Biomolecular Spectroscopy & Mass spectrometry
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. [3] • 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] • 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 edition, 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

I2B 521: Systems Biology & Imaging Lab [3 0 0 3]	
Prerequisites	I2B 421 Systems Biology Applications, I2B 424 Bio-Imaging & 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. [3] • Modelling biological networks. [12] • Matlab and R packages. [9] • NMR spectroscopy. [9] • AFM imaging. [9] • Cryo-electron microscopy. [9]
Text & Reference Books	Methods’ articles will be shared during the course.

I2C 521: Pharmacology and Pharmacokinetics [3 0 0 3]	
Prerequisites	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.
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 Edition, 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.

I2C 521: Pharmacology and Pharmacokinetics [3 0 0 3]	
	4. Molecular Biology in Medicinal Chemistry 1st Edn, 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 Edition, Academic Press, 2008.

Laboratory Courses

BIO 315: Advanced Biology Lab I [0 0 9 3]	
Prerequisites	NA
Learning Outcomes	To provide a hands-on training of advanced Biological experimental methods.
Syllabus	• Microbiology: Microbial growth kinetics, antibiotics susceptibility testing, Construction of bacterial gene deletions by homologous recombination, microbial experimental evolution. [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]

BIO 325: Advanced Biology Lab II [0 0 9 3]	
Prerequisites	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]

BIO 412: Advanced Biology Lab III [0 0 9 3]	
Prerequisites	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]

BIO 412: Advanced Biology Lab III [0 0 9 3]	
	• Neurobiology experiments – [24]

Elective Courses (General and Department specific)

BIO 3011: Genome Stability [3 0 0 3]	
Prerequisites	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] • 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 & Reference Books	1. James Haber, Genome Stability, Garland Science, Edition 1, December 16, 2013 2. Jac A. Nickoloff, Merl F. Hoekstra, DNA Damage and Repair, Humana Press, Volume III, October 4, 2014 3. Errol C. Friedberg, DNA repair and mutagenesis, American Society for Microbiology Press, 2nd edition, February 23, 2006

BIO 3012: Bacterial genetics [3 0 0 3]	
Prerequisites	BIO 212 Principles of Life IV: Microbiology
Learning Outcomes	Students will learn the cutting edge of dynamics of molecular and cellular mechanisms underlying morphodynamics in plants. The course offers the possibility to learn integrating how internal cues respond to changes in external inductive cues in plants, which continuously get exposed to fluctuating environmental conditions throughout their growth phase.
Syllabus	• Chromosome structure and replication [6] • Mutations and DNA repair in bacteria [6] • Gene expression, transcriptional and post-transcriptional regulation [6] • Conjugation, transformation, transduction, transposition [6] • Antibiotic resistance [3] • Genetic engineering, biology and application of Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) [6]

BIO 3012: Bacterial genetics [3 0 0 3]	
	• Genomics and evolution [6]
Text & Reference Books	1. Lori A.S. Snyder, Bacterial genetics and genomics; 2024 Garland Science 2. Tina M. Henkin, Joseph E. Peters, Snyder and Champness Molecular Genetics of Bacteria, 5th Edition; 2020 ASM Press 3. Research articles will be provided in the course

BIO 4003: Cryo-Electron microscopy and 3D image processing for Life sciences [3 0 0 3]	
Prerequisites	Preferable: BIO321 course: Structural Biology (not compulsory).
Learning Outcomes	To introduce Biology major students, the importance of the new resolution revolution in electron cryo microscopy (that led to the 2017 Nobel Prize in Chemistry) and the kindred subjects. The objective of the course is to provide biology students with information to understand the history of cryoEM, the basic physics behind negative stain and cryo-EM of bio-molecules, its potential and limitations and an introduction to cellular tomography and future challenges of cryo-EM. It will also introduce single particle cryoEM and their applications in structure based drug design.
Syllabus	• 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]
Text & Reference Books	1. John J. Bozzola and Lonnie D. Russell. Electron Microscopy, Second Edition, Jones and Bartlett Publishers, Inc., Sudbury, MA, 1999 2. Joachim Frank (2006). Three-Dimensional Electron Microscopy of Macromolecular Assemblies: Visualization of Biological Molecules in Their Native State. 2nd Ed. (New York, Oxford U. Press). 3. Single-particle Cryo-electron Microscopy: The Path Toward Atomic Resolution/ Selected Papers of Joachim Frank with Commentaries (Series in Structural Biology)

BIO 4003: Cryo-Electron microscopy and 3D image processing for Life sciences [3 0 0 3]	
	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"

BIO 4006: Drug Discovery and Development [3 0 0 3]	
Prerequisites	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 a 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, a 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; currently approved drugs targeting kinase families. [2] • Drug repurposing. [2] • Drug development for infectious diseases (malaria and tuberculosis)- antibioticshost- 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 developing drugs against various disease models (cancer and infectious diseases). [5]
Text & 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.

<table>
<tr><th colspan="2">BIO 4208: Stem Cells and Regenerative Medicine [3 0 0 3]</th></tr>
<tr><td>Prerequisites</td><td>NA</td></tr>
<tr><td>Learning Outcomes</td><td>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.</td></tr>
<tr><td>Syllabus</td><td>
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]
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]
</td></tr>
<tr><td>Text & Reference Books</td><td>
Essentials of Stem Cell Biology by Robert Lanza Anthony Atala (Eds.): Academic Press. 3rd Edition 2013.
Stem Cells: An Insider's Guide by Dr. Paul Knoepfler: World Scietific publishing Co. Pvt. Ltd. 1st Edition 2013.
The science of stem cells by JMW Slack: Wiley Blackwell publishers. 1st Edition 2017.
Stem Cells, Tissue Engineering and Regenerative Medicine by David Warburton (Ed.) World Scietific publishing Co. Pvt. Ltd. 1st Edition 2014.
Stem Cells Handbook by Stewart Sell (Ed.). Springer 1st edition 2013.
Stem Cells: A Short Course Rob Burgess. Wiley Blackwell publishers. 1st Edition 2016.
Principles of Tissue Engineering Robert Lanza Robert Langer Joseph Vacanti (Eds.). Academic Press 4th edition 2013.
The Biomedical Engineering Handbook by Joseph D. Bronzino, Donald R. Peterson. CRC Press Taylor & Francis. 1st edition. 2015.
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</table>

BIO 4011: Chronobiology [3 0 0 3]	
Prerequisites	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].
Text & Reference Books	1. Jay C. Dunlap, Jennifer J. Loros, Patricia J. DeCoursey, Chronobiology: Biological time keeping, Sinauer Associates, Inc. Publishers, First Edition, December 2009. 2. D.S. Saunders, Insect clocks, Elsevier science & Technology, Third Edition, November 2002

BIO 4012: Host-Pathogen Interactions [3 0 0 3]	
Prerequisites	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].

BIO 4012: Host-Pathogen Interactions [3 0 0 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] • Infection of the human host: Gastrointestinal Infections, Respiratory infections, CNS infections, and organ infections [4].
Text & Reference Books	1. Gerald Karp, Cell Biology, WILEY (Feb. 4th, 2013) 2. Wayne M. Becker et al., World of the Cell; Benjamin Cummings; 7th edition (February 19, 2008) 3. Bruce Alberts et al., Essential Cell Biology; Richard Goldsby and Thomas J, &F/Garland, 4th Edition, (2014) 4. Kindt, Kuby, Immunology, W. H. Freeman; 6th edition (9 October 2006)

BIO 4014: Evolutionary Ecology [3 0 0 3]	
Prerequisites	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	• Prey-predator coevolution: 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; Experimental methods to study anti-predatory adaptations; Phenotypic plasticity versus adaptations in anti-predatory strategies. Anti-herbivory strategies in plants (constitutive and induced defenses, secondary metabolites). [20] • 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 tectonics and its impact on diversification; Importance of dispersal for diversification [2] • Macroevolutionary patterns and Phylogenetic Comparative Methods: Types of Macroevolutionary patterns - adaptive radiations, convergent evolution, etc; Mechanisms of adaptive radiations; Testing evolutionary hypotheses using phylogenies; Importance of taking into account phylogenetic non-independence; Order of origin of traits; Correlations across traits, Diversification rates; Key innovations and evolutionary dead ends. [6]

BIO 4014: Evolutionary Ecology [3 0 0 3]	
	• Coevolution: Coevolution as a driver of diversification [2] • 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 [2]
Text & Reference Books	1. Avoiding Attack - The Evolutionary Ecology of Crypsis, Aposematism and Mimicry. By Graeme D. Ruxton, William L. Allen, Thomas N. Sherratt and Michael P. Speed. Oxford University Press 2. Developmental Plasticity and Evolution. By Mary Jane West-Eberhard, Oxford University Press 3. Evolution. By Douglas J. Futuyma and Mark Kirkpatrick. Oxford University 4. Modern Phylogenetic Comparative Methods and Their Application in Evolutionary Biology: Concepts and Practice. Edited by Lszl Zsolt Garamszegi. 5. Sensory Ecology: How organisms acquire and respond to information. By David B Dusenbery. Freeman and Co. USA

BIO 4015: Advances in Plant Biology [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	Students will learn the cutting edge of dynamics of molecular and cellular mechanisms underlying morphodynamics in plants. The course offers the possibility to learn integrating how internal cues respond to changes in external inductive cues in plants, which continuously get exposed to fluctuating environmental conditions throughout their growth phase.
Syllabus	• 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]
Text & Reference Books	1. Leyser, O. and Dey, S. (2009) Mechanisms in Plant Development. John Wiley & Sons.

BIO 4016: Laboratory Animal Science [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	The aim of the course is to make the students aware of the applications of laboratory animals in biological research. After the course, the students should be able to make informed decisions on the

BIO 4016: Laboratory Animal Science [3 0 0 3]	
	selection of animal models for specific research questions. The students will know what are the humane ways to handle the animals and the related ethical and legal issues. The students will be taught about the basic biology of common laboratory animals including phyisological, genetic, immunological and nutritional aspects, among others. The course will also impart knowledge on the ideal conditions to breed, maintain animals in the best of health conditions, and perform animal experimentation such as injections, sampling, anaesthesia etc. Importantly, the students will receive knowledge about Indian laws and legal structures for obtaining permissions regarding the use of animals in laboratory research.
Syllabus	Introduction to Laboratory Animal Sciences [4] • What is a laboratory animal? • History and development of laboratory animal sciences as a discipline • Classification of laboratory animals • Macro (housing) and micro (caging) environment of laboratory animals • Laboratory animal identification and nutrition • General principles of laboratory animal breeding Biology of laboratory animals other than mouse and rat [4] • Guinea pig and rabbit, Rodents other than rat and mouse • Mammalian domestic animal species, Wild animal species • Non mammalian vertebrate species • Invertebrates species Laboratory mouse and rat [9] • Biology and behaviour • Nutrition and housing • Reproductive biology and breeding • Genetics: strains and stocks • Transgenics and nomenclature • Phenotyping and genotyping Animal models in basic and translational research [8] • Comparative anatomy and physiology • Use of laboratory animals in fundamental, applied and translational research • Factors that influence research data • Animals as models of human diseases • Laboratory Animal Technology [9] • Handling and restraint of animals • Routes of administration of experimental agents • Surgical techniques in animal experiments • Animal experiment designs and data collection and analysis methods • Collection of tissues and body fluids • Non-invasive animal experiment techniques • Anaesthesia, analgesia and euthanasia Laboratory Animal Welfare [6] • Ethics in use of animals for research • Animal welfare activism • Principles of 3Rs in animal experimentation • Enrichments in laboratory animal housing and nutrition • Invasiveness of animal experiments

BIO 4016: Laboratory Animal Science [3 0 0 3]	
	• Laboratory animal welfare laws and regulations
Text & Reference Books	1. Bayne K, Turner P (2014), Laboratory Animal Welfare, Elsevier Inc. 2. Hedrich HJ (2012), The Laboratory Mouse (Second edition), Elsevier Inc. 3. Hubrecht R, Kirkwood J (2010) The UFAW Handbook on the Care and Management of Laboratory and Other Research Animals (Eighth Edition), CRC Press Inc. 4. Liu E, Fan J (2020/2018) Fundamentals of Laboratory Animal Science, CRC Press Inc. 5. Suckow MA, Hankenson FC, Wilson RP, Foley PL (2020), The Laboratory Rat, Elsevier Inc. 6. Suckow MA, Stevensons KA, Wilson RP (2012), The Laboratory Rabbit, Guinea Pig, Hamster and Other Rodents, Elsevier Inc. 7. http://cpcsea.nic.in/Auth/index.aspx

BIO 4017: Biosafety and Regulation [3 0 0 3]	
Prerequisites	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 & Reference Books	1. Sasson A, Biotechnologies and Development, UNESCO Publications 2. Rajmohan Joshi (Ed.). 2006. Biosafety and Bioethics. Isha Books, Delhi. 3. DBT, India Biosafety guidelines: http://dbtindia.gov.in/guidelines-biosafety

BIO 4022: Biological Image processing using Python [2 0 0 2]	
Prerequisites	NA
Learning Outcomes	Infuse quantitative thinking in biology students by combining scripting with image and data analyses in biology
Syllabus	• Basic scripting using Python: indexing numpy arrays, for loops, conditional statements masks. [2] • Electronic images: image acquisition, representation and display. [2] • Image handling basics: reading-writing images, multipage tiffs, etc., intensity value composition. [2]

BIO 4022: Biological Image processing using Python [2 0 0 2]	
	• Optical microscopy: Point-spread-function, Image formation • Image formation: Deconvolution. [2] • Fluorescence: fluorophores & fluorescent proteins, photophysical properties, filters. [2] • Single molecule imaging: diffraction-limited image, TIRF microscopy, single-molecule imaging. [2] • Tracking movement of particles tracking: trackpy, linking. [2] • Image segmentation: obtain a binding curve with microtubule-binding proteins. [2] • Image segmentation, morphometry: using the cellpose neural network for segmentation; DNA-based segmentation. [2] • Intensity measurements: image corrections, Application to the cell-cycle protein Cyclin B. [2] • FRET measurement: FRET sensors, sensitized emission measurement to compare FRET. [2]
Text & Reference Books	1. Rafael C. Gonzalez, Richard Eugene Woods, Digital Image Processing, Prentice Hall, 2002 2. Kenneth R. Castleman, Digital Image Processing, Prentice Hall, 1996

BIO 4023: Bacterial Communication and Pathogenesis [2 0 0 2]	
Prerequisites	NA
Learning Outcomes	▪ Understanding of fundamental concepts in microbe-host interactions including antibiotic action, microbial communication and sensing. ▪ This is important to understand immunology and pathogenicity of host-microbe interactions.
Syllabus	• Fascinating world of Microbiology: History of Microbiology, Introduction of Golden Era of Microbiology, Debate over Spontaneous Generation Vs Abiogenesis, Introduction to bacteria, Archaea and Viruses, Koch's and River's Postulate. [1] • Bacterial Cell Wall Structure and Function and Protein secretion system in bacteria: Gram positive and Gram negative, bacterial cell wall architecture, Peptidoglycan composition, Bacterial cytoskeletal elements, Bacterial division mechanism, Mechanism of Antibiotic action and development of AMR, Protein secretion system. [4] • Bacterial Quorum sensing: Concept of Bacterial Quorum sensing, History of Quorum Sensing, Molecules involved in bacterial communication, programmed cell death in bacterial, Hierarchical quorum, sensing system in Pseudomonas, Genetics of Quorum sensing. [4] • Intracellular lifestyles of Bacteria: Concepts of Intracellular and Extracellular pathogens, Secretion system in Intracellular bacteria, Immune evasion strategies in bacteria- Salmonella, Mycobacterium, Helicobacter pylori. [4] • Innate Immune sensors for pathogen recognition: TLR, NLR innate immune sensing mechanism in mammalian system, PAMPS recognised by the innate immune system, Evasion of the Innate immune system by bacteria and viruses. [4] • Antigen presentation and Dendritic cell cultures: Details about the discovery of Dendritic cells, long term dendritic cells in Culture, Antigen presentation by Dendritic cells. [4]
Text & Reference Books	1. Joanne M. Willey (Author), Lansing M. Prescott (Author), Kathleen M. Sandman (Author), Dorothy H. Wood, Prescott's microbiology, McGraw-Hill Education, New York, NY, 11th Edition, 2020.

BIO 4023: Bacterial Communication and Pathogenesis [2 0 0 2]	
	2. Michael T. Madigan, CarbondaleKelly S. Bender, Daniel H. Buckley W Matthew Sattley, David A. Stahl, Brock Biology of Microorganisms, Pearson, 15th edition, 2020

BIO 4024: Population Genetics [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	The course will offer an introduction to the quantitative foundations of population genetics. It will also discuss several intermediate-level nuances within the field and help the students understand the mechanisms behind evolutionary change in quantitative terms. The course also offers several simulations that will help the students visualize many theoretical notions in population genetics.
Syllabus	• Allele and Genotype Frequencies: An introduction to basic terminology in population genetics; the Hardy-Weinberg equilibrium; making sense of data from real populations using the Hardy-Weinberg equilibrium. (Supplemented with simulation sessions using R to discuss real-world examples) [5] • Genetic variation: Randomness in evolution; the neutral theory of molecular evolution; levels of genetic diversity within populations; the concept of allele fixation; fixation probabilities; fixation index and the loss of variation; key differences between asexual and sexual reproduction; mutation-driven evolution. (Supplemented with simulation sessions using R) [12] • Adaptation and natural selection: Non-random shifts in allele frequencies; weak and strong selection; the effect of selection on allele vs. genotype frequencies; selection strength and population size; selection coefficients; dominance, underdominance, and overdominance. Multilocus population genetics; epistasis; magnitude versus sign epistasis. (Supplemented with simulation sessions using R). [13] • Key theories in population genetics: Fisher's fundamental theorem of natural selection; Price's equation; Fisher's geometrical model. (Supplemented with discussions of relevant published articles based on these ideas.) [10]
Text & Reference Books	1. Láruson, Á. J., and F. A. Reed. 2021. Population Genetics with R: An Introduction for Life Scientists. Oxford University Press. 2. Weinreich, D. M. 2023. The foundations of population genetics. The MIT Press, Cambridge, Massachusetts. 3. Nielsen, R., and M. Slatkin. 2013. An introduction to population genetics: theory and applications. Sinauer Associates, Sunderland, Massachusetts.

BIO 5011: Advanced Developmental Biology [3 0 0 3]	
Prerequisites	BIO323: Cell Biology and BIO 324: Molecular Biology
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

BIO 5011: Advanced Developmental Biology [3 0 0 3]	
	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. Mode of teaching and evaluation:
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] • Cell Polarity in development and changes in cell polarity [2] • Development and behavior [2] • New molecular tools in development [2]
Text & 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

BIO 5013: Cancer Biology [3 0 0 3]	
Prerequisites	BIO 322, BIO 323, 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

BIO 5013: Cancer Biology [3 0 0 3]	
	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 & 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

BIO 5014: Scientific Writing [3 0 0 3]	
Prerequisites	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.
Syllabus	• Writing manuscripts for journals [4] • Effective oral presentations (seminars, conferences, popular talks) [4] • Popular science writing [4]

BIO 6011: Research Methodology [1 0 0 1]	
Prerequisites	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]

BIO 6011: Research Methodology [1 0 0 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]
Text & 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

CHEMICAL SCIENCES

CURRICULUM FOR

BS-MS (SEM: 4 - 10)

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

CORE & ELECTIVE COURSES

BS-MS Courses

Semester 4	Semester 5	Semester 6	Semester 7	Semester 8
CHY 221 [3003] Chemistry of Biomolecules and Heterocycles	CHY 321 [3003] Organometallic Chemistry	CHY 411 [3003] Main Group Chemistry	*CHY 421 [3003] Advanced Organic Chemistry-II	*CHY 521 [3003] Physical Organic Chemistry
CHY 311 [3003] Coordination Chemistry	CHY 322 [3003] Bioinorganic Chemistry	CHY 412 [3003] Advanced Organic Chemistry-I	*CHY 422 [3003] Solid-State Chemistry	*CHY 522 [3003] Frontiers in Inorganic Chemistry
CHY 312 [3003] Organic Chemistry - Reactions and Mechanisms	CHY 323 [3003] Organic Chemistry- Synthetic Methods	CHY 413 [3003] Chemical and Statistical Thermodynamics	*CHY 423 [3003] Advanced Quantum Chemistry	*CHY 523 [3003] Chemical Kinetics and Dynamics
CHY 313 [3003] Quantum Chemistry	CHY 324 [3003] Theoretical Spectroscopy	CHY 414 [3003] Instrumental Methods for Structure Determination	DSE [3003] CHY 5XXX	**DSE** [3003] CHY 5XXX
CHY 314 [3003] Physical Chemistry-II	CHY 325 [0093] Advanced Chemistry Lab I (Inorganic & Physical Lab)	CHY 415 [0093] Advanced Chemistry Lab II (Organic & Physical Lab)	CHY 424 [0093] Advanced Chemistry Lab III (Inorganic & Organic Lab)	Project (12)
GE	**GE**	**GE**	**GE + GE**	

- In each of these semesters 7 and 8, students must credit two out of three starred courses shown in the table.

I2C Courses

Semester 4	Semester 5	Semester 6	Semester 7	Semester 8
CHY 221 [3003] Chemistry of Biomolecules and Heterocycles	CHY 321 [3003] Organometallic Chemistry	CHY 411 [3003] Main Group Chemistry	CHY 421 [3003] Advanced Organic Chemistry-II	CHY 521 [3003] Physical Organic Chemistry
CHY 311 [3003] Coordination Chemistry	CHY 322 [3003] Bioinorganic Chemistry	CHY 412 [3003] Advanced Organic Chemistry-I	I2C 411 [3003] Soft Matter and Polymers	I2C 521 [3003] Pharmacology and Pharmacokinetics
CHY 312 [3003] Organic Chemistry-Reactions and Mechanisms	CHY 323 [3003] Organic Chemistry-Synthetic Methods	CHY 414 [3003] Instrumental Methods for Structure Determination	I2C 412 [3003] Computational Chemical Biology	DSE [3003] CHY 5XXX
CHY 313 [3003] Quantum Chemistry	I2C 311 [3003] Medicinal Chemistry	I2C 322 [3003] Enzymology and Biocatalysts	I2C 413 [3003] Biomaterials	Project (12)
CHY 314 [3003] Physical Chemistry-II	CHY 325 [0093] Advanced Chemistry Lab I (Inorganic & Physical Lab)	CHY 415 [0093] Advanced Chemistry Lab II (Organic & Physical Lab)	I2C 414 [0093] Chemical Biology Lab	
BIO 313 [3003] Biochemistry	I2C 312 [3003] Biophysical Chemistry	BIO 323 [3003] Molecular Biology	DSE [3003] CHY 5XXX	

Minor Courses (General Electives)

Semester	Code	Title
IV	CHY 2201	Chemistry of Biomolecules and heterocycles
V	CHY 3202	Bioorganic Chemistry
VI	CHY 3104	Physical Chemistry II
VII	CHY 4103	Biomaterials
	CHY 4202	Solid State Chemistry

Elective Courses

Organic Chemistry	Inorganic Chemistry	Physical Chemistry	GE Courses
CHY 5XXX [3003] Name Reactions and Rearrangements - Application in Organic Synthesis	CHY 5XXX [3003] Biomaterials	CHY 5XXX [3003] Computational Chemistry	CHY 2201 [3003] Chemistry of Biomolecules and Heterocycles [3003]
CHY 5XXX [3003] Catalysis in Organic Synthesis	CHY 5XXX [3003] Inorganic Rings, Chains and Polymers	CHY 5XXX [3003] Symmetry and Group Theory in Chemistry	CHY 3202 [3003] Bioinorganic Chemistry
CHY 5XXX [3003] Chemistry of Natural Products	CHY 5XXX [3003] Main Group Catalysis	CHY 5XXX [3003] Advanced Electrochemistry	CHY 3104 [3003] Physical Chemistry-II
CHY 5XXX [3003] Modern Organic Synthesis	CHY 5XXX [3003] Applied Organometallic Chemistry	CHY 5XXX [3003] Ultrafast Spectroscopy	CHY 4103 [3003] Biomaterials
CHY 5XXX [3003] Organic Solid-State Chemistry	CHY 5XXX [3003] Advanced Materials Chemistry	CHY 5XXX [3003] Batteries, Fuel cells, and Electrolyzers	CHY 4202 [3003] Solid-State Chemistry
CHY 5XXX [3003] Supramolecular Chemistry	CHY 5XXX [3003] Advanced Main Group Chemistry	CHY 5XXX [3003] Fundamentals of Solution-State NMR Spectroscopy: Principles and Applications	
CHY 5XXX [3003] Nanotechnology: Basic Principles and Applications		CHY 5XXX [3003] Molecular Dynamics Simulations	
CHY 5XXX [3003] Photocatalysis in Organic Synthesis		CHY 5XXX [3003] Advanced Optical Spectroscopy	

BS-MS Courses

CHY 221/CHY 2201: Chemistry of Biomolecules and Heterocycles [3 0 0 3]	
Prerequisites	CHY 111 and CHY 211
Learning Outcomes	Upon completion of the course the students will have knowledge about the structures, syntheses, reactions and properties of heterocyclic compounds, carbohydrates and amino acids.
Syllabus	• Systematic nomenclature of heterocyclic compounds: Three-membered heterocycles; four-membered heterocycles; five-membered heterocycles; six-membered heterocycles; seven-membered heterocycles. [6] • Structure, preparation, properties and reactions of common aromatic heterocyclic compounds containing one or two heteroatoms O, N, and S like furan, pyrrole, thiophene, pyridine, indole, quinoline and isoquinoline. [14] • Carbohydrate chemistry: Structure, nomenclature, properties and reactions of mono- and di-saccharides: protection-deprotection; anomeric effect, mutarotaion, oxidation, reduction, osazone formation; Kiliani-Fischer synthesis and Ruff degradation. [10] • Synthesis, nomenclature and properties of natural amino acids; acid-base properties of amino acids - isoelectric point; determination of N-terminal and C-terminal amino acids; methods for the preparation of dipeptides and tripeptides. [10]
Text & Reference Books	1. Heterocyclic Chemistry - 5th Edition, John Joule and Kenneth Mills, Wiley-Blackwell 2010 2. M. Loudon and J. Parise, Organic Chemistry, 6ed., W. H. Freeman and Company, 2016. 3. David L. Nelson, and Michael M. Cox. 2017. Lehninger Principles of Biochemistry. 7th ed. NewYork, NY: W.H. Freeman. 4. I. L. Finar, Organic Chemistry, Volume 2: Stereochemistry and the Chemistry Natural Products, 5ed., Pearson, 2002.

CHY 311: Coordination Chemistry [3 0 0 3]	
Prerequisites	CHY 111 and CHY 211
Learning Outcomes	This course covers theories of structure and bonding in coordination complexes including the perspective of applications of group theory. The course also incorporates electronic spectra, magnetism, and various reactions of coordination compounds.
Syllabus	• Applications of group theory: Brief definition of terminologies with examples (symmetry, symmetry elements and symmetry group); classes of operations and similarity transformations; reducible and irreducible representations; construction of character tables for point groups; applications of group theory in molecular vibrations and molecular orbital diagram construction of H2O, NH3, nitrite, and nitrate/carbonate/BF3. [14] • Bonding, electronic spectra, and properties: Classification of ligands; σ-type, π-type, δ-type interactions in transition metal complexes; ligand field theory and MO theory of transition metal complexes in various geometries such as octahedral, tetrahedral, square

CHY 311: Coordination Chemistry [3 0 0 3]	
	planar, and trigonal bipyramidal; electronic spectra of compounds, spectroscopic term symbols, selection rules, Tanabe-Sugano diagram, and charge transfer bands. [14] • Magnetism of coordination complexes: Magnetic susceptibility and magnetic moment; spin-orbit coupling; ferromagnetism and antiferromagnetism; anomalous magnetic moment; thermal effects; single molecular magnets. [2] • Reactions of coordination Compounds I: Mechanism and stereochemistry of associative and dissociative ligand substitution reactions in square-planar and octahedral complexes (including kinetics of ligand substitution reaction, ligand field effect); ligand centered reactions. [5] • Reactions of coordination Compounds II: Electron transfer reactions (outer–sphere and inner–sphere reactions) and photochemical reaction of coordination complexes. [5]
Text & Reference Books	1. F. A. Cotton, Chemical Applications of Group Theory, 3ed; Wiley, 2010. 2. Y. Jean, Molecular Orbitals of Transition Metal Complexes, Oxford press, 2005. 3. S. F. A. Kettle, Physical Inorganic Chemistry – A Coordination Chemistry Approach, Springer, 1996. 4. K. F. Purcell and J. C. Kotz, Inorganic Chemistry, Cengage, 2017. 5. P. Atkins, T. Overton, J. Rourke, F. Armstrong, and M. Hagerman, Shriver and Atkins' Inorganic Chemistry, 5ed, W. H. Freeman and Company New York, 2009. 6. G. L. Miessler and D. A. Tarr, Inorganic Chemistry, 3ed, Pearson, 2008. 7. J. E. House, Inorganic Chemistry, 3ed, Academic Press, 2019. 8. B. Douglas, D. McDaniel, and J. Alexander, Concepts and Models of Inorganic Chemistry, 3ed, Wiley, 2001. 9. J. E. Huheey, E. A. Keiter, and R. L. Keiter, Inorganic Chemistry – Principles of Structure and Reactivity, 4ed, Pearson Education, 2006. 10. R. L. Dutta and A. Syamal; Elements of Magnetochemistry, 2ed, Affiliated East-West Press, 2004.

CHY 312: Organic Chemistry - Reactions and Mechanisms [3 0 0 3]	
Prerequisites	CHY 111 and CHY 211
Learning Outcomes	The course will cover various aspects of organic reaction mechanisms with emphasis on the structure and reactivity of reactive intermediates. The topics covered will also include molecular rearrangements and carbonyl chemistry.
Syllabus	• Reactive Intermediates: Structure, stability and reactivity of carbocations (classical and non-classical carbocation, sigma and π-participation), neighboring group participation; carbanions (homoenolate anion, etc.); free radicals (electrophilic and nucleophilic radicals, radical cations, radical anions); carbenes and carbenoids; nitrenes; benzyne. [11] • 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, Favorskii, Fries, Baeyer-Villiger, Dakin;

CHY 312: Organic Chemistry - Reactions and Mechanisms [3 0 0 3]	
	rearrangements involving migration from nitrogen to ring carbon such as Hoffman-Martius, Fischer-Hepp, Bamberger, Orton, benzidine, etc. [9] • Chemistry of carbonyl compounds: Nucleophilic addition to the carbonyl group (cyanohydrin, hemiacetal, acetal, dithiane, imine & enamine); formation of enols and enolates - catalyzed by acids and bases, silyl enol ethers, generation of thermodynamic vs kinetically-controlled enolates; reactions of enolates - α-alkylation of carbonyl compounds including dianions, alkylation using acyl anion equivalent such as dithiane; C-alkylation vs O-alkylation; reactions of enamine. [10] • Aldol and Mukaiyama aldol reaction, Mannich reaction, Henry reaction, Knoevenagel-Stobbe condensation, Claisen-ester condensation, Dieckmann condensation, Darzens reaction, acyloin condensation, Reformatsky reaction, Wittig and Horner-Emmons reactions, Baylis-Hillman reaction. [7] • Conjugate additions to α,β-unsaturated systems; direct addition versus conjugate addition; Robinson annulation. [3]
Text & Reference Books	1. a) F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part A: Structure and Mechanisms, 5ed., Springer, 2008., b) F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part B: Reaction and Synthesis, 5ed., Springer, 2008. 2. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2ed., Oxford University Press, 2012. 3. R. Bruckner, Advanced Organic Chemistry, Reaction Mechanisms, 3ed., Springer, 2010. 4. W.S. Carruthers and I. Coldham, Modern Methods of Organic Synthesis, 4ed., Cambridge University Press, 2004. 5. C. M. Rojas, Molecular Rearrangements in Organic Synthesis, 1st Ed., Wiley (2015)

CHY 313: Quantum Chemistry [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	▪ To provide an understanding of the basic formalisms of quantum theory involving the operator approach ▪ To equip the students with the techniques of obtaining solutions to the Schrödinger equation for exactly-solvable model systems ▪ To appreciate the need to adopt approximation methods for the description of many-electron systems and beyond
Syllabus	• Formal Development of Quantum Mechanics: Operators in quantum mechanics, postulates of quantum mechanics, Born interpretation, properties of Hermitian operators [4] • 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 [4] • 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 [4]

CHY 313: Quantum Chemistry [3 0 0 3]	
	• 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 [4] • Scattering state solutions, harmonic oscillator, building up of the solutions from the recursion relations of Hermite polynomials [4] • 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 [4] • Electronic Spectroscopy of Atoms: Orbital picture of electronic energy levels, derivation of selection rules based on the components of the transition moment integrals [4] • Fine structure and hyperfine structure in the atomic spectra [4] • Coupling of orbital and spin angular momenta, term symbols, concepts of microstates, Stark and Zeeman effects, and Hund's rules [6]
Text & Reference Books	1. P. Atkins and R. Friedman, Molecular Quantum Mechanics, 5th Ed., Oxford University Press (2011). 2. I. N. Levine, Quantum Chemistry, 7th Ed., Pearson (2016). 3. T. Engel, Quantum Chemistry and Spectroscopy, 3rd Ed., Pearson (2006). 4. J. P. Lowe and K. A. Peterson, Quantum Chemistry, 3rd Ed., Elsevier Academic Press (2006). 5. D. A. McQuarrie, Quantum Chemistry, Viva Student Edition, Viva (2011). 6. F. L. Pilar, Elementary Quantum Chemistry, 2nd Ed., Dover Publications (2001).

CHY 314/CHY 3104: Physical Chemistry II [3 0 0 3]	
Prerequisites	CHY 121
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	• Ionics: Fundamentals of Electrochemistry, Faradaic and Non-faradaic process, Electrical double layer, Electrical energy, Nernst equation, electrochemical cells [4] • Electrolytic conductance, Kohlrausch's law, conductometric and potentiometric titrations [4] • Electrochemical potential, liquid junction potential, ion-selective electrodes [4] • Debye-Hückel theory, activity coefficients, extended Debye-Hückel law and Onsager limiting law [4] • Electrodics: Electrochemical cells and reactions, Arrhenius and transition state theory, One-electron transfer reactions, Butler-Volmer equation mass transfer-controlled reactions, [4] • Tafel equation, multistep electrode reactions, Marcus theory of microscopic model [4] • Electrochemical Methods: polarography, linear sweep voltammetry, cyclic voltammetry, chronoamperometry, chronopotentiometry [4]

CHY 314/CHY 3104: Physical Chemistry II [3 0 0 3]	
	• Surfaces: Physisorption and chemisorption, Langmuir adsorption isotherm, Brunauer-Emmett-Teller (BET) equation, Freundlich adsorption isotherm, estimation of surface area [4] • 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 and microemulsions [4] • 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 Edition (2004). 2. S. Glasstone, An Introduction to Electrochemistry, Franklin Classics Trade Press (2018). 3. P. Atkins, J. de Paula and J. Keeler, Atkins' Physical Chemistry, 11th Ed., Oxford University Press (2018). 4. G. W. Castellan, Physical Chemistry, 3rd Ed., Narosa Publishing House (2004).

CHY 321: Organometallic Chemistry [3 0 0 3]	
Prerequisites	CHY 311
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] • Metal–ligand multiple bonds: Fischer and Schrock type carbene complexes, carbyne complexes, and metal–heteroatom (O/N) multiple bonds. [4] • 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] • Complexes with metal–H/C sigma bonds: Synthesis, bonding, and reactivity patterns of metal–dihydrogen, metal–alkane, metal–hydride, metal–C(sp3), metal–C(sp2), 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. [6]

CHY 321: Organometallic Chemistry [3 0 0 3]	
	• Catalysis: Mechanism driven catalyst/ process developments for various catalytic transformations such as carbonylation, alkene hydrofunctionalization, deuteration reaction, coupling reactions, alkene/ alkyne metathesis, alkene polymerization, and C–H functionalization. [10]
Text & Reference Books	1. R. H. Crabtree, The Organometallic Chemistry of the Transition Metals, 6ed, Wiley, 2013. 2. J. Hartwig, Organo-transition Metal Chemistry: From Bonding to Catalysis, University Science Books, 2010. 3. B. D. Gupta and A. J. Elias, Basic Organometallic Chemistry: Concepts, Syntheses and Applications, 2ed, Universities Press, 2013. 4. G. L. Miessler and D. A. Tarr, Inorganic Chemistry, 3ed, Pearson, 2008. 5. B. Douglas, D. McDaniel, and J. Alexander, Concepts and Models of Inorganic Chemistry, 3ed, Wiley, 2010.

CHY 322/CHY 3202: Bioinorganic Chemistry [3 0 0 3]	
Prerequisites	CHY 111 and CHY 211
Learning Outcomes	The course focuses on the role of alkali as well as transition metals in various essential biological processes. This course also includes the mechanistic illustrations of the chemical transformations at the biological active sites.
Syllabus	• Overview of ligands, essential and trace metal ions in biological systems [1] • Redox-noninnocence ligands: Concept of the redox activity of ligands with examples. [2] • Oxygen binding and O-O bond activating metalloproteins: Structure and function (including mechanism) of haemoglobin, myoglobin, hemocyanin, hemerythrin, cytochrome P-450, cytochrome c oxidase, catalase, peroxidase, NO-synthase, rieske dioxygenase, tyrosinase, ascorbate oxidase, galactose oxidase, superoxide dismutase etc. [15] • Electron transport proteins: Fe-S proteins, cytochromes, and type 1 copper proteins. [3] • Photosynthesis and water oxidation: Photosystems and oxygen evolving complex. [2] • Nitrogenase and nitrogen-cycle enzymes: Nitrogen fixation FeMoCo cofactor; various oxidoreductases involved in NOx transformations. [5] • Hydrogenase: FeFe, NiFe, and Fe-only hydrogenase active sites and their importance. [3] • Metalloenzymes with redox-neutral metal sites: Carbonic anhydrase, carboxypeptidase, DNA and RNA polymerases. [2] • Function and transport of alkali and alkaline earth metal ions: Na+, K+ ion transports, ion channels and ion pumps in biological systems. [1] • Carbon, sulfur, and phosphorus cycles. [2] • Biological functions of early transition metals (Mo, W, V, Cr). [1] • Application of bioinorganic chemistry – therapeutic and diagnostic aspects. [3]

CHY 322/CHY 3202: Bioinorganic Chemistry [3 0 0 3]	
Text & Reference Books	1. W. Kaim and B. Schwederski, Bioinorganic Chemistry: Inorganic Elements in the Chemistry of Life, 2ed, Wiley, 2013. 2. R. R. Crichton, Biological Inorganic Chemistry - An Introduction, Elsevier, 2008.

CHY 323: Organic Chemistry - Synthetic Methods [3 0 0 3]	
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. The transformations of carbonyl compounds, focusing on strategies to control the stereochemistry of these reactions will also be covered. Stereochemical problems related to chemical reactions will be dealt with in detail.
Syllabus	• Specific rotation, optical purity (enantiomeric excess), racemization (through cationic, anionic and radical intermediates); kinetic resolution and dynamic kinetic resolution. [4] • 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. [4] • Dynamic stereochemistry: Effect of conformation on reactivity of acyclic and cyclic molecules dealing with SN1, SN2, SN2' reactions and neighbouring group participation; E2 and syn-eliminations; oxidation of alcohols; enols and enolates; electrophilic addition to alkenes; nucleophilic addition to enones. [8] • Oxidation: Oxidations involving sulfur (such as Kornblum, Swern, Parikh-Doering, etc.); Cr, Mn, and Ru based reagents; Dess-Martin, and IBX oxidations; Ag2CO3/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 OsO4, 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. [13] • 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 (McMurry coupling); discussions with emphasis on chemo-, regio-, and stereoselectivities. [11]
Text & Reference Books	1. D. Nasipuri, Stereochemistry of Organic Compounds-Principle and Applications, 4 Revised Ed., New Academic Science, 2012. 2. E. L. Eliel, S. H. Wilen and L. N. Mander, Stereochemistry of Carbon Compounds, 1ed., Wiley, 2010. 3. W.S. Carruthers and I. Coldham, Modern Methods of Organic Synthesis, 4ed., Cambridge University Press, 2004.

CHY 323: Organic Chemistry - Synthetic Methods [3 0 0 3]	
	4. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2ed., Oxford University Press, 2012. 5. H.O. House, Modern Synthetic Reactions, 2 Revised ed., Benjamin-Cummings Publishing, 1972. 6. R. Bruckner, Advanced Organic Chemistry, Reaction Mechanisms, 3ed., Springer, 2010. 7. a) F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part A: Structure and Mechanisms, 5th Ed., Springer, 2008., b) F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part B: Reaction and Synthesis, 5ed., Springer, 2008.

CHY 324: Theoretical Spectroscopy [3 0 0 3]	
Prerequisites	CHY 313
Learning Outcomes	The course focuses on the role of alkali as well as transition metals in various essential biological processes. This course also includes the mechanistic illustrations of the chemical transformations at the biological active sites.
Syllabus	• Overview of ligands, essential and trace metal ions in biological systems [1] • Redox-noninnocence ligands: Concept of the redox activity of ligands with examples. [2] • Oxygen binding and O-O bond activating metalloproteins: Structure and function (including mechanism) of haemoglobin, myoglobin, hemocyanin, hemerythrin, cytochrome P-450, cytochrome c oxidase, catalase, peroxidase, NO-synthase, rieske dioxygenase, tyrosinase, ascorbate oxidase, galactose oxidase, superoxide dismutase etc. [15] • Electron transport proteins: Fe-S proteins, cytochromes, and type 1 copper proteins. [3] • Photosynthesis and water oxidation: Photosystems and oxygen evolving complex. [2] • Nitrogenase and nitrogen-cycle enzymes: Nitrogen fixation FeMoCo cofactor; various oxidoreductases involved in NOx transformations. [5] • Hydrogenase: FeFe, NiFe, and Fe-only hydrogenase active sites and their importance. [3] • Metalloenzymes with redox-neutral metal sites: Carbonic anhydrase, carboxypeptidase, DNA and RNA polymerases. [2] • Function and transport of alkali and alkaline earth metal ions: Na+, K+ ion transports, ion channels and ion pumps in biological systems. [1] • Carbon, sulfur, and phosphorus cycles. [2] • Biological functions of early transition metals (Mo, W, V, Cr). [1] • Application of bioinorganic chemistry – therapeutic and diagnostic aspects. [3]
Text & Reference Books	1. W. Kaim and B. Schwederski, Bioinorganic Chemistry: Inorganic Elements in the Chemistry of Life, 2ed, Wiley, 2013. 2. R. R. Crichton, Biological Inorganic Chemistry - An Introduction, Elsevier, 2008.

CHY 411: Main Group Chemistry [3 0 0 3]	
Prerequisites	CHY 111 and CHY 211
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. [3] • s-block elements: Alkali metal solutions in liquid ammonia, oxides, hydroxides, nitrides, halides, and oxoacids; crown ether and cryptand complexes; organometallic compounds of Li, Na, Be, Mg and Ca. [5] • Boron group: Structure and bonding of diborane, higher boranes, and borohydrides; mno-Jemmis and 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; zintl compounds. [9] • 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; silicon based polymers. [7] • Pnictogens: N2 and P4 activation; oxides of nitrogen and phosphorus; pnictogen halides; representative examples of phosphazenes, rings and clusters. [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. [4] • 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. [4] • Noble gases: Occurrence and chemical properties, Bartlett's discovery of reactivity of noble gases; synthesis, structure, and reactivity of fluorides and oxides of xenon. [2]
Text & Reference Books	1. P. Atkins, T. Overton, J. Rourke, F. Armstrong, and M. Hagerman, Shriver and Atkins' Inorganic Chemistry, 5ed, W. H. Freeman and Company New York, 2009. 2. N. N. Greenwood, A. Earnshaw; Chemistry of the Elements, 2ed, Elsevier, 1997. 3. F. A. Cotton, G. Wilkinson, C. A. Murillo, and M. Bochmann, Advanced Inorganic Chemistry, 6ed, Wiley, Wiley. 4. A. J. Elias; The Chemistry of p-Block Elements: Synthesis, Reactions, and Applications, 2ed, Universities Press, 2019. 5. J. E. House; Inorganic Chemistry, 3ed, Academic Press, 2019.9. J. E. Huheey, E. A. Keiter, and R. L. Keiter, Inorganic Chemistry – Principles of Structure and Reactivity, 4ed, Pearson Education, 2006.

CHY 412: Advanced Organic Chemistry-I [3 0 0 3]	
Prerequisites	CHY 312 and CHY 323

CHY 412: Advanced Organic Chemistry-I [3 0 0 3]	
Learning Outcomes	Advanced synthetic methods in organic chemistry will be covered in this course. Topics include thermal and photochemical pericyclic reactions and their synthetic applications, asymmetric synthesis..
Syllabus	• General aspects of pericyclic reactions: Frontier molecular orbitals of ethylene, 1,3-butadiene, 1,3,5-hexatriene and allylic system; classification of pericyclic reactions, conservation of orbital symmetry, and Woodward and Hoffmann rules; suprafacial and antarafacial processes. [4] • Electrocyclic reactions: Allowed and forbidden reactions; conrotatory and disrotatory motions of 4n and 4n+2 systems; torquoselectivity. [4] • Cycloaddition Reactions: [2+2] additions of alkenes and ketene, [4+2] cycloaddition - Diels-Alder reaction, hetero Diels-Alder reaction and inverse Diels-Alder reaction; [3+2]-cycloaddition – 1,3-dipolar addition reaction; [4,1]-Cheletropic reactions; regioselectivity and stereoselectivity in cycloaddition reaction. [10] • Sigmatropic rearrangements: [1,2], [1,3], [1,5], [2,3], [3,3]-sigmatropic rearrangements, including Claisen, Johnson-Claisen, Ireland-Claisen, Cope and oxy-Cope, Wittig rearrangements (both 1,2 and 2,3). [7] • Group transfer and ene-reaction [2] • Stereoselective 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 reactions. [13]
Text & Reference Books	1. I. Fleming, Pericyclic Reactions, 2ed., Oxford University Press, 2015. 2. W.S. Carruthers and I. Coldham, Modern Methods of Organic Synthesis, 4ed., Cambridge University Press, 2004. 3. F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part A: Structure and Mechanisms, 5th Ed., Springer, 2008., b) F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part B: Reaction and Synthesis, 5ed., Springer, 2008. 4. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2ed., Oxford University Press, 2012. 5. E. L. Eliel, S. H. Wilen and L. N. Mander, Stereochemistry of Carbon Compounds, 1ed., Wiley, 2010. 6. D. Nasipuri, Stereochemistry of Organic Compounds-Principle and Applications, 4 Revised ed., New Academic Science, 2012. 7. I. L. Finar, Organic Chemistry, Volume 2: Stereochemistry and the Chemistry Natural Products, 5ed., Pearson, 2002.

CHY 413: Chemical and Statistical Thermodynamics [3 0 0 3]	
Prerequisites	CHY 313
Learning Outcomes	To provide a molecular level interpretation of the bulk properties of chemical systems in terms of the concepts of probability theory.

CHY 413: Chemical and Statistical Thermodynamics [3 0 0 3]	
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 [4] • Macrostates, microstates, configurations, Boltzmann distribution, classical and quantum particles, and Stirling's approximation [4] • Ensembles and averages: Ergodic hypothesis, canonical ensemble, microcanonical ensemble, grand canonical ensemble [4] • Partition functions, equivalence of various ensembles, and fluctuations [4] • 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] • 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 [4] • 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 [4]
Text & Reference Books	1. D. A. McQuarrie, Statistical Mechanics, Viva Student Edition, Viva (2018). 2. D. Chandler, Introduction to Modern Statistical Mechanics, 1st Ed., Oxford University Press (1987). 3. T. L. Hill, An Introduction to Statistical Thermodynamics, 1st Ed., Dover Publications (1986). 4. D. A. McQuarrie and J. D. Simon, Molecular Thermodynamics, Viva Student Edition (2018). 5. H. B. Callen, Thermodynamics and an Introduction to Thermostatistics, 2nd Ed., Wiley (2006).

CHY 414: Instrumental Methods for Structure Determination [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	The course will deal with the applications and interpretations of major types of spectroscopy: absorption, infrared, nuclear magnetic resonance spectroscopy, and mass spectrometry. Moreover, this course will target 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]

<table>
<tr><th colspan="2">CHY 414: Instrumental Methods for Structure Determination [3 0 0 3]</th></tr>
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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]

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

R. M. Silverstein, F. X. Webster, D. J. Kiemle, and D. L. Bryce, Spectrometric Identification of Organic Compounds, 8ed., Wiley, 2014.
W. Kemp, Organic spectroscopy, 2ed., Macmillan, 2019.
L. D. Field, S. Sternhelland and J.R. Kalmann, Organic Structures from Spectra, 5ed., Wiley, 2012.
M. H. Levitt, Spin Dynamics, 2ed., Wiley, 2008.
S. Braun, H. O. Kalinowski and S. Berger, 150 and More Basic NMR Experiments, 2 Revised ed., Wiley-VCH, 1998.
D. Neuhaus and M. Williamson, The Nuclear Overhauser Effect in Structural and Conformational Analysis, 2ed., Wiley-Blackwell, 2008.
D. L. Pavia, G. M. Lampman, G. S. Kriz and J. A. Vyvyan, Introduction to Spectroscopy 5ed., Cengage, 2014.
R. S. Drago; Physical Methods in Inorganic Chemistry, Affiliated East-West Press, 2015.

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CHY 414: Instrumental Methods for Structure Determination [3 0 0 3]	
	9. L. Que, Jr.; Physical Methods in Bioinorganic Chemistry, University Science Books, 2000. 10. Encyclopedia of Inorganic and Bioinorganic Chemistry, Wiley, 2011.

CHY 421: Advanced Organic Chemistry-II [3 0 0 3]	
Prerequisites	CHY 323 and CHY 412
Learning Outcomes	Advanced synthetic methods in organic chemistry will be covered in this course. Topics include catalytic asymmetric methods (oxidation and reduction reactions), organosilicon and organosulfur chemistry, metal-mediated/catalyzed synthetic methods, organic photochemistry.
Syllabus	• Asymmetric synthesis: Sharpless epoxidation and dihydroxylation; Jacobsen-Katsuki and Shi epoxidation; CBS reduction, Midland-alpine borane reduction, Noyori asymmetric reduction. [10] • 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.) [6] • Transition metal-catalyzed reactions: Heck reaction, Stille, Kumada, Negishi, Suzuki, Sonogashira, Buchwald-Hartwig, and Chan Lam coupling; ring-closing, ring-opening and cross metathesis. [10] • Organic photochemistry: Energy and electronic spin states, spectroscopic transitions, photophysical processes, fluorescence and phosphorescence, energy transfer and electron transfer; photochemical reactions of carbonyl compounds, olefins, and aromatic compounds, including Norrish type I & II, Patterno-Buchi, and Barton reactions, Photo-Fries rearrangement, Di-□-methane and Oxadi-□-methane rearrangement; photochemistry of diazo compounds. [12] • Electron-Transfer reactions: Theoretical basis; examples of photo-induced and chemically induced electron transfer reactions (PET and CET). [2]
Text & Reference Books	1. W.S. Carruthers and I. Coldham, Modern Methods of Organic Synthesis, 4ed., Cambridge University Press, 2004. 2. F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part A: Structure and Mechanisms, 5th Ed., Springer, 2008., b) F. A. Carey and R. J. Sundberg, Advanced Organic Chemistry, Part B: Reaction and Synthesis, 5ed., Springer, 2008. 3. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2ed., Oxford University Press, 2012. 4. D. Nasipuri, Stereochemistry of Organic Compounds-Principle and Applications, 4 Revised ed., New Academic Science, 2012. 5. I. L. Finar, Organic Chemistry, Volume 2: Stereochemistry and the Chemistry Natural Products, 5ed., Pearson, 2002. 6. M. L. Crawley and B. M. Trost, Applications of Transition Metal Catalysis in Drug Discovery and Development: An Industrial Perspective; Wiley-VCH (2012).

CHY 421: Advanced Organic Chemistry-II [3 0 0 3]	
	7. D. O. Cowan and R. L. Drisko, Elements of Organic Photochemistry, 1ed., Plenum Press, 1976. 8. G. S. Cox, K. Dimroth, J. –F. Labarre, M. A. Paczkowski, M. B. Rubin and N. J. Turro, Photochemistry and Organic Synthesis, 1ed., Springer, 2005.

CHY 422/CHY 4202: Solid State Chemistry [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	The course aims to provide required knowledge for understanding material science problems. Initially, students are introduced to the structure of solids, crystal (dis)order and defects for materials properties. The electronic structure of crystals and the properties of materials are also included in this course.
Syllabus	• Solid state structure and structure determination: Types of solids, symmetry in crystals, X-ray diffraction, common crystal structure motifs, quasicrystals and structure determination. [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, 2ed, Wiley, 2014. 2. C. N. R. Rao and J. Gopalakrishnan, New Directions in Solid State Chemistry, 2ed, Cambridge University Press, 2010. 3. P. A. Cox, The Electronic Structure and Chemistry of Solids, Oxford Science Publications, 1987. 4. G. Gottstein, Physical Foundation of Material Science, Springer, 2004.

CHY 423: Advanced Quantum Chemistry [3 0 0 3]	
Prerequisites	CHY 313
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	• 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 H2+, LCAO-MO approach, confocal elliptic coordinates, evaluation of the Coulomb, resonance and overlap integrals, valence bond and molecular orbital descriptions of H2, Slater determinants, configuration interaction treatment of H2, molecular orbital theory (MOT) of diatomics, bond lengths, bond orders, and bond energies [4] • Concept of hybridization, sp, sp2, and sp3 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]
Text & Reference Books	1. P. Atkins and R. Friedman, Molecular Quantum Mechanics, 5th Ed., Oxford University Press (2011). 2. A. Szabo and N. S. Ostlund, Modern Quantum Chemistry: Introduction to Advanced Electronic Structure Theory, Dover Publications (1996). 3. F. Jensen, Introduction to Computational Chemistry, 2nd Ed., John Wiley (2006). 4. D. A. McQuarrie, Quantum Chemistry, Viva Student Edition, Viva (2011). 5. A. Leach, Molecular Modelling: Principles and Applications, 2nd Ed., Pearson (2009).

CHY 521: Physical Organic Chemistry [3 0 0 3]	
Prerequisites	CHY 312, CHY 323 and CHY 412

CHY 521: Physical Organic Chemistry [3 0 0 3]	
Learning Outcomes	This course will examine the tools that the modern organic chemists have at their 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. [10] • 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. [5] • Isotope effects: Classification – primary, secondary and solvent isotope effects - origin and application for mechanistic interpretations. [5] • 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. [5] • Stereoelectronic effects: Acetals, esters, amides and related functional group compounds; reactions at sp3, sp2, and sp carbons with examples in synthesis and biological processes. [12]
Text & Reference Books	1. N. S. Isaacs, Physical Organic Chemistry, 2ed., Pearson, 1995. 2. T. H. Lowry and K. S. Richardson, Mechanism and Theory in Organic Chemistry, 3ed., Pearson, 1997. 3. P. Deslongchamps, 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, 1ed., Wiley-Blackwell, 2007. 6. H. Maskill, The Physical Basis of Organic Chemistry, Oxford University Press, 1985.

CHY 522: Frontiers in Inorganic Chemistry [3 0 0 3]	
Prerequisites	CHY 311 and CHY 414
Learning Outcomes	The course illustrates the most recent advances in the various fields of Inorganic Chemistry as reported in the scientific literature. The focus will be to provide in-depth exposure to the latest (last 15 years) and exemplary advances of inorganic chemistry research.
Syllabus	• Reductive activation of O2, N2, and relevant small molecules: Design principles of active site analogue reaction models and structural models of small molecule activating metalloenzymes. [13]

CHY 522: Frontiers in Inorganic Chemistry [3 0 0 3]	
	• Inorganic compounds in energy research and novel organic transformations such as methane to methanol. [4] • Structure and reactivity of unusual inorganic compounds containing unusual oxidation states, metal-ligand multiple bonds, and redox-active ligands. [10] • Bonding and reactivity of compounds with metal-metal bonds. [5] • Complexes of f-block elements and their utility of f-block complexes in shift reagents, molecular magnets, fluorescence imaging. [3] • Material aspects of inorganic compounds. [5]
Text & Reference Books	1. Recent literatures published over the last 15 years. 2. Literature reporting the key examples of the advanced topic relevant to the content.

CHY 523: Chemical Kinetics and Dynamics [3 0 0 3]	
Prerequisites	CHY 314 and CHY 413
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: Methods of determining the rate constants, Order of the reaction, First, pseudo first, second and multiple order reactions [4] • Complex reactions and enzyme kinetics. [4] • Introduction to the theory of chemical kinetics, Arrhenius equation, potential dependent pre-exponential factor, Potential energy surfaces, [4] • Kinetic theory of collisions, modified collision theory, activated complex theory (transition state theory) [4] • Unimolecular reactions: Lindemann -Cristiansen Hypothesis, Hinshelwood theory [4] • Rice-Ramsperger-Kessal (RRK) theory, RRKM theory. [4] • Fast reactions: study of fast reactions by flow method, relaxation method, flash photolysis, pulsed radiolysis, laser and molecular beam methods [4] • Kinetics at Surfaces: Physical and chemical adsorption, adsorption isotherms, surface catalysis, Langmuir-Hinshelwood mechanism, Eley-Rideal mechanism, heats of adsorption, and kinetics of solid-state reactions, [4] • Photochemistry: Kinetics in the excited electronic states, Jablonski diagram, photophysical and photochemical processes [4] • Excimers, exciplexes, sensitization, quantum yields, static and dynamic quenching, Stern-Volmer equation [4]
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).

CHY 523: Chemical Kinetics and Dynamics [3 0 0 3]	
	4. J. I. Steinfeld, J.S. Francisco and W. L. Hase, Chemical Kinetics and Dynamics, 2nd Ed., Prentice Hall (1999). 5. N. J. Turrro, V. Ramamurthy and J. C. Scaiano, Modern Molecular Photochemistry of Organic Molecules, Viva Student Edition, Viva (2017).

Laboratory Courses

CHY 325: Advanced Chemistry Lab I [0 0 9 3]	
Prerequisites	CHY 121 and CHY 311
Learning Outcomes	The course focuses on the role of alkali as well as transition metals in various essential biological processes. This course also includes the mechanistic illustrations of the chemical transformations at the biological active sites.
Syllabus	• IC1. Synthesis of nickel(II) complexes and their electronic spectra (d8 systems). [9] • IC2. (a) Synthesis and characterization of metal acetylacetonate M(acac)3 complexes; (b) study of magnetic properties of M(acac)3 complexes using Gouy balance. [6] • IC3. (a) Synthesis of the linkage isomers of nitro-pentammine-cobalt(III); (b) UV/Vis studies for determining the kinetic and activation parameters for the isomerization reaction. [12] • IC4. Synthesis and characterization of germanium tetraiodide from germanium oxide. [9] • PC1. Liquid vapour equilibria of binary solvents: Azeotropic mixture. [9] • PC2. Determination of stoichiometry and association/binding constant using UV-Vis spectroscopy. [9] • PC3. Validation of Freundlich and Langmuir adsorption isotherms. [9] • PC4. Inversion of sucrose and mutarotation of glucose using polarimetry. [9]
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. 2. G. H. Jeffery, J. Bassett, R. C. Denny, Vogel's Quantitative Chemical Analysis, 5ed, ELBS and Longmans Green & Co Ltd, 1971. 3. A. J. Elias, General Chemistry Experiments, 3ed, Universities Press (India) Pvt Ltd, 2002. 4. J. Derek Woollins, Inorganic Experiments, 3ed, Wiley, 2010. 5. M. Halpern and G. C. McBane, Experimental Physical Chemistry: A Laboratory Text Book, 3rd Edition, W. H. Freeman, 2006. 6. D. P. Shoemaker, G. W. Garland and J. W. Nibler, Experiments in Physical Chemistry, 5th Edition, McGraw Hill, London. 7. References mentioned in the laboratory manual.

CHY 415: Advanced Chemistry Lab II [0 0 9 3]	
Prerequisites	CHY 312 and CHY 314
Learning Outcomes	This laboratory course will provide opportunities for hands-on laboratory experiences related to synthetic organic chemistry and diverse aspects of physical chemistry through experimental methods.
Syllabus	• OC1. Stereoselective synthesis of ethyl trans-cinnamate via Wittig reaction [9] • OC2. Hantzsch ester synthesis - a multi-component reaction [9]

CHY 415: Advanced Chemistry Lab II [0 0 9 3]	
	• OC3. Synthesis of indigo dye from o-nitrobenzaldehyde. [9] • OC4. Oxidative synthesis of (±)-BINOL from 2-naphthol. [9] • PC1. Supramolecular chemistry, electrochemistry: estimating the critical molar concentration [9] • PC2. Electrochemistry: estimation of the diffusion coefficient of redox species on aqueous and non-aqueous medium [9] • PC3. Photochemistry: estimation of quantum yield of perylene and pyrene excimer formation [9] • PC4. Photochemistry: construction of Jablonski diagram of polyaromatic compounds
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. M. Halpern and G. C. McBane, Experimental Physical Chemistry: A Laboratory Text Book, 3rd Edition, W. H. Freeman, 2006. 3. D. P. Shoemaker, G. W. Garland and J. W. Nibler, Experiments in Physical Chemistry, 5th Edition, McGraw Hill, London. 4. References mentioned in the laboratory manual.

CHY 424: Advanced Chemistry Lab III [0 0 9 3]	
Prerequisites	CHY 322 and CHY 412
Learning Outcomes	This laboratory course provides opportunities for hands-on laboratory experiences related to synthetic organic chemistry, bioinorganic chemistry, and organometallic chemistry.
Syllabus	• OC1. One-pot synthesis of chalcone epoxide via Claisen-Schmidt condensation and epoxidation [9] • OC2. Chiral resolution of racemic □-phenylethylamine with optically pure D-tartaric acid. [9] • OC3. Synthesis of benzyl azide. [9] • OC4. Click Reaction - Copper(I)-catalyzed alkyne-azide cycloaddition reaction. [9] • IC1. (a) Synthesis and characterization of tetraphenylporphyrin (TPPH2); (b) Synthesis and characterization of cobalt(II) complex (TPP)Co(II); (c) Synthesis and characterization of porphyrin cobalt-nitrosyl (TPP)Co(NO). [12] • IC2. Activation of elemental sulfur (S8) and investigations of the reactive intermediates by UV/Vis studies. [3] • IC3. Synthesis of copper(II) complex of organic ligand and its EPR spectroscopic characterization. [6] • IC4. Synthesis and characterization of [RuHCl(CO)(PPh3)3]. [9] • IC5. Synthesis and characterization of microporous zeolitic imidazolate framework (ZIF-8) material. [6]

CHY 424: Advanced Chemistry Lab III [0 0 9 3]	
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. G. H. Jeffery, J. Bassett, R. C. Denny, Vogel's Quantitative Chemical Analysis, 5ed, ELBS and Longmans Green & Co Ltd, 1971. 3. A. J. Elias, General Chemistry Experiments, 3ed, Universities Press (India) Pvt Ltd, 2002. 4. J. Derek Woollins, Inorganic Experiments, 3ed, Wiley, 2010. 5. References mentioned in the laboratory manual.

I2C Courses

I2C 311: Medicinal Chemistry [3 0 0 3]	
Prerequisites	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.
Syllabus	• 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]
Text & Reference Books	1. The Organic Chemistry of Drug Design and Drug action. Richard B. Silverman, 2nd Edn, Academic Press, 2004. 2. Medicinal Chemistry: Principles and Practice, F. D. King, 2nd Edn, RSC, 2002. 3. Real World Drug Discovery: A Chemist's Guide to Biotech and Pharmaceutical Research. Robert M. Rydzewski, Elsevier, 2008. 4. The Practice of Medicinal Chemistry, Camille-Georges Wermuth, 3rd Edn, Academic Press, 2008. 5. Graham L. Patrick. An Introduction to Medicinal Chemistry, Oxford 6th edition, 2013. 6. John Saunders. Top Drugs, Top Synthetic Routes, Oxford University Press, 1st edition, 2012.

I2C 312: Biophysical Chemistry [3 0 0 3]	
Prerequisites	Physical Chemistry I & 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 [5] • Electrophysiology: patch clamp method [2] • Methods: • Optical spectroscopy, linear and circular dichroism and IR [3] • 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 [4] • Atomic force Microscopy: Force spectroscopy with AFM optical and magnetic tweezers [4]
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. 7. Modern Biophysical Chemistry by Peter Jomo Wall, Second edition, Wiley-VCH, 2014.

I2C 322: Enzymology and Biocatalysis [3 0 0 3]	
Prerequisites	Physical Chemistry I
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]

I2C 322: Enzymology and Biocatalysis [3 0 0 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 edition, 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.

I2C 411: Soft Matter and Polymers [3 0 0 3]	
Prerequisites	Physical Chemistry I
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

I2C 411: Soft Matter and Polymers [3 0 0 3]	
	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. 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, NJ, 2004.

I2C 412: Computational Chemical Biology [3 0 0 3]	
Prerequisites	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)
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]

I2C 412: Computational Chemical Biology [3 0 0 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.

I2C 413/CHY 4103: Biomaterials [3 0 0 3]	
Prerequisites	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]

I2C 413/CHY 4103: Biomaterials [3 0 0 3]	
	• 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.

I2C 414: Chemical Biology Lab [0 0 9 3]	
Prerequisites	Fundamental Chemistry courses and polymer & soft matter (desirable)
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	• Recombinant Protein Expression and Purification: Small Ubiquitin like Modifier 2 (SUMO 2) [18] • Characterization of the protein SUMO 2: Determination of Molar Extinction Coefficient and Secondary Structure [6] • Determination of Bacterial Growth Curve in a Closed Culture [10] • Determination of minimum inhibitory concentrations (MICs) by Broth microdilution method [9] • Enzyme-Linked Immunosorbent Assay (ELISA) to understand specific antibody-antigen interactions [9] • Preparation of selective organ targeting (SORT) LNPs for tissue specific RNA delivery by pipette mixing [9] • Fluorescent Labelling of Bovine Serum Albumin [9]
Text & Reference Books	1. Chemical Biology, A practical course. Herbert Waldmann, Petra Janning. Wiley-VCH, 2004. 2. Lab Manual.

I2C 521: Pharmacology and Pharmacokinetics [3 0 0 3]	
Prerequisites	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.

I2C 521: Pharmacology and Pharmacokinetics [3 0 0 3]	
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 Edition, 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 Edn, 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 Edition, Academic Press, 2008.

Elective Courses: Organic Chemistry

CHY 5XXX: Name Reactions and Rearrangements - Application in Organic Synthesis [3 0 0 3]	
Prerequisites	CHY 312 and CHY 323
Learning Outcomes	The course will cover important common name reactions and rearrangements, and their application in organic synthesis.
Syllabus	• Name Reactions • Synthesis of alkenes and alkynes: Burgess dehydration reaction, Chugaev elimination reaction, Corey-Winter olefination, Shapiro olefination, Tebbe olefination/Petasis-Tebbe olefination, Regitz diazo transfer, Corey-Fuchs alkyne synthesis, and Ohira-Bestmann reaction. [8] • Fragmentation: Eschenmoser-Tanabe fragmentation, and Wharton fragmentation. [2] • Arbuzov reaction, Barton nitrite ester reaction, Meerwein arylation, Petasis boronic acid-Mannich reaction, Weinreb ketone synthesis. [5] • Barbier coupling reaction, Kagan-Molander samarium diiodide-mediated coupling, Chichibabin reaction, Minisci reaction, Doering-LaFlamme allene synthesis, Miyaura boration, Larock indole synthesis, Eschweiler-Clarke methylation (reductive alkylation), Rubottom oxidation, and Mitsunobu reaction. [10] • Application of above-mentioned name reactions in organic synthesis. [5] • Rearrangements • Ciamician-Dennstedt rearrangement, Ferrier rearrangement, Petasis-Ferrier rearrangement, Meyer-Schuster/Rupe rearrangement, Overman rearrangement, Payne rearrangement, Pummerer rearrangement, Vinylcyclopropane (VCP)–cyclopentene (CP) rearrangement. [7] • Application of above-mentioned rearrangements in organic synthesis. [3]
Text & Reference Books	1. L. Kurti, and B. Czako, Strategic Applications of Named Reactions in Organic Synthesis,1st Ed., Elsevier (2005). 2. C. M. Rojas, Molecular Rearrangements in Organic Synthesis, 1st Ed., Wiley (2015).

CHY 5XXX : Catalysis in Organic Synthesis [3 0 0 3]	
Prerequisites	CHY 312 and CHY 323
Learning Outcomes	The course will walk through the recent advancement in catalytic reactions, and this will allow the learners to have a better understanding of current trends in catalytic reactions and subsequently helps them when they start their research career.
Syllabus	• Transfer hydrogenation: Introduction and development of transfer hydrogenation; asymmetric transfer hydrogenation and hydrogenation of ketones; the selective applications of pincer complexes. [8] • Reductive coupling: Introduction to reductive cross-coupling reactions; synthetic application of various metal mediated reductive cross-coupling reactions. [6]

CHY 5XXX : Catalysis in Organic Synthesis [3 0 0 3]	
	• Industrial catalysis: Catalysis on industrial scale and continuous-flow chemistry. [4] • Transition metal - catalyzed coupling reactions: Fukuyama coupling, Nozaki-Hiyama-Kishi (NHK) reaction, Glaser coupling, intramolecular Heck reaction. [5] • 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. [8] • 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. [8]
Text & Reference Books	1. R. Bates, Organic Synthesis Using Transition Metals, 2ed., Wiley, 2012. 2. J. F. Hartwig, Organotransition metal chemistry: from bonding to catalysis, University Science Books, 2010. 3. J. Hagen, Industrial catalysis, 3ed., Wiley, 2016.

CHY 5XXX: Chemistry of Natural Products [3 0 0 3]	
Prerequisites	CHY 221 and CHY 412
Learning Outcomes	Students will gain the knowledge of molecular complexity, disconnection of complex molecules into simpler fragments; understanding of different synthetic pathways; apply organic chemistry principles practically; explore the mechanisms of biosynthesis of natural products; design strategic approaches for creating bioactive compounds in medicinal and industrial contexts.
Syllabus	• Introduction to natural products: Classification, nomenclature, isolation methods and structure determination techniques. [4] • 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, mechanistic based disconnection approach. [10] • Biosynthesis approaches: Biosynthetic routes for various secondary metabolites; fatty acid, polyketides, phenylpropanoids, terpenes, steroids and alkaloids. [5] • Sustainable synthesis: Atom economy, step economy and green chemistry protocols & environmental aspects in synthesis. [3] • Different synthetic approaches: Linear synthesis, convergent synthesis, semi synthesis, diversity oriented synthesis, combinatorial synthesis. [4] • Chemistry of selected natural products and drugs: Total synthesis to polyketides, macrolides, terpenes, steroids, alkaloids, penicillins and prostaglandins; case studies of drug molecules for the process development. [14]
Text & Reference Books	1. J. Clayden, N. Greeves, S. Warren and P. Wothers, Organic Chemistry, 2ed., Oxford University Press, 2012. The Logic of Chemical Synthesis by E. J. Corey and X-M. Cheng. 2. Classics in Total Synthesis, Volumes I, II and III by K. C. Nicolau. 3. Organic Synthesis: The Disconnection Approach, Stuart Warren and Paul Wyatt.

CHY 5XXX: Chemistry of Natural Products [3 0 0 3]	
	4. Organic Chemistry by Clayden, Greeves, Warren and Wothers. 5. Medicinal Natural Products: A Biosynthetic Approach, 3rd Edition. Paul M. Dewick.

CHY 5XXX: Modern Organic Synthesis [3 0 0 3]	
Prerequisites	CHY 323 and CHY 412
Learning Outcomes	This course will 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: Synthesis of cyclic, spirocyclic and fused systems via cation- and radical-olefin cyclization, Nazarov cyclization, rearrangements, intramolecular McMurry coupling, Pauson Khand reaction, etc.; inter-conversion of ring systems (contraction and expansion); ring closing metathesis for macrocyclic ring formation. [10] • Modern electroorganic synthesis-: Basics of electro-synthesis; anodic oxidation and cathodic reduction; constant current electrolysis, constant voltage electrolysis; reactions in divided and undivided cell set-up; application of electroorganic synthesis. [6] • (Asymmetric) Organocatalysis: Amine catalysis (iminium catalysis, enamine catalysis, and SOMO catalysis); hydrogen-bonding catalysis (thiourea, squaramide, etc.); chiral Brønsted Acid and Lewis-Acid/Base catalysis; (d) NHC-catalysis. [8] • Molecular editing: Types of skeletal editing reactions – deleting atoms, inserting atoms and swapping atoms; ring contraction and expansion via single atom deletion and insertion; aromatic and heteroaromatic interconversion; application of molecular editing strategies. [6] • Selected reagents: Nucleophilic fluorinating reagents (Olah reagent, DAST and its modifications, etc.) and electrophilic fluorinating reagents (NFSI, Selectfluor, etc.); nucleophilic perfluoroalkylating (CnF2n+1) reagents (Langlois's and Baran's reagents, Ruppert-Prakash reagent, etc.) and electrophilic perfluoroalkylating(CnF2n+1) reagents (Togni's and Umemoto's reagents, etc.); polyvalent iodine reagents; Lawesson's and Woollin's reagent; coupling reagents in macrolactonization and peptide synthesis (DCC, EDC+HOBt, Ghosez's reagent, Yamaguchi's reagent, etc.); reagents for borylation and silylation.
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. F. Marken and M. Atobe, Modern Electrosynthetic Methods in Organic Chemistry, CRC Press, Taylor and Francis group (2019). 4. Allen J. Bard, Larry R. Faulkner, Electrochemical Methods: Fundamentals and Applications, 2ed, Wiley, 2000. 5. B. List and S. Arseniyadis, Asymmetric Organocatalysis, Vol. 2, Springer (2010). 6. A. Berkessel and H. Gröger, Asymmetric Organocatalysis: From Biomimetic Concepts to Applications in Asymmetric Synthesis, Wiley-VCH (2005).

CHY 5XXX: Modern Organic Synthesis [3 0 0 3]	
	7. Peer Kirsch, Modern Fluoroorganic Chemistry: Synthesis, Reactivity, Applications, 2nd, Completely Revised and Enlarged Edition, Wiley-VCH (2013). 8. W. Carruthers and I. Coldham, Modern Methods of Organic Synthesis, 4th Ed. Cambridge University Press (2004). 9. V. V. Zhdankin, Hypervalent Iodine Chemistry: Preparation, Structure and Synthetic Applications of Polyvalent Iodine Compounds, Wiley-VCH (2013). 10. J. Jurczyk, J. Woo, S. F. Kim, B. D. Dherenge, R. Sarpong and M. D. Levin, Single-Atom Logic for Heterocycle Editing. Nature Synthesis 2022, 1, 352-364. Recent Primary Research Papers (relevant references will be provided during the course).

CHY 5XXX: Organic Solid-State Chemistry [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	The course will cover important common organic solid-state reactions, topochemical reactions and their application in organic synthesis
Syllabus	• Organic solid-state reactions [4] • Topochemical postulates [2] • Reaction cavity [2] • Intermolecular interactions: General properties, van der Waals interactions, hydrogen bonds, halogen bonds, other interactions, methods of study of interactions, analysis of typical crystal structures [6] • Crystal design strategies: Synthesis in chemistry, supramolecular chemistry, the synthon in crystal engineering [6] • Different class of topochemical reactions: Photochemical [2+2] cycloaddition, photochemical [4+4] cycloaddition, thermal [2+4] cycloaddition, thermal [2+3] cycloaddition, photochemical or thermal polymerization diynes, polymerization of dienes [20]
Text & Reference Books	1. F. Toda, Organic Solid-state reactions, Springer, 2005. 2. Organic Solid state reactions, G. Kaupp in Encyclopedia of Physical Organic Chemistry, 2016. 3. Recent Primary Research Papers (relevant references will be provided during the course).

CHY 5XXX: Supramolecular Chemistry [3 0 0 3]	
Prerequisites	CHY 311 and CHY 323
Learning Outcomes	The course will provide a general overview and basic knowledge of supramolecular chemistry, based on non-covalent interactions, emphasizing its character as a versatile and effective tool for building complex systems from well-defined units and their application in different areas of work and research.

CHY 5XXX: Supramolecular Chemistry [3 0 0 3]	
Syllabus	• Introduction to supramolecular chemistry: Concepts and languages of supramolecular chemistry – various types of noncovalent interactions such as Ion pairing, ion-dipole interactions, dipole-dipole interactions, dipole-induced dipole and ion-induced dipole interactions, van der Waals or dispersion interactions, hydrogen bonding, halogen bonding, cation- interactions, anion-pi interactions, pi - pi interactions. [8] • Molecular recognition and Host-Guest systems: Cation binding hosts -crown ether, cryptand, spherand; calixarenes and siderophores; • anion binding hosts - challenges and concepts, biological receptors, conversion of cation hosts to anion hosts, neutral receptors, metal-containing receptors, cholapods;ion pair receptors - contact ion pairs, cascade complexes, remote anion and cation binding sites, symport and metals extraction; • hosts for neutral receptors -clathrates, inclusion compounds, zeolites, intercalates, coordination polymers, guest binding by cavitands and cyclodextrins, cucurbituril. [12] • Principles of self-assembly: Metallo supramolecular architectures, hydrogen bonded supramolecular architectures, halogen bonded architectures, mechanically bonded architectures-rotaxanes, catenanes etc. [8] • Physical methods in understanding supramolecular chemistry: Kinetics and thermodynamics of representative systems, Determination of binding constant, JOB's plot. Cooperativity, Supramolecular chirality. [5] • Applications of supramolecular chemistry: • Supramolecular catalysis, sensors, selective uptake and release of guests, molecular switches and machines. [7]
Text & Reference Books	1. J. W. Steed and J. L. Atwood, Supramolecular Chemistry, 2nd Ed John Wiley, 2009. 2. M. Lehn, Supramolecular Chemistry, VCH, Weinheim, 1995.

CHY 5XXX: Nanobiotechnology: Basic Principles and Applications [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	The course will cover nanotechnology and its applications in materials science and biotechnology
Syllabus	• Basics of biology - cell, organelles and nucleic acids as genetic material [4] • Biomacromolecules Carbohydrates, lipids, proteins and Nucleic acids [4] • Basics of noncovalent interactions in biomolecules: Various noncovalent interactions: hydrogen bonding, pi-stacking, van der Waals interactions with from biomolecules including peptide, DNA etc. [4] • Introduction of DNA, synthesis, molecular recognition, structural understanding, self-assembly: Different approaches for the synthesis of DNA, DNA structures: P, M, Z-DNA, different DNA structures including duplex, G-quadraplex, i-motif etc. [4] • Characterization of various bionanostructures using spectroscopic techniques: Different techniques for the characterization of nanostructures including electronic absorption, circular dichroism (CD), NMR etc. [4]

CHY 5XXX: Nanobiotechnology: Basic Principles and Applications [3 0 0 3]	
	• Different types of secondary structures of DNA: duplex, G-quadraplex, i-motif etc.: Synthesis of different secondary structures of DNA, effect of sequence in secondary structure formation, different types of hydrogen bonding exist in various secondary structures, structural stability and characterization. [4] • Introduction to structural DNA nanotechnology, principles of structural DNA nanotechnology: Origin of DNA nanotechnology, design principle for the synthesis of higher order DNA nanostructures, structural DNA nanotechnology, various methods to characterize DNA nanostructures. [6] • DNA origami: Principle of DNA origami, folding mechanism and structural understandings; • principle of DNA origami approach, various DNA nanostructures by using DNA origami, 1D, 2D and 3D nanostructures. [4] • Applications of DNA nanostructures in various fields including material science, medicine, nanotechnology and biotechnology: Applications of DNA nanostructures in drug delivery, nanotechnology, materials science, and bioimaging [6]
Text & Reference Books	1. G. Michael Blackburn, Nucleic acids in chemistry a biology, Oxford University Press. 2. Nadrian C. Seeman and Hanadi F. Sleiman, DNA nanotechnology, Nature Reviews, 2017, 3, 17068 and the reference cited therein.

CHY 5XXX: Photocatalysis in Organic Synthesis [3 0 0 3]	
Prerequisites	CHY 323 and CHY 412
Learning Outcomes	The course will allow learning of modern catalytic reactions in organic synthesis driven by visible light.
Syllabus	• Introduction to photocatalysis: Synthesis and photophysical properties of metal-based photocatalysts; single electron transfer (SET), energy transfer (ET); proton-coupled electron transfer (PCET); hydrogen atom transfer (HAT); halogen atom transfer (XAT), ligand to metal Charge transfer (LMCT) [6] • Visible-light-enabled net oxidative reactions, net redox reactions, redox neutral reactions; photocatalytic oxidative C-C bond formation reactions; decarboxylative coupling reactions [3] • Light induced proton-coupled electron transfer in organic synthesis; visible light mediated Sp3C–H functionalization; remote C–H functionalization via selective 1,5-hydrogen atom transfer; EDA-complex enabled organic synthesis [6] • Ligand to Metal Charge Transfer enabled organic synthesis using Cerium, Iron, Copper and Bismuth; Dual metal (Au, Ni, Pd, Cu, Co) and photoredox catalysis in organic synthesis; Dual triplet ketone and metal catalysis, Dual metal and halogen atom transfer-enabled organic synthesis [9] • Acridinium dyes and quinones in photocatalysis; Flavins in photocatalysis; organic dyes in photocatalytic reductive C-H arylations; organocatalysis with amines in photocatalysis; enantioselective photocatalysis [8]

CHY 5XXX: Photocatalysis in Organic Synthesis [3 0 0 3]	
	• Photocatalytic mono/difluoro/trifluoromethylation and trifluoromethoxylation of organic molecules; [3] • Industrial applications of photocatalysis: Photocatalysis to the synthesis of natural products and pharmaceutically relevant compounds; late-stage functionalization of drug-like molecules; Continuous-flow photochemistry in organic synthesis; Photoelectrocatalytic organic synthesis [5]
Text & Reference Books	1. C. Stephenson, T. Yoon, D. W. C. MacMillan, Visible Light Photocatalysis in Organic Chemistry. Wiley-VCH Verlag, 2017. 2. B. Koenig, Science of Synthesis: Photocatalysis in Organic Synthesis" 1st ed. Thieme, 2019. 3. C. Prentice, J. Morrisson, A. D. Smith, E. Zysman-Colman, Recent Developments in Enantioselective Photocatalysis. Beilstein J. Org. Chem. 2020, 16, 2363–2441. 4. Recent Primary Research Papers (relevant references will be provided during the course).

Elective Courses: Inorganic Chemistry

CHY 5XXX: Biomaterials [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	Describes the applications of biomaterials as metals, ceramics, polymers, and composites in Healthcare. Explain methods to modify surfaces of biomaterials and choose material for desired biological response. Next, explain the possible interactions between biomaterials, proteins and cells including testing of biomaterials or implants in in vitro, ex-vivo and in vivo models.
Syllabus	• Topic 1 - Introduction to biomaterials: Introduction to materials at the interface with biological sciences and medicine. [3] • Topic 2 - Classifications of biomaterials (structure, properties, characterization) - part 1: Metals, polymers, ceramics, glasses, composites, bulk properties of materials, mechanical properties of materials; surface properties of materials, metallic biomaterials (alloys, corrosion resistance, surface modifications); ceramic biomaterials, glass-ceramic biomaterials. [6] • Topic 3 - Classifications of biomaterials (structure, properties, characterization) - part 2: Polymeric biomaterials; composite biomaterials (polymeric, carbon fiber, dental and ceramic composites); naturally-derived biomaterials. [3] • Topic 4 - Processing of biomaterials, surface engineering & biofunctionalization: biomaterials processing, surface engineering techniques, coatings, self-assembly, Langmuir–Blodgett deposition, Layer-by-layer assembly, micro-contact printing, 3D-bioprinting, biological functionalization of biomaterials; bio-responsive surfaces; biomimetics. [6] • Topic 5 - Biological response to biomaterials: Adsorption to Surfaces; cells, blood-material interactions, inflammation, tumorigenesis, wound healing, and the foreign body response,

CHY 5XXX: Biomaterials [3 0 0 3]	
	degradation of materials in the biological environment; implant-associated infections; bacterial adhesion, and biofilm formation. [5] • Topic 6 - Testing biomaterials: In vitro assessment of tissue compatibility; in vivo assessment of tissue compatibility; animal models. [4] • Topic 7 - Application of biomaterials in medicine - Part 1: Orthopaedic implants, cardiovascular biomaterials, dental implants, nonthrombogenic treatments and strategies, adhesives and sealants, sutures, ophthalmologic applications; burn dressings, bioelectrodes. [6] • Topic 8 - Application of biomaterials in medicine - Part 2: Drug delivery systems, biosensors, bioimaging, nanotheranostics, tissue engineering, artificial organs, and bioelectronics implants. [5]
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.

CHY 5XXX: Inorganic Rings, Chains and Polymers [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	The course focuses on the synthesis, structure, and reactivity of the macrocycles/ rings/ polymers containing inorganic elements. The representative bonding models of these compounds will also be covered
Syllabus	• Inorganic heterocyclic rings: Synthesis, structure, and reactivity of (a) P-N rings: cyclophosphazenes and cyclophosphazanes; (b) P-N-X rings: carbophosphazenes, thiophosphazenes, metallaphosphazenes; (c) Si-O rings: cyclosiloxanes; (d) Sn-O rings: stannoxanes; (e) B-containing rings: boranes, carboranes, metallacarboranes, borazine; (f) Al-containing rings: Al-N rings and cages, Al-C rings and cages, alumoxanes. [18] • Inorganic homocyclic rings: Inorganic homocyclic rings and cages containing silicon, germanium, boron, aluminum, and gallium. [5] • Macrocycles: Porphyrin, porphyrinoids, and their metal compounds. [5] • Inorganic polymers. A brief review of organic polymers-methods of synthesis, polymer characteristics-molecular weights, glass-transition temperatures, stress-strain characteristics etc; synthetic methods, structure-property relationships, applications of polyphosphazenes, polysiloxanes, polysilanes, polysiloles, and various organometallic polymers (such as poly(ferrocenylsilane)). [12]
Text & Reference Books	1. Inorganic and Organometallic Polymers. Chandrasekhar, V. Springer-Verlag, Heidelberg, 2005. 2. Contemporary Polymer Chemistry. 3rd Ed. Allcock H.R.; Lampe, F.W.; Mark, J. Prentice Hall, N, 2004. 3. Inorganic Polymers. Mark, J.E.; West, R.; Allcock, H.R.; Prentice-Hall, NY, 1992.

CHY 5XXX: Inorganic Rings, Chains and Polymers [3 0 0 3]	
	Synthetic Metal Containing Polymers. Manners, I. Wiley-VCH, Weinheim, 2004.

CHY 5XXX: Main Group Catalysis [3 0 0 3]	
Prerequisites	CHY 411
Learning Outcomes	The course provides insights into the applied area of main group chemistry. Homogeneous catalysis promoted by main group compounds is of topical interest. In the past decade, main group compounds have surged as potential alternatives to transition metal complexes. Fundamental catalytic processes mediated by s- and p-block compounds will be discussed.
Syllabus	• Classification s- and p-block compounds in catalysis: Pre-catalysts and catalysts; metal alkyls and hydrides; Lewis acids and bases. [8] • Lewis acid catalysis - activation of small molecules: Carbon monoxide and carbon dioxide insertion in to p-block compounds; reduction of carbon dioxide to formate, aldehyde, methanol and methane; olefin hydrogenation; reduction of dinitrogen. [8] • Hydroelementation of unsaturated organic molecules: Hydroboration and hydrosilylation of olefins, carbonyls, CO, CO2, nitriles, and imines. [5] • p-Block compounds as co-catalysts in transition metal catalysis: B(C6F5)3 and Al(C6F5)3 as Lewis acids to generate group 4 cations for olefin polymerization; z-type ligand for electrophilic activation of transition metal centers. [6] • Frustrated Lewis-acid bases: Definition; various combination of frustrated Lewis acid base pairs; activation of H2, reduction of unsaturated organic molecules. [4] • Redox catalysis: Main group redox catalysis of organopnictogens; vertical periodic trends and emerging opportunities Bi (III)/Bi(V) and Bi(I)/Bi(III) systems. [4]
Text & Reference Books	1. Organometallics and Catalysis: An Introduction, OUP Oxford, 2014. 2. Early Main Group Metal Catalysis: Concepts and Reactions, S. Harder, 2020 Wiley- VCH Verlag GmbH & Co. KGaA. 3. Frustrated Lewis Pairs, C. J. Slootweg, A. Jupp, 2021, Springer International Publishing. 4. A Primer in Frustrated Lewis Pair Hydrogenation: Concepts to Applications, D. W. Stephan, 2021, Royal Society of Chemistry.

CHY 5XXX: Applied Organometallic Chemistry [3 0 0 3]	
Prerequisites	CHY 321
Learning Outcomes	This course provides an overview of the current state of the art strategies in developing organometallic complex based catalysts.
Syllabus	• Introduction to catalysis, catalyst activation and deactivation, key examples highlighting industrial and medicinal chemistry relevance, green chemistry principles, environmental concern, contemporary challenging chemical transformations. [7]

CHY 5XXX: Applied Organometallic Chemistry [3 0 0 3]	
	• Recent progress in hydroformylation and hydrogenation reactions; hydrogenation of arenes and heteroarenes; chiral catalysts in the synthesis of enantiopure molecules; importance of the development of phosphine and ylide-functionalized phosphine (YPhos) ligands, N-heterocyclic (NHC) and cyclic alkyl amino carbene (CAAC). [12] • Hydroamination, hydrophosphination of alkenes, directing group assisted C-H bond activation reactions in pre-functionalized arene derivatives. [6] • Earth abundant catalysts in C-X (X = C, N, B, Si, O) cross-coupling (sp2-sp2 and sp2-sp3) reactions - an organometallic perspective. [10] • Development of catalysts for oligomerization: The Shell higher olefin process using ethylene, linear oligomerization of ethylene and single site polymerization catalysts. [5]
Text & Reference Books	1. J. Hartwig, Organo-transition Metal Chemistry: From Bonding to Catalysis, University Science Books, 2010. 2. B. D. Gupta and A. J. Elias, Basic Organometallic Chemistry: Concepts, Syntheses and Applications, 2nd ed., Universities Press, 2013. 3. Manfred Bochmann, Organometallics and Catalysis: An Introduction: 2014, Oxford University Press. 4. Applied Organometallic Chemistry and Catalysis (Oxford Chemistry Primers) – Whyman, Robin, 2004.

CHY 5XXX: Advanced Materials Chemistry [3 0 0 3]	
Prerequisites	CHY 422
Learning Outcomes	The course highlights the links between aspects of structure, properties, and applications in materials chemistry through specific examples of inorganic and hybrid materials. It also covers topics that are of prime importance to applications in energy research.
Syllabus	• Overview of general chemical and physical principles: Materials chemistry applied to synthesis, structure and properties of various inorganic and hybrid materials. [3] • Classification based on structure: Various molecular solids, layered materials, 3D-materials and nanostructured materials. [6] • Classification based on function: Porous materials, optical materials, semiconductors, ionic conductors, superconductors, thermoelectric and magnetic materials. [9] • Structure-function-property relations, illustrative and specific examples with some case studies involving molecular 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. [12]
Text & Reference Books	1. Advanced Materials, (Eds: Theo van de Ven, Robert Gauvin and Armand Soldera), De Gruyter, 2020. 2. Solid State Chemistry, A. R. West, Wiley Second Edition, 2003.

CHY 5XXX: Advanced Materials Chemistry [3 0 0 3]	
	3. New Directions in Solid State Chemistry, C.N.R. Rao and J. Gopalakrishnan, Cambridge University Press, Second Edition, 1997. 4. Introduction to Materials for Advanced Energy Systems, Colin Tong, Springer, 2019. 5. Advanced Nanomaterials for Electrochemical Energy Conversion and Storage, (Eds: Fen Ran Shaowei Chen), Elsevier, 2019.

CHY 5XXX: Advanced Main Group Chemistry [3 0 0 3]	
Prerequisites	CHY 411
Learning Outcomes	The aim of this course is to acquaint students with the most recent advancements in main group chemistry. The evolution of advanced synthetic techniques and enhancements in characterization tools has catalyzed significant growth in main group chemistry over the past three decades. This growth has not only facilitated the discovery of numerous fundamental breakthroughs but has also yielded various functional molecules and materials.
Syllabus	• Group 2: Synthesis, bonding and reactivity of zero and mono-valent group 2 complexes. [4] • Group 13: Synthesis, bonding and reactivity of neutral and anionic E(0) and E(I) (E = B, Al) complexes. [6] • Group 14: Synthesis and properties of different types of carbenes and their uses in transition metal catalysts, stabilizing reactive species, functional materials (such as transition metal surfaces and nano-clusters); synthesis and properties of low-valent Si, Ge and Sn complexes, multiple bonding in heavier group-14 compounds. [12] • Group 15: Organophosphorus compounds as catalysts; synthesis and reactivity of P4; low valent compounds of group 15 elements; bismuth complexes for small molecule activation and catalysis. [8] • Miscellaneous: Frustrated Lewis pair chemistry; superacids and their uses; non-VSEPR compounds; bonding and small molecule activation; hypervalent iodine compounds (synthesis, bonding and reactivity). [10]
Text & Reference Books	1. The chemistry of the p-block elements by Anil J Elias, Universities Press (India) Pr. Ltd. 2019. 2. 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. 3. Organometallics and Catalysis: An Introduction, OUP Oxford, 2014. 4. Recent literatures published over the last 20 years.

Elective Courses: Physical Chemistry

CHY 5XXX: Computational Chemistry [3 0 0 3]	
Prerequisites	CHY 313 and CHY 324

CHY 5XXX: Computational Chemistry [3 0 0 3]	
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	• Introduction to the electronic structure theory of many-electron systems, review of Born-Oppenheimer approximation, and review of Hartree and Hartree-Fock methods [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 [4] • Moller-Plesset (MP) perturbation theory, MP0, MP1 and MP2 methods [4] • Density functional theory, Concepts of electron density and functionals, Thomas-Fermi model, Hohenberg-Kohn theorem, and Kohn-Sham equations [4] • Illustration of key exchange-correlation functionals, and Jacob's ladder of density functional theory [4] • Potential energy surfaces, geometry optimization, single point energies, stationary points, gradients, Hessian, transition states, intrinsic reaction coordinates, and minimum energy path [4] • Normal modes of vibration, internal coordinates, mass-weighted coordinates, and normal mode analysis in diatomics and polyatomics [4] • Molecular mechanics, force fields, stretching, bending, torsions, non-bonded interactions, and illustrative examples [4] • Ion-ion, ion-dipole, dipole-dipole, dipole-induced dipole, induced dipole-induced dipole interactions, and quantum mechanical description of dispersion interactions [4] • Molecular dynamics, hard sphere potential, Lennard-Jones potential, Verlet and velocity Verlet algorithms, ergodic hypothesis, and estimation of averages [4]
Text & Reference Books	1. P. Atkins and R. Friedman, Molecular Quantum Mechanics, 5th Ed., Oxford University Press (2011). 2. A. Szabo and N. S. Ostlund, Modern Quantum Chemistry: Introduction to Advanced Electronic Structure Theory, Dover Publications (1996). 3. F. Jensen, Introduction to Computational Chemistry, 2nd Ed., John Wiley (2006). 4. D. A. McQuarrie, Quantum Chemistry, Viva Student Edition, Viva (2011). 5. A. Leach, Molecular Modelling: Principles and Applications, 2nd Ed., Pearson (2009).

CHY 5XXX: Symmetry and Group Theory in Chemistry [3 0 0 3]	
Prerequisites	CHY 121, CHY 313 and CHY 324
Learning Outcomes	The objective of the course is to help recognize symmetry in molecules and understand its role in Chemistry. The course will explore the role of symmetry in (a) determining molecular properties (e.g. optical activity, dipole moment), (b) classifying and assigning nomenclature to molecules, molecular states and molecular motions and (c) bringing about simplifications in the application of quantum mechanics to molecules, and (d) determining spectroscopic selection rules based on molecular symmetry. Group theory applied to the study of molecular

CHY 5XXX: Symmetry and Group Theory in Chemistry [3 0 0 3]	
	symmetry has far reaching consequences in chemistry and the course will provide an in-depth appreciation of this.

Syllabus	• Basic idea of Groups and the characteristics, Definition of symmetry, symmetry elements and symmetry group. [4]
	• Symmetry operations in molecules, classes of operations and similarity transformations. [4]
	• Point group classification (Overview): Systematic procedure to determine symmetry point group of molecules. [3]
	• Matrix representation of symmetry operations. [4]
	• Basis vectors, reducible and irreducible representations [3]
	• Characters representations, the Great Orthogonality theorem, basis of representation [4]
	• Construction of character tables for point groups [3]
	• Symmetry adapted linear combinations (SALC), direct products [3]
	• Applications:
	  ○ Molecular vibrations: Infrared and Raman spectroscopy [3]
	  ○ Chemical bonding: Hybridization in molecules [3]
	  ○ Molecular orbitals and electronic spectra [3]
	  ○ Group theory and molecular complexes. Ligand filed theory [3]

Text & Reference Books	1. F A Cotton, Chemical Applications of Group Theory, 3rd Ed. Wiley (2010) 2. V. Ramakrishnan, M S Gopinathan, Group theory in Chemistry, Vishal Publishing (2013) 3. Group Theory and Chemistry, David M Bishop, Dover Publications (1993)

CHY 5XXX: Advanced Electrochemistry [3 0 0 3]	
Prerequisites	CHY 314
Learning Outcomes	The course aims to acquaint the students with the advanced aspects of electrochemistry so that they can understand the mechanism and processes of different measurements routinely done in research laboratories.
Syllabus	• Potentially confusing potentials: differentiating electrochemical potential, chemical potential, electrode potential, solution potential and over potential. A detailed case study of solid-state vacuum level energetics to solution state reference electrode energetics. [4] • A short revisit to the dynamics of electron transfer (Kinetics and Thermodynamics-Nernst, Butler-Volmer and Tafel equations), importance will be given in understanding the plots of Butler-Volmer and Tafel from recently published articles. [4] • Electrochemical Instrumentation: importance of understanding the circuit diagrams for measuring voltage or current (Voltmeter vs Ammeter), measuring 2,3 and 4 wire systems, potential drop at the interfaces, contact vs. sheet vs. solution resistance.[4] • Controlled Potential Methods: polarography (current sampled polarography and AC polarography)- stripping analysis, Basic potential step methods: Controlled current and potential techniques-chronoamperometry and chronopotentiometry. [4]

CHY 5XXX: Advanced Electrochemistry [3 0 0 3]	
	• Voltammograms: linear sweep Voltammetry, square wave voltammetry and cyclic voltammetry, how to read a cyclic voltammogram (reversible, quasi-reversible and irreversible voltammogram), determining standard rate constants from different CV's, electrochemical irreversibility and different EC coupled reactions. [4] • Hydrodynamic techniques: rotating disk electrode (RDE), rotating ring-disk electrode (RRDE), Koutecký-Levich analysis and UME Voltammetry. electrochemical impedance spectroscopy: impedance and phase shifts, equivalent circuits, Nyquist Plots, Bode plots, determining the value of circuit elements from the impedance plots. [4] • Scanning probe microscopy techniques: scanning electrochemical microscopy, AFM based SEM. different modes of SECM, electron transfer and transport reactions at electrodes, advantages and disadvantages of using micro- and nanostructured materials and surface-modified electrodes in electrochemical investigations.[4] • Solid state devices: ET vs. ETp, molecular junctions, different types of single and ensemble junctions its characterization and applications.[4] • Some recently published articles relevant to the topic of the course will be reviewed and discussed in detail.[4] • A short presentation on topics published in articles relevant to the course will be done [4]
Text & Reference Books	1. Electrochemical Methods: Fundamentals and Applications by Allen J Bard and Larry R. Faulkner 2. Electrochemistry for Chemists by Donald T. Sawyer, Andrzej Sobkowiak and Julian L. Roberts

CHY 5XXX: Ultrafast Spectroscopy [3 0 0 3]	
Prerequisites	CHY 313 and CHY 324
Learning Outcomes	▪ To understand the origin of nonlinear susceptibilities and their properties ▪ Implication of phase matching to enhance nonlinearity ▪ To analyze the frequencies generated by a nonlinear optical process ▪ To understand the importance of multidimension spectroscopy in analyzing coherent effects
Syllabus	• Basics of lasers: Einstein A, B Coefficients, population inversion, amplification and saturation, relationship between Linewidth of stimulated emission and pulse duration, active and passive mode-locking, Q-switching, and cavity dumping [4] • Nonlinear Phenomena: tensor nature of linear and nonlinear susceptibilities, Ordinary ray and extraordinary ray in uniaxial materials, Type I and Type II angular phase matching using birefringence [4] • Nonlinear dispersion phenomena, group velocity dispersion, self-phase modulation [4] • Second order nonlinear phenomena, phase matching methods, parametric oscillator, third order nonlinear processes [4] • Diagnosis methods of ultrashort pulses: autocorrelation, frequency resolved optical gating (FROG), spectral phase interferometry for direct electric-field reconstruction (SPIDER) [4]

CHY 5XXX: Ultrafast Spectroscopy [3 0 0 3]	
	• Coherent Effects: equation of evolution using Bloch-equation, two-level system time-dependent perturbation theory, induced polarization [5] • Response functions: first, second and third order processes using density matrix formalism, Feymann doubled-sided diagrams [5] • Principles of pump-probe method, frequency degenerate four-wave mixing, frequency non-degenerate mixing, time-resolved absorption, time-resolved emission spectroscopy (Kerr shutter and upconversion) [5] • Transient vibrational methods: stimulated Raman scattering, coherent anti-Stokes Raman scattering (CARS), time-resolved mid-IR [5]
Text & Reference Books	1. R.W. Boyd, Nonlinear Optics, Academic Press, Boston, 1992. 2. Y.R. Shen, The Principles of Nonlinear Spectroscopy, J. Wiley, New York, 2003. 3. W. Demtroder. Laser spectroscopy: basic concepts and instrumentation. Berlin; New York: Springer-Verlag. 4. A. Siegman. Lasers. University Science Books, c1986. UCB Physics QC688. S561 1986 Reserve. 5. P. N. Butcher, The Elements of Nonlinear Optics, Cambridge University Press (1990). 6. Fredrik Jonsson, Lecture Notes on Nonlinear Optics (2003); online material, available at http://jonsson.eu/research/lectures

CHY 5XXX: Batteries, Fuel cells, and Electrolyzers [3 0 0 3]	
Prerequisites	CHY 314
Learning Outcomes	▪ To provide the knowledge on the fundamental electrochemistry of applied electrochemical systems ▪ To understand the mass transport and kinetics of the electrochemical reactions ▪ To understand the fundamental concepts on energy devices ▪ To acquire the knowledge of functioning batteries, fuel cells and electrolyzer
Syllabus	• Fundamentals of electrochemical systems, Thermodynamics of electrochemical reactions, Electrochemical cells [4] • Electrode kinetics, overview of Butler Volmer equation and Tafel equations pertaining to various mass transport [4] • Fuel cells - History of fuel cells, Types of fuel cells, Fuel cell thermodynamics [4] • Overpotentials – various potential losses (activation, ohmic and concentration) [4] • Experimental methods of low temperature fuel cells- Rotating disk electrode voltammetry, Koutecky-Levich equation [4] • Fuel cell assembly - electrodes, membranes, membrane electrode assembly, polarization plots [4] • Batteries – Primary and secondary batteries, Power and energy densities [4] • Lithium-ion batteries, metal-air batteries and next generation batteries [4] • Super capacitors – Types of super capacitors (double layer, hybrid and pseudo), Performance factors of supper capacitors [4]

CHY 5XXX: Batteries, Fuel cells, and Electrolyzers [3 0 0 3]	
	• Electrolyzers – Basic concepts in electrolyzers, water electrolyzers for hydrogen production, industrial electrolyzers [4]
Text & Reference Books	1. A. J. Bard and L. R. Faulkner, Electrochemical Methods: Fundamentals and Applications, 2nd Edition, Wiley (2000) 2. Supramaniam srinivasan, Fuel Cells: From Fundamentals to Applications, Springer (2006) 3. J. Newmann and N P Balsara, Electrochemical Systems (4th Edition), ECS series, Wiley (2021)

CHY 5XXX: Fundamentals of Solution-State NMR Spectroscopy: Principles and Applications [3 0 0 3]	
Prerequisites	CHY 313 and 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 2 X 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 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, distortion less enhancement by polarization transfer (DEPT) - 45º, 90º, 135º and its application to distinguish methyl, methylene and methine group [2]

CHY 5XXX: Fundamentals of Solution-State NMR Spectroscopy: Principles and Applications [3 0 0 3]	
	• 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 NMR Pipe, 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 Edition, Viva (2011). 5. A. Leach, Molecular Modelling: Principles and Applications, 2 nd Ed., Pearson (2009).

CHY 5XXX: Molecular Dynamics Simulations [3 0 0 3]	
Prerequisites	CHY 313
Learning Outcomes	This course will introduce basic understanding on how nuclei move classically and quantum mechanically within the molecular potential energy landscape. It also introduces underlying mechanisms of combined electron-nuclear motion that is essential to explain many chemical events.
Syllabus	• Nuclear Motion: Classical dynamics, rovibrational spectra of diatomic molecules, Coordinate system and Hamiltonian, potential energy surfaces, force fields, local molecular mechanics, global molecular mechanics [4] • Molecular dynamics: trajectory of the system, space correlation, time correlation, time autocorrelation, Newton equations of motion, Verlet algorithm, constraints, Periodic boundary conditions, conformation, starting velocities, thermalization, simulated annealing, applications in research and engineering - drug design, biochemistry, material science, environmental science and nanotechnology [8]

CHY 5XXX: Molecular Dynamics Simulations [3 0 0 3]	
	• Langevin dynamics, Langevin dynamics, Monte Carlo dynamics, Car-Parrinello dynamics, Semiclassical dynamics - mean-field (Ehrenfest) approach and surface-hopping approach [6] • Quantum dynamics: ab initio molecular dynamics, Born-Oppenheimer approximation, Hartree-Fock Molecular Dynamics, Kohn–Sham Molecular Dynamics, Path Integral Dynamics, "on the fly" potential energy surfaces, finite-temperature dynamical trajectories [6] • Nonadiabatic quantum dynamics: full quantum dynamics and classical trajectory-based approaches [4] • Practical training through hands-on use of the softwares (GAUSSIAN, SCHRODINGER, GROMACS) [12]
Text & Reference Books	1. R. Leach, Molecular Modelling, Principles and Applications, 2nd edition, Pearson Education Ltd. UK (2001). 2. D. Frenkel and B. Smit, Understanding Molecular Simulation: From Algorithms to Applications, 2nd edition, 3. J. M. Haile, Molecular Dynamics Simulation: Elementary Methods, Wiley-Interscience; 1st edition (1997). 4. D. Marx and J. Hutter, Ab Initio Molecular Dynamics: Theory and Implementation, Cambridge University Press (2009)

CHY 5XXX: Advanced Optical Spectroscopy [3 0 0 3]	
Prerequisites	CHY 121
Learning Outcomes	▪ To provide a comprehensive understanding of absorption and emission phenomena in molecules and materials ▪ To introduce the fundamental principles that govern light-induced energy and electron transfer processes. ▪ To explore advanced applications of various light-induced processes.
Syllabus	• Module 1- Optical transitions: Boltzmann distribution and relative population of energy states, Born-Oppenheimer approximation and electronic motion, Franck–Condon (FC) principle and electronic transition, vibrational transitions and electronic states, transition dipole moment and intensity of bands in electronic spectroscopy, oscillator strength. [3] • Module 2 - Energy diagram of molecules: Construction of energy diagram of the molecular system, spin of electrons and defining singlet, triplet, and doublet, absorption, fluorescence, and phosphorescence, construction of energy diagram of organic molecules and Jablonski diagram, FC states and intensity of spectrum.[3] • Module 3 - Quantifying various optical processes: Time scales of various transitions, fluorescence/phosphorescence quantum yield and lifetime, calculation of rate constants of various electronic transitions, experimental methods for determining fluorescence/phosphorescence quantum yield and lifetime. [3] • Module 4 - Solvation of molecules:

CHY 5XXX: Advanced Optical Spectroscopy [3 0 0 3]	
	Line width of the electronic spectrum, line broadening, specific solvent and general solvent effects, concept of solvent reorganization, bathochromic, and hypsochromic shift, hypochromicity and hyperchromicity, Stokes shift, Lippert-Mataga equation, and excited state dipole moment, solvatochromism and its application [4] • Module 5- Molecular interactions: Ground and excited state interactions of molecules and optical transitions, spectral shifts and types of aggregations, J- and H- aggregates, excimer and exciplex [2] • Module 6 - Quenching of emission: Perrin equation, Stern-Volmer equation based on lifetime and intensity, types of quenching – static and dynamics, quenching based on energy/electron transfer process [3] • Module 7 - Light-induced energy transfer: Design of energy transfer donor-acceptors, requirements of energy donor and acceptor, golden rule approximation for the energy transfer rate, Dexter Energy transfer and Förster energy transfer processes, experimental determination of efficiency and rate constant of energy transfer, power dependence on distance [4] • Module 8 - Light-induced electron transfer: Free energy requirements of electron donor/acceptor, electron level diagram of donor and acceptor, Rehm-Weller equation, effect of solvent on electron transfer, concept of reorganization energy and Marcus equation, forward and back electron transfer processes, experimental determination of efficiency and rate constant of electron transfer [5] • Module 9 - Light-induced process in nature: Natural photosynthesis, vision, and plant gene expression. [2] • Module 10 - Applications of light-induced energy and electron transfer: Applications of energy and electron transfer processes in physics, chemistry and biology, development of various optoelectronic devices, design of molecular sensors and switiches, photovoltaic devices, [2] • Module 11 - Semiconductor nanocrystals: Formation of band structure and trap states, concept of excitons, quantum confinement, and dimensionality, quantum dots, optical transitions and photoluminescence, applications of quantum dots in optoelectronic devices. [4] • Module 12 - Plasmonic nanostructures: Localized and propagating surface plasmons, Drude–Lorentz model, Mie theory, extinction spectrum, and size-dependent scattering, application in surface-enhanced Raman spectroscopy. [4]
Text & Reference Books	1. Modern Molecular photochemistry of organic molecules N. J. Turro, V. Ramamurthy, J. C. Scaiano, University Science Books. 2. Principles of Fluorescence Spectroscopy Joseph R. Lakowicz, Springer, 3rd edition. 3. Semiconductor and Metal Nanocrystals: Synthesis and Electronic and Optical Properties Victor I. Klimov (Ed), CRC Press Inc (2003).

DATA SCIENCES

CURRICULUM FOR

*i*² Data Sciences (SEM: 4-10)

CORE & ELECTIVE COURSES

I2D Courses

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</table>

I2D Courses

DSC 311: Mathematical Statistics [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	This course provides students with decision theory, estimation, confidence intervals, and hypothesis testing.
Syllabus	• Sampling Distributions: 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. [9] • Estimation of Parameters: 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. [9] • Bivariate Samples: Sample from a bivariate population; least square curve fitting; maxi-mum 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; χ^2 test of goodness of fit. [15]
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.

DSC 312: Optimization Techniques [2 0 0 2]	
Prerequisites	NA
Learning Outcomes	On completion of this course, Students should be able to ▪ To apply optimization techniques. ▪ Understanding of linear and nonlinear techniques

DSC 312: Optimization Techniques [2 0 0 2]	

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.

DSC 313: Database Management System [3 0 0 3]	
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.

DSC 313: Database Management System [3 0 0 3]	
	3. Peter Rob and Carlos Coronel, Database System- Design, Implementation and Management, 7th ed., Cengage Learning, 2007.

DSC 314: Data Structures [3 0 0 3]	
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]
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.

DSC 315: Computer Organization and Operating System [3 0 0 3]	
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]

DSC 315: Computer Organization and Operating System [3 0 0 3]	
	• 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 • 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.

DSC 316: Machine Learning I [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	On completion of this course, Students should be able to ▪ Introduce fundamental problems in machine learning.

DSC 316: Machine Learning I [3 0 0 3]	
	▪ Provide an understanding of theoretical foundations, techniques, mathematical concepts, common architectures, and algorithms used in machine learning. ▪ Implement end-to-end machine learning experimental protocols ▪ Implement a large variety of classification models, handle basic classification problems using machine learning
Syllabus	• Introduction to Machine Learning: General introduction to Machine Learning with applications, including some applications in basic sciences, Supervised and Unsupervised learning, Classification and regression problems, Decision boundaries, Different modes of data used for machine learning [3] • Basic data Exploration: Analysis of the quality of data, Handling of missing values, Measuring relationships among features, Data preparation using Normalization, Binning and Sampling, Preliminary feature selection techniques (Chi-Square test, Recursive feature elimination) [3] • Basic classification and regression models: k-Nearest Neighbors, Basics of Simple and Multiple linear regression, Why not linear regression for classification tasks, Logistic regression, Linear Discriminant Analysis [6] • Revision of basic clustering and dimensionality reduction: k-Means, Hierarchical and Density Based clustering, Dimensionality reduction algorithms: PCA, SVD, t-SNE and UMAP [4] • Model assessment and selection Bias-variance trade-off for machine learning models, Cross-validation (train-test split, leave-one-out- cross validation, k-fold cross validation), Cross validation with bootstrapping, Lasso and Ridge regression in context of linear models and their roles in feature scoring [4] • Tree-based models: Regression and Classification trees, Shannon Entropy Model, Information Gain, Bagging and Boosting (Random Forest and Important Boosting models), Alternative Feature Selection and Impunity Metrics using Tree-based models [3] • Probability-based models: Bayes' Theorem, Bayesian Prediction, Conditional Independence and Factorization, Naïve Bayes Prediction model. Extensions and Variations of the Naïve Bayes Model, Bayesian Networks, Maximum Likelihood Method and EM algorithm [6] • Support Vector Machines: Classification using a separating hyperplane, Calculating Maximum-Margin as an optimization problem, Soft and Hard margin support vector classifier, SVM for non-linear decision boundaries using Kernel Trick, SVM for multi-class classification [5] • Evaluation Metrics: Accuracy, TP, FP, TN, FN, Sensitivity, Specificity, Precision, F1-Score, Kappa Score, MCC Score, demonstrating practical scenarios where different performance measures might be useful, ROC-curve and PR-curve. [4] • Interpretation of machine learning models: Partial Dependency Plots, Individual Conditional Expectation Plots, Accumulated Local Effects, Shapely Additive Explanation values, Interpreting and ranking feature contributions [2] • Concluding: Limitations of Classical Machine Learning, and its link to Deep Learning, Deployment of Machine Learning models [2]
Text & Reference Books	1. G. Casella, S. Fienberg, I. Olkin, An Introduction to Statistical Learning ISBN 978-1-4614-7137-0, DOI 10.1007/978-1-4614-7138-7, Springer New York Heidelberg Dordrecht London 2. John D. Kelleher, Brian McNamee, Aoife D'Arcy, Fundamentals of Machine Learning for predictive data analytics, The MIT Press, Cambridge Massachusetts 3. Trevor Hastie, Robert Tibshirani, Jerome Friedman, The Elements of Statistical Learning, Springer Series in Statistics 4. Tom Mitchell, "Machine Learning", McGraw Hill, 1997

DSC 317: Data Structures Lab [0 0 2 1]	
Prerequisites	NA
Learning Outcomes	On completion of this course, Students should be able to ▪ Learn to organize data using various linear and non-linear data structures like array, linked list, Queue, Stact, Tree and Graph ▪ Learn to design different algorithms and implement them using different data structures. ▪ Learn to apply different data structures on various real-time problems
Syllabus	• Basic understanding implementing codes for data insertion, deletion, concatenation and appending operations in arrays. • Implement various functions including insertion (beginning, middle, end), deletion (beginning, middle, end), reverse, searching, concatenation, etc. using Single and Double Linked List. • Implementing various functions like insertion, deletion, functions of Stack, Queue, Dequeue, Priority Queue using Array and Linked List. • Create Binary Tree and perform insertion and deletion operations in Binary Tree. • Create Binary Search Tree and perform insertion and deletion operations in Binary Tree. • Implement Tree Traversal Algorithms in Binary Trees. Implement Max Heap and Mean Heap of Binary Tree. • Implement various sorting techniques including Bubble, Selection, Insertion, Merge Sort, Quick Sort, Radix Sort, Heap sort using array. • Search an element from a list using linear search and binary search. • Write the code of finding the shortest path and minimum spanning tree of a graph. • Implement DFS and BFS algorithms over various graphs.
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.

DSC 318: Mathematical Statistics Lab [0 0 2 1]	
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.

DSC 318: Mathematical Statistics Lab [0 0 2 1]	
Syllabus	• Objects and functions, Arithmetical and Boolean operators, Importing and Exporting Data sets, Packages, Loops and Conditional statements, • Measure of central tendency for grouped and ungrouped data • Basic plots. • Density, distribution function, quantile function and random generation for standard discrete and continuous distributions. Generating bivariate random samples. • Correlation coefficients • Q-Q plots and P-P plots. Fitting distributions. • Maximum Like-lihood estimation. • Type I and Type II Error, p values, Power curves • Test for mean, variance, proportion and independency, Goodness of fit
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.

DSC 321: Design and Analysis of Algorithms [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	On completion of this course, Students should be able to ▪ Understand the basics of algorithms ▪ Perform complexity analysis of algorithms ▪ Implement 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]

DSC 321: Design and Analysis of Algorithms [3 0 0 3]	
	• 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.

DSC 322: Applied Regression Analysis [3 0 0 3]	
Prerequisites	Mathematical Statistics
Learning Outcomes	On completion of this course, Students should be able to ▪ Understand the theoretical foundations of various statistical models ▪ Perform fitting of linear and nonlinear regression
Syllabus	• Linear regression with one regressor, Regression with multiple regressors – estimation, tests, and confidence regions. Simultaneous testing methods. [8] • Model Adequacy Checking: Analysis of residuals. Lack of fit tests. Checks (graphical procedures and tests) for model assumptions: Normality, homogeneity of errors, independence, correlation of covariates and errors. [5] • Multicollinearity, outliers, leverage and measures of influence. [3] • Model selection (stepwise, forward and backward, best subset selection) and model validation. [3] • Regression models with indicator variables. [3] • Polynomial regression models. [3] • Regression models with interaction terms. Transformation of response variables and covariates. Variance stabilizing transformations, Box-Cox method. Ridge's regression. Weighted Regression. [5] • Regression with a binary dependent variable, Panel Data Regression [5] • Generalized Linear Models [5]
Text & Reference Books	1. Draper, N. and Smith, H. Applied Regression Analysis, 3rd Edition, John Wiley and Sons Series in Probability and Statistics, New York, 1998. 2. Montgomery, D., Peck, E., Vining, G. Introduction to Linear Regression Analysis, 5th Edition, John Wiley, New York, 2012. 3. Sen, A. and Srivastava, M. Regression Analysis – Theory, Methods & Applications, 1st Edition, Springer-Verlag Berlin Heidelberg, New York, 1990. 4. Kutner, M., Nachtsheim, C., Neter, J. and Li, W. Applied Linear Statistical Models, 5th Edition, McGraw-Hill Companies, Boston, 2005. 5. Linear Model Methodology by Andre I. Khuri (CRC Press, 2010)

DSC 323: Numerical Analysis [3 0 0 3]	
Prerequisites	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] • Numerical solutions of nonlinear algebraic equations: Bisection, Secant and Newton's method, fixed-point iteration. [4] • 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, QR algorithm. [4] • Initial Value Problems: Euler method, Higher order methods of Runge-Kutta type. Boundary Value Problems: Finite differences. [8]
Text & Reference Books	1. K. E. Atkinson, An Introduction to Numerical Analysis, 2nd ed., John Wiley, 1989. 2. R. L. Burden and J. D. Faires, Numerical Analysis, 7th ed., Brookes/Cole, 2011. 3. S. D. Conte and C. deBoor, Elementary Numerical Analysis-an algorithmic approach, 3rd ed., McGraw Hill, 1980. 4. David Kincaid, Ward Cheney, Numerical Analysis, mathematics of scientific computing, American Mathematical Society, 2009. 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. E. Sueli and F. D. Mayers, An Introduction to Numerical Analysis, Cambridge University Press, 2003.

DSC 324: Machine Learning II [3 0 0 3]	
Prerequisites	Machine Learning I Introduction to Artificial Intelligence
Learning Outcomes	On completion of this course, Students should be able to ▪ Understanding Neural Network structures and learning. ▪ Understanding the deep learning algorithms for domains. ▪ Implementing deep learning algorithms to solve real-world problems
Syllabus	Module 1: Introduction [5] 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. Module 2: Feedforward Networks [5]

DSC 324: Machine Learning II [3 0 0 3]	
	Multilayer Perceptron, Gradient Descent, Backpropagation, Empirical Risk Minimization, regularization. Module 3: Deep Neural Networks [4] Difficulty of training deep neural networks, Greedy layerwise training. 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). Module 4: Convolutional Neural Networks [3] Architectures, convolution/pooling layers, LeNet, AlexNet.. Module 5: Recurrent Neural Networks [3] Backpropagation through time, Long Short Term Memory, Gated Recurrent Units, Bidirectional LSTMs, Bidirectional RNNs. Module 6: Generative models [5] Restrictive Boltzmann Machines (RBMs), Introduction to MCMC and Gibbs Sampling, gradient computations in RBMs, Deep Boltzmann Machines. Module 7: Deep Unsupervised Learning and Recent Trends [5] Autoencoders (standard, sparse, denoising, contractive, etc), VariationalAutoencoders, Adversarial Generative Adversarial Networks, Autoencoder and DBM, Multi-task Deep Learning, Multi-view Deep Learning. Module 8: Applications of Deep Learning to Computer Vision [5] 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. Module 9: Applications of Deep Learning to NLP [5] 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.
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.

DSC 325: Data Science Lab I [0 0 3 1]	
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

DSC 325: Data Science Lab I [0 0 3 1]	
	• Simple and Multiple Linear Regression, Model adequacy checking, Variable selection • 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. 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.

DSC 411: Probability Theory and Stochastic Processes [3 0 0 3]	
Prerequisites	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.
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. 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.

DSC 412: Scientific Computing [3 0 3 4]	
Prerequisites	Numerical Analysis
Learning Outcomes	On completion of this course, Students should be able to ▪ 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.
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. [2] • 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. [8] • Non-stationary iterative methods-conjugate gradient (CG), convergence analysis; preconditioning. Estimation and computation of eigenvalues- Gershgorin disc, power methods, the QR algorithm [10] • 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. [8] • Constrained Optimisation: Optimality/KKT conditions, penalty and augmented Lagrangian for equality-constrained optimisation, interior-point/barrier methods for inequality constrained optimisation. Quadratic optimization [11]
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. David Kincaid, Ward Cheney, Numerical Analysis: Mathematics of Scientific Computing, American Mathematical Society, 2009. 4. A. Greenbaum, Iterative Methods for Solving Linear Systems, SIAM, 1997. 5. G. H. Golub and C. F. van Loan, Matrix Computations, John Hopkins University Press, 1996. 6. H. C. Elman, D. J. Silvester and A. J. Wathen, Finite Elements and Fast Iterative Solvers, Oxford University Press, 1995. 7. J. Nocedal and S. J. Wright, Numerical Optimisation, Springer, 2006. 8. D. P. O'Leary, Scientific Computing with Case Studies, SIAM, 2009.

DSC 413: Data Warehousing & Business Intelligence [3 0 0 3]	
Prerequisites	NA
Learning Outcomes	On completion of this course, Students should be able to ▪ 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.

DSC 413: Data Warehousing & Business Intelligence [3 0 0 3]	
	▪ 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.

DSC 414: Advanced Artificial Intelligence [3 0 0 3]	
Prerequisites	Machine Learning II
Learning Outcomes	On completion of this course, Students should be able to ▪ Model search problems, Markov decision processes, Reinforcement Learning problem ▪ Gain a good understanding on the broad academic domain of AI ▪ Gain coding skills good enough to solve basic Reinforcement Learning problems
Syllabus	• Reflex-based model: Revision of Machine learning; Classical supervised models; Revision and overview of dimensionality reduction models; Revision of parameter optimization strategies like random grid search; Necessary coding demonstration [3] • Revision of Deep learning: Revision of Dense, Convolutional and Recurrent Neural Networks with practical examples; Transfer learning with practical examples; Variational Autoencoders for dimension reduction; Noise removal and synthetic data generation and Generative Adversarial Networks with implementation [3] • State-based model: Modelling a search problem; formulating state spaces and actions; Backtracking search and its special cases such as depth-first search; breadth-first search and depth-first search with iterative deepening; coding demonstration of backtracking search with details on complexity analysis; Dynamic programming coding demonstration of backtracking search with details on complexity analysis; Uniform cost search coding demonstration of

DSC 414: Advanced Artificial Intelligence [3 0 0 3]	
	backtracking search with details on complexity analysis; A* search coding demonstration of backtracking search with details on complexity; Algorithms for learning costs of a search problem given a state space [8] • Markov Decision Process (MDP) and Reinforcement learning: Modelling a search problem with stochasticity; Concepts of chance nodes and transition probability; Detailing on concepts such as policy; utility and value with formal definitions and concrete examples; Detailed discussion on policy evaluation; Extending the idea of policy evaluation to value iteration; Bellman's equation; Transition from MDP to Reinforcement Learning (RL); Mone Carlo Approach to RL; Model-based and model-free Monte Carlo; SARSA algorithm for RL; Q-Learning; Brief insight into Deep Reinforcement Learning; A practical demonstration of RL [8] • Adversarial games: Modelling two-player zero-sum games; Concepts of expectimax and minimax; Evaluation of Games; Coding example with a simple game; Inequalities related to the Minimax policy and their interpretation; Modelling games with a component of randomness; The concept of Expectiminimax; Alpha-Beta pruning for game trees; Temporal difference learning with example; Game evaluation [6] • Constraint satisfaction problem: Factor graph with example; Dynamic ordering; Arc consistency; Beam search; Local search and Conditional Independence; Variable elimination [6] • Logic: Relating Logic with Natural Language; Syntax versus semantics; Propositional logic; Syntax of propositional logic; Interpretation function; Contingency Contradiction and entailment; Tell operation; Ask operation; Satisfiability; Model checking; Inference framework; Desiderata for inference rules; Resolution and Soundness of Resolution; Limitation of Propositional Logic; First-order logic [6]
Text & Reference Books	1. Stuart Russell and Peter Norvig, Artificial Intelligence: A Modern Approach, 4th US ed. 2. Stanford Lecture Series: Artificial Intelligence: Principles and Techniques 3. Trevor Hastie, Robert Tibshirani, Jerome Friedman, The Elements of Statistical Learning 4. Ian Goodfellow, Yoshua Bengio and Aaron Courville, Deep Learning

DSC 415: Data Science Lab II [1 0 3 2]	
Prerequisites	NA
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. ▪ Create Neural Networks on their own using Keras ▪ Write models like CNN, RNN, Transformers
Syllabus	• Supervised learning using scikit-learn: Basic data handling, cleaning, Implementation of classification algorithms using sklearn, Implementation of cross validation protocols, parameter optimization using random grid search, Imbalance classification, implementing feature selection techniques like recursive feature elimination, tree-based feature selection, implementing explainability techniques like partial dependency plots and Shapely plots [6]

DSC 415: Data Science Lab II [1 0 3 2]	
	• Unsupervised learning using scikit-learn: Implementation of several clustering (k-Means, Agglomerative clustering, DBSCAN) and dimensionality reduction techniques (PCA, t-SNE and UMAP), Case study on detection, visualization (using dimensionality reduction) and interpretation of clusters [4] • Basics of Deep Learning: Creating a small perceptron model on a dummy dataset (e.g. low resolution hand-written digits dataset) from scratch and training the model with the gradient descent algorithm. [4] • Basics of Keras: Creating a dense neural network in Keras, Sequential way of writing a model. Model compilation, training, validation and testing, creating custom Keras layers, creating customized loss functions, several ways of saving and loading a trained model, Gradient-tape method of training a model. Exercises can be done on low resolution hand-written digits dataset [3] • Image classification using CNN: Writing a Convolutional Neural Network, training and testing on the MNIST dataset. Using VGG-Net for pretraining for a smaller training dataset. [6] • Noise removal, segmentation & dimensionality reduction using Autoencoder: Writing a Convolution-based autoencoder for noise removal on the low resolution hand-written digits dataset. Using autoencoder for dimensionality reduction and segmentation using the pet image segmentation dataset [6] • Time series prediction: Using RNN model on historical stock data from Google (see Python library yfinance) [3] • Machine Translation using Transformer: Learning to train a transformer model for English to Spanish translation [6]
Text & Reference Books	1. Chris Albon, Machine Learning with Python Cookbook, 2018, O'Reilly Media, Inc. 2. Andreas C. Müller and Sarah Guido, Introduction to Machine Learning with Python, 2017, O'Reilly Media, Inc. 3. François Chollet, Deep Learning with Python, ISBN 9781617294433, Manning Publications 4. Seth Weidman, Deep Learning from Scratch: Building with Python from First Principles, 2019, O'Reilly Media 5. Josh Patterson and Adam Gibson, Deep Learning: A Practitioners Approach, August 2017 O'Reilly Media, Inc., ISBN: 9781491914250 6. https://www.geeksforgeeks.org/time-series-forecasting-using-recurrent-neural-networks-rnn-in-tensorflow/ 7. https://keras.io/examples/nlp/neural_machine_translation_with_transformer/ 8. https://keras.io/examples/generative/conditional_gan/ 9. https://keras.io/examples/generative/vae/ 10. https://keras.io/examples/

DSC 421: Time Series Analysis [3 0 0 3]	
Prerequisites	Applied Regression Analysis
Learning Outcomes	On completion of this course, Students should be able to ▪ Students will learn to use visual and numerical diagnostics to assess the soundness of their models.

<table>
<tr><th colspan="2">DSC 421: Time Series Analysis [3 0 0 3]</th></tr>
<tr><td></td><td>▪ Students will learn to communicate the statistical analyses of substantial datasets through explanatory text, tables and graphs
▪ Students will learn to combine and adapt different statistical models to analyze larger and more complex data</td></tr>
<tr><td>Syllabus</td><td>• Introduction to time series, its various applications [1]
• Stochastic process and its main characteristics. [6]
• Time series as a discrete stochastic process. Stationarity. Main characteristics of stochastic processes (means, autocovariation and autocorrelation functions). Stationary stochastic processes. Stationarity as the main characteristic of stochastic component of time series. Ergodicity in time series, Deterministic, purely non-deterministic Processes Wold decomposition. Lag operator.
• Autoregressive-moving average models ARMA (p,q) [5]
• Moving average models MA(q). Condition of invertability. Autoregressive models AR(p). Yull-Worker equations. Stationarity conditions. Autoregressive-moving average models ARMA (p,q).
• Estimation of parameters of autoregressive models [6]
• Coefficients estimation in autoregressive models. Coefficient estimation in ARMA (p) processes. Quality of adjustment of time series models. AIC information criterion. BIC information criterion. “Portmonto”-statistics. Box-Jenkins methodology to identification of stationary time series models.
• Diagnostics Checking [2]
• Diagnostics Checking for Stationary Processes, residual analysis, graphical techniques for model validation, Tests of Serial Uncorrelatedness, Q test, tests for randomness, QQ plot.
• Forecasting in the framework of Box-Jenkins model [3]
• Forecasting, trend and seasonality in Box-Jenkins model
• Frequency domain analysis [6]
• Processes in Frequency Domain, Frequency domain analysis, and time domain analysis, spectral representation of time series, Spectral density and its estimation, transfer functions.
• Non-Stationary and Long Memory Processes [6]
• ARIMA Processes, Random Walk, Unit Root Problem, Implications of presence of unit root, Weiner process, Geometric Brownian motion, Unit Root hypothesis and test for unit rootNon-Stationary and Long Memory Processes, Dickey-Fuller test for unit root hypothesis, Phillips-Perron Test for unit root, Autoregressive Fractionally Integrated Moving Average (ARFIMA) models, Seasonal Autoregressive Integrated Moving Average (SARIMA) Processes.
• Stochastic Volatility Models [5]
• Introduction of Stochastic Volatility Models, Autoregressive Conditional Heteroscedastic (ARCH) ModelsStochastic Volatility Models, Order determination for ARCH models, Generalized ARCH (GARCH) Models, properties of GARCH models, Forecasting in ARCH and GARCH models.</td></tr>
<tr><td>Text & Reference Books</td><td>1. Brockwell P. and Davis R., Introduction to Time Series and Forecasting, Springer, New York, 2000.
2. Box G.E.P., Jenkins G., Reinsel G. and Ljung, Time Series Analysis-Forecasting and Control, 5th Edition, Wiley, New York, 2016.
3. Chatfield C., The Analysis of Time Series – An Introduction, 6th Edition, Chapman and Hall / CRC, New York, 2016.
4. Shumway R.H. and Soffer D.S., Time Series Analysis and Its Applications, 4th Edition, Springer, New York, 2016.</td></tr>
</table>

DSC 421: Time Series Analysis [3 0 0 3]	
	5. Shumway, R.H., Stoffer, D.S. (2006). Time Series Analysis and Its Applications (with R examples). Springer-Verlag, New York.

DSC 422: Parallel & Distributed Computing [3 0 0 3]	
Prerequisites	Computer Organisation & Operating System
Learning Outcomes	On completion of this course, Students should be able to ▪ 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. 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.

DSC 423: Data Analysis & Visualization [2 0 3 3]	
Prerequisites	NA
Learning Outcomes	On completion of this course, Students should be able to ▪ Familiarizing with data visualization tools such as Tableau, VTK Tool, and Python ▪ Making reports and dashboards
Syllabus	Module 1: Introduction to Data Analysis & Visualization [5] Data Analytics, Role of Data Analytics, Components of Data Analytics, Types of Data Analytics, Data Analytics Techniques, Advantages of Data Analytics, Applications of Data Analytics, Data analytics tools. Data Visualization, Importance of Data Visualization, Categories of Data Visualization, Types of Data Visualization Techniques, Advantages and Disadvantages of Data Visualization, Difference

DSC 423: Data Analysis & Visualization [2 0 3 3]	
	Between Data Visualization and Data Analytics, Data Visualization Techniques, Data Visualization Tools, Benefits of Data Visualization Tools, Common features of Data Visualization Tool, Data Visualization Libraries, Data Visualization examples, Concerns Regarding Data Visualization Module 2: Data Analysis and Visualization Using Python [5] Steps from data to knowledge, Data analysis and processing, Python libraries in data analysis, how to choose the right Python libraries, Data Visualization (Line Plot, Bar Plot, Pie Chart, Box Plot, Histogram Plot, Scatter Plot): - Direct Plotting, Seaborn Plotting System, Matplotlib Plot Case Studies: - Data Gathering, Data Analysis, Data Visualization, Findings Advanced Visualization: - simulation, animation Module 3: Visualization for deep learning [5] Interactive overview of model analysis, Why do we want to visualize models?, What can we visualize? When is visualization most relevant? How can we visualize models? Tools and frameworks for model visualization, Understanding, Visualizations, and Explanation of Deep Neural Networks, Deep Learning Visualization Methods, Visualizing a Neural Network using Keras Library, Visualize Deep Learning Models using Visualkeras, Why Model Visualization is Important?, What are the benefits of Model Visualization? Module 4: Visualization Toolkit [10] 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. Module 5: Data Visualization BI Tool Tableau 9. X [5] Tableau 9. x-Introduction to Data Visualization with Tableau Exploring Data Visualization with Tableau, Exporting Data and Working with Tableau. Module 6: Building Data Visualization BI Project with Tableau 9. X [10] BI Reporting Understanding Report and Dashboard Template Document Tableau Design and Development Database Source Connection.
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.

DSC 511: Big Data Analytics [2 0 3 3]	
Prerequisites	Machine Learning-II, Data Warehousing & Business Intelligence
Learning Outcomes	On completion of this course, Students should be able to ▪ 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.

<table>
<tr><th colspan="2">DSC 511: Big Data Analytics [2 0 3 3]</th></tr>
<tr><td>Syllabus</td><td>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]
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]</td></tr>
<tr><td>Text & Reference Books</td><td>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.</td></tr>
</table>

<table>
<tr><th colspan="2">DSC 512: Humans and Data [1 0 0 1]</th></tr>
<tr><td>Prerequisites</td><td>NA</td></tr>
<tr><td>Learning Outcomes</td><td>On completion of this course, Students should be able to
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</td></tr>
</table>

DSC 512: Humans and Data [1 0 0 1]	
	▪ Perform their own evaluation and critique of the validity and soundness of arguments with care and clarity, both orally and in writing
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.

DSC 513: Statistical Simulation and Computation [1 0 0 1]	
Prerequisites	Mathematical Statistics
Learning Outcomes	On completion of this course, Students should be able to ▪ Develop an understanding of the basic concepts underlying the Bayesian approach to statistical thinking. ▪ Provide knowledge on Bayesian computing, for the practical application of Bayesian models to data problems solving. ▪ Develop knowledge about various statistical simulation tools for data analysis.
Syllabus	• Introduction to Bayesian Theory and methods; non-informative priors and conjugate priors [6] • Posterior inference (with special reference to one parameter exponential family)-credible intervals and hypothesis testing [6] • Bayesian linear models, Advanced Bayesian modeling, Bayesian Model comparisons hierarchical and empirical Bayesian models [8]

DSC 513: Statistical Simulation and Computation [1 0 0 1]	
	• Computational techniques for use in Bayesian analysis, especially the use of simulation from posterior distributions. [5] • Simulation of random variables from discrete, continuous, multivariate distributions and stochastic processes [4] • Monte-Carlo methods (Markov chains; Metropolis-Hastings algorithm; Gibbs sampling; convergence) [5] • EM algorithm, Bootstrap (Bootstrapping; jackknife resampling; percentile confidence intervals). [6]
Text & Reference Books	1. Brian J. Reich, Sujit K. Ghosh, Bayesian Statistical Methods, published in 2019, by Chapman and Hall/CRC. 2. Jean-Michel Marin and Christian P. Robert, Bayesian Essentials with R, published in 2014, by Springer. 3. Andrew Gelman, John Carlin, Hal Stern, David Dunson, Aki Vehtari, and Donald Rubin, Bayesian Data Analysis, published in 2013 by Chapman and Hall/CRC. 4. W.R. Gilks, S. Richardson, D.J. Spiegelhalter, Markov Chain Monte Carlo in Practice, Chapman and Hall. 5. R.Y. Rubinston and D.P Kroese, Simulation and the Monte Carlo Method, Wiley. 6. An Introduction to the Bootstrap" by B. Efron and R.J. Tibshirani (Chapman and Hall), 1994 7. Sheldon M. Ross, Simulation, Academic Press, Fourth Edition, 2006. 8. G. M. McLachlan and T. Krishnan, The EM Algorithm and. Extensions,Wiley.1997

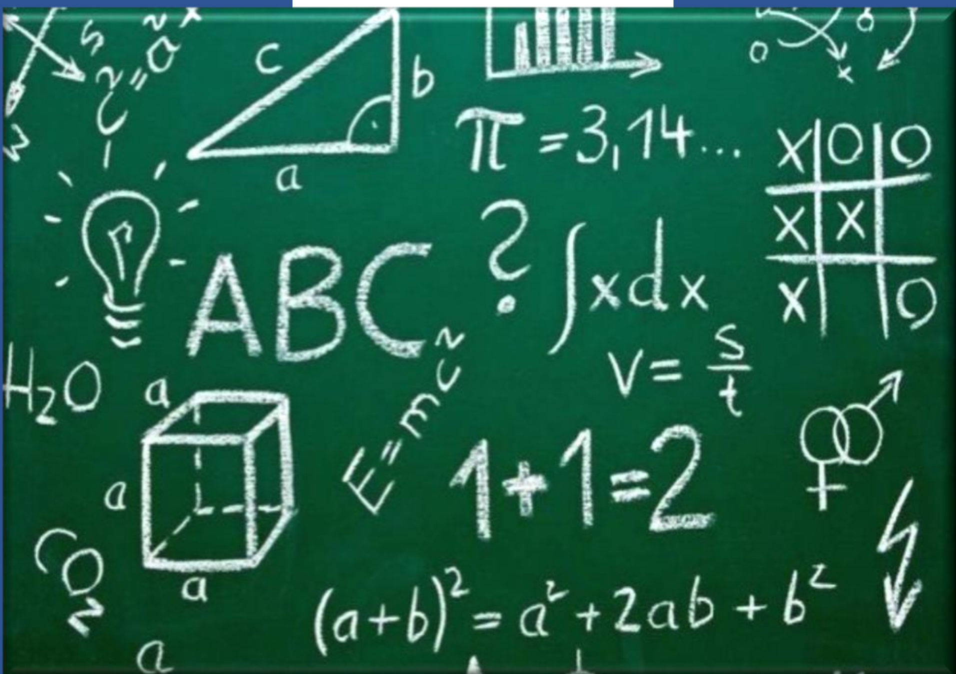
MATHEMATICAL SCIENCES

CURRICULUM FOR

BS-MS (SEM: 4 - 10)

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

CORE & ELECTIVE COURSES



BS-MS Courses

Semester 4	Semester 5	Semester 6	Semester 7	Semester 8
MAT 203 [3003] Introduction to Real analysis	MAT 303 [3003] Metric Spaces	MAT 324 [3003] Theory of Ordinary Differential Equations	MAT 407 [3003] Multivariable Analysis	MAT 501 [3003] Curves and Surfaces
MAT 204 [3003] Introduction to Groups and Rings	MAT 304 [3003] Abstract Algebra	MAT 402 [3003] Galois Theory	List C Course 1 [3003]	DSE 2 [3003]
MAT 205 [3003] Linear Algebra and Complex Analysis	MAT 313 [3003] Linear Algebra	MAT 403 [3003] Topology	List C Course 2 2* [3003]	GE 5/DSE 1 [3003]
MAT 315 [3003] Mathematical Statistics	MAT 314 [3003] Numerical Analysis	MAT 411 [3003] Measure Theory	MAT 421 [3003] Functional Analysis	Project (12)
List A Course [2002]	MAT 321 [3003] Complex Analysis	List B Course [3003]	GE 5/DSE 1	
GE 1	GE 2	GE 3	GE 4	
MAT 316 [0021] Mathematical Statistics Lab	MAT 308 [0031] Mathematics Lab			

I2M Courses

Semester 4	Semester 5	Semester 6	Semester 7	Semester 8
MAT 203 [3003] Introduction to Real analysis	MAT 303 [3003] Metric Spaces	MAT 411 [3003] Measure Theory	MAT 414 [3003] Partial Differential Equations	I2M 501 [3003] Finite element Methods and Implementation
MAT 204 [3003] Introduction to Groups and Rings	MAT 304 [3003] Abstract Algebra or GE 1	DSC 314 [3003] Data Structures	MAT 421 [3003] Functional Analysis	GE 5
MAT 205 [3003] Linear Algebra and Complex Analysis	MAT 321 [3003] Complex Analysis or GE 2	MAT 324 [3003] Theory of Ordinary Differential Equations	I2M 404 [2002] Numerical Solutions of Differential Equations	DSE 2
MAT 315 [3003] Mathematical Statistics	MAT 306 [3003] Linear Algebra	MAT 403 [3003] Topology or GE 3	I2M 411 [3003] Applied Stochastic Analysis	Project (12)
List A Courses* [2002]	MAT 314 [3003] Numerical Analysis	MAT 325 [3003] Probability theory & Stochastic Processes	GE 4	
DSC 316 [3003] Machine Learning I	I2M 322 [2002] Mathematical Modeling	I2M 401 [3003] Scientific Computing and Optimization	DSE 1	
MAT 316 [0021] Mathematical Statistics Lab	MAT 308 [0031] Mathematics Lab	I2M 402 [0031] Scientific Computing and Optimization Lab	I2M 405 [0031] NSDE Lab	
		DSC 317 [0021] Data Structures Lab		

Following 3 lists of courses (A, B and C) will be offered in the respective semesters as shown in the table above.

List A Courses

- MAT 2011 - Optimization technique and linear programming [2 0 0 2]
- MAT 2012 - Number Theory [2 0 0 2]

List B Courses

- MAT 325 - Probability Theory and Stochastic Processes
- DSC 314 & DSC 317 - Data Structures & Data Structures Lab
- MAT 331 - Representation theory

List C Courses

- MAT 412 - Commutative Algebra
- MAT 414 - Partial Differential Equations
- MAT 422 - Algebraic Topology
- I2M 411 - Applied Stochastic Analysis
- I2M 404 & I2M 405 - Numerical Solutions of Differential Equations & NSDE Lab

Minor Courses (General Electives)

Semester	Code	Title
IV	MAT 2003	Introduction to Real Analysis
	MAT 2004	Introduction to Groups and Rings
	MAT 2005	Linear Algebra and Complex Analysis I
V	MAT 303	Metric Spaces
	MAT 307	Numerical Analysis
	MAT 306	Linear Algebra
	MAT 305	Complex Analysis
	MAT 304	Abstract Algebra
VI	MAT 309	Theory Of ordinary Differential Equations
	MAT 403	Topology
VII	MAT 404	MultiVariable Analysis

BS-MS Courses

MAT 203: Introduction to Real Analysis [3 0 0 3]	
Prerequisites	MAT 201
Learning Outcomes	Aim of this course is to introduce the fundamental concepts in real analysis, starting with the properties of real numbers. They will also develop proficiency in other topics such as convergence of sequences and series, continuity and differentiability of real functions, and properties of Riemann-Stieltjes integrals.
Syllabus	• Ordered sets, Least-upper-bound and greatest lower bound property, Field axioms, Dedekind cut construction of the real number system, Archimedean principle, nth roots for positive real numbers, The complex field. [6] • Distance on the real line, Open subsets, closed subsets, compact subsets and connected subsets of the real line, Nested intervals theorem, Heine-Borel theorem, Perfect set, and Cantor's set. [6] • Convergence and divergence of sequences, Cauchy sequences, Limits of sequences, Algebra of limits of sequences, Subsequences, Monotone sequences, liminf and limsup of sequences, Bolzano-Weierstrass theorem. Convergence and divergence of series, Power series, Algebra of limits of series, Rearrangements in series. [12] • Limits of functions, Continuity and compactness, Continuity and connectedness, Discontinuities, Monotone functions, Infinity as a limit and limit at infinity. [6] • Derivatives of real function, Mean value Theorems, continuity of derivatives, Higher order derivatives, L'Hospital rule, Taylor's Theorem and differentiation of vector valued function. [5] • Upper and lower Riemann sums, Refinement of intervals, Riemann-Stieltjes integral as a limit, Properties of the integral, Integration and Differentiation. [5]
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. S. Lang, Undergraduate Analysis, 2nd ed., Springer, 1996. 4. W. Rudin, Principles of Mathematical Analysis, 3rd ed., McGraw-Hill, 1976. 5. T. Tao, Analysis I, Hindustan Book Agency, 2006. 6. H. L. Royden, Real Analysis, 3rd ed., PHI Learning, 2009 7. S. R. Ghorpade and B. V. Limaye, A Course in Calculus and Real Analysis, Springer, 2006. 8. R. R. Goldberg, Methods of Real Analysis, 2nd ed Wiley, 1976. 9. R. M. Dudley, Real Analysis and Probability, Cambridge University Press, 2002.

MAT 204: Introduction to Groups and Rings [3 0 0 3]	
Prerequisites	MAT 201
Learning Outcomes	Definitions and standard examples of groups and rings. Students will also learn some simple properties and construction related to groups and rings.

MAT 204: Introduction to Groups and Rings [3 0 0 3]	
Syllabus	• Definition of group, examples of symmetric groups, cyclic groups, multiplicative group Z_n*, Dihedral groups, Matrix groups, subgroups and normal subgroups, homomorphisms. [10] • Quotient groups, Noether Isomorphism Theorems, Theorems of Lagrange and Cauchy. [7] • Group actions, examples of group actions, Cayley's Theorem (Statement only), [8] • Direct products [2] • Rings, Ideals, Ring homomorphisms, subrings, examples of rings, Prime ideals, maximal ideals, Integral domains, Power series rings, Noether Isomorphism theorems • Euclidean domains, PID's, UFD's (Only definitions and examples, no theorems) [10] • Fields definition and examples, finite field examples [3]
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.

MAT 205: Linear Algebra and Complex Analysis [3 0 0 3]	
Prerequisites	MAT 201
Learning Outcomes	▪ The course is divided into two modules: Linear Algebra and Complex Analysis. ▪ In the linear algebra part, the main objective is to understand the definition of an abstract finite dimensional vector space and linear maps. Some simple properties and results on a finite dimensional vector space will also be learnt. ▪ Complex analysis part of this course equips students with the geometric interpretation of complex numbers, analytic functions and complex integration techniques.
Syllabus	• Vector spaces, subspaces, quotient spaces, basis, change of basis [4] • Linear transformations, matrix representation, similar matrices, dual spaces, linear functional, projection [4] • Eigenvalues and eigenvectors, Cayley Hamilton Theorem [5] • Simultaneous diagonalization, triangularization [7] • Geometric representation of complex numbers and the stereographic projection of the complex plane, Analytic functions: limits, derivatives, Cauchy-Riemann equations. [5] • Mobius maps, The exponential function and the logarithmic function. Power series representation of analytic functions. [6] • Complex Integration, Cauchy’s theorem, Cauchy’s integral formula for convex regions. [9]
Text & Reference Books	1. S. Axler, Linear Algebra Done Right, Springer, 1997. 2. K. Hoffman and R. Kunze, Linear Algebra, 2nd ed., Pearson Education, New Delhi, 2006 3. L. V. Ahlfors, Complex Analysis, Mcgraw-Hill, 1980. 4. John B. Conway, Function of One Complex Variables-I, Second Edition, GTM, Vol. 11, Springer-Verlag New York, 1973. 5. T. W. Gamelin, Complex Analysis, Springer-Verlag, 2001. 6. E. M. Stein and R. Shakarchi, Complex Analysis, Princeton University Press, 2003 7. R. Greene and S. G. Krantz, Function Theory of One Complex Variable, 3rd ed., GSM, Vol. 40, AMS, 2006.

MAT 303: Metric Spaces [3 0 0 3]	
Prerequisites	MAT 203
Learning Outcomes	Objective of this course is to provide a comprehensive understanding of metric spaces and its topology. Students will learn advanced concepts including continuity, convergence, compactness and Riemann-Stieltjes' integral.
Syllabus	• Metric spaces and Normed vector spaces: Properties and Examples. Open subsets, closed subsets, bounded subsets, Sequences and limit points in metric spaces. Cauchy sequences and completeness, Completion of metric spaces. [9] • Totally bounded subsets and Compact subsets of metric spaces. Separated sets and connected sets in metric spaces. Continuous functions on metric spaces, Lipschitz continuity and uniform continuity, Equivalence of metrics in a metric space. [9] • Contraction principle and fixed points, Baire category theorem. Sequence and series of functions: Pointwise convergence, Uniform convergence. Equicontinuity, Arzela-Ascoli theorem, Uniform convergence and differentiation. [9] • Functions of bounded variation and Riemann-Stieltjes' integral, Uniform convergence and integration. [8] • Weierstrass' approximation theorem. Trigonometric polynomials and Fourier series of continuous functions. Stone-Weierstrass theorem. [5]
Text & Reference Books	1. W. Rudin, Principles of Mathematical Analysis, 3rd ed., McGraw-Hill, 1976. 2. N. L. Carothers, Real Analysis, Cambridge University Press 2000. 3. S. Kumaresan, Topology of Metric Spaces, Alpha Science International Ltd. 2005 4. R. G. Bartle and D. R. Sherbert, Introduction to Real Analysis, 4th ed., Wiley, 2011. 5. T. M. Apostol, Mathematical Analysis, 2nd ed., Addison Wesley, 1974 6. H. L. Royden, Real Analysis, 3rd ed., PHI Learning, 2009.

MAT 304: Abstract Algebra [3 0 0 3]	
Prerequisites	MAT 204
Learning Outcomes	Main focus is abstract group theory and rings. The course also provides some basic knowledge of modules.
Syllabus	• Group action, Proof of Cayley's theorem, Orbit Stabilizer theorem, Class Equation, Burnside's Counting lemma [6.5] • Sylow's theorems and examples, solvable groups, Nilpotent groups [7.5] • Semi-direct product. [2] • Euclidean domains, PID's, UFD's (in details), Gauss theorem, Eisenstein Criterion for Irreducibility, Chinese remainder Theorem [10] • Modules, definitions and examples, Fundamental theorem of finitely generated modules over a PID, Noetherian rings, Hilbert Basis Theorem [14]

MAT 304: Abstract Algebra [3 0 0 3]	
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.

MAT 306: Linear Algebra [3 0 0 3]	
Prerequisites	MAT 205
Learning Outcomes	The course focuses on abstract treatment of linear algebra, with a focus on decomposition and spectral theorems. The course also discusses certain topics relevant for applied/numerical methods.
Syllabus	• Invariant subspaces, direct sum decomposition, invariant direct sum [6] • the primary decomposition theorem. [7] • Nilpotent Operators, Jordan Canonical form. [9] • Inner product spaces, orthonormal basis, Gram-Schmidt process; adjoint operators [6] • the least squares problem, normal and unitary operators, self adjoint operators, spectral theorem for self adjoint and normal operators [7.5] • Bilinear forms, Symmetric and skew symmetric bilinear forms, QR factorization [4.5]
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

MAT 308: Mathematics Lab [0 0 3 1]	
Prerequisites	NA
Learning Outcomes	The aim of this course is to familiarize students with implementation of various numerical analysis techniques. Students will especially learn numerical integration and solving techniques for linear systems of equations. A set of sample weekly lab assignment are given.
Syllabus	Lab 1: Introduction to Python/MATLAB
	Lab 2: Computer Arithmetics Q1. Machine epsilon ϵ is the smallest number of the form 2^{-n} such that $1+\epsilon \neq 1$. By writing a code, compute the approximate value of the machine epsilon of your assigned machine or your PC. Q2. Let $f(x)=\sin x$ and $x_0 = 1.2$. Compute the error in the following approximation manually $f'(x_0) \approx \frac{f(x_0+h)-f(x_0)}{h}$ and show that the error depends on the parameter h. Plot the h vs absolute error graph for values $h \leq 10^{-10}$ (in log-log scale). Indicate what happens when we reduce the size of h drastically? write your comments on this behavior.
	Lab 3: Root finding:

MAT 308: Mathematics Lab [0 0 3 1]	
	Q. Let $f(x) = e^x - x - 1$. Use Newton's method and fixed-point iteration to find the zero in $[-1, 1]$. In both the cases compute the root up to an accuracy of 10^{-6}.
	Lab 4: Interpolation: Q. Consider the function $f : x \to \frac{1}{1+x^2}, \quad x \in [-5, 5]$. Find the Lagrange interpolation polynomial of degree 10, interpolating the function f at 11 equally spaced points. Plot both f and p_{10} in the same frame and compare.
	Lab 5: Numerical Integration: Q.The equation $\int_0^x \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dt = 0.45$ can be solved for x using Newton's method with $f(x) = \int_0^x \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dt - 0.45$. a) Find a solution to $f(x) = 0$ accurate to within 10^{-5} using Newton's method with $p_0 = 0.5$ and the composite Simpson's rule. b) Repeat (a) using the composite Trapezoidal rule in place of the composite Simpson's rule. Tabulate all your results.
	Lab 6: Solutions of linear system: **Q.** Write a script for factorizing the following matrices in to LU decomposition using the LU factorization algorithm with $l_{ii} = 1$ for all i. **a.** $\begin{bmatrix} 2 & -1 & 1 \\ 3 & 3 & 9 \\ 3 & 3 & 5 \end{bmatrix}$ **b.** $\begin{bmatrix} 1.012 & -2.132 & 3.104 \\ -2.132 & 4.096 & -7.013 \\ 3.104 & -7.013 & 0.014 \end{bmatrix}$ **c.** $\begin{bmatrix} 2 & 0 & 0 & 0 \\ 1 & 1.5 & 0 & 0 \\ 0 & -3 & 0.5 & 0 \\ 2 & -2 & 1 & 1 \end{bmatrix}$ **d.** $\begin{bmatrix} 2.1756 & 4.0231 & -2.1732 & 5.1967 \\ -4.0231 & 6.0000 & 0 & 1.1973 \\ -1.0000 & -5.2107 & 1.1111 & 0 \\ 6.0235 & 7.0000 & 0 & -4.1561 \end{bmatrix}$
	Lab 7: Solutions of linear system: **Q.** Write a script for the Gauss-seidel and Jacobi Methods to solve the linear system AX=b and test it for the following systems: $a)\ A = \begin{bmatrix} 4 & -2 & 1 \\ 3 & 6 & -1 \\ 3 & 5 & 9 \end{bmatrix},\ b = \begin{bmatrix} 5 \\ 25 \\ 71 \end{bmatrix}$ and $b)\ A = \begin{bmatrix} 2 & 1 & 3 \\ 3 & 4 & -2 \\ 4 & 1 & 1 \end{bmatrix},\ b = \begin{bmatrix} 7 \\ 9 \\ 7 \end{bmatrix}$ $c)\ A = \begin{bmatrix} 10 & -1 & 2 & 0 \\ -1 & 11 & -1 & 3 \\ 2 & -1 & 10 & -1 \\ 0 & 3 & -1 & 8 \end{bmatrix},\ b = \begin{bmatrix} 6 \\ 25 \\ -11 \\ 15 \end{bmatrix}$
	Lab 8: Initial Value Problems:

MAT 308: Mathematics Lab [0 0 3 1]

Q. Consider the IVP $y' = te^{3t} - 2y, \quad 0 \le t \le 2, \quad y(0) = 0$. The exact solution to this IVP is obtained as $y(t) = \frac{1}{5}te^{3t} - \frac{1}{25}e^{3t} + \frac{1}{25}e^{-2t}$. Using Runge-Kutta method of order 2 and 4 (RK2 and RK4)compute and list the absolute error at t=2.0 for different values of h (must take 7 steps, starting from $h = 0.2$). Also compute the corresponding rate of convergence and include it in the same table.

Lab 9: Boundary Value Problems:

Q.

Use the Nonlinear Finite-Difference method with $h = 0.5$ to approximate the solution to the boundary-value problem

$$y'' = -(y')^2 - y + \ln x, \quad 1 \le x \le 2, \quad y(1) = 0, \quad y(2) = \ln 2.$$

Compare your results to the actual solution $y = \ln x$.

Lab 10: Eigenvalue and Eigenvector:

Q. Write a script for the Power method iteration to approximate the most dominant eigenvalue of the following matrices (iterate unital a tolerance of 10^{-4} is achieved or until the number of iterations exceeds 25)

a. $\begin{bmatrix} 4 & 2 & 1 \\ 0 & 3 & 2 \\ 1 & 1 & 4 \end{bmatrix}$; Use $\mathbf{x}^{(0)} = (1, 2, 1)^t$.

b. $\begin{bmatrix} 1 & 1 & 0 & 0 \\ 1 & 2 & 0 & 1 \\ 0 & 0 & 3 & 3 \\ 0 & 1 & 3 & 2 \end{bmatrix}$; Use $\mathbf{x}^{(0)} = (1, 1, 0, 1)^t$.

c. $\begin{bmatrix} 5 & -2 & -\frac{1}{2} & \frac{3}{2} \\ -2 & 5 & \frac{3}{2} & -\frac{1}{2} \\ -\frac{1}{2} & \frac{3}{2} & 5 & -2 \\ \frac{3}{2} & -\frac{1}{2} & -2 & 5 \end{bmatrix}$; Use $\mathbf{x}^{(0)} = (1, 1, 0, -3)^t$.

d. $\begin{bmatrix} -4 & 0 & \frac{1}{2} & \frac{1}{2} \\ \frac{1}{2} & -2 & 0 & \frac{1}{2} \\ \frac{1}{2} & \frac{1}{2} & 0 & 0 \\ 0 & 1 & 1 & 4 \end{bmatrix}$; Use $\mathbf{x}^{(0)} = (0, 0, 0, 1)^t$.

Text & Reference Books

1. Dimitrios Mitsotakis, An Introduction to Numerical Analysis and Scientific Computing with Python, CRC press, 2023
2. R. L. Burden and J. D. Faires, Numerical Analysis, 7th edition, Brookes/ Cole, 2011.
3. S. D. Conte and C. deBoor, Elementary Numerical Analysis-an algorithmic approach, 3rd edition, McGraw Hill, 1980.

MAT 314: Numerical Analysis [3 0 0 3]

Prerequisites	NA

MAT 314: Numerical Analysis [3 0 0 3]	
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.
Syllabus	• Round off Errors and Computer Arithmetic. [2] • Numerical solutions of nonlinear algebraic equations: Bisection, Secant and Newton's method, fixed-point iteration. [4] • 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, QR algorithm. [4] • Initial Value Problems: Euler method, Higher order methods of Runge-Kutta type. Boundary Value Problems: Finite differences. [8]
Text & Reference Books	1. K. E. Atkinson, An Introduction to Numerical Analysis, 2nd ed., John Wiley, 1989. 2. R. L. Burden and J. D. Faires, Numerical Analysis, 7th ed., Brookes/Cole, 2011. 3. S. D. Conte and C. deBoor, Elementary Numerical Analysis-an algorithmic approach, 3rd ed., McGraw Hill, 1980. 4. David Kincaid, Ward Cheney, Numerical Analysis, mathematics of scientific computing, American Mathematical Society, 2009. 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. E. Sueli and F. D. Mayers, An Introduction to Numerical Analysis, Cambridge University Press, 2003.

MAT 315: Mathematical Statistics [3 0 0 3]	
Prerequisites	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, □2 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

MAT 315: Mathematical Statistics [3 0 0 3]	
	and comparison; binomial populations and comparison; Poisson population; multinomial population; □2- test of goodness of fit. [15]
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, 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.

MAT 316: Mathematical Statistics Lab [0 0 2 1]	
Prerequisites	NA
Learning Outcomes	This is an introductory course on statistics. This course provides students with decision theory, estimation, confidence intervals, and hypothesis testing.
Syllabus	• Objects and functions, Arithmetic 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 samples. • 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, 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.

MAT 316: Mathematical Statistics Lab [0 0 2 1]	
	7. Alain F. Zuur, Elena N. Ieno, and Erik H. W. G. Meesters. A Beginner's Guide to R. Springer Science & Business Media, 2009.

MAT 321: Complex Analysis [3 0 0 3]	
Prerequisites	MAT 205
Learning Outcomes	This is an advanced course in Complex Analysis which deals with CR equations, complex integration, singularities and residue calculus. Course also focuses on some important theorems in Complex Analysis.
Syllabus	• Cauchy-Riemann equations in Cartesian and polar forms, Harmonic functions and its Harmonic conjugates. Homotopy between paths and Complex integration along homotopic paths. [3] • Homotopy version of Cauchy's theorem and simple connectivity of domains. Cauchy's integral formula and its consequences. Taylor series of analytic functions. [7] • Zeros of analytic functions, Zero counting and the Open Mapping theorem. [4] • Singularities and their classifications. Meromorphic function and its Laurent's series. Residue Theorem and Residue Calculus. Argument principle, Rouche's theorem. [10] • Maximum modulus principle and its applications. Schwarz lemma and its applications. Weierstrass' theorem on limits of analytic functions. [8] • Topology of uniform convergence on compact subsets. Uniform boundedness, Montel's theorem and Equicontinuity. Riemann Mapping theorem. [8]
Text & Reference Books	1. L. V. Ahlfors, Complex Analysis, Mcgraw-Hill, 1980. 2. John B. Conway, Function of One Complex Variables-I, Second Edition, GTM, Vol. 11, Springer-Verlag New York, 1973. 3. T. W. Gamelin, Complex Analysis, Springer-Verlag, 2001. 4. E. M. Stein and R. Shakarchi, Complex Analysis, Princeton University Press, 2003. 5. R. Greene and S. G. Krantz, Function Theory of One Complex Variable, 3rd ed.,GSM, Vol. 40, AMS, 2006.

MAT 324: Theory of Ordinary Differential Equations [3 0 0 3]	
Prerequisites	MAT 205
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 - Lindelöf theorem, existence via fixed point theory, dependence on initial conditions and parameters, continuation and maximal interval of existence. [10]

MAT 324: Theory of Ordinary Differential Equations [3 0 0 3]	
	• 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, eigenfunction expansion. [6]
Text & Reference Books	1. A. K. Nandakumaran, P. S. Datti and R. K. George, Ordinary Differential Equations - Principles and Applications, Cambridge-IISC Series, Cambridge University Press, 2017. DSC 317 2. P. 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. 9. Qualitative Theory of ODE. An Introduction: by Fred Brauer & John A Nohel Dover Publications.

MAT 325: Probability Theory and Stochastic Processes [3 0 0 3]	
Prerequisites	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.
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]

MAT 325: Probability Theory and Stochastic Processes [3 0 0 3]	
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.

MAT 331: Representation Theory [3 0 0 3]	
Prerequisites	MAT 304, MAT 306
Learning Outcomes	This course will help a student to understand the concepts of irreducible representations, indecomposable representations, group algebras, semisimplicity and the concepts of characters, induction and restrictions. Students will be able to understand labeling of representations for small groups, find the dimensions and characters of representations of the symmetric groups, dihedral groups, and cyclic groups.
Syllabus	• Representations: Definition and basic examples, irreducible representations [8], character of a representation, symmetric and exterior powers of a representation [4], orthogonality relations for characters, complete reducibility, Schur's Lemma [6] • Examples of representations of symmetric group, alternating group and dihedral groups [5] • The group algebra, decomposition of group algebra, induced representations [5], examples of induced representations, restriction to subgroups, Mackey's irreducibility criterion. [5] • Young diagrams, representations of S_n, A_n using the Young diagrams [5], GL_2(F_q) and SL_2(F_q) [2]
Text & Reference Books	1. Amritanshu Prasad, Representation Theory: A Combinatorial Viewpoint, Cambridge Studies in Advanced Mathematics, Vol. 147, Cambridge University Press, Delhi, 2015. 2. Bruce E. Sagan, The Symmetric Group, Representations, Combinatorial Algorithms, and Symmetric Functions, GTM Vol. 203, Springer, 2001. 3. Gordon James and Martin W. Liebeck, Representations and Characters of Groups, Cambridge University Press. 4. W. Fulton and J. Harris, Representation Theory: A First Course, Springer-Verlag, 1991. 5. J.P. Serre, Linear Representations of Finite Groups, Springer-Verlag, 1977.

MAT 402: Galois Theory [3 0 0 3]	
Prerequisites	MAT 304
Learning Outcomes	To learn the basics of field theory, finite fields, Fundamental Theorem of Galois Theory, Solvability of radicals and basics of Module theory

MAT 402: Galois Theory [3 0 0 3]	
Syllabus	• Field extensions, algebraic closure [6] • splitting fields, separable and inseparable extensions, normal extensions, [7] • Galois extensions, finite fields, fundamental Theorem of Galois theory [11] • cyclic and cyclotomic extensions. [3] • Morphism of modules, exact sequences, Hom set and Snake Lemma [6.5] • Hilbert Nullstellensatz [6.5]
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.

MAT 403: Topology [3 0 0 3]	
Prerequisites	MAT 303
Learning Outcomes	This is a first formal course in topology which covers point set topology and important theorems in topology.
Syllabus	• Topology: Definition and examples, Euclidean topology. Basis for a topology, closed sets and limit points, Hausdorff spaces. Order topology. Subspace topology. [8] • Product topology, Quotient topology., Metric topology. Continuous functions and Homeomorphisms. [9] • Connectedness and Compactness: Connected spaces, connected Components and path components, Local Connectedness, Compact spaces, local compactness, Stone-Cech compactification. Tychonoff's theorem. [15] • Countability and Separation Axioms: The countability axioms, The separation axioms, The Urysohn lemma, Completely regular spaces, Baire space and the Baire category theorem.[8]
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. 4. Simmons, George F. Introduction to topology and modern analysis. Vol. 44. Tokyo, 1963.

MAT 407: Multivariable Analysis [3 0 0 3]	
Prerequisites	MAT 203, MAT 205
Learning Outcomes	Aim of this course is to deal with the theory of integration and differentiation of functions of several variables, introduction to differential forms and its application.
Syllabus	• Review of algebra and topology on R^n. Differentiation theory, Jacobian matrix for a differentiable function. Higher order partial derivatives, Composition of functions, Chain rule. Diffeomorphisms, Inverse function theorem and Implicit function theorem, Surfaces in R^n. [12]

MAT 407: Multivariable Analysis [3 0 0 3]	
	• Taylor's theorem, Maxima and minima, Lagrange multipliers. Integration over a rectangle, Sets of measure zero, Integrability of a function and continuity. Fubini's theorem for a rectangle. Integration over a bounded region. Compact exhaustions and Improper integrals. [13] • Local finiteness, Partitions of unity, Change of variables and Diffeomorphisms. Tangent vectors and tangent spaces, Differential forms, wedge products and exterior differentiation. [9] • Integration on chains, Orientation, Integration of forms, Classical Theorems like Green's Theorem, Divergence Theorem and Stokes Theorem. [6]
Text & Reference Books	1. J. R. Munkres, Analysis on Manifolds, Westview Press, 1997. 2. W. Rudin, Principles of Mathematical Analysis, Vol. 3. New York: McGraw-hill, 1976. 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.

MAT 411: Measure Theory [3 0 0 3]	
Prerequisites	MAT 203
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] • 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.

MAT 411: Measure Theory [3 0 0 3]	
	8. T. Tao, An Introduction to Measure Theory, GSM, Vol.126, AMS, 2011. 9. 9. M. Taylor, Measure Theory and Integration, American Mathematical Society, 2006

MAT 412: Commutative Algebra [3 0 0 3]	
Prerequisites	MAT 304, MAT 402
Learning Outcomes	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. [5] • Modules: 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, Primary decomposition, primary decomposition in Noetherian rings. [8] • Integral dependence and valuations: Integral dependence, going-up theorem, integrally closed integral domain, going-down theorem, valuation rings. [9] • Discrete valuation ring and Dedekind domains. [3]
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.

MAT 414: Partial Differential Equations [3 0 0 3]	
Prerequisites	MAT 309
Learning Outcomes	This course aims at developing theory of first order partial differential equations and second order equations namely Laplace, Heat and Wave equation.
Syllabus	• First order partial differential equations: semilinear equations, quasilinear equations, solution of a Cauchy problem; first order nonlinear equations, Charpit's equations, Cauchy problem. [10] • Second order linear partial differential equations: Laplace's equation, fundamental solution, mean value formulas, Green's function, maximum principle, energy methods. [15] • Heat equation, fundamental solution, mean value formulas, energy methods. [8] • Wave equation, solution by spherical means, non-homogeneous problem, energy methods. [7]
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.

MAT 414: Partial Differential Equations [3 0 0 3]	
	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.

MAT 421: Functional Analysis [3 0 0 3]	
Prerequisites	MAT 303, MAT 401
Learning Outcomes	Based on core analysis courses 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, partial differential equations and mathematical physics.
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 orthonormalization, 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

MAT 422: Algebraic Topology [3 0 0 3]	
Prerequisites	MAT 403, MAT 304
Learning Outcomes	▪ Understanding basic homotopy theory. ▪ Understanding the notions of simplicial homologies, their homotopy invariances. ▪ Learning computational techniques for homologies and their applications.
Syllabus	• Homotopy, Fundamental Groups, examples Pi_1(S1), [5] • Van Kampen Theorem, computations [5] • Covering spaces, [3] Homotopy lifting, [3] Existence of covering spaces and classification of covering spaces [3], Deck Transformations and Group actions [3] • Singular homology, Examples, [4] Homotopy invariance. [4] Mayer-Vietoris, Applications of Mayer Vietoris, [5] Relative and reduced homology [4] cup-product [3]
Text & Reference Books	1. Allen Hatcher, Algebraic Topology, Cambridge Univ Pr; 1st ed., 2005 2. James W. Vick, Homology Theory, An Introduction to Algebraic Topology, Springer; 2nd ed. 1994. 3. Joseph Rotman, An Introduction to Algebraic Topology, Springer; 1st ed., 1998.

MAT 501: Curves and Surfaces [3 0 0 3]	
Prerequisites	MAT 306, MAT 403, MAT 407
Learning Outcomes	▪ A surface as a prototype of 2 dimensional manifolds. ▪ Distinction between local and global properties of a surface. ▪ Behavior of curves on a surface. ▪ Relation between geodesics and parallel transport. Local Gauss Bonnet theorem.
Syllabus	• Parametrized curves in Rn, Reparametrization, Unit speed reparametrization [3] • Curves in R3: Curvature and torsion of a curve, Frenet-Serret formulae, Fundamental theorem of curves in R3 (Frenet-Serret theorem) [5] • Parametrized Surfaces: Definition, examples. Tangent spaces, Reparametrization of a surface. Reparametrization invariance of a tangent space. [4] • Embedded surfaces in R3: Definition, Examples, First fundamental forms [4] • Normal vectors, Orientations, Examples [4] • Curves on an embedded surface: Length of a curve, Geodesic and normal curvatures. A Geodesic as a curve with a zero geodesic curvature, Examples [5] • The second Fundamental form of a surface, Principal curvatures, Gauss curvature, Intrinsic property of the Gauss curvature. [6] • 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] • Local Gauss-Bonnet Theorem [3]
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

MAT 2011: Optimization Techniques and linear programming [2 0 0 2]	
Prerequisites	NA
Learning Outcomes	▪ To learn various optimization techniques and their applications ▪ Understanding of linear and nonlinear techniques
Syllabus	• Classification and general theory of optimization. [2] • Linear programming (LP): Formulation and geometric ideas, simplex and Big M method and Duality methods for LP problems. [8] • Nonlinear optimization: Method of Lagrange multipliers. [2] • Karush-Kuhn-Tucker theory. [4] • Convex optimization, quadratic optimization. [6] • Transportation- assignment-and integer programming problems. [5]
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.

MAT 2012: Number Theory [2 0 0 2]	
Prerequisites	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.
Syllabus	• Divisibility, greatest common divisor, Euclid’s algorithm, Linear Diophantine [6] • Wilson’s theorem, Fermat’s little theorem, Euler’s theorem, primitive roots, Arithmetic functions, Euler's totient function, perfect numbers, Mobius inversion formula. [6] • Sum of squares, Introduction to 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 and Pell’s equation. [6]
Text & Reference Books	1. Niven, H. S. Zuckerman and H. L. Montgomery, An Introduction to the Theory of Numbers, 5th Edition, Wiley, 1991. 2. Kenneth Ireland and Michael Rosen, A Classical Introduction to Modern Number Theory, 2nd Edition, Springer, 1990. 3. David M. Burton, Elementary Number Theory, Wm. C. Brown, Dubuque, Iowa, 2nd edition 1989 4. M. H. Weissman, An Illustrated Theory of Numbers, American Mathematical Society 2017.

I2M Courses

I2M 322: Mathematical Modelling [2 0 0 2]	
Prerequisites	NA
Learning Outcomes	▪ This course will introduce student to mathematical models of real world problems ▪ Various models will be discussed with examples taken from Biology, Chemistry, Physics and other fields.
Syllabus	• Introduction- Modelling philosophy: Why model? What's a good model? Model validation. Example problems: Growth of a Yeast Culture, Spread of a Contagious Disease, Decay of Digoxin in the Bloodstream, Heating of a Cooled Object. [2] • Modeling 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 [8] • The Modelling Process, Proportionality, and Geometric Similarity: Example from Model Fitting, Experimental Modelling, Simulation Modelling, Discrete Probabilistic Modelling, Optimization of Discrete Models. [8] • 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. [8]
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.

I2M 401: Scientific Computing and Optimization [3 0 0 3]	
Prerequisites	MAT 307
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. ▪ Derive and analyse numerical methods for constrained and unconstrained optimisation problems.
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. [2 • 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. [8]

<table>
<tr><th colspan="2">I2M 401: Scientific Computing and Optimization [3 0 0 3]</th></tr>
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Non-stationary iterative methods-conjugate gradient (CG), convergence analysis; preconditioning. Estimation and computation of eigenvalues- Gershgorin disc, power methods, the QR algorithm [10]
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. [8]
Constrained Optimisation: Optimality/KKT conditions, penalty and augmented Lagrangian for equality-constrained optimisation, interior-point/barrier methods for inequality constrained optimisation. Quadratic optimization [11]

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<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. David Kincaid, Ward Cheney, Numerical Analysis: Mathematics of Scientific Computing, American Mathematical Society, 2009.
4. A. Greenbaum, Iterative Methods for Solving Linear Systems, SIAM, 1997.
5. G. H. Golub and C. F. van Loan, Matrix Computations, John Hopkins University Press, 1996.
6. H. C. Elman, D. J. Silvester and A. J. Wathen, Finite Elements and Fast Iterative Solvers, Oxford University Press, 1995.
7. J. Nocedal and S. J. Wright, Numerical Optimisation, Springer, 2006.
8. D. P. O'Leary, Scientific Computing with Case Studies, SIAM, 2009.
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<tr><th colspan="2">I2M 402: Scientific Computing and Optimication Lab [0 0 3 1]</th></tr>
<tr><td>Prerequisites</td><td>MAT 307</td></tr>
<tr><td>Learning Outcomes</td><td>Implementation of algorithms for Scientific Computing</td></tr>
<tr><td>Syllabus</td><td>

Computer arithmetic; Truncation error; Error propagation and amplification; Condition number and ill-conditioned problems
Solution of linear system of equations: Gaussian elimination, LU, Jacobi, Gauss-Seidel, successive over-relaxation and conjugate gradient (CG) methods.
Estimation and computation of eigenvalues- power methods, the QR algorithm.
Nonlinear equations and optimisation: Steepest descent method, Newton and quasi-Newton methods, General line search methods, Trust region methods, Least squares problems and methods. Quadratic optimization.
Optimality/KKT conditions, penalty and augmented Lagrangian for equality-constrained optimisation,

</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. David Kincaid, Ward Cheney, Numerical Analysis: Mathematics of Scientific Computing, American Mathematical Society, 2009.
4. A. Greenbaum, Iterative Methods for Solving Linear Systems, SIAM, 1997.
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I2M 402: Scientific Computing and Optimication Lab [0 0 3 1]	
	5. G. H. Golub and C. F. van Loan, Matrix Computations, John Hopkins University Press, 1996. 6. H. C. Elman, D. J. Silvester and A. J. Wathen, Finite Elements and Fast Iterative Solvers, Oxford University Press, 1995. 7. J. Nocedal and S. J. Wright, Numerical Optimisation, Springer, 2006. 8. D. P. O'Leary, Scientific Computing with Case Studies, SIAM, 2009.

I2M 404: Numerical Solutions of Differential Equations [2 0 0 2]	
Prerequisites	MAT 205, MAT 307, MAT 308
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. ▪ Analyze an algorithm's accuracy, efficiency and convergence properties.
Syllabus	• Numerical methods for initial value problems (IVPs): Recap (Euler forward and backward methods, stability analysis, error estimates. Higher order methods, Runge-Kutta methods, convergence) Multistep methods [8] • Numerical methods for boundary value problems (BVPs): Finite difference schemes, consistency, truncation error, stability and convergence. [5] • Finite difference method for linear advection equation, method of lines, upwind scheme, CFL condition, stability and convergence. [5 • Finite difference method for heat equation, Crank-Nicolson method, theta method, CFL condition, stability and convergence [4 • Numerical methods for partial differential equations: Review of Poisson equation in one dimension, finite difference method for Poisson equation, stability and convergence [5]
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.

I2M 405: Numerical Solutions of Differential Equations Lab [0 0 3 1]	
Prerequisites	MAT 205, MAT 307, MAT 308
Learning Outcomes	Implement algorithms learnt for numerical solution of differential equations in a programming language and test and validate codes to solve a given differential equation numerically.

I2M 405: Numerical Solutions of Differential Equations Lab [0 0 3 1]	
Syllabus	• Numerical methods for initial value problems (IVPs: Euler methods, Runge-Kutta order two and four methods. • Numerical methods for boundary value problems (BVPs): Finite difference schemes, • Finite difference method for linear advection equation: Upwind schemes, Lax-Fredrich and Lax-Wendroff scheme. • Finite difference method for heat equation:Crank Nickolson, Theta method • Finite difference method for poisson equation
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.

I2M 411: Applied Stochastic Analysis [3 0 0 3]	
Prerequisites	However, knowledge of MAT 303 and MAT 401 may be an added advantage.
Learning Outcomes	This course will introduce the major topics in stochastic analysis from an applied mathematics perspective, 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	• Measure theory preliminaries, probability spaces, random variables, distributions, expectation, conditional probability and conditional expectation; [6] • Martingales in Discrete Times - sequence of random variables, filtrations, Martingales, stopping times, Doob’s Martingale inequalities; [6] • Stochastic Processes in Continuous Times: • Poisson Process - Exponential distribution and lack of memory, construction of the Poisson process, properties; [3] • Brownian Motion - Construction, properties, increment of Brownian motion, Doob’ Maximal inequality; [5] • Itô stochastic integration - construction, properties and examples, stochastic differential and Itô formula; [8] • Stochastic Differential Equation - Existence and uniqueness results, different notions of solutions, examples from finance and biology; [8] • Numerically solving SDEs (basic concepts). [4]
Text & Reference Books	1. Z. Brzeźniak and T. Zastawniak, Basic Stochastic Processes. Springer Verlag, 2002. 2. G. A. Pavliotis, Stochastic Processes and Applications, Springer Verlag, 2014. 3. C. Gardiner, Stochastic Methods: A Handbook for the Natural and Social Sciences, 4th ed., Springer 2009. 4. B. Oksendal, Stochastic Differential Equations, 6th ed., Springer, 2014.

I2M 501: Finite Element Methods and Specifications [3 0 0 3]	
Prerequisites	MAT 406, I2M 404
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.
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. [12] • Time dependent Problems: Heat Equations [8]
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.

BS-MS Elective Courses

MAT 3101: Discrete Mathematics [2 0 0 2]	
Prerequisites	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 Eigenvalues, 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.

MAT 4204 / MAT 6204: Sobolev Spaces and Elliptic Boundary Value Problems [3 0 0 3]	
Prerequisites	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

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

I2M Elective Courses

I2M 4006: Variational Methods and Control Theory [3 0 0 3]	
Prerequisites	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.

I2M 4007: High Performance Computing [3 0 0 3]	
Prerequisites	I2M 401 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 analysis and modeling 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 five major aspects of the course: • Part-I: Introduction to Parallel Computing: principles for parallel and concurrent program design, units of measure in HPC, Multi-core and Many-core architectures, Cache memory versus regular memory, classification of parallel computers, Goals of parallel systems. [4] • Part-II: Distributed Memory Programming with MPI: Writing the first MPI program, using the common MPI functions, MPI-derived datatypes, matrix-vector operations using MPI, numerical integration in MPI, collective communication, performance evaluation of MPI programs, parallel sorting, Parallel I/O, and safety in MPI programs. [12] • Part-III: Shared Memory Programming with OpenMP: Writing the first OpenMP program, using OpenMP to parallelize many serial for loops, task parallelism, explicit thread synchronization, and standard problems in shared-memory programming. [8]

I2M 4007: High Performance Computing [3 0 0 3]	
	• Part-IV: Manycore programming with GPU: introduction to the CUDA Platform, CUDA-accelerated applications, OpenACC directives, GPU programming languages, GPU threads, CUDA programming, and solving standard problems. [12] • Part V: 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. [4]
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. 2. Ian Foster's, Designing and Building Parallel Programming. 3. Peter Pacheco, An introduction to Parallel Programming. 4. Sergei Kurgalin and Sergei Borzunov, A Practical Approach to High-Performance Computing. 5. John Cheng, Max Grossman, and Ty McKercher, Professional CUDA C Programming. 6. Ananth Grama, Anshul Gupta, George Karypis and Vipin Kumar, Introduction to Parallel Computing, Addison-Wesley, 2003.

PHYSICAL SCIENCES

CURRICULUM FOR

BS-MS (SEM: 4 - 10)

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

CORE & ELECTIVE COURSES

BS-MS Courses (Experiment track)

Semester 4	Semester 5	Semester 6	Semester 7	Semester 8
PHY 301 [3003] Mathematical Methods I	PHY 312 [3003] Classical Mechanics	PHY 321 [3003] Statistical Mechanics	PHY 412 [3003] Condensed Matter II	Experiment Electives III
PHY 313 [3003] Electronics	PHY 322 [3003] Condensed Matter Physics I	PHY 401 [3003] Electrodynamics	PHY 423 [2033] Modeling Materials	Experiment Electives IV
PHY 314 [3003] Quantum Mechanics I	PHY 324 [3003] Numerical Methods	PHY 4205 [3003] Electronic Devices and computer interfacing (Adv. electronics)	Experiment Electives I	Project (12)
PHY 317 [3003] Mechanics II	PHY 327 [3003] Quantum Mechanics II	PHY 4110 [3003] Experimental Methods	Experiment Electives II	
PHY 315 [0093] Advanced Physics Lab I	PHY 325 [0093] Advanced Physics Lab II	PHY 415 [0093] Advanced Physics Lab III	GE*	
GE*	GE*	GE*	GE*	
Scientific Computing				
HUM	Skills/HUM (6)			

BS-MS Courses (Theory track)

Semester 4	Semester 5	Semester 6	Semester 7	Semester 8
PHY 301 [3003] Mathematical Methods I	PHY 312 [3003] Classical Mechanics	PHY 321 [3003] Statistical Mechanics	PHY 412 [3003] Condensed Matter II	Theory Electives III
PHY 313 [3003] Electronics	PHY 322 [3003] Condensed Matter Physics I	PHY 402 [3003] Classical Electrodynamics	PHY 422 [3003] Nuclear and Particle Physics	Theory Electives IV
PHY 314 [3003] Quantum Mechanics I	PHY 324 [3003] Numerical Methods	PHY 403 [3003] Mathematical Methods II	Theory Electives I	Project (12)
PHY 317 [3003] Mechanics II	PHY 327 [3003] Quantum Mechanics II	PHY 404 [3003] Quantum Mechanics III	Theory Electives II	
PHY 315 [0093] Advanced Physics Lab I	PHY 4217 [3003] Quantum Information/ PHY 5125 [3003] Foundations of Quantum Mechanics	PHY 419 [2013] Statistics and Data Analysis in Physical Sciences	GE*	
GE*	GE*	GE*	GE*	
Scientific Computing				
HUM	Skills/HUM (6)			

I2P Courses

Semester 4	Semester 5	Semester 6	Semester 7	Semester 8
PHY 301 [3003] Mathematical Methods I	PHY 312 [3003] Classical Mechanics	PHY 321 [3003] Statistical Mechanics	PHY 412 [3003] Condensed Matter II	I2P 515 [2033] Machine Learning for Physical Sciences
PHY 313 [3003] Electronics	PHY 322 [3003] Condensed Matter Physics I	PHY 4110 [3003] Experimental Methods	I2P 423 [2033] Modeling Materials	Elective
PHY 314 [3003] Quantum Mechanics I	PHY 324 [3003] Numerical methods	I2P 412 [3003] Semiconductor Physics	I2P 413 [3003] Fluid mechanics and transport phenomena	Project (12)
PHY 317 [3003] Mechanics II	PHY 327 [3003] Quantum Mechanics II	I2P 425 [1063] Finite Element Modelling	Elective	
PHY 315 [0093] Advanced Physics Lab I	I2P 321 [3003] Electrochemical Energy Systems / I2C 421 Soft matter and Polymers	I2P 321 [3003] Electrochemical Energy Systems / I2C 421 Soft matter and Polymers	Elective	
DSC 311 [3014] Mathematical Statistics	Elective	Lab Elective	Elective	
Scientific Computing				
HUM	Skills/HUM (6)			

Minor Courses (General Electives)

Semester	Code	Title
IV	PHY 312	Quantum mechanics
	PHY 3134	Electronics
V	PHY 322	Condensed Matter Physics I
VI	PHY 411	Statistical mechanics
	PHY 414	Experimental Methods
	PHY 419	Statistical and Data Analytic Methods in Physical Sciences
VII	PHY 422	Nuclear and Particle Physics
	PHY 423	Modeling Materials

List of Electives

Experiment track	Theory track
Atomic and Molecular Physics	Atomic and Molecular Physics
Quantum Transport	Introduction to Cosmology
Plasmonics and Nanophotonics	Particle Physics
Nonlinear Optics and Photonics	General Relativity and cosmology
Probes in Condensed Matter Physics	Theory of Open Quantum Systems
Materials Growth and Processing Techniques (SoP Open Elective)	Quantum Field Theory-I
Electrochemical Energy Systems	Quantum Field Theory-II
Lasers and Fiber Optic Communications	Finite Element Modelling
Nuclear Particle Physics	Fluid dynamics
Semiconductor Physics and Technology	Astrophysics
Material & Device Characterization Techniques (SoP Open Elective)	Modeling Materials
Lasers and Fiber Optic Communications	Advanced Mathematical Methods in Physics
Physics at Low Temperatures	Nonlinear Dynamics
Nanoscale Physics	Advanced Statistical Physics
Organic Semiconductors: Fundamentals and Applications	Quantum Many Body Theory
Principles of Digital imaging	Quantum Information Theory
Digital Image Processing	Foundations of Quantum Mechanics
	Complex Systems
	Solar Physics

I2P electives

I2P4201	Computer interfacing (1032)
I2P4202	Energy Materials Laboratory (0031)
I2P4203	Battery & Fuel Cell Laboratory (0031)
I2P4204	Organic Photovoltaic Devices Laboratory (0031)
I2P4205	Renewable Energy Systems (2002)
I2P422	Optoelectronic Devices
I2P524	Thermal Transport and Thermoelectrics

BS-MS Courses

PHY 301: Mathematical Methods in Physics I [3 0 0 3]	
Learning Outcomes	▪ Classify a complex function and its singularities. ▪ Perform Taylor/Laurent expansion of complex functions. ▪ Evaluate non trivial real integrals using the method of contour integrals and residue theorem. ▪ Find Fourier Transform of functions and study their properties. ▪ Use Fourier Transform to solve certain differential equations. ▪ Convert Partial Differential equations to Ordinary differential equations using the technique of separation of variables. ▪ Illustrate the properties of a Sturm Liouville eigenvalue problem. ▪ Solve homogeneous linear Ordinary Differential Equation (ODE) using the series method and Wronskians. ▪ Use Bessel's and related functions to solve various Physical problems with circular/cylindrical symmetries.
Syllabus	• Complex Analysis: 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. [12] • Fourier Transform and inverse Fourier Transform with examples, Fourier Transform of derivatives, Convolution Theorem. [3] • Differential Equations: Partial differential equations and Ordinary differential equations, Separation of Variables to solve Partial differential equation, Solving simple partial differential equation such as heat equation in 1 dimension using the method of separation of variables. [3] • Sturm Liouville Theory: Self adjoint ODE, Finite dimensional Vector space and inner products, Function space and inner products on function spaces with and without a weight factor, Hermitian or Self adjoint Operators, Sturm-Liouville Eigenvalue problem and its properties, Gram-Schmidt Orthogonalization, Completeness of Eigenfunctions [4] • Gamma function and its different definitions (Infinite limit, Definite integral, Infinite product), Factorial and Double Factorial Notation, Contour integral representation of Gamma function, Digamma function and Euler Mascheroni constant, Beta function [3] • Ordinary Differential Equations: Classification of singular points of an ordinary differential equation, Series Solution (Frobenius Method), Limitations of series approach, Linear independence of solutions, Wronskian, Second solution via Wronskian. [4] • Application of series approach: Bessel equation, Bessel function of the first kind, Orthogonality, Bessel function of the second kind (Neumann function), Hankel function, Modified Bessel functions, Simple applications of Bessel functions to problems with circular/cylindrical symmetry. [7]
Text & Reference Books	1. Weber, Hans J., and George B. Arfken. *Essential mathematical methods for physicists, ISE*. Elsevier, 2003. 2. Murray Spiegel, Seymour Lipschutz, John Schiller and Dennis Spellman, Schaum's Outline of Complex Variables, 2ed (Schaum's Outline Series). 3. Dennery, Philippe, and André Krzywicki. *Mathematics for physicists*. Courier Corporation, 2012.

PHY 301: Mathematical Methods in Physics I [3 0 0 3]	
	4. Tulsi Dass and Satish K Sharma, Mathematical Methods in Classical and Quantum Physics, Universities Press, 1998.

PHY 312: Classical Mechanics [3 0 0 3]	
Learning Outcomes	▪ Compute the motion of objects within a classical framework like motion under a central force, motion of rigid bodies, oscillators etc. using analytical techniques. ▪ Apply techniques like least action principles and calculus of variations on intuitively understandable models of classical objects in motion.
Syllabus	• Variational Principle and Lagrange's equation: 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, Laplace-Runge-Lenz vector [10] • Rigid Body Motion: 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. [6] • Small oscillations: Eigenvalue equation and principal axis transformation, frequency of free vibration and normal coordinates, Example of a linear triatomic molecule. Forced, damped and anharmonic oscillations. [6] • Hamiltonian Formulation: Legendre transformations, The Hamilton equations of motion, Cyclic coordinates, Routhian; Principle of least action, Invariance properties of the Lagrangian and Hamiltonian descriptions. [6] • Canonical Transformations, Poisson and Lagrange brackets [3] • Hamilton-Jacobi theory and action-angle variables with examples (Harmonic oscillator, Kepler problem). [5]
Text & Reference Books	1. N. W. Ashcroft, N. David Mermin, Solid state physics, Harcourt, 1976. 2. C. Kittel, Introduction to solid state physics, 7th ed., John Wiley, 2004. 3. S. H. Simon, The Oxford Solid State Basics, Oxford, U.K., 2013. 4. A. J. Dekker, Solid state physics, Macmillan India, 2005.

PHY 313: Electronics [3 0 0 3]	
Learning Outcomes	▪ Differentiate between conduction band, valence band, Fermi level, intrinsic and extrinsic semiconductors ▪ Apply PN junction device physics and its characteristics for designing devices ▪ Analysis of transistors and apply the concept to device design ▪ Applications of operational amplifier to waveform generation, filters and mathematical function implementation and analysis of operational amplifier ▪ Differentiate between analog and digital devices.

PHY 313: Electronics [3 0 0 3]	
Syllabus	• 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]
Text & Reference Books	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.

PHY 314: Quantum Mechanics I [3 0 0 3]	
Learning Outcomes	▪ Solve time independent and time dependent Schrodinger equations for simple 1D potentials. ▪ Calculate probability, probability current density, and reflection and transmission coefficients. ▪ Use linear algebra and principles of quantum mechanics to calculate observables.
Syllabus	• Origins and Essential Features of Quantum Mechanics, Wave-Particle Duality, Matter Waves, Stationary Phase and Group Velocity [5] • Vector Spaces and Operators, State vectors and Dirac Bra-Ket Notation, Hilbert space, Non commuting operators and Uncertainty principle [5] • Basis states and wave functions, Position space and momentum space wave functions, Schrodinger equation in position and momentum space, probability density, probability current and continuity equation, Expectation values of operators and its time dependence, Hermitian Operators and properties of its eigenvalues and eigenfunctions, Postulates of Quantum Mechanics [10] • Stationary states, Time independent Schrodinger equation and solving for energy eigenstates. [2]

PHY 314: Quantum Mechanics I [3 0 0 3]	
	• Applications: Free Particle, Infinite square well, finite square well, delta function potential, linear potential, step potential, wave packets in a step potential, Potential Barrier and Tunneling. [8] • Harmonic Oscillator: Solving the differential equation, Algebraic solution for the spectrum. [6]
Text & Reference Books	1. Griffiths, David J. (2017). *Introduction to quantum mechanics* (2nd ed.). Cambridge: Cambridge University Press. 2. Shankar, R. (2012). *Principles of quantum mechanics*. Springer Science & Business Media. 3. Nouredine Zettili, (2022) *Quantum Mechanics: Concepts and Applications*, 3rd Edition. 4. Zwiebach, B. (2022). *Mastering Quantum Mechanics: Essentials, Theory, and Applications*. MIT Press.

PHY 317: Mechanics II [3 0 0 3]	
Learning Outcomes	▪ Solve equations of motion (EOM) with suitable initial and boundary conditions ▪ Comprehend relativistic concepts of space and time, reference frames.
Syllabus	• Central Forces and Kepler's Laws: A recap of Central Force Motion and Kepler's laws, Energy equation and energy diagrams, Gravitational Forces as a Central Force (Two-body problem), Equations of motion and solutions, Classification of orbits, Planetary motion and Rutherford scattering. [6] • Non-Inertial Systems and Fictitious Forces: Uniformly Accelerating Systems, The Principle of Equivalence, Physics in a Rotating Coordinate System (Coriolis Force and Centrifugal Force) [6] • Introduction to Special Relativity: Historical context and motivation, Postulates of Special Relativity, Simultaneity and space-time diagrams, Time dilation and length contraction [4] • Lorentz Transformations: Deriving the Lorentz transformations, Relativistic velocity addition, Proper time and space-time intervals, Doppler effect in special relativity [5] • Relativistic Mechanics: Relativistic momentum and energy, Relativistic kinematics: Relativistic particle decay and lifetime, Relativistic dynamics [5] • Electromagnetism in Relativity: Electromagnetic fields in different frames, Transformation of electric and magnetic fields, Relativistic electrodynamics: The Lorentz force, Magnetic forces and relativistic charge density [5] • Minkowski Space-time: Introduction to Minkowski space-time, The metric tensor and space-time geometry, World lines and proper time in space-time, Light cones and causality in special relativity, Four-vectors in special relativity: Energy-momentum four vectors [5]

PHY 317: Mechanics II [3 0 0 3]	
Text & Reference Books	1. D. Kleppner and R. Kolenkow, An introduction to Mechanics, McGraw-Hill Science/ Engineering/ Math, second reprint 2008 2. Wolfgang Rindler, Introduction to Special Relativity, Crendon Press, OXFORD 1982.

PHY 321: Statistical Mechanics [3 0 0 3]	
Learning Outcomes	▪ To calculate the most probable macrostate of a given Thermodynamical system in equilibrium ▪ Distinguish the nature distributions (workout the number of microstates) in microcanonical, canonical and grand canonical ensembles. To relate the resulting statistics with thermodynamics parameters with applications to physical systems ▪ Evaluate the distribution of particles in Maxwell Boltzman's, Fermi-Dirac and Bose-Einstein distributions along with their applications. ▪ To estimate the phase transitions and order parameters.
Syllabus	• 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 Mcgraw Hill, 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.

PHY 322: Condensed Matter Physics- I [3 0 0 3]	
Learning Outcomes	To provide an exposure to the basic principles and essential concepts in condensed matter physics.
Syllabus	• Electrons in metals: Drude theory, electrical conductivity, Hall effect, thermal conductivity, Widemann-Franz law, drawback of Drude theory. [4] • Sommerfeld's theory of metals: Fermi-Dirac distribution, Free electrons, Fermi momentum, Fermi energy, Fermi surface, Ground state energy, Thermal properties of a free electron gas. [4] • Crystal structure: Bravais lattice, two and three dimensional lattices, unit cells, example of crystal structures, Reciprocal lattice, Brillouin zone. [4] • Experimental determination of crystal structure: Lattice plane and Miller indices, Scattering from crystals: Bragg's law, Laue condition, Structure factor, form factor, experimental methods: powder XRD, Laue method etc. [4] • Nearly free electron model: Periodic potential, Nearly free electron model, Bragg conditions-energy gap [4] • Electrons in a periodic potential: Bloch's theorem, crystal momentum, energy band diagram, Fermi surface, density of states, Kronig-Penney model, band structure, classification of solids based on band structure. [8] • Tight binding approximation: Linear combination of atomic orbitals, Applications to s-band, General features, Wannier functions. [4] • Crystal vibrations: Harmonic approximation, monoatomic and diatomic lattice, normal modes and phonons, Einstein and Debye models of specific heat, thermal conductivity. [8]
Text & Reference Books	1. N. W. Ashcroft, N. David Mermin, Solid state physics, Harcourt, 1976. 2. C. Kittel, Introduction to solid state physics, 7th ed., John Wiley, 2004. 3. S. H. Simon, The Oxford Solid State Basics, Oxford, U.K., 2013. 4. A. J. Dekker, Solid state physics, Macmillan India, 2005.

PHY 324: Numerical Methods [3 0 0 3]	
Prerequisites	Fundamentals of Programming (IDC 112), Electronics (PHY 313)
Learning Outcomes	▪ Perform numerical computation using a programming language. ▪ Find root of an equation, numerical differentiation and integration. ▪ Solve differential equations, linear algebra problems numerically. ▪ Obtain numerical solutions to problems in classical and quantum physics and classical statistical mechanics problems using Monte Carlo simulation.
Syllabus	• 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]

PHY 324: Numerical Methods [3 0 0 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

PHY 327: Quantum Mechanics II [3 0 0 3]	
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 time-independent Hamiltonians ▪ Use time-dependent perturbation methods to determine transition rates and decay widths for time-dependent Hamiltonians. ▪ Apply approximate semi classical techniques such as WKB to solve Schrodinger equation.
Syllabus	• Stern Gerlach Experiment and spin half quantum system; Bra-Kets, Operators, Hilbert space revisited [3] • Pictures of Quantum Mechanics: Schrodinger picture and unitary time evolution, Heisenberg picture and Heisenberg equations of motion, Postulates of Quantum Mechanics [4] • Central Potential and Angular Momentum in Quantum Mechanics, Angular Momentum Operator and algebra, Eigenstates of Angular Momentum, Addition of angular momentum. [7] • Motion in a central potential, spherical waves, Radial equation and asymptotic properties of radial wavefunction, coulomb potential and accidental degeneracy, Application: Hydrogen atom spectrum. [6] • Time-independent perturbation theory (non-degenerate and degenerate cases), Fine structure of hydrogen, Zeeman effect, Stark effect. [6]

PHY 327: Quantum Mechanics II [3 0 0 3]	
	• WKB and semiclassical approximation. [4] • Time-dependent Hamiltonian, Interaction Picture, Perturbative solution in the interaction picture, Fermi's Golden rule, Transition rates, Spontaneous emission, Energy shift and decay width. [6]
Text & Reference Books	1. Sakurai, Jun John, and Eugene D. Commins. "Modern quantum mechanics, revised edition." (1995): 93-95. 2. Shankar, R. (2012). Principles of quantum mechanics. Springer Science & Business Media. 3. Tannoudji, Claude Cohen, Bernard Diu, and Franck Laloë. Quantum Mechanics: Vol. One and Two. John Wiley and Sons, 2002. 4. Zwiebach, B. (2022). Mastering Quantum Mechanics: Essentials, Theory, and Applications. MIT Press. 5. Landau, Lev Davidovich, and E. M. Lifshitz. Course of theoretical physics. Vol. 3: Quantum mechanics. *Non-relativistic theory*. London, 1965.

PHY 401: Electrodynamics [3 0 0 3]	
Prerequisites	PHY 121 Electromagnetism
Learning Outcomes	▪ Solve boundary value problems by various methods. ▪ Calculate quantities related to wave propogation in media ▪ Calculate scattering and radiation from a system of moving charges.
Syllabus	• Review of Electromagnetism: Electrostatics, Magnetostatics and Maxwell's Equations [2] • Properties of electromagnetic fields: Conservation Laws, Poynting's Theorem, Vector and Scalar Potentials, Gauge Transformations. [3] • Boundary value problems in electrostatics: Poisson and Laplace Equations, Green's Theorem, Uniqueness of the Solution with Dirichlet or Neumann Boundary Conditions, Green's Functions Boundary Value Problems – Image Method. Introduction to Finite Element Analysis of Electrostatics [6+4] • Plane waves and propagation in homogeneous media: Polarization, Reflection and Refraction; Dispersion in Dielectric, Conductive, and Dissipative Media; Group Velocity Causality, Kramers-Kronig Relations [3+4+4] • Guided and confined waves: Energy Flow in Waveguides, Monochromatic Modes, Attenuation. Resonant Cavities and Q-Factor. Dielectric Waveguides Optical Fibers [4] Radiating systems, scattering, and diffraction: Retarded Potentials, Lienard-Wiechert Potentials for a Point Charge, Angular Distribution. Radiation from Electric Dipoles and

PHY 401: Electrodynamics [3 0 0 3]	
	Magnetic Dipoles, Quadrupole radiation, Radiation Reaction; Scattering at Long Wavelengths, Rayleigh Scattering, Optical Theorem. [3+3+3]
Text & Reference Books	1. Introduction to Electrodynamics by D. Griffiths, 4th Ed, Pearson 2. Classical Electrodynamics by J. D. Jackson, 3rd Ed, Wiley 3. Electrodynamics of Continuous Media by L. Landau and E. Lifshitz, 2nd Ed, Pergamon Press 4. The Feynman Lectures on Physics Vol II by Richard Feynman, Robert B. Leighton and Matthew Sands, Online Edition https://www.feynmanlectures.caltech.edu/II_toc.html

PHY 402: Classical Electrodynamics [3 0 0 3]	
Prerequisites	Classical Mechanics [PHY 323]
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 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; Quadrupole 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 Theory of Fields, Vol-2 of course of theoretical physics, Pergamon, 2000. 2. J. D. Jackson, Classical Electrodynamics, 3rd ed., John Wiley, 1999.

PHY 403: Mathematical Methods in Physics II [3 0 0 3]	
Prerequisites	Mathematical Methods in Physics I
Learning Outcomes	▪ Apply various special functions and their properties in solving various physical problems. ▪ Apply the technique of Green's function to solve non-homogenous ordinary as well as partial differential equations. ▪ Solve Integral equations using various techniques. ▪ Find the cosets, conjugacy class and the invariant subgroup of a group. ▪ Find the factor group corresponding to an invariant subgroup of a group. ▪ Classify the representation of a group. ▪ Find the Character of a group corresponding to a representation. ▪ Classify normal frequencies and normal modes of polyatomic molecules using group theory. ▪ Find the local structure of a Lie group and the corresponding Lie algebra. ▪ Apply the concepts of a general Lie group in studying specific Lie groups such as SO(3) and SU(2).
Syllabus	• Special Functions and Applications: Hermite Polynomial and functions, Legendre Polynomial and functions, Associated Legendre function, Spherical Harmonics, Laguerre Polynomials, Hypergeometric functions, Application of special functions to Physical problems. [7] • Non-homogenous differential equation: Solving via Green's function approach, Green's function for ordinary differential operator and partial differential operator, Solution of boundary value problems using Green's function. [7] • Integral equations: A brief recap of Fourier and Laplace Transform, Different kinds of integral equations (Fredholm and Volterra equation), Transformation of a differential equation to an integral equation, Solving specific integral equations via integral transforms, Other approaches for solving general integral equations: Neumann Series, Separable Kernels and Numerical Methods. [7] • Basic Group Theory: Definition of a group, Cosets, Conjugacy Classes, Invariant Subgroup and Factor group, Direct product of group [3] • Representation of Groups: Definition of a Representation, Unitary Representations, Reducible and Irreducible Representations, Orthogonality relations, Characters, Regular Representation, Representations on function spaces, Product Representations, Symmetry and degeneracy; Vibrations of Polyatomic molecules. [6] • Lie Groups and Lie Algebras: Definition of a Lie group, Global Properties of Lie groups, Local structure of Lie groups and Lie algebras, Locally isomorphic groups; Universal Covering Group, Representation of Lie groups and Lie algebras, Adjoint Representation, SO(3) and SU(2). [6]
Text & Reference Books	1. Weber, Hans J., and George B. Arfken. Essential mathematical methods for physicists, ISE. Elsevier, 2003. 2. Dennery, Philippe, and André Krzywicki. Mathematics for physicists. Courier Corporation, 2012. 3. Tulsi Dass and Satish K Sharma, Mathematical Methods in Classical and Quantum Physics, Universities Press, 1998.

PHY 404: Quantum Mechanics III [3 0 0 3]	
Prerequisites	Quantum Mechanics II
Learning Outcomes	▪ Determine the relevant bosonic and fermionic Fock space by using the symmetrization postulate for identical particles. ▪ Apply scattering theory in elastic and inelastic collisions. ▪ Apply path integral formulation to calculate observables. ▪ Use the Lorentz transformation properties of a Dirac Spinor to show that it corresponds to a spin-1/2 particle. ▪ Calculate relativistic corrections to the spectrum of hydrogen-like atoms.
Syllabus	• Identical Particles: Permutation symmetry, Symmetrizer and Anti-symmetrizer, Symmetrization postulate, Bosonic and Fermionic Fock Space. [6] • Scattering Theory: Scattering cross-section, Lippmann-Schwinger equation, Born approximation; Application to scattering from various spherically symmetric potentials, including Yukawa and Coulomb, Optical theorem, Method of Partial Waves, Low-Energy Scattering and Bound States. [10] • Path integral formulation of Quantum Mechanics [4] • Relativistic wave equations: Klein Gordon equation, Negative energy and negative probability density, Dirac equation, Lorentz Covariance of Dirac Equation and the concept of Dirac Spinor, Orbital and Spin angular momentum [4] • Probability current and continuity equation for Dirac spinor, Plane wave solutions, positive energy and negative energy solutions, Concept of helicity, Interpretation of negative energy solutions, Dirac Sea and the concept of anti-particles, Orthogonality and Completeness of the basis of positive energy as well as negative energy solutions [4] • Interaction of Klein Gordon and Dirac particles with electromagnetic fields, Foldy Wouthuysen transformation and Relativistic Corrections [4] • Symmetries of the Dirac Equation under Poincare transformation, parity, time reversal and charge conjugation, massless fermions and chirality [4]
Text & Reference Books	1. Tannoudji, Claude Cohen, Bernard Diu, and Franck Laloë. Quantum Mechanics: Vol. One and Two. John Wiley and Sons, 2002. 2. Zwiebach, B. (2022). Mastering Quantum Mechanics: Essentials, Theory, and Applications. MIT Press. 3. Landau, Lev Davidovich, and E. M. Lifshitz. Course of theoretical physics. Vol. 3: Quantum mechanics. Non-relativistic theory. London, 1965. 4. Schwabl, Franz. Advanced quantum mechanics. Springer Science & Business Media, 2005. 5. Sakurai, Jun John, and Eugene D. Commins. "Modern quantum mechanics, revised edition." (1995): 93-95. 6. Sakurai, Jun John. Advanced quantum mechanics. Pearson Education India, 1967.

PHY 411: Nuclear and Particle Physics [3 0 0 3]	
Prerequisites	Quantum Mechanics - I, Electrodynamics / Classical Electrodynamics
Learning Outcomes	▪ Calculate Rutherford scattering cross section, estimate nuclear radius, matter and charge distributions and explain various experimental results

PHY 411: Nuclear and Particle Physics [3 0 0 3]	
	▪ 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] • 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.

PHY 412: Condensed Matter Physics- II [3 0 0 3]	
Prerequisites	Condensed Matter I (PHY 322)
Learning Outcomes	▪ Understand the dynamics of Bloch electrons in solid under external electric and magnetic fields. ▪ Basic knowledge of thermoelectric transport phenomena. ▪ Basic physics of semiconductors. ▪ Optical properties of solids and microscopic theory. ▪ Quantum theory of magnetism in atoms, ionic solids and free electron gas. Magnetic ordering, Heisenberg model, mean-field solutions. ▪ Phenomenology of superconductors, Ginzberg-Landau theory, Microscopic BCS theory. ▪ Solve simple problems in all the above topics.

PHY 412: Condensed Matter Physics- II [3 0 0 3]	
Syllabus	• Semiclassical transport theory: Wave packets of Bloch electrons, semiclassical equations of motion, motion under DC electric field, concept of holes and effective mass, motion under uniform magnetic field, Landau levels, quantum oscillations. Boltzmann transport equation, DC electrical conductivity. [6] • Thermoelectric transport: Phenomenological description, Seeback effect, Peltier effect. [2] • Semiconductors: Band structure, density of states, homogeneous semiconductors, doping and impurity levels, carrier densities. [6] • Optical properties: Classification of optical processes, optical coefficients, characteristic optical properties of metals, insulators, semiconductors. Conductivity and Dielectric Function, Classical theory of propagation, Drude and Lorentz model, Kramers-Kronig relations, interband transitions, applications to metals and semiconductors. [6] • Magnetism: Diamagnetism, Paramagnetism, Curie-Weiss law, Hund's rules, Pauli paramagnetism. [5] Magnetic ordering, ferromagnetism, antiferromagnetism, microscopic origin, exchange interaction. Heisenberg model, mean-field theories. [5] • Superconductivity: Phenomenology, Meissner effect, Type-I & Type-II superconductors, London equations, thermodynamics of superconductors. Ginzberg-Landau theory, condensation energy, flux quantization. [6] • Cooper pairs, BCS theory, Josephson effect and SQUID [4]
Text & Reference Books	1. Ashcroft and Mermin, Solid State Physics, Cengage, 2003 2. C. Kittel, Introduction to solid state physics, 7th ed., John Wiley, 2004 3. Girvin and Yang, Modern Condensed Matter Physics, CUP, 2019 4. Stephen Blundell, Magnetism in Condensed Matter, OUP, 2001 5. James F. Annett, Superconductivity, Superfluids, and Condensates, OUP, 2004

PHY 419: Statistical and data analysis methods in Physical Sciences [3 0 0 3]	
Prerequisites	Numeric Computing (IDC 122), 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: Probability and Statistics, Context of data science in 20th century. [1] • Probability: Axioms of probability, Conditional probability, Bayes theorem, Independent events, Random variables - discrete and continuous distributions, Quantile function, Central limit theorem. [3] • Probability Distribution functions: Different univariate probability distributions, moments, multivariate distributions [2] L • Data smoothing- density estimation: Concept of density estimation, histograms, Kernel density estimators. [1] + [2] L

PHY 419: Statistical and data analysis methods in Physical Sciences [3 0 0 3]	
	• Statistical Inference: 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. [3] + [2] L • Regression: Concept of regression, Least-squares linear regression, model validation and selection. [3] + [2] L • Multivariate analysis: Concepts of multivariate analysis, hypotheses tests, relationship among the variables - linear regression, principal component analysis, outliers, multivariate visualisation. [4] + [2] L • Clustering and classification: Concept of clustering and classification, K-means and mixture models and supervised multivariate normal clusters. [3] + [2] L • Time series analysis: Concept of time series analysis, analysis of evenly spaced data, autocorrelation, cross-correlation, dynamic time warping machine learning technique. [3] + [2] L
Text & Reference Books	1. Modern Statistical Methods for Astronomy by Eric D Feigelson and G. Jogesh Babu 2. Principles of Data Analysis by Prasenjit Saha 3. Statistical Methods for Astronomical Data Analysis by Asis Kumar Chattopadhyay and Tanuka Chattopadhyay 4. Python for Astronomers, An introduction to Scientific Computing by Imad Pasha and Chris Ago stino 5. Advances in Machine Learning and Data mining for Astronomy Edited by Michael J Way, Jeffrey D. Scargle, Kamal M. Ali and Ashok N.Srivastava.

PHY 421: Computational Techniques and Programming Languages [3 0 0 3]	
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

PHY 421: Computational Techniques and Programming Languages [3 0 0 3]	
	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

PHY 422: Atomic and Molecular Physics [3 0 0 3]	
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. ▪ Calculate rotational & vibrational energy levels of molecules ▪ Study many electron systems and molecules using central field approximation and self-consistent field.
Syllabus	• Foundation experiments: Discoveries leading to the concepts of Atoms, Molecules, discrete charge, Spin, [1] • One electron atoms: Bohr model, Solving Schrodinger equation for Hydrogenic atoms, origin of degeneracies, Internal conversion [3] • Fine structure, J-degeneracy, Energy level diagram, Lamb shift, Effect of nucleus in shifting/splitting of energy levels, Hyperfine structure [4] • Two level system under EM wave: Dipole approximation, Transition dipole moment, transition rates. [4] • Selection rules and spectrum, lineshape and linewidths, Doppler effect. [3] • The photoelectric effect, spontaneous emission, Einstein coefficients, Lasers: population inversion, optical pumping [2] • Stark effects and Zeeman: Weak and strong field stark effect, very strong and strong field Zeeman effect, Intermediate and weak field Zeeman effect, Splitting of energy levels from weak to very strong magnetic field, transition lines [4] • Two electron atoms: Para and Ortho states, Energy level scheme for independent particle approximation, ground state, excited state, doubly excited states, perturbation theory for excited states Energy level scheme for singlet and triplet, calculation of ground state energy. [4]

PHY 422: Atomic and Molecular Physics [3 0 0 3]	
	• Many electron atoms: Central field approximation, configuration, term-symbols, application of Hund's rules, description of Hartree-Fock method and self-consistent field. [3] • L-S coupling, j-j coupling, Zeeman effect, quadratic Stark effect [3] • Molecules: Born-Oppenheimer separation for diatomic molecules, rotation and vibration of diatomic molecules [4] • Electronic structure, rotational & vibrational energy levels, nuclear spin. [3] • Atomic collisions: Review of quantum mechanical scattering including partial waves and Born approximation [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.

PHY 423/ I2P 423: Modelling Materials 3 0 0 3]	
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 [4] • Density Functional Theory and the total-energy pseudopotential method [6] • Errors and accuracy of quantitative predictions [2] • Monte Carlo sampling and molecular dynamics simulations [4] + [12] L • Free energy and phase transitions; fluctuations and transport properties; and coarse-graining approaches and mesoscale models. [8] • Predictive Simulations of Novel Functional Materials [24] L • 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. 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.

PHY 423/ I2P 423: Modelling Materials 3 0 0 3]	
	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.

PHY 4110: Experimental Methods [3 0 0 3]	
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. ▪ Syllabus 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]

PHY 4110: Experimental Methods [3 0 0 3]	
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.

PHY 4205: Electronic Devices and Computer Interfacing [3 0 0 3]	
Prerequisites	Fundamentals of Programming (IDC 112), Electronics (PHY 313)
Learning Outcomes	▪ Hands on experience in interfacing data acquisition and control systems ▪ Apply special device physics and its characteristics for designing circuits. ▪ Analysis of oscillator circuits and apply the concept to device design. ▪ To interface microcontrollers with analog devices and convert signal to digitally processable form.
Syllabus	• Heterojunctions, Special purpose diodes: Zener, Varactor diode, Tunnel diode, Diac, Triac, LED, PV cell, Photodetectors, SCR, UJT, IGBT. [4] • Oscillator design and applications. [3] • Review of ADC and DAC. Analog and Digital data acquisition and generation. Counters and Timers, real-time data acquisition and instrument control and acquisition speed. Brief overview of microprocessors and microcontrollers. [4] • 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 [4] • Softwares: Labview, Python, Arduino IDE, C++ etc [4] • Project: Interfacing project to be conceived and executed by each student, using any one of the software. [9]
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.

PHY 4217 / PHY 6217: Quantum Information Theory [3 0 0 3]	
Prerequisites	Quantum Mechanics 1

PHY 4217 / PHY 6217: Quantum Information Theory [3 0 0 3]	
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: Review of probabilities, betting odds and the Dutch book. The probability simplex. [3] • Classical Information theory: Shannon entropy and Shannon's theorems. [2] • Bits and Qubits: The quantum two level system and its Hilbert space. [2] • Quantum states: Mixed quantum states and the density matrix. Quantum super-position, multipartite states and entanglement. [4] • Quantum measurements: The measurement super operator, generalized measurements and POVMs [3] • Quantum dynamics, open and dosed dynamics: Unitary evolution, Super operators and dynamical maps [3] • The circuit model: The circuit model of quantum computation, operations on qubits, distinguishability of states. [5] • Quantum entropy and quantum correlations: Quantum versions of the fundamental theorems in information theory, non-classical correlations, discord etc. [4] • Elements of quantum computing: Quantum algorithms, possible implementations [5]
Text & Reference Books	1. M. A. Nielsen and I. L Chuang, Quantum Computation and Quantum Information 2. J. Preskill, Quantum Information and Quantum Computation, Available online (Caltech) 3. J. J. Sakurai, Modem quantum mechanics Addison-Wesley, 1994.

PHY 5125: Foundations of Quantum Mechanics [3 0 0 3]	
Prerequisites	PHY 314: Quantum Mechanics I
Learning Outcomes	▪ Will be able to explain the basics mathematical formulation of quantum theory and will be able to identify it as an operational theory rather than an ontological theory ▪ Will learn some of the most profound debates regarding the foundational status of quantum theory, viz. Bohr-Einstein debate and Einstein–Podolsky–Rosen paradox, Wigner's friend paradox, Pusey-Barrett-Rudolph theorem ▪ Will Identify in what sense quantum theory provides a completely new world view than the old classical physics. In particular, will learn Bell's theorem, the most profound discovery of science ▪ Will be able to apply Bell's theorem to certify device-independent randomness and will learn how device independent cryptography shared key can be obtained from quantum nonlocal correlation ▪ Will appraise Kochen-Specker theorem and its remarkable application in Binary constraint system games, also learn some use of graph theory at this point ▪ Will recognize that quantum world allows very peculiar causal structure than what we generally perceive in our classical macroscopic world

PHY 5125: Foundations of Quantum Mechanics [3 0 0 3]	
Syllabus	• Review: Mach-Zehnder interferometer; Stern-Gerlach experiment; Linear Algebra [3] • Introduction: Postulate of Quantum Theory; Einstein-Podolsky-Rosen paradox [4] • Programme of Hidden Variable Theory (HVT): 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) [3] • Bell's Nonlocality: Proof of Bell's theorem; Quantum entanglement; Quantum violation of Bell inequality; Study of different sets of correlations [4] • Application of Bell's theorem: Device independent (DI) randomness certification; Quantum cryptography protocols (BB84 and E91); DI cryptography [4] • Kochen-Specker contextuality: State independent / dependent contextuality proof; Generalized contextuality of Spekkens [4] • Application of Kochen-Specker contextuality: Some basic topics in graph theory; Binary Constraint System Games, Parity-oblivious multiplexing task [3] • Reality of quantum wavefunction: Pusey-Barrett-Rudolph theorem; Maroney's theorem [4] • Quantum Measurement Problem: Wigner's friend paradox and its extended version [3] • Indefinite causal order: Oreshkov-Costa-Brukner game; Quantum switch [4]
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.

I2P Courses

I2P 321: Electrochemical Energy Systems [3 0 0 3]	
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.
Syllabus	• 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.

DSC 311: Mathematical Statistics [3 0 1 4]	
Prerequisite	NA
Learning Outcomes	This course provides students with decision theory, estimation, confidence intervals, and hypothesis testing.

DSC 311: Mathematical Statistics [3 0 1 4]	
Syllabus	• Sampling Distributions: 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. [9] • Estimation of Parameters: 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. [9] • Bivariate Samples: Sample from a bivariate population; least square curve fitting; maxi-mum 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; χ^2 test of goodness of fit. [15] Practicals: [16] • 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, 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.

DSC 318: Mathematical Statistics Lab [0 0 2 1]	
Prerequisite	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.

DSC 318: Mathematical Statistics Lab [0 0 2 1]	
Syllabus	• Objects and functions, Arithmetical and Boolean operators, Importing and Exporting Data sets, Packages, Loops and Conditional statements, • Measure of central tendency for grouped and ungrouped data • Basic plots. • Density, distribution function, quantile function and random generation for standard discrete and continuous distributions. Generating bivariate random samples. • Correlation coefficients • Q-Q plots and P-P plots. Fitting distributions. • Maximum Like-lihood estimation. • Type I and Type II Error, p values, Power curves • Test for mean, variance, proportion and independency, Goodness of fit
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.

I2P 413: Fluid Mechanics and Transport Phenomena [3 0 0 3]	
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.
Syllabus	• 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]

I2P 413: Fluid Mechanics and Transport Phenomena [3 0 0 3]	
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.

I2C 421: Soft Matter and Polymers [3 0 0 3]	
Prerequisites	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]

I2C 421: Soft Matter and Polymers [3 0 0 3]	
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. 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, NJ, 2004.

I2P 423: Modelling Materials [2 0 3 3]	
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 [4] • Density Functional Theory and the total-energy pseudopotential method [6] • Errors and accuracy of quantitative predictions [2] • Monte Carlo sampling and molecular dynamics simulations [4] + [12] L • Free energy and phase transitions; fluctuations and transport properties; and coarse-graining approaches and mesoscale models. [8] • Predictive Simulations of Novel Functional Materials [24] L
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.

I2P 324: Numerical Methods [3 0 0 3]	
Prerequisites	Programming courses in semesters 1-4
Learning Outcomes	▪ Perform numerical computation using a programming language. ▪ Find root of an equation, numerical differentiation and integration. ▪ Solve differential equations, linear algebra problems numerically. ▪ Obtain numerical solutions to problems in classical and quantum physics and classical statistical mechanics problems using Monte Carlo simulation.
Syllabus	• Obtain numerical solutions to problems in classical and quantum physics and classical statistical mechanics problems using Monte Carlo simulation. • 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

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

I2P 422: Optoelectronic Devices [3 0 0 3]	
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.
Syllabus	• 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.

I2P 423: Device Technology [0 0 9 3]	
Prerequisites	Material Characterisation, Condensed Matter I
Learning Outcomes	▪ 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.

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<tr><th colspan="2">I2P 423: Device Technology [0 0 9 3]</th></tr>
<tr><td></td><td>
▪ 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.
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<tr><td>Syllabus</td><td>
Part A: (8 weeks)
• Micro-fabrication techniques (photolithography, soft lithography) [5]
• Deposition, growth and engineering of materials (physical and chemical routes) [5]
• Thermal and e-beam evaporation, DC-RF magnetron sputtering, sol-gel method, spin and dip coating. Etching: Wet (chemical), dry (Ar ion plasma) [4]
• Advanced nano-fabrication and characterisation techniques (electron-beam lithography, focused ion-beam etching and scanning probe microscopy) [4]
• Electrical and Optical characterisation: DC/AC I-V, C-V methods, RF electronics. Reflection, transmission and emission spectroscopy. [5]
• Fabrication and Characterisation of a device
• Sensors: chemical and bio-sensors using electrical, optical, acoustic, magnetic etc. [4]
• Mechanical Energy harvester: piezoelectric or magnetic material based micro-cantilever fabrication by PCB or 3D printing. Demonstration of electricity generation from vibration of cantilever. [2]
• Photovoltaic Energy conversion: Fabrication of thin film solar cell using Physical vapour deposition and spin coating (organic) techniques. Determination of device efficiency, fill factor. [6]
• 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. [6]
• Si photonic structures and wave guide using lithography and etching. [3]
• 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. [5]
• Fluorescent materials based sensor arrays and principle component analysis. [4]
Part B: (4 weeks)
• One Mini Project — Building prototypes integrating devices. Examples:
• Project 1: Robotics – Build an automated robot (e.g. driverless car using Raspberry Pi and sensor, GPS/GSM based animal tracker) [10]
• Project 2: Photovoltaic Device —Build a solar light by using the solar cell film and other electronics. [10]
• Project 3: Analysis of climatic changes or health of student community and analysis by using Python/MATLAB. [10]
</td></tr>
<tr><td>Text & Reference Books</td><td>
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.
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I2P 424: Thermal Transport and Thermoelectrics [3 0 0 3]	
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.
Syllabus	• 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] • 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.Bharat Bhushan (editor), Springer Handbook of Nanotechnogy, Springer-Verlag Berlin Heidelberg 2010.

I2P 425: Finite Element Modelling [1 0 6 3]	
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.
Syllabus	• 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] • 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] • Simulating Electrical conduction, Optical reflection, transmission, absorption, meta-materials, thermal and fluid transport [1] + [12] L • 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] + [24] L • 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.[2] + [36] L
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.

I2P 4201: Computer Interfacing [1 0 3 2]	
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.

I2P 4201: Computer Interfacing [1 0 3 2]	
Syllabus	• 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]
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.

I2P 4202: Energy Materials Laboratory [0 0 3 1]	
Prerequisites	Electrochemical Energy Systems, 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
Syllabus	• Measurement of various thermal transport (conduction/radiation) • Measurement of Specific Heat of Metals & Semiconductors [3] • Synthesis of thermoelectric materials (Bi2Te3) by Solution methods, Powder metallurgy, [3] • Characterising the Thermal Efficiency of Thermoelectric Modules [3] • Design, modelling and simulation of solar concentrators [3] • Synthesis and characterisation of electrode materials for Li ion battery applications [3] • Experimental investigation of hydrogen storage properties of porous carbon materials [3] • Investigation on the electrocatalytic properties of noble metal catalysts towards hydrogen generation [3] • Photocatalytic hydrogen generation and quantification of hydrogen evolution [3] • Synthesis and characterisation of porous carbon materials [3] • Electrochemical synthesis and characterisation of metal nanowires [3]
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.

I2P 4203: Battery and Fuel Cell Laboratory [0 0 3 1]	
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.
Syllabus	• Fabrication of coin cell devices and charge/discharge characterization of Lithium ion battery electrodes [6] • Electrochemical Impedance spectroscopy studies of Lithium ion battery electrodes [6] • Fabrication and electrochemical characterization of carbon-based supercapacitor devices [3] • Electrochemical characterization of Hydrogen fuel cell device [3] • Fabrication electrochemical characterization of microbattery devices [6]
Text & Reference Books	1. Allen J. Bard and Larry Faulkner, Electrochemical Methods: Fundamentals and Applications, 2nd ed., Wiley, Jan 2001.

I2P 4204: Organic Photovoltaic Devices Laboratory [0 0 3 1]	
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.
Syllabus	• Fabrication and characterisation of Photodetectors. • Fabrication and characterisation of solar cells. [5] • Fabrication and characterisation of light emitting diodes. [5] • Fabrication and characterisation of field effect transistors. [5] • Fabrication and characterisation of electrochromic devices. [5] • Fabrication and characterisation of electrochemical transistors. [5]
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.

I2P 4204: Organic Photovoltaic Devices Laboratory [0 0 3 1]	
	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

I2P 522: Machine Learning for Physical Sciences [2 0 3 3]	
Prerequisites	Fundamentals of Programming (IDC 112), Numerical Methods and Applied Statistics.
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.
Syllabus	• Introduction to the core concepts, theory and tools of machine learning as required by physicists addressing practical data analysis tasks. [3] • Supervised learning: linear models for regression and classification [10] • Nonlinear models; Neural networks, Structure, Training and Analysing Neural Networks. Convolutional Neural Networks, Auto-encoders, Principal Component Analysis [6] • Unsupervised learning: dimensionality reduction for clustering. [3] • Recurrent networks, time series and sentence analysis. [5] • Implementation of ML in real applications, relevant to problems in physics. [7] • Free software, libraries and publicly available data-sets will be used. [2]
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.

I2P 5201: Principles of Digital Imaging [3 0 0 3]	
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.

I2P 5201: Principles of Digital Imaging [3 0 0 3]	
Syllabus	• 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] • 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] • 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] • Tomography in selective imaging modalities - X-ray, ultrasound, magnetic resonance imaging (MRI), positron emission tomography (PET), photoacoustic tomography (PAT), diffuse optical tomography (DOT) [4]
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.

Laboratory Courses

PHY 315: Advanced Physics Experiments I [0 0 9 3]	
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

PHY 325: Advanced Physics Experiments II [0 0 9 3]	
Learning Outcomes	Develop practical skills, which includes understanding of objectives, related experimental design and operation, record observations in a logical order, reaching final results and conclusions, and finally make a detailed discussion by identifying the sources of error.
Syllabus	1. Velocity of light- Foucoult's method 2. Photoelectric effect 3. Arc Spectrum- Iron or Brass 4. X-ray diffractometer 5. FET characteristics and amplifier using FET 6. Op-Amp: Frequency response and mathematical tools 7. Op-Amp: Square, triangular and saw-tooth wave generator 8. Band pass and band reject filters 9. Differential amplifier using transistor 10. Amplitude modulation 11. Digital electronics using trainer kit-Binary to decimal, decimal to binary and D/A converter 12. Schmitt trigger 13. Chaotic Oscillator 14. Scanning Tunneling Microscope - Topography

PHY 415: Advanced Physics Experiments III [0 0 9 3]	
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

PHY 4110 / PHY 6110 / I2P 411: Experimental Methods [3 0 0 3]	
Prerequisites	Electronics (PHY 313)
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. ▪ Syllabus 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]
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.

PHY 4120 / PHY 6120 / I2P 412: Semiconductor Physics and Technology [3 0 0 3]	
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] • 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

PHY 4140 / PHY 6140 / I2P 414: Modelling Materials [2 0 3 3]	
Prerequisites	Quantum Mechanics, Condensed Matter Physics I

PHY 4140 / PHY 6140 / I2P 414: Modelling Materials [2 0 3 3]	
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 [4] • Density Functional Theory and the total-energy pseudopotential method [6] • Errors and accuracy of quantitative predictions [2] • Monte Carlo sampling and molecular dynamics simulations [4] + [12] L • Free energy and phase transitions; fluctuations and transport properties; and coarse-graining approaches and mesoscale models. [8] • Predictive Simulations of Novel Functional Materials [24] L
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.

PHY 4204 / PHY 6204: Nonlinear Optics and Photonics [3 0 0 3]	
Prerequisites	Mathematical Methods in Physics
Learning Outcomes	▪ Write wave equation using nonlinear polarization ▪ Analysis of wave equation for second- and third order optical nonlinearities under different conditions ▪ Analyse the effect of dispersion and nonlinearities on wave propagation ▪ Write Nonlinear Schrodinger equation and simulate pulse broadening and self-phase modulation ▪ Use coupled wave equations to analyse the evolution of the probe field in stimulated Brillouin and Raman scattering under different conditions.
Syllabus	• Light-matter interaction, Polarization, Nonlinear Polarization, Wave Equation with driving polarization [4] • 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 [6]

PHY 4204 / PHY 6204: Nonlinear Optics and Photonics [3 0 0 3]	
	• Pulse propagation in optical fibre, Nonlinear pulse propagation, Group Velocity dispersion, Dispersion induced pulse broadening, Gaussian pulses, chirped Gaussian pulse, Dispersion management. [4] • 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 [6] • Introduction to four-wave mixing, third harmonic generation, Phase matching techniques, Stimulated Raman Scattering, Stimulated Brillouin scattering, Electromagnetically Induced Transparency. [6] • Applications of nonlinear optics, slow-light, microwave photonics, Ultra-fast communication and signal processing. [4] • Project [10]
Text & Reference Books	1. Nonlinear Optics by Robert W. Boyd, Academic Press. 2. Nonlinear Fibre Optics by Govind P Agarawal, Academic Press.

PHY 4205 / PHY 6205: Electronic Devices and Computer Interfacing [2 0 1 3]	
Prerequisites	Basics of Programming, Electronics
Learning Outcomes	▪ Hands on experience in interfacing data acquisition and control systems
Syllabus	• Heterojunctions, Special purpose diodes: Zener, Varactor diode, Tunnel diode, Diac, Triac, LED, PV cell, Photodetectors, SCR, UJT, IGBT. [4] • Oscillator design and applications. [3] • Review of ADC and DAC. Analog and Digital data acquisition and generation. [3] • Counters and Timers, real-time data acquisition and instrument control and acquisition speed. Brief overview of microprocessors and microcontrollers. [4] • Practical aspects of interfacing external hardware with a computer. [3] • Serial and Parallel Interfacing. Virtual instrumentation using IEEE GPIB, RS232, USB interfaces. Interfacing external hardware platforms like Arduino [4] • Softwares: Labview, Python, Arduino IDE, C++ etc [4] • Project: Interfacing project to be conceived and executed by each student, using any one of the software. [9]
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.

PHY 4206 / PHY 6206: Astrophysics [3 0 0 3]	
Prerequisites	ED & STR, classical mechanics, Statistical Mechanics
Learning Outcomes	▪ Understand the basic tools of astrophysical observations such as the celestial sphere, galactic coordinates, and various units for measurements. ▪ Learn about the interplay between the thermal and gravitational energy in stars, collapse of stars and the formations of astrophysical objects such as black holes, white dwarf and neutron stars. ▪ Learn about the basic characteristics of galaxies such as galactic rotations and stellar mass distribution ▪ Understand the conditions of matter and radiation in the early universe and how the universe has evolved through expansion.
Syllabus	• Overview of the universe. Astronomical scales, Coordinates, Magnitudes. Telescopes and Observations in various EM bands. [8] • 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. [22] • Interstellar medium, Jeans instability. [3] • 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. [7]
Text & Reference Books	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.

PHY 4207: Quantum Information Theory [3 1 03]	
Prerequisites	PHY 314: Quantum Mechanics 1
Learning Outcomes	▪ 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
Syllabus	• 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]

PHY 4207: Quantum Information Theory [3 1 03]	
	• 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] • 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.

PHY 4217 / PHY 6217: Quantum Information Theory [3 0 0 3]	
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: Review of probabilities, betting odds and the Dutch book. The probability simplex. [3] • Classical Information theory: Shannon entropy and Shannon's theorems. [2] • Bits and Qubits: The quantum two level system and its Hilbert space. [2] • Quantum states: Mixed quantum states and the density matrix. Quantum super-position, multipartite states and entanglement. [4] • Quantum measurements: The measurement super operator, generalized measurements and POVMs [3] • Quantum dynamics, open and dosed dynamics: Unitary evolution, Super operators and dynamical maps [3]

PHY 4217 / PHY 6217: Quantum Information Theory [3 0 0 3]	
	• The circuit model: The circuit model of quantum computation, operations on qubits, distinguishability of states. [5] • Quantum entropy and quantum correlations: Quantum versions of the fundamental theorems in information theory, non-classical correlations, discord etc. [4] • Elements of quantum computing: Quantum algorithms, possible implementations [5]
Text & Reference Books	1. M. A. Nielsen and I. L Chuang, Quantum Computation and Quantum Information 2. J. Preskill, Quantum Information and Quantum Computation, Available online (Caltech) 3. J. J. Sakurai, Modem quantum mechanics Addison-Wesley, 1994.

PHY 4218 / PHY 6218: Nonlinear Dynamics [3 0 0 3]	
Prerequisites	Mathematical Methods in Physics
Learning Outcomes	▪ Analyse the basic difference between the linear and nonlinear dynamical systems along with the nature of dynamics (solutions) exhibited by them. ▪ Able to apply various nonlinear techniques to analyse the dynamical systems. ▪ Able to unravel the bifurcations leading to chaotic dynamics and its properties along with various applications in real world systems. ▪ Estimate the stability criterion using linear stability analysis. ▪ Calculate the Lyapunov exponents, power spectra and Poincare' section.
Syllabus	• 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. [8] • 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. [8] • 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. [2] • Fractals: Self similarity - Self-similarity in Henon attractor - Properties of fractals - Examples of fractals • Fractal dimension. [4] • Soliton: Linear and nonlinear waves - cotiidial and solitary waves - John Scott Russel's observation of solitary wave - Korteweg-de vries equation and solitons. [4]
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.

PHY 5101 / PHY 6101 / I2P 5101: Digital Image Processing [3 0 0 3]	
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. [1] • 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) [4] • Mathematical preliminaries - convolution and linear time invariant (LTI), correlation, random signals and random processes (Markov random process), probability distribution function (pdf) (Gaussian or normal). [4] • 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) [4] • Image transform – orthogonal and unitary, cosine, sine, Karhunen Loeve (KL), Hadamard, Haar, slant, wavelet. [3] • Image enhancement – point and spatial operation, histogram modelling, transform operation [3] • Image filtering and restoration – image model and inverse filtering, Wiener filtering, filtering in frequency domain, single value decomposition (SVD) and recursive filtering [4] • Image analysis – feature extraction, registration, segmentation (point, line, and edge detection; thresholding; region growing and region splitting [3] • Image analysis – classification, SVD and principle component analysis (PCA) [3] • Morphological image processing – erosion and dilation, opening and closing, Hit-or-Miss transform, morphological reconstruction [3] • Image reconstruction – Radon transform, Fourier slice theorem, projection, sectioning [3] • Image reconstruction - tomography (numerical method) [3] • Image data compression – pixel coding, predictive technique, transform coding theory, interframe coding. [3]
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.

PHY 5121 / PHY 6121: Lasers and Fiber Optic Communications [3 0 0 3]	
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). [12] • Optical communications: data sampling and Nyquist criteria, analog to digital conversion [6] • 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. [6] • Effect of dispersion and nonlinearity on data propagation, Erbium doped fiber amplifier (EDFA). Detectors: photodiode, PIN photodiode, avalanche photodetector, detector as low pass filter, receiver noise, thermal noise, shot noise, signal-to-noise ratio, noise figure, bit error rate (BER), eye-diagram, Shannon limit, basic coding schemes. [6] • Final Project [10]
Text & Reference Books	1. Lasers by Siegman, Anthony E. (1986), University Science Books. 2. Govind P. Agrawal, Fiber-Optic Communication Systems, Wiley Interscience.

PHY 5122 / PHY 6122: Physics at Low temperatures [3 0 0 3]	
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. [6] • 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,

PHY 5122 / PHY 6122: Physics at Low temperatures [3 0 0 3]	
	properties of this mixture, topological defects in superfluid 4He and superfluid 3He and salient properties of quantum solids. [6] • Solids at low temperatures: Electrical transport, thermal, mechanical and magnetic properties, Kondo effect, Superconductivity and heavy fermion materials. [4] • Production of low and ultra-low temperatures, Liquid helium cryostats, Closed Circuit refrigerators: Gifford-McMahon refrigeration cycle, Pulse tube refrigerator, Physics of adiabatic and nuclear demagnetization, Pomeranchuk cooling, dilution refrigerators. [6] • 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. [6] • 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. [8] • Materials: Sapphire, substrate, below 10 K. [4]
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. Reference Books: 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.

PHY 5123 / PHY 6123: Nanoscale Physics [3 0 0 3]	
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 [6] • Size matters: effect on structural, physical and chemical properties Nanomagnetism Nanophotonics. [4] • Electronic structure of semiconductor nanoparticles, size dependent optical properties: photoluminescence, absorption spectra, excitons and plasmons, vibrational and thermal properties of nanosystems; zone folding. Raman characterization. [6] • Synthesis of nanomaterials: Bottom up and top down approaches - Physical and chemical methods. [8] • Story of carbon nanoscience: Fullerenes, carbon nanotubes, graphene and beyond graphene - physics and applications. [4] • Nanotools: Scanning probe techniques - tools for characterization, manipulation and constructions of the nanoscale structures and devices. [6] • Applications of nanomaterials, nanoscale devices. [6]
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.

PHY 5124 / PHY 6124: Superconductivity [3 0 0 3]	
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, MgB_2 and Fe pnictides. [4] • Basic properties of metals in normal state: Resistivity, electronic and phonon specific heats, thermal conductivity, magnetic susceptibility and Hall effect. [4] • Phenomenon of superconductivity: Zero resistance, persistent currents, superconducting transition temperature T_c, isotope effect, perfect diamagnetism and Meissner effect, penetration depth and critical field. [6] • Thermodynamics of superconducting transition: First-order and second-order transition, specific heat above and below T_c, thermal conductivity. [4]

PHY 5124 / PHY 6124: Superconductivity [3 0 0 3]	
	• Phenomenological theory of superconductivity: Free energy, order parameter, Ginzburg-Landau equations, predictions of Ginzburg Landau equations, flux-quantization, penetration depth. [4] • 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. [6] • Tunneling and the energy gap: Tunneling phenomenon, energy-level diagram, Josephson effect, quantum interference. [4] • Type-I and Type-II superconductivity: Type-I and type-II superconductors, intermediate states, mixed states. [4] • Experimental methods for probing the nature of the superconducting state: Superconducting quantum interference device and point-contact spectroscopy. [4] • Basics of High-Tc superconductivity. [2]
Text & Reference Books	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.

PHY 5125 / PHY 6125: Foundations of Quantum Mechanics [3 0 0 3]	
Prerequisites	PHY 314: Quantum Mechanics I
Learning Outcomes	▪ Will be able to explain the basics mathematical formulation of quantum theory and will be able to identify it as an operational theory rather than an ontological theory ▪ Will learn some of the most profound debates regarding the foundational status of quantum theory, viz. Bohr-Einstein debate and Einstein–Podolsky–Rosen paradox, Wigner's friend paradox, Pusey-Barrett-Rudolph theorem ▪ Will Identify in what sense quantum theory provides a completely new world view than the old classical physics. In particular, will learn Bell's theorem, the most profound discovery of science ▪ Will be able to apply Bell's theorem to certify device-independent randomness and will learn how device independent cryptography shared key can be obtained from quantum nonlocal correlation ▪ Will appraise Kochen-Specker theorem and its remarkable application in Binary constraint system games, also learn some use of graph theory at this point

PHY 5125 / PHY 6125: Foundations of Quantum Mechanics [3 0 0 3]	
	▪ Will recognize that quantum world allows very peculiar causal structure than what we generally perceive in our classical macroscopic world
Syllabus	• Review: Mach-Zehnder interferometer; Stern-Gerlach experiment; Linear Algebra [3] • Introduction: Postulate of Quantum Theory; Einstein-Podolsky-Rosen paradox [4] • Programme of Hidden Variable Theory (HVT): 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) [3] • Bell's Nonlocality: Proof of Bell's theorem; Quantum entanglement; Quantum violation of Bell inequality; Study of different sets of correlations [4] • Application of Bell's theorem: Device independent (DI) randomness certification; Quantum cryptography protocols (BB84 and E91); DI cryptography [4] • Kochen-Specker contextuality: State independent / dependent contextuality proof; Generalized contextuality of Spekkens [4] • Application of Kochen-Specker contextuality: Some basic topics in graph theory; Binary Constraint System Games, Parity-oblivious multiplexing task [3] • Reality of quantum wavefunction: Pusey-Barrett-Rudolph theorem; Maroney's theorem [4] • Quantum Measurement Problem: Wigner's friend paradox and its extended version [3] • Indefinite causal order: Oreshkov-Costa-Brukner game; Quantum switch [4]
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.

PHY 5126 / PHY 6126: Advanced Statistical Physics [3 0 0 3]	
Prerequisites	Statistical Mechanics
Learning Outcomes	▪ Recall phase transitions, and characterize critical phenomena by their symmetries (order parameter) and critical exponents. ▪ Establish connection between statistical and quantum systems, transfer matrix and path integrals. ▪ Solve Ising model in 1D and 2D using transfer matrix methods, and determine large-distance correlation functions. ▪ Use Landau-Ginzburg theory to describe Ising model, and apply various mean-field methods to obtain correlation functions and exponents. ▪ Use Renormalization group techniques to identify relevant couplings, determine their flow under scaling, and find the critical exponents.
Syllabus	• 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. [6]

PHY 5126 / PHY 6126: Advanced Statistical Physics [3 0 0 3]	
	• 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. [6] • Collective excitations: Continuous symmetry breaking and Goldstone modes, Mermin-Wagner theorem, spin-waves in ferromagnets. [5] • Exact solution of Ising model in one and two dimensions, Relation between transfer matrix method and path integrals in quantum mechanics. [5] • Landau-Ginzburg theory: Mean-field approach. Saddle-point approximation, Breakdown of mean-field and Ginzburg criterion. [8] • 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. [6]
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.

PHY 5127 / PHY 6127: Fluid Dynamics [3 0 0 3]	
Prerequisites	Classical Mechanics, Electrodynamics & STR, Statistical Mechanics
Learning Outcomes	▪ Assimilate hydrodynamic principles, and identify the relevant dissipative processes, transport coefficients and Onsager relations. ▪ Apply the entropy principle to construct the constitutive relations in non-relativistic (simple and multi-component) fluids, in relativistic fluids, and in superfluids. ▪ Solve relativistic fluid dynamical equations for stationary flows and irrotational flows. ▪ Rectify non-causal behaviour of first-order relativistic fluids by adding higher-order corrections.
Syllabus	• 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]

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

PHY 5128 / PHY 6128: General Relativity and Cosmology [3 0 0 3]	
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 Relativity [2] • The Equivalence Principle [2] • Space and Spacetime Curvature Tensors in Curved Spacetime [4] • The Geodesic equation [4] • Curvature and Einstein Field Equations [2] • Geodesic Deviation Equation Geometry [4] • Outside of a Spherical Star Tests of caslativity [2] • Gravitational Radiation • Black Holes [3] • Cosmology [3]
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.

PHY 5129 / PHY 6129: Quantum Many-body Theory [3 0 0 3]	
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	• 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) [10]

PHY 5129 / PHY 6129: Quantum Many-body Theory [3 0 0 3]	
	• Path integral formulation: Coherent states, Construction of the many-body path integral, Perturbation theory and diagramatics [8] • 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. [10] • Fermi Liquid theory: Quasi-particles and their interactions, Observable prop-erties of normal Fermi liquid, Collective modes [8]
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.

PHY 5131 / PHY 6131: Spintronics Fundamental and device applications [3 0 0 3]	
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]

PHY 5131 / PHY 6131: Spintronics Fundamental and device applications [3 0 0 3]	
	• 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

PHY 5132 / PHY 6132: Statistical and data analysis methods in Physical Sciences [3 0 0 3]	
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: Probability and Statistics, Context of data science in 20th century. [1] • Probability: Axioms of probability, Conditional probability, Bayes theorem, Independent events, Random variables - discrete and continuous distributions, Quantile function, Central limit theorem. [3] • Probability Distribution functions: Different univariate probability distributions, moments, multivariate distributions [2] + [2] L • Data smoothing- density estimation: Concept of density estimation, histograms, Kernel density estimators. [1] + [2] L • Statistical Inference: 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. [3] + [2] L • Regression: Concept of regression, Least-squares linear regression, model validation and selection. [3] + [2] L • Multivariate analysis: Concepts of multivariate analysis, hypotheses tests, relationship among the variables - linear regression, principal component analysis, outliers, multivariate visualisation. [4] + [2] L • Clustering and classification: Concept of clustering and classification, K-means and mixture models and supervised multivariate normal clusters. [3] + [2] L • Time series analysis: Concept of time series analysis, analysis of evenly spaced data, autocorrelation, cross-correlation, dynamic time warping machine learning technique. [3] + [2] L

PHY 5132 / PHY 6132: Statistical and data analysis methods in Physical Sciences [3 0 0 3]	
Text & Reference Books	1. Modern Statistical Methods for Astronomy by Eric D Feigelson and G. Jogesh Babu 2. Principles of Data Analysis by Prasenjit Saha 3. Statistical Methods for Astronomical Data Analysis by Asis Kumar Chattopadhyay and Tanuka Chattopadhyay 4. Python for Astronomers, An introduction to Scientific Computing by Imad Pasha and Chris Ago stino 5. Advances in Machine Learning and Data mining for Astronomy Edited by Michael J Way, Jeffrey D. Scargle, Kamal M. Ali and Ashok N.Srivastava.

PHY 5202 / PHY 6202 / I2P 5202: Organic Semiconductors: Fundamentals and Applications [3 0 0 3]	
Prerequisites	Condensed Matter Physics - I
Learning Outcomes	▪ Describe physical models and applications of unconventional semiconductors and organic molecules. ▪ Analyse the of photophysics of organic semiconductors and identify their difference with inorganic counterparts ▪ Comprehend applications of organic semiconductors in optoelectronics ▪ Device physics of the optoelectronic devices based on organic semiconductors
Syllabus	Part I • 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] • 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] • Excitons : Wannier Exciton, Charge-transfer Exciton Frenkel Exciton, Exciton Diffusion, Excitonic Energy Transfer. [2] • ConductionMn Organic Solids: Conductivity: carrier concentration versus mobility, Carrier generation, Hopping transport, Mobility measurements, Traps. [2] • Photovoltaics and Photodetectors: Photovoltaic Devices: Organic Heterojunction Photovoltaic Cells, Organic/Nanorod hybrid Photovoltaics, Gratzel Cells (Dye sensitized solar 1 cells), Photodetector Devices [5] • Organic Light Emitting Devices: Basic OLED Properties, Charged Carrier Transport, Organic LEDs, Quantum Dot LEDs. [8] • Lasing Action in Organic Semiconductors: Lasing Process, Optically Pumped Organic Lasers, Electrical Pumping of Organic Lasers. [2] • Organic Thin Film Transistors: OFETs: Materials, Contacts, Applications, And Nanotube Transistors. [2] • Device Fabrication Technology: Growth Techniques: Evaporation, Langmuir-Blodgett, Chemical Vapor Phase Deposition, Ink-Jet Printing, Self-Assembly. [3] Part II • Project: Literature review on a certain relevant topic. [10]
Text & Reference Books	1. Gilbert & Baggott, Essentials of Molecular Photochemistry, CRC Press, 1991. 2. K. K. Rohatgi-Mukherjee, Fundamentals of Photochemistry, NewAge International, 1978.

PHY 5202 / PHY 6202 / I2P 5202: Organic Semiconductors: Fundamentals and Applications [3 0 0 3]	
	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, 7. Electrical transport in solids: with particular reference to organic semiconductors, Kao, Pergamon Press; 1st ed., 1981.

PHY 5203 / PHY 6203 / I2P 5203: Sensor Technology [3 0 0 3]	
Prerequisites	Condensed Matter Physics - I, Electronics
Learning Outcomes	▪ Understand the working principles and designs of sensors used to monitor gases, humidity, and pressure. ▪ design miniature nanoscale and microscale sensors ▪ Apply of sensor devices in technological areas.
Syllabus	• 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. [8] • 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. [6] • Composite material based sensors, ChemFETs and eNose, manufacturing of gas sensor. [6] • 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. [8] • Application of ceramic sensors [4] • MEMS based sensor, Nanotechnology in Sensor applications, recent developments in this area. [6]
Text & Reference Books	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.

PHY 5207 / PHY 6207: Numerical Simulation techniques in Physics [3 0 0 3]	
Prerequisites	Condensed Matter Physics-II

PHY 5207 / PHY 6207: Numerical Simulation techniques in Physics [3 0 0 3]	
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.

PHY 5208 / PHY 6208: Introduction to Cosmology [3 0 0 3]	
Prerequisites	General Relativity and Cosmology
Learning Outcomes	▪ Define the principles and equations that are the foundation of models of the universe in the general theory of relativity. ▪ Explain important cosmological observations and how they are used to determine the characteristics of the Universe. ▪ Describe important eras in the history of the universe: inflationary phase, radiation dominated phase with disengagement of dark matter and neutrinos, nucleosynthesis, matter dominated universe and the formation of CMB. ▪ Describe how quantum fluctuations during inflation are the source of fluctuations of CMB.
Syllabus	• Historical overview and expansion of the Universe: Ptolemaic Universe – Copernican Revolution – Expanding Universe -Measurement of motion – Redshift – Hubble's law – Cosmological principle [3] • Friedman-Robertson-Walter (FRW) metric: Metric of constant curvature – Standard forms of the FRW metric – Open, closed and flat Universes - Friedman equation – Acceleration equation – Energy conservation [4.5]

PHY 5208 / PHY 6208: Introduction to Cosmology [3 0 0 3]	
	• Cosmological Models: 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 [3] • Cosmological distances: Proper distance – Angular diameter distance - Luminosity distance – Horizon distance [3] • Nucleosynthesis: Thermal history of the early Universe - Equilibrium process - Neutron free-out - Deuterium bottleneck – Formation of light elements [4.5] • Inflation: Problems with Big Bang Theory – Horizon Problem – Flatness Problem – Accelerated expansion in early Universe – Solving Horizon and Flatness problem [4.5] • Cosmic Microwave Background: 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 [7.5] • Precession measurement of CMB: Satellite experiment – Ground–based measurements – Balloon-bourne measurement [3] • Numerical cosmology: 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 [4.5]
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.

PHY 5209 / PHY 6209: Particle Physics [3 0 0 3]	
Prerequisites	Electrodynamics and Special Theory of Relativity, Nuclear and Particle Physics, Quantum Mechanics-II
Learning Outcomes	▪ Apply symmetries to classify mesons and baryons ▪ Solve problems related to relativistic kinematics ▪ Reproduce the solutions of free Klein-Gordon, Dirac and Maxwell's equations ▪ Calculate cross sections of simple particle scattering processes and decay widths ▪ Explain spontaneous symmetry breaking and analyze various interaction terms of a Lagrangian
Syllabus	• 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]

PHY 5209 / PHY 6209: Particle Physics [3 0 0 3]	
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,

PHY 5212 / PHY 6212: Theory of Open Quantum Systems [3 0 0 3]	
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]
	  ○ The density matrix representation of quantum states
	  ○ Composite quantum systems
	  ○ Quantum entropies
	  ○ Theory of quantum measurements
	• Quantum master equations [8]
	  ○ Closed and open quantum systems: von Neumann equation, open evolution
	  ○ Classical and Quantum Markov Processes
	  ○ Derivation of generic master equations from microscopic considerations
	  ○ Example: The quantum optical master equation
	  ○ The Caldeira-Leggett Model
	  ○ Nonlinear quantum master equations
	• Decoherence theory [6]
	  ○ The decoherence function
	  ○ Markovian decoherence
	  ○ Models exhibiting decoherence
	  ○ Decohrence and the quantum environment– pointer states and einselection
	• Quantum dynamical maps [5]
	  ○ Completely positive trace preserving maps
	  ○ Choi-Jamiolkovski isomorphism
	  ○ Going beyond complete positivity
	  ○ Quantum information and open quantum dynamics
	• Stochastic Dynamics in Hilbert Space [6]
	  ○ Dynamical semigroups and piecewise deterministic processes
	  ○ Stochastic representation of continuous measurements
	  ○ Example: Photodetection
	• Non-Markovian open quantum dynamics [8]
	  ○ Quantifying non-Markovianity in quantum systems
	  ○ Projection operator techniques and the Nakajima-Zwanzig equation
	  ○ Time convolution less master equation
	  ○ Example: Spontaneous decay of a two level system
	  ○ Example: The spin boson model

PHY 5212 / PHY 6212: Theory of Open Quantum Systems [3 0 0 3]	
Text & Reference Books	1. Francesco Petruccione, The Theory of Open Quantum Systems, Heinz-Peter Breuer, Oxford University Press, 2007.

PHY 5213 / PHY 6213: Quantum Field Theory I [3 0 0 3]	
Prerequisites	Quantum Mechanics-2, ED & STR
Learning Outcomes	▪ Construct Fock spaces for bosons and fermions, and illustrate their connection to many-particle quantum mechanics. ▪ Establish Lorentz algebra and determine its representations. ▪ Use canonical quantization prescription to quantize free fields. ▪ Establish relation between scattering amplitudes and Green functions of interacting QFTs. ▪ Develop perturbative QFT methods including diagramatics suitable for analyzing scattering experiments.
Syllabus	• Introduction: Need for quantum field theory, Many-particle quantum mechanics, Bosons and fermions, Many-body theory, Fock spaces. [6] • Symmetries: Lorentz and Poincare symmetries in QFT, Lorentz algebra and representations [4] • Classical field theory: Continuous Symmetries and Noether theorem, Conserved currents and charges [6] • Klein-Gordon Field: Canonical quantization, Klein-Gordan Propagator, real and complex scalar fields. [8] • Dirac Field: Relativistic covariance, Dirac equation, Dirac matrices, Quantization, Discrete symmetries C, P, T. [6] • Interacting Field theory: Interaction picture and relativistic perturbation theory, Wick's theorem, Feynman Rules, S-matrix, Diagrammatics [6] • QED: Maxwell field, Canonical quantization of the gauge field, interactions with Dirac fields [4]
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.

PHY 5214 / PHY 6214: Probes in Condensed Matter Physics [3 0 0 3]	
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.

PHY 5214 / PHY 6214: Probes in Condensed Matter Physics [3 0 0 3]	
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. [8] • Spectroscopic probes: Fourier-transform infrared spectroscopy, Mossbauer spectroscopy, positron annihilation technique. [8] • Thermal properties measurement probes: specific heat, thermal conductivity, thermal expansion, differential scanning calorimetry (DSC), thermogravimetric analysis (TGA) [8] • Transport properties measurement probes: ac and dc conductivity, Hall effect, magnetoresistance, magnetic susceptibility, dc and ac magnetization. [8] • Optical probes: Optical conductivity [6]
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.

PHY 5215 / PHY 6215: Quantum Transport [3 0 0 3]	
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. [4] • Transport regimes & quantization effects: Classical diffusive, quantum diffusive & Quantum Ballistic transport regimes. [4] • Micro and Nanoscale device fabrication, Photo-lithography, e-beam lithography [2] • Two-dimensional systems: Quantum well heterostructures, remote doping, band bending, surface states, Schottky & Ohmic contacts, Graphene and other 2D layered systems. [4] • 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 [4]

PHY 5215 / PHY 6215: Quantum Transport [3 0 0 3]	
	• Electron-electron interactions and weak localization, quantum interference effects in disordered systems. Aharanov Bohm effect in metals and semiconductors. [4] • 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 [4] • 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 [6] • 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 [4] • DC josephson effect. AC josephson effect Shapiro steps, SQUID, Superconducting quantum dots. Coulomb Blockade and charge quantization effects in Superconducting quantum Dots [4]
Text & Reference Books	1. S Datta, Electronic transport in mesoscopic systems. 2. Nazarov & Blanter, Quantum Transport. 3. Ferry, Goodnick & Bird, Transport in nanostructures.

PHY 5216 / PHY 6216: Advanced Mathematical Methods in Physics [3 0 0 3]	
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: Topological Spaces, Metric Spaces, Basis, Closure, Connected and Compact Spaces, Continuous functions, Homeomorphisms and Topological Invariants, Separability [4.5] • Homotopy: Paths and Loops, Homotopy, Fundamental Group, Higher Homotopy Groups, Applications in Physics [4.5] • Differential Geometry: 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 [9]: • Introduction to Group Theory: Definition of a group, Subgroups, Cosets, Normal subgroup, Factor group, Abelian groups, Commutator subgroup, Solvable, Nilpotent, semisimple and simple groups [4.5] • Group Representations: Definition of representation, Invariant subspaces, Reducibility of representations, Equivalence of Representations, Unitary, orthogonal, contragradient, adjoint and complex conjugate representations. [3]

PHY 5216 / PHY 6216: Advanced Mathematical Methods in Physics [3 0 0 3]	
	• Lie groups and Lie algebras: 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. [4.5] • More Lie algebras: Complexification and classification of Lie algebras, Cartan Weyl Basis and roots of a Lie algebra, Positive roots, simple roots and Dynkin diagrams. [6]
Text & Reference Books	1. Mukhi and Mukund, Lectures on Advanced Mathematical Methods for Physicists. 2. M Nakahara, Geometry, Topology and Physics.

PHY 5232 / PHY 6232: Atmospheric Dynamics and Cloud Physics [3 0 0 3]	
Prerequisites	None
Learning Outcomes	▪ Derive thermodynamics of dry and moist air. ▪ Describe the process of cloud formation and classify them based on their height and shape. ▪ Derive the equations governing the atmospheric motion (momentum equation, continuity equation, thermodynamic energy equation). ▪ Derive dispersion relation for different atmospheric waves. ▪ Apply atmospheric wave dynamics to analyze atmospheric oscillations and circulations and their impact on the redistribution of chemical species
Syllabus	• The course develops fundamental knowledge and understanding in two topics, atmospheric dynamics and cloud physics. Part I: • Introduction and overview: basics and properties of the Earth's Atmosphere [2] • Atmospheric thermodynamics: Potential temperature, vapor pressure, Clauius-Clapeyron equation, saturation vapor pressure, thermodynamics of dry and moist air [4] • Fundamental concepts of cloud physics: clouds, cloud formation, Classification of clouds, Liquid water content, other parameters of macroscale cloud, cloud drop size distribution [3] • Formation of cloud droplets: Curvature effect, Solute effect, combining the curvature and solute effect, atmospheric aerosols, cloud condensation nuclei [3] • Droplet growth: Diffusion, collisions and coalescences, growth of ice crystals [3] Part II: • Introduction to atmospheric dynamics: Zonal distribution of winds and temperature and their seasonal variation [2] • Forces acting in the atmosphere: Pressure gradient force, effective gravity, Viscous forces, apparent forces, momentum equation, continuity equation, thermodynamic energy equation, scale analysis [5] • Balanced Motion: Gradient wind, thermal wind, Geostrophic balance [3] • Vorticity: circulation and vorticity [3] • Atmospheric waves: Perturbation theory,Sound waves, gravity waves Kelvin waves and Rossby waves, Momentum and energy transports by waves,Atmospheric solar tides [5] • Atmospheric Circulation: General circulation of atmosphere, Hadley circulation, Brewer-Dobson Circulation, Pole to pole circulation, Monsoon circulation, Tibetan

PHY 5232 / PHY 6232: Atmospheric Dynamics and Cloud Physics [3 0 0 3]	
	anticyclone,Walker Circulation, Polar vortex, Polar stratospheric Cloud and Ozone hole [4] • Atmospheric oscillation: Quasi Bi-ennial oscillation, El Nino Southern Oscillation, Semi Annual Oscillation, Annual Oscillation, Indian Ocean Di-pole [3]
Text & Reference Books	1. Vallis, G. K., Atmospheric and Oceanic Fluid Dynamics, Cambridge University Press (2006) 2. Holton, J. R., An Introduction to Dynamic Meteorology, 4th Edition, Academic Press (2004) 3. Marshall, J. and R. A. Plumb, Atmosphere, Ocean, and Climate Dynamics, An Introductory Text, Academic Press (2008) 4. Andrews,D.G., Holton, J.R., and Leovy, C.B., Middle Atmosphere Dynamics, Academic Press (1987) 5. Wallace, J.M., and Hobbs, P.V.,Atmospheric Sciences: An Introductory Survey Academic Press (2006) 6. G.C.Asnani, Tropical Meteorology,Vol 1, G.C. Asnani(2016) 7. Kerry H. Cook,Climate Dynamics, Princeton University Press (2013) 8. J. Hoghton, Physics of the Atmosphere,Cambridge University Press (2002) 9. Robert A. Houze, Cloud Dynamics ,Academic Press (1993)

PHY 5233 / PHY 6233: Plasmonics and Nanophotonics [3 0 0 3]	
Prerequisites	Basic electromagnetism or optics, and condensed matter physics or semiconductor physics.
Learning Outcomes	▪ Combine previously acquired knowledge and skills in electromagnetism, optics and material properties to comprehend light-matter interactions. ▪ Solve practical problems in nano-photonics and manipulation of light at the nanoscale ▪ Construct models for theoretical and experimental investigation on nanoscale and mesoscale material systems. ▪ Understand nanoscale and near-field optics to design optical near-field probes, optical antennas, and semiconductor quantum structures. ▪ Design photonic crystals, metamaterials with specific attributes and their applications in nano-lasers, single photon sources, nano-structured solar cells and sensors.
Syllabus	• The course develops fundamental knowledge and understanding in two topics surface plasmons and nanophotonics, their material aspects and discusses applications in various fields. Part I • Optics and Electromagnetics of Metals and Dielectrics [4] • Localized Surface Plasmons [2] • Surface Plasmon Polaritons at Surfaces and Interfaces [2] • Excitation of Plasmons, Manipulating Light, Imaging with plasmonic nanostructures [4] • Applications of Plasmonics (spectroscopy, sensing, energy and data storage and biomedical) [3] Part II • Near-field optics and Nanophotonics [4] • Materials for photonics (silicon/diamond/graphene/metal oxides and nitrides) [3]

PHY 5233 / PHY 6233: Plasmonics and Nanophotonics [3 0 0 3]	
	• Metamaterials and applications: epsilon near zero materials, negative refractive index, photonic crystals [3] • Enabling Nanophotonics with Plasmonics and Metamaterials [3] • Quantum photonics: Challenges and Perspectives [2] Part III • Recent Topics in plasmonics and nanophotonics [10] • Example topics (not exhaustive): Random Lasers, Photonic Topological Insulators, ENZ and MNZ Metamaterials, Parity-Time Symmetry in Optics and Photonics, Phase-Change Materials for Photonics, Optical Nano-tweezers, Orbital Angular Momentum of Light and Its Control, Nanoscale thermal coupling, Emissivity control and Metamaterials, Spintronics with Nanophotonics
Text & Reference Books	1. D. J. Griffiths, Introduction to Electrodynamics (4th Ed), Pearson (2015) 2. Born and Wolf, Principles of Optics (7th Ed), Cambridge University Press (1999) 3. W. Cai and V. Shalaev, Optical Metamaterials: Fundamentals and Applications, Springer (2009) 4. S. Maier, Plasmonics: Fundamentals and Applications, Springer (2007) 5. Lukas Novotny and Bert Hecht, Principles of Nano-Optics, Cambridge University Press (2006) Reference books: 1. J. D. Jackson, Classical Electromagnetism 2. R. Marques, F. Martin and M. Sorolla, Metamaterials with negative parameters 3. M. Sadiku, Principles of Electromagnetics 4. A. Taflove and S. C. Hagness, Computational Electrodynamics

Open Electives

PHY 4111 / PHY 6111: Material & device characterization techniques [2 0 3 3]	
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 [3] • X-ray, Neutron diffraction [3] • TEM, SEM, XPS, EDAX/EDS [4] • Raman, PL, Ellipsometry [3] • AFM & STM [3] • Electrical properties & characterization techniques: I-V measurement: 2-probe and 4-probe, low noise electronics; C-V measurements [4] • 3Terminal devices and characterization, FET, BJ [4] • Hall effect, Mobility and Carrier concentration [4] • Microwave measurements, ESR, NMR [4] • Defects: DLTS, Channelling; Photoconductivity-Carrier-lifetime, Kelvin-probe [4] • Magnetic Properties & Characterization: Magneto-transport, MFM, VSM, SQUID [4]
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 .

PHY 4211 / PHY 6211: Materials Growth and Processing Techniques [2 0 3 3]	
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.
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 [8] • Self-assembly, Langmuir-Blodgett (LB) films, clusters, colloids [6]

PHY 4211 / PHY 6211: Materials Growth and Processing Techniques [2 0 3 3]	
	• Templated synthesis, anodic oxidation of alumina films, porous silicon, and pulsed electrochemical deposition [8] • Basic concepts and experimental methods of crystal growth: nucleation phenomena, mechanisms of growth, dislocations and crystal growth phase diagrams and material preparation [6] • Growth from liquid-solid equilibria, vapour- solid equilibria, mono-component and multi-component techniques [6] • 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 [6]
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.

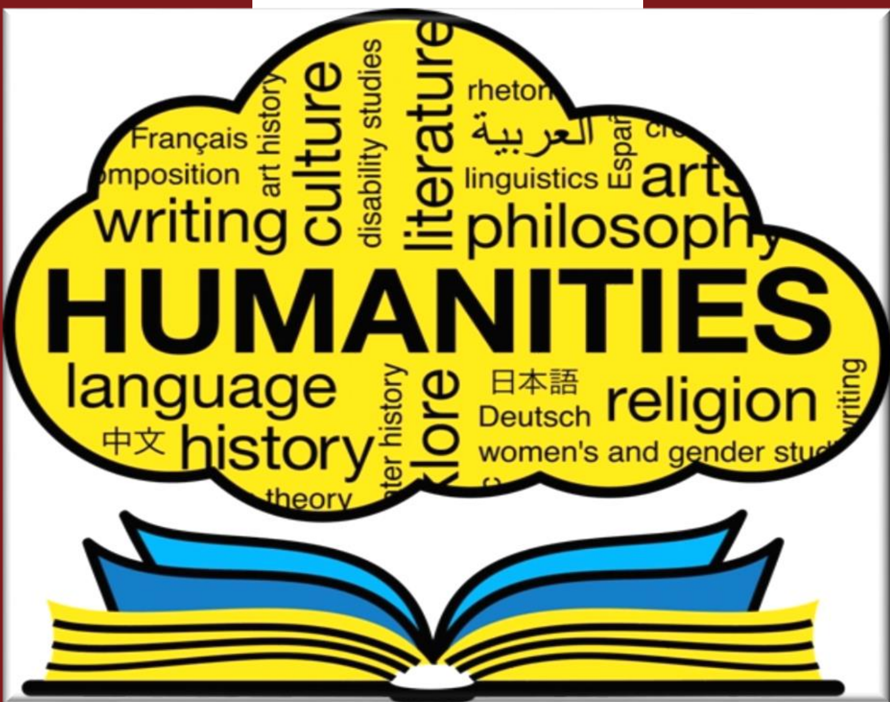
HUMANITIES

CURRICULUM FOR

BS-MS (SEM: 4 - 10)

MSc & IPHD (1 - 4)

CORE AND ELECTIVE COURSES



Core Courses

HUM 3XX / 4XX / 5XX: Planning and Economic Development [3 0 0 3]	
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 (2) • Many facets of Development in Economics and Human Development (4) • Strategies of Economic Development and Structural Change: Population Growth, Resource Constraint and Economic Development (3) • Growth and Distribution: Poverty and inequality (6) • Planning for Economic development: Changing contours of state and market in India (2) • Strategies, planning techniques and Models in Indian plans (4) • Discussion on Industry, Public Sector and Technology (2) • International Trade and Development (external sector) (3) • Economic Reforms (3) • Political Economy of Development (3) • Grassroots and the Globe: Poor and the Informal Economy (4)
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.

HUM 3XX / 4XX / 5XX: Introduction to Science, Technology and Society [3 0 0 3]	
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) ○ 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)

HUM 3XX / 4XX / 5XX: Introduction to Science, Technology and Society [3 0 0 3]	
	○ 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) ○ Logical Positivism (The Vienna Circle); ○ Falsifiability (Karl Popper); ○ Functionalism (Robert Merton); ○ Kuhnian revolution; Strong programme; ○ Actor Network Theory. • Module 2b: Technology and Society Relation (6) ○ 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? ○ Use and governance of emerging technologies; Evaluating risk: role of the State, civil society and industry • Module 2c: Science, Technology and Economy (6) ○ 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 (6 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.
Text & Reference Books	1. Sergio Sismondo, An Introduction to Science and Technology Studies, 2nd ed., Wiley-Blackwell, Chichester, 2010. 2. Arun Bala, The Dialogue of Civilizations in the Birth of Modern Science. New York: Palgrave MacMillan, 2006. 3. Alvares, C. A. Science, Development and Violence: The Twilight of Modernity, Oxford: Oxford University Press, 1992. 4. Bruno Latour, Science in Action: How to Follow Scientists and Engineers Through Society? Cambridge, M A: Harvard University Press, 1987. 5. David Hardiman and Projit Bihari Mukharji (eds.), Medical Marginality in South Asia: Situating Subaltern Therapeutics, London and New York: Routledge, 2012. 6. Dharampal, Indian Science and Technology in the Eighteenth Century: Some contemporary European accounts, Goa, Other India Press, 1971.

HUM 3XX / 4XX / 5XX: An Introduction to Game Theory [3 0 0 3]	
Prerequisites	This is an introductory course designed to introduce students to game theory and strategic thinking. Ideas such as dominance, nash equilibrium, backward induction, commitment, credibility among others will be introduced. Students are expected to have basic knowledge of mathematics (plus two level).
Learning Outcomes	▪ introduce the basic concepts of game theory, ▪ provide a theoretical understanding of different game theory models, equilibrium solution concepts and approaches ▪ discuss some applications.
Syllabus	• Module 1: Background concepts (2) The objective of this module is to revise the concepts of Microeconomics as a primer to the course and to familiarize students with the various terminologies and concepts that will help in game theory. • Module 2: Game theory primer (4) The objective of this module is to use concepts of strategic interaction, the difference between decision theory and game theory, terminologies associated with understanding game theories and the critical assumptions related to game theory models. The module will also present objectives of game theory, a brief description of various types of games. • Module 3: Simultaneous games (6) This module will examine simultaneous games- using discrete and continuous choices. Students will be introduced to different models of simultaneous games, different equilibrium concepts and applications in real life. • Module 4: Sequential games (6) This module will introduce students to the concept, models and approaches to sequential models. Real life examples and applications will be discussed in the class. • Module 5: Combining simultaneous and sequential games (4) This module will be an advanced level of training where models of simultaneous and sequential games will be combined. The students will be introduced to different approaches of solving games of this nature. • Module 6: Mixed games (4) This module will introduce students to uncertainty and we will incorporate uncertainty in our models- leading to the concept of mixed game theory models • Module 7: Repeated games (6) This module will examine how real life dilemmas can be solved using repeated games framework. Both finite and infinite time period models will be considered. Students will be introduced to different strategies such as tit-for-tat strategy and trigger strategy • Module 8: Group presentations (4)
Text & Reference Books	1. Selected portions of Games of Strategy by Avinash Dixit, Susan Skeath and David H Reiley, Jr 2. The Economy: Economics for a Changing World, Oxford. This textbook, produced by a large team of economists, is freely available online. **OPTIONAL TEXT BOOKS** 1. The theory of industrial organization- Oz Shy 2. Game Theory for applied economics- R.S. Gibbons

HUM 3XX / 4XX / 5XX: International Economics [3 0 0 3]	
Prerequisites	Basic Economics knowledge (foundation course)
Learning Outcomes	▪ Aims to provide some advanced understanding on the conceptual and theoretical back ground of the macroeconomics and international integration of the economies and hence the creation of the globalised economy. ▪ It attempts is to teach students how economic theory can be employed to analyse the benefits from globalization, and to diagnose its problems. ▪ It familiarizes the political economic discussions on the role of international organizations in the approaches to development
Syllabus	• Theme 1: Conceptualising the Macro economy (3) o Note on our approach o conceptualising the past and present of the economy o Economy as an embedded system and web of flows o Growth in the open economy • Theme 2: The classical Argument – International Trade (5) o International Vs. Domestic Trade o Reasons for international Trade o Principles of comparative advantage o Resources and Trade: The Heckscher-Ohlin Model o The economics of protectionism o Market failure and public policy • Theme 3: The Instruments and political economy of Trade policy (3) o Tariffs o Export subsidies o Import quotas o Free trade arguments o Distribution and trade policy • Theme 5: Multi-national Corporations and Direct Foreign Investment (5) o Multinationals and competition efforts o FDI in India o Motives for FDI o Welfare effects of International Capital flows o MNCs and problems in host country • Theme 6: Balance of Payment, Capital mobility and policy coordination (5) o Balance of payment accounting o The exchange rate and balance of payments o Fixed and floating exchange rates o Dominant International currencies o International monetary system and recent financial crises • Theme 7: The flaws: Capitalist revolution (4) o Income inequality o Economy and environment o The permanent technological revolution o Redefined capitalism: Private property, markets and firms o Varieties of Capitalism: Institutions, government and the economy • Theme 8: Developing Countries in the New International Economic Order (5) o The WTO and negotiations o Trade and Labour rights

HUM 3XX / 4XX / 5XX: International Economics [3 0 0 3]	
	○ Commodity Chain and Global capitalism ○ Globalization, low skilled labour and Migration ○ TRIPS and TRIMS • Theme 9: Globalization and its discontents (6) ○ Alternative thinking in International integration ○ Case: Economic barriers to access to medicine ○ India's pharmaceutical Innovations ○ Patent and access to medicine and essential vaccines
Text & Reference Books	1. CORE Econ (2022) The Economy: A south Asian Perspective, Econ CORE reader. 2. Salvatore, Dominick (2021) International Economics, 13ed, An Indian Adaptation, Wiley (Chandan Sharma). 3. Paul Krugman, Maurice Obstfeld, and Marc Malitz (2022) International Economics: Theory and Policy, Pearson. 4. Sikdar, Soumyen (2002), Contemporary issues in Globalization: An introduction to Theory and Policy in India, Oxford University Press, India. 5. Stiglitz, Joseph, E. (2006) Making Globalization work, W.W. Norton and Company, New York, USA.

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: 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: 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: 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: 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.

Preparatory Courses

HUM 101: Primer for Communication Skills [1 0 0 1]	
Prerequisites	Nil
Learning Outcomes	▪ Better guide their own communication skills and encourage themselves towards improving communication skills. ▪ Gain writing skills and understanding of the language in terms of structure of sentences, grammar, and use of words. ▪ Improve comprehension skills ▪ Enhance confidence and sustain conversations with the peer group.
Syllabus	• Introduction to language; why should we speak and how can we speak better in an error-free manner using correct grammar (2 lectures) • To speak, listening is imperative. What are listening skills and how can it be used to aid communication and understanding? (2 lectures) • Fundamentals of reading and how should reading be so as to make communication sharper and focused. (2 lectures) • How to structure a sentence, follow basic rules, draft a neat document, and make it as error-free as possible. (2 lectures) • Practical sessions (2 lectures, suggestion to make available 2 more lectures)
Assignment	Students could be encouraged to launch a community radio or a Youtube channel where they will post interesting topics they find on campus with regard to campus life, research work, poetry sessions, interviews, etc., that can help them put to use their speaking, writing, reading, and listening skills.
Text & Reference Books	1. NCERT books on language skills: Interactions, Activity books on Listening and Speaking 2. Grammar and Language Skills–Basics NCERT 3. The Communication Book, by Mikael Krogerus and Roman Tschappeler 4. Quick and easy way to effective speaking, Dale Carnegie 5. Essential Language Skills, Macmillian Education 6. British Council's Learn English Modules 7. Book on essays and for comprehension (to be selected as per the choice of the students)

MAT 101: Primer for Mathematics [1 0 0 1]	
Prerequisites	Nil
Learning Outcomes	▪ This course is aimed towards the students, who didn't have mathematics in their higher secondary (10+2), to prepare them for better understanding of the foundational mathematics courses at IISER TVM offered during the first year of study. Specific topics from 10+2 level mathematics will be taught in this course.
Syllabus	• Algebra [8 lectures]: Set, example of sets, finite and infinite sets, empty sets, subsets, set of reals, rationals, natural numbers, set operations and Venn diagrams. Relations and functions, domain, codomain, range, example of standard functions (modulus, exponential, logarithmic, trigonometric), injective, surjective and bijective functions, inverse of a function, composition of functions

MAT 101: Primer for Mathematics [1 0 0 1]	
	Complex numbers, algebra of complex numbers, modulus and argument of complex numbers Matrices, row, column and square matrices, diagonal matrices, equality of matrices, operations involving matrices, notion of inverse of a matrix Determinants, expansion rules for determinants • Geometry [2 lectures]: Basic coordinate geometry, plotting of functions, equation of lines in different forms Distance formula, equation of a circle • Calculus [10 lectures]: Sequence and series, formula for arithmetic and geometric progression Limits, calculating limits for different functions, L'Hospital rule Notion of continuity, examples Derivatives, rules of derivatives, calculating derivatives of different functions, composition rule, derivative as tangent to a curve Integrals, calculating integrals of standard functions, rules of integrals, definite integrals and area under a curve
Text & Reference Books	NCERT Mathematics - XI and XII

Academic Office

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