INDIAN INSTITUTE OF SCIENCE EDUCATION AND RESEARCH THIRUVANANTHAPURAM

An autonomous institution under the
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IISER
THIRUVANANTHAPURAM

CURRICULUM AND SYLLABUS FOR THE INTEGRATED Ph. D. PROGRAMME

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Contents

Structure

School of Biology Curriculum

SCHOOL OF BIOLOGY CURRICULUM

Semester –I						Semester -II					
Course	**Course Name**	**L**	**T**	**P**	**C**	**Course**	**Course Name**	**L**	**T**	**P**	**C**
BIO 311	Microbiology	3	0	0	3	BIO 321	Structural Biology	3	0	0	3
BIO 312	Advanced Genetics and Genomics	3	0	0	3	BIO 322	Immunology	3	0	0	3
BIO 313	Physiology	3	0	0	3	BIO 323	Cell Biology	3	0	0	3
BIO 314	Biochemistry	3	0	0	3	BIO 324	Molecular Biology	3	0	0	3
BIO 315	Advanced Biology Lab-I	0	0	9	3	BIO 325	Advanced Biology Lab-II	0	0	9	3
Total		**12**	**0**	**9**	**15**	**Total**		**12**	**0**	**9**	**15**
Cumulative Credits at the End of First Year: 30											
Semester –III						**Semester -IV**					
Course	**Course Name**	**L**	**T**	**P**	**C**	**Course**	**Course Name**	**L**	**T**	**P**	**C**
BIO 411	Developmental Biology	3	0	0	3	BIO 4201	Elective -IV	3	0	0	3
BIO 4101	Elective -I	3	0	0	3	BIO 4202	Elective -V	3	0	0	3
BIO 4102	Elective -II	3	0	0	3	BIO 4203	Elective -VI	3	0	0	3
BIO 4103	Elective -III	3	0	0	3	BIO 424	Research Work	6	0	0	6
BIO 412	Advanced Biology Lab-III	0	0	9	3						
Total		**12**	**0**	**9**	**15**	**Total**		**15**	**0**	**0**	**15**
Cumulative Credits at the End of Second Year: 60											

School of Chemistry Curriculum

SCHOOL OF CHEMISTRY CURRICULUM

Semester - I						Semester - II					
Course	**Course Name**	**L**	**T**	**P**	**C**	**Course**	**Course Name**	**L**	**T**	**P**	**C**
CHY 311	Coordination Chemistry	3	0	0	3	CHY 321	Organometallics and Bioinorganic Chemistry	3	0	0	3
CHY 312	Stereochemistry-Principles & Applications	3	0	0	3	CHY 322	Methods in Structure Determination	3	0	0	3
CHY 313	Quantum Chemistry	3	0	0	3	CHY 323	Pericyclic Reactions and Reactive intermediates	3	0	0	3
CHY 314	Group Theory in Chemistry	3	0	0	3	CHY 324	Theoretical Spectroscopy	3	0	0	3
CHY 315	Chemical Kinetics	3	0	0	3	CHY 325	Inorganic Chemistry Lab	0	0	9	3
CHY 316	Organic Chemistry Lab	0	0	9	3						
Total		**15**	**0**	**9**	**18**	**Total**		**15**	**0**	**9**	**15**
Cumulative Credits at the End of Third Year: 33											
Semester - III						**Semester - IV**					
Course	**Course Name**	**L**	**T**	**P**	**C**	**Course**	**Course Name**	**L**	**T**	**P**	**C**
CHY 411	Chemistry of Solids & Materials	3	0	0	3	CHY 421	Chemistry of s,p and f-block elements	3	0	0	3
CHY 412	Chemistry of C-C & C-X Bonds	3	0	0	3	CHY 422	Physical Organic Chemistry	3	0	0	3
CHY 413	Instrumental Methods	4	0	0	4	CHY 423	Advanced Organic Chemistry	3	0	0	3
CHY 414	Physical Chemistry Lab	0	0	9	3	CHY 424	Electrochemistry and Statistical Thermodynamics	3	0	0	3
CHY 4101	Elective-I	2	0	0	2	CHY 425	Research Work	6	0	0	6
Total		**12**	**0**	**9**	**15**	**Total**		**18**	**0**	**0**	**18**
Cumulative Credits at the End of Fourth Year: 66											

School of Mathematics Curriculum

SCHOOL OF MATHEMATICS CURRICULUM

Semester –I						Semester -II					
Course	**Course Name**	**L**	**T**	**P**	**C**	**Course**	**Course Name**	**L**	**T**	**P**	**C**
MAT 311	Real Analysis	3	0	0	3	MAT 321	Complex Analysis	3	0	0	3
MAT 312	Abstract Algebra	3	0	0	3	MAT 322	Measure Theory and Integration	3	0	0	3
MAT 313	Linear Algebra	3	0	0	3	MAT 323	Galois Theory & Commutative Algebra	3	0	0	3
MAT 314	Numerical Analysis	3	0	0	3	MAT 324	Theory of Ordinary Differential Equations	3	0	0	3
MAT 315	Number Theory and Cryptography	3	0	0	3	MAT 325	General Topology	3	0	0	3
Total		**15**	**0**	**0**	**15**	**Total**		**15**	**0**	**0**	**15**
Cumulative Credits at the End of Third Year: 30											
Semester –III						**Semester -IV**					
Course	**Course Name**	**L**	**T**	**P**	**C**	**Course**	**Course Name**	**L**	**T**	**P**	**C**
MAT 411	Functional Analysis	3	0	0	3	MAT 421	Probability Theory and Stochastic Processes	3	0	0	3
MAT 412	Analysis on Manifolds	3	0	0	3	MAT 42..	Elective-II	3	0	0	3
MAT 413	Partial Differential Equations	3	0	0	3	MAT 42..	Elective-III	3	0	0	3
MAT 414	Rings, Modules and Algebras	3	0	0	3	MAT 62..	Elective-IV	3	0	0	3
MAT 41..	Elective I	3	0	0	3	MAT 62..	Elective-V	3	0	0	3
Total		**15**	**0**	**0**	**15**	**Total**		**15**	**0**	**0**	**15**
Cumulative Credits at the End of Fourth Year: 60											

Remark: IPhD students must choose the 600 level electives in Semester IV in such a way that their choice of comprehensive streams (at least two of the four) is complete by the end of their two-year of study Students are also required to take one non-credit compulsory course on Research Methodology during their course of study. For more details, contact the Head, School of Mathematics.

School of Physics Curriculum

Semester – I							Semester – II					
Course	**Course Name**	**L**	**T**	**P**	**C**		**Course**	**Course Name**	**L**	**T**	**P**	**C**
PHY 311	Mathematical Methods	3	0	0	3		PHY 321	Statistical Mechanics	3	0	0	3
PHY 312	Classical Mechanics	3	0	0	3		PHY 322	Condensed Matter-I	3	0	0	3
PHY 313	Electronics-I	3	0	0	3		PHY 323	Electronics-II	3	0	0	3
PHY 314	Quantum Mechanics-I	3	0	0	3		PHY 324	Electrodynamics & Special Theory of Relativity	3	0	0	3
PHY 315	Advanced Physics Experiments Lab-I	0	0	9	3		PHY 325	Advanced Physics Experiments Lab-II	0	0	9	3
PHY 316	Seminar	0	0	0	1		PHY 326	Seminar	0	0	0	1
Total		**12**	**0**	**9**	**16**		**Total**		**12**	**0**	**9**	**16**
Cumulative credits at the end of first year: 32												
Semester – III							**Semester – IV**					
Course	**Course Name**	**L**	**T**	**P**	**C**		**Course**	**Course Name**	**L**	**T**	**P**	**C**
PHY 411	Experimental Methods	3	0	0	3		PHY 42XX	Elective-II	3	0	0	3
PHY 412	Condensed Matter-II	3	0	0	3		PHY 42XX	Elective-III	3	0	0	3
PHY 413	Quantum Mechanics-II	3	0	0	3		PHY 62XX	Elective-IV	3	0	0	3
PHY 414	Advanced Physics Experiments Lab-III	0	0	9	3		PHY 62XX	Elective-V	3	0	0	3
PHY 41XX	Elective-I	3	0	0	3		PHY 424	Research Work	6	0	0	6
PHY 416	Seminar	0	0	0	1							
Total		**12**	**0**	**9**	**16**		**Total**		**18**	**0**	**0**	**18**
Cumulative credits at the end of second year: 66												

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

Biology Syllabus

List of courses

1. **Core courses**
    a. **Theory courses**
        i. BIO 311 Microbiology
        ii. BIO 312 Advanced Genetics and Genomics
        iii. BIO 313 Physiology
        iv. BIO 314 Biochemistry
        v. BIO 321 Structural Biology
        vi. BIO 322 Immunology
        vii. BIO 323 Cell Biology
        viii. BIO 324 Molecular Biology
        ix. BIO 411 Developmental Biology
    b. **Lab Courses**
        i. BIO 315 Advanced Biology Lab-I
        ii. BIO 325 Advanced Biology Lab-II
        iii. BIO 412 Advanced Biology Lab-III
2. **Elective courses**
    a. Biological Data analysis
    b. Neurobiology
    c. Plant Molecular Biology
    d. Evolutionary Ecology
    e. Stem Cells and Regenerative medicine (Prerequisite: Developmental Biology)
    f. Chronobiology (Prerequisite: Neurobiology)
    g. Advanced Developmental Biology (Prerequisite: Developmental Biology)
    h. Bacterial Genetics (Prerequisite: Microbiology)
    i. Animal Behaviour (Prerequisite: Evolutionary Ecology)
    j. Research Methodology
    k. Scientific Writing (1 credit)
    l. Biosafety and Regulation (1 credit)

m. Bioinformatics
n. Host-pathogen Interactions
o. Biodiversity and Field Biology
p. Synthetic Biology
q. Cancer Biology
r. Genome Stability
s. Ecological Interactions

Theory Courses

Syllabi of Core Courses:

BIO 311 Microbiology [3003]

History of Microbiology, microbial diversity, microbial nutrition and growth kinetics.

Viruses and prions: Introduction, general characteristics, viruses of bacteria and archea.

Microbial physiology: structure of microbes, autotrophic and heterotrophic metabolisms, growth and its control factors.

Microbial development: division, sporulation, organelle (flagella, pili, holdfast, chemosensory apparatus etc.) development.

Overview of microbial development with examples from model systems such as Bacillus, cyanobacteria, yeast, filamentous fungi and protozoa.

Microbial communication and chemosensory response.

Microbial pathogenesis: types, mode of infection with examples of human and plant pathogens. Antimicrobial agents and their mode of action.

Applied microbiology: biodegradation, bioremediation, fermentation, use of bacteria in recombinant protein production.

BIO 312 Advanced Genetics and Genomics [3003]

Model genomes.

Scale of genome variation: mutations, SNPs, indels, structural variation, ploidy changes.

Methods to study genomes: PCR, microarrays, next generation sequencing technologies, comparative genomic hybridization, pulse ?eld gel analysis, synthetic genetic array analysis.

DNA Repair and Recombination.

Genome mapping: genetic markers, genetic and physical maps, recombination rates, linkage analysis, linkage disequilibrium, haplotype analysis, meiotic hotspots.

Co-relating genotype with phenotype: forward and reverse genetics, candidate gene approach, insertional mutagenesis, screening genomic libraries, complex trait analysis.

Genomics and medicine: genome sequencing, personalized medicine.

Genome evolution: stability of haploid versus diploid genomes, plasticity of genomes, inter-species variation, genetic incompatibilities, gene duplication.

BIO 313 Physiology [3003]

Animal physiology: Mechanisms and origin of animal physiology.

Nervous system and Sensory processing: central and peripheral nervous system; sensory systems-vision, hearing, taste, smell and touch.

Endocrine system and Reproduction: endocrine glands and functions; neuroendocrine systems; reproductive physiology.

Biological Clocks: internal biological clocks; circadian rhythms.

Feeding and Digestive system: nutrition, feeding and digestion; energy metabolism.

Thermoregulation: temperature regulation in warm and cold-blooded animals.

Muscular system and movement: control of movement; muscle types and functions.

Respiratory system: physiology of breathing; transport of oxygen and carbon dioxide, oxygen and evolution of animals.

Circulatory system: circulatory systems in invertebrates and vertebrates.

Excretory system: managing water, salt and body ?uids in animals.

Environment and physiology: in?uence of environment on animals, adap-

tations to extreme environments.

Animal navigation and migration: why and how do animals migrate?

Physiological changes during migration, Physiological diseases.

BIO 314 Biochemistry [3003]

Carbohydrate metabolism: Glycolysis, gluconeogenesis, glycogen synthesis and breakdown, enzymatic mechanisms, reciprocal regulations and hormonal regulations pentose phosphate pathway, Krebs or TCA cycle (PDH complex, cofactors, TPP), amphibolic nature of citric acid cycle, regulation of CAC, oxidative phosphorylation, respiration, proton transport, electron carriers glutathione and NADPH.

Fatty acid metabolism: fatty acid oxidation, beta-oxidation pathway, fatty acid synthesis, cholesterol synthesis.

Amino acid metabolism: Nitrate and ammonium assimilation; amino acid biosynthesis, degradation, urea cycle, heme synthesis.

Nucleic acid metabolism: purine and pyrimidine biosynthesis.

Bioenergetics: Oxidation reduction reactions.

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 and their roles.

Secondary metabolism.

Analytical Methods in Biochemistry

BIO 321 Structural Biology [3003]

Principles of proteins and nucleic acid structures, conformation and analysis. Structural Bioinformatics. Molecular phylogenetic analysis. Tools for analysing protein structures to understand the molecular basis of their functions. Structure Based Drug Design. X-ray crystallography, electron microscopy and NMR in structural biology. Graphics and structural validation. Structural databases. Other biophysical and spectroscopic techniques to understand conformations of biomolecules.

TEXTBOOKS/REFERENCES

1. Schulz GE and Schirmer RH, *Principles of protein structure*, Springer-Verlag.
2. Branden C and Tooze J, *Introduction to protein structure*, Garland Science.
3. Stout GH and Jensen LH, *X-ray structure determination, John;Wiley and Sons Inc.*, New York, 1989.
4. Jan Drenth, *Principles of protein crystallography*, Springer Science & Business Media.
5. Liljas A, Liljas L, Piskur J, st Lindblom G, Nissen P and Kjeldgaard M. (2009). *Textbook of Structural Biology*, 1st edition, World Scientific Publishing.
6. Joachim Frank, *Three-Dimensional Electron Microscopy of Macromolecular Assemblies*, Academic Press.
7. A. K. Downing, *Protein NMR techniques, Methods in Molecular Biology*, Volume 278, 2004.

BIO 322 Immunology [3003]

Introduction, Organization of the immune system (lymphoid tissues and organs).

Immune cell development (hematopoiesis, T and B cell development).

Innate and adaptive immunity (including cellular and humoral responses).

Antigens and Antibodies (antibody classes, Ag/Ab structure and function).

Immune signaling (T cell receptor, TLRs, inflammatory and cytokine responses).

The MHC and Ag presentation and T cell development.

Immunity mechanisms in disease (allergies, autoimmunity, immuno-deficiency).

Immunotherapy (clinical use of monoclonal antibodies).

Tumour Immunology.

BIO 323 Cell Biology [3003]

Methods used in cell biology: microscopy, cell sorting, fractionation of cellular components, radioisotopes and antibodies as tools to study cellular functions.

Cell membrane: organization and composition of the cell membrane, structural micro-geneity and micro-domain in membrane, membrane transport-endocytosis and exocytosis Vesicular transport system and intracellular trafficking, protein targeting.

Organelle biogenesis.

Components of the cytoskeleton and their regulations: organization and function of actin, intermediary ?laments, microtubules and motor proteins, integrins, cadherins.

Cell-cell signaling: overview of extracellular signaling, cell surface receptors, cell signaling during growth and differentiation.

Cell cycle and its control: mechanisms of growth and division of eukaryotic cells, cell cycle checkpoints.

Cell death: Apoptosis and autophagy pathways.

BIO 324 Molecular Biology [3003]

Molecular aspects of RNA processing, transcription and translation.

Epigenetics: DNA methylation in prokaryotes and eukaryotes, epigenetic gene regulation by DNA methylation in plants and mammals.

Protein-nucleic acid interactions - nucleic acid recognition by proteins binding motifs - techniques to study protein-nucleic acid interactions.

Non-coding RNA: Biogenesis and its function.

Recombinant DNA technology and molecular cloning.

BIO 411 Developmental Biology [3003]

About the course: In this course students will be introduced to the main principles of development. There will be a strong emphasis on classic developmental model organisms to illustrate fundamental processes in development. Early events in development, developmental processes behind generation of body plan and formation of tissues and organs will be the main focus of the course. Regulation of gene expression, cell signaling pathways and cytoskeletal rearrangements in development will be discussed. Also, sexual maturation, regeneration in adult organisms and developmental diseases will be covered. Finally, evolution of development

will be covered to help the students to understand the significance of evolutionary pressures that has converged on development.

Course Content:

1. **Basic Concepts and history of developmental biology - Model systems: developmental model organisms:** Sea urchin, Drosophila, Xenopus, Chick
2. **Early embryonic development:** Cleavage, gastrulation and development of germinal layers; Maternal inheritance; Maternal to zygotic transition of gene expression; Early control of cell cycle
3. **Morphogenesis and development of body plan, Cellular differentiation and Organogenesis:** neurogenesis and limb development; 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 sex determination, Regeneration and tissue repair
5. **Evolution and development, Defects in development and diseases:** Neural tube defects, limb formation defects, growth defects

The lectures won't be based on textbooks alone, but basic information needed to cover this course can be found in:

1. Principles of Development: Scott F Gilbert
2. Developmental Biology: Lewis Wolpert
3. Other references would be provided during the lectures

Syllabi of Selected Elective Courses:

Cancer Biology[3003]

Prerequisite: Cell Biology (BIO 323) and Molecular Biology (BIO 324)

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.

1. Types of cancers (both solid tumors and leukemias) and hall marks of cancers

2. The common cellular and molecular mechanisms that are deregulated in cancerous cells, and how does their deregulation contribute to the development of cancer?
3. Oncogenes and their role in tumor development
4. Tumor suppressor genes and their role in neoplasia
5. Gene translocations and types of gene mutations that contribute to tumor formation
6. Chronic inflammation and infectious agents and their role in cancer development
7. Cancer detection/screening and therapy

References:

Weinberg, Robert A. The Biology of Cancer, Second Edition. New York: Garland Science, 2013.

Reviews on specific topics related to cancer

Biological Data Analysis [3003]

1. Concept of data, structure, security, storage, retrieval
2. Biological data and their sources
3. Methods for data exploration
4. Concept of data mining
5. Analysis of nucleic acid sequences- composition and asymmetry, repeats (direct, inverted and interspersed), similarity searches, both global and local algorithms, details of blast algorithms
6. Analysis of protein sequences, similarity searches including remote homologue searches
7. Motif finding algorithms
8. RNA structure analysis
9. Next generation sequencing and principles of NGS data analysis
10. Using R for analysis of biological data

Neurobiology [3003]

Historical overview from Empedocles to Bernstein; The Nernst Potential and Cable Equations; Resting and Action Potentials; Hodgkin & Huxley; Electrophysiological recording techniques; Voltage Gated Ion Channels; Ligand gated Ion Channels; Electrical & Chemical Synapses; Synaptic

Plasticity; Sensory Physiology: Vision, Hearing, Somatosensory; Motor systems and Central Pattern Generators; Optical methods of detection and stimulation; Energetics of the Nervous System.

Plant Molecular Biology [3003]

A general introduction to embryonic and postembryonic plant development, regulatory action of plant hormones in controlling the continuous patterning, Enhancer and suppressor screens to design regulatory network, tissue specific mis-expression and Ectopic over expression studies and their implications, genetic screens to identify upstream regulators, molecular analysis to identify downstream regulators of patterning regulators (transcription factors), molecular genetic interactions to generate regulatory network of shoot and root meristem function.

Stem cell and regeneration (nursery rhymes across the kingdom): regulatory network controlling the stem cell initiation and maintenance in plants, molecular mechanisms of regeneration and reprogramming of cell fate, pluripotency, multipotency and totipotency in plants.

Polarity: Plant cell polarity, mechanisms of onset of polarity in plant cell, hormonal flux controlling the polarity, link between cell fate and cell polarity.

Patterning: Control of organ positioning in plants, regulatory module linking phyllotaxis (shoot organ positioning) and rhyzotaxis (root organ positioning), control of organ outgrowth in plants, plant hormone regulating architecture.

Evolutionary developmental biology: morphological diversity in different plant species utilizing conserved regulatory module.

Evolutionary Ecology [3003]

1. Recapitulation of fundamental concepts
2. Prey-predator interactions: Mimicry, aposematism, crypsis (background matching, disruptive colouration, etc); Frequency Dependent Predation and Selection; Anti-herbivory strategies in plants.
3. Phylogenetics and Biogeography: Basic phylogenetic methods; Historical biogeography; Comparative methods in evolutionary biology

4. Phylogeography and Population genetics: Understanding history of populations using Haplotype Networks; HW Equilibrium; Population genetic structuring, Conservation genetics
5. Coevolution: Coevolution of antagonistic and mutualistic interactions, Diffuse coevolution, Arms race.
6. Phenotypic plasticity: Polyphenisms, Reaction norms, Reversible versus irreversible plasticity, Adaptive plasticity
7. Sensory ecology: Sensory systems (vision, olfaction, chemosensory mechanisms and special senses). Signalling in plants and animals, plant-animal communication; Pollination and dispersal ecology.
8. Cooperation and conflict in animal societies
9. Macroevolutionary patterns
10. Hominid evolution and ecology

Stem Cells And Regenerative Medicine [3003]

(Prerequisite: Developmental Biology)

1. **Introduction to Stem cells:** Basics of stem cells and principles of stemness, Early mammalian development, Evolution of stem cells
2. **Biology of stem cells:** Cell cycle regulation in stem cells, Mechanisms of differentiation, Signal transduction (More elaborative for mechanisms involved in development), Metabolism of stem cells
3. **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
4. **Adult stem cells:** Properties, identification and separation of various stem cells, Biological principles of HSCs; development, regulation od proliferation and differentiation, Sources of HSCs and their clinical use
5. **Cancer stem cells:** Concepts, identification, biology, Potential application
6. **Stem Cell niches:** Extrinsic factors in the regulation of stem cell function. Biological, physio-mechanical properties of stem cell microenvironment (for HSCs, epidermal, germ and intestinal stem cells).
7. **Transplantation biology:** Immunology of transplantation and graft rejection, Homing mechanism of transplanted stem cells

8. **Tissue engineering:** Ex vivo expansion of stem cells, Ex vivo construction of tissues, scaffolds, bioreactors
9. **Stem cells in clinic:** Avenues for stem cell use (metabolic, genetic diseases, cancers and trauma), Potential application of stem cells in clinic and present clinical use. Hurdles and future directions
10. **Methods in stem cells:** In vitro methods to assay stem cells, In vivo methods to assay stem cells

Chronobiology [3003]

(Prerequisite: Neurobiology)

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.

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.

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.

Circadian photoreception: Input signals into the circadian clock, molecular pathway of circadian photoreception, light entrainment of circadian clock, extra-ocular photoreception. Neural circuitry of sleep: Genetics of sleep, organization of sleep arousal circuit, wake promoting and sleep promoting neurotransmitters. Sleep for memory consolidation, Sleep disorders.

Circadian clock and metabolism: Central and peripheral circadian clocks, circadian disruptions and metabolic disorders, neuro-degenerative diseases, ageing and circadian clock. Evolution of the circadian timing system: Evolution of circadian clocks, fitness, adaptive significance of circadian clocks.

Advanced Developmental Biology [3003]

(prerequisite: Developmental Biology)

This course is designed to address current advances in the field of Developmental Biology, an exciting field of Biology that gives mechanistic insights into basic biological aspects. Developmental Biologists worldwide are combining novel genetic approaches and molecular techniques to understand how a fertilised egg is progressively transformed into a complex multicellular organism. The main emphasis of this course will be on molecular, cellular and genetic tools that aids in the understanding of developmental processes better. The idea is not to cover everything in the field but to highlight some of the key areas of research in Developmental Biology.

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 of lectures will be taught by the instructor, there will be 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. They also have to write a 2 page research proposal addressing an interesting question in the field and how they would test this.

Syllabus:

1. Maternal inheritance and maternal to zygotic transition during early development: molecular players in maternal inheritance; mechanisms that regulate transition from maternal to zygotic gene expression: recent genetic studies in Drosophila and Zebrafish will be discussed
2. Cell migration and cell adhesion in development: cell migration and cell adhesion in early embryos; recent literature on Drosophila germ cell and border cell migration, tracheal development and dorsal closure will be discussed
3. Interpretation of morphogen gradients: various models of morphogen gradient formation; functions of morphogen gradients during morphogenesis and patterning of tissues; experimental approaches to measure the morphogen gradients.
4. Asymmetry in the germ cells and in developing embryo: asymmetric distribution of messenger RNA and protein in germ cells and in developing Drosophila embryos, scientific papers that deal with the molecular machinery that leads to this asymmetry during early development will be referred to.

5. Cell Polarity in development and changes in cell polarity: epithelial cell polarity in development; players in epithelial polarity; cytoskeletal mechanisms; protein trafficking machinery in cell polarity, factors that lead to epithelial polarity loss and transition to mesenchymal states in various developmental contexts
6. Development of behavior: courtship behaviour, aggression, modification of behaviour by pathogens will be dealt with

Bacterial Genetics [3003]

(prerequisite: Microbiology)

Bacterial chromosome structure and replication, Mutations and repair in bacteria (classes of mutations, measuring mutations, mutator strains, mechanisms of bacterial DNA repair, SOS response), transposition, mapping of mutations, plasmids, bacterial two-hybrid systems, genetics of bacteriophages, conjugation, transformation, transduction as a tool in bacterial genetics, recombination, gene expression and transcriptional regulation in bacteria, post-transcriptional regulation in bacteria, Function and use of Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR).

Animal Behaviour [3003]

(prerequisite: Evolutionary Ecology)

1. Life-history strategies
2. Game theory
3. Reproductive strategies, sexual systems
4. Evolutionary psychology
5. Eusociality
6. Social organization hierarchy and dominance
7. Deceit, conceit, prestige
8. Animal personality
9. Territoriality, Space and information usage
10. Learning, memory and cognition

Genome Stability[3003]

(prerequisite: Adv. Genetics and Genomics)

1. DNA damage and recognition (sources and types of DNA damage, random and programmed double strand breaks, chromosome structural variations)
2. Cellular responses to DNA damage (signalling of DNA damage, choice of DNA repair and recombination pathways)
3. DNA repair mechanisms (mismatch repair, Base excision repair, Nucleotide excision repair, non-homologous end joining, Homologous recombination)
4. Mechanisms of meiotic recombination and chromosome segregation (Chromosome pairing and synaptonemal complex assembly, Regulation of meiotic recombination pathways, processing of Holliday junctions, spindle assembly)
5. Genomic instability and human disease (cancer, birth defects, genomic disorders due to chromosome structural variation), Genome editing (targeted modification of the genome using nucleases).

Reference Books:

1. Genome Stability: James Haber, Garland Science
2. DNA Damage and Repair: Jac A. Nickoloff, Merl F. Hoekstra, Humana Press
3. DNA repair and mutagenesis: Errol C. Friedberg, American Society for Microbiology Press

Ecological Interactions[3003]

1. The central role of interactions in the ecology and evolution of organisms.
2. Interactions at different scales: Studying the process of interactions and macroevolutionary patterns generated by them. Importance of accounting for phylogenetic non-independence. Phylogenetic comparative methods to study the role of interactions in diversification.
3. Specialization and generalization as alternate strategies: Defining and measuring specialization and generalization. Multiple axes of specialization. When is each strategy favoured?

4. Insect plant interactions: Why are herbivorous insects so diverse - diffuse coevolution between insects and their hostplants. Oviposition preference hierachy, larval performance hierarchy and concordance between them.
5. Insect pollinator interactions: Insect pollination as a key innovation. Specialisation and generalisation in plant-pollinator interactions. Obligate mutualisms.
6. Experimental coevolution: What is experimental coevolution and how does this differ from other types of empirical coevolution studies. Advantages of experimental coevolution. Popularity of microbial systems in such studies. Case studies from microbial and insect systems.
7. Host parasite interactions: Diversity of host parasite interactions in nature. Case studies of the widespread endosymbiont Wolbachia and its insect hosts.
8. Inter- and intra-specific competition: Spatial and temporal mechanisms of competition avoidance. Concept of niche and niche partitioning.
9. Dispersal ecology: Causes and consequences of dispersal in plants and animals; invasive species and their effects on community organisation.

Reference Books:

1. Modern Phylogenetic Comparative Methods and Their Application in Evolutionary Biology: Concepts and Practice. Edited by Lszl Zsolt Garamszegi.
2. The Geographic Mosaic of Coevolution. By John N. Thompson
3. Parasitism: The Ecology and Evolution of Intimate Interactions. By Claude Combes
4. Plant-Pollinator Interactions: From Specialization to Generalization. Edited By Nickolas M. Waser and Jeff Ollerton
5. Experimental Evolution: Concepts, Methods, and Applications of Selection Experiments. Edited By Theodore Garland and Michael R. Rose
6. Dispersal Ecology and Evolution. By Jean Clobert, Michael Baguette, Tim G Benton, James M. Bullock

Laboratory Courses

BIO 315 Advanced Lab Course I [0093]

Microbiology: Microbial growth kinetics, bacterial motility assay; antibiotics susceptibility testing, MIC

Genetics: Conjugation; Transduction; transcription; transposon mutagenesis, construction of bacterial gene deletions by homologous recombination(including primer designing; PCR; cloning; plasmid isolation; Transformation and screening for knock-outs); tetrad analysis in yeast, analysis of genomics data

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.

BIO 325 Advanced Lab Course II [0093]

Structural Biology: Basic UNIX commands, shell scripts and the first 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 Procheck, HBPLUS, DSSP, CCP4.

- Immunology: 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, actin and microtubule polymerization

BIO 412 Advanced Lab Course III [0093]

Biological Data Analysis: Statistical distributions of ecological parameters, Crypsis as an anti-predatory strategy, Sampling techniques for plants and insects, Spectral measurements of natural objects, Variant analysis in genomic data.

Drosophila Developmental Biology and Physiology:

1. Life cycle and external morphology of Drosophila:
   - Embryo, larval, pupal and adult stages
   - Segregation of male and female flies
   - Basics of setting up a cross
2. Dominant Vs recessive mutations:
   - External phenotypes (eye, wing and bristle)
3. Simple genetic crosses:
4. Gal4-UAS system:
   - express reaper in the eye (inducing apoptosis in the compound eyes)
   - express GFP in larval salivary glands (tissue specific expression and observation of a fluorescent protein)
   - express reaper in insulin producing neurons: (growth phenotype by blocking insulin growth factor levels)
5. Behavior studies using flies:
   - Motor neuron defects (hyperactivation or inactivation of motor neurons)
   - Feeding assays
6. Developmental biology experiments:
   - Oogenesis, border cell migration
   - Early embryonic patterning

Chemistry Syllabus

List of Courses:

1. **Core courses**

   a. **Theory courses**
      i. CHY 311 Coordination Chemistry
      ii. CHY 312 Stereochemistry- Principles & Applications
      iii. CHY 313 Quantum Chemistry
      iv. CHY 314 Group Theory in Chemistry
      v. CHY 315 Chemical Kinetics
      vi. CHY 321 Organometallics and Bioinorganic Chemistry
      vii. CHY 322 Methods in Structure Determination
      viii. CHY 323 Pericyclic Reactions and Reactive intermediates
      ix. CHY 324 Theoretical Spectroscopy
      x. CHY 411 Chemistry of Solids & Materials
      xi. CHY 412 Chemistry of C-C and C-X Bonds
      xii. CHY 413 Instrumental Methods
      xiii. CHY 421 Chemistry of s,p and f-block elements
      xiv. CHY 422 Physical Organic Chemistry
      xv. CHY 423 Advanced Organic Chemistry
      xvi. CHY 424 Electrochemistry and Statistical Thermodynamics

   b. **Lab Courses**
      i. CHY 316 Organic Chemistry Lab
      ii. CHY 325 Inorganic Chemistry Lab
      iii. CHY 414 Physical Chemistry Lab

2. **Partial List of Elective Courses**

   a. Bioinorganic Chemistry
   b. X-ray Crystallography and Symmetry
   c. Heterocycles, Carbohydrates and Aminoacids
   d. Contemporary Methods in Organic Synthesis
   e. Inorganic Rings and Cages
   f. Computational Chemistry
   g. Research Methodology

Theory Courses

CHY 311 Coordination Chemistry [3003]

Bonding in MetalComplexes: Molecular orbitals; σ-type, π-type, δ-type interactions in transition metal complexes; Bonding situation in various geometry complexes.

Electronic Spectra of Metal Complexes: Russell-Saunders symbols; Electronic transitions in metals complexes; Selection rules; Effect of Jahn-Teller distortion; Charge transfer spectra.

Magnetism: Magnetic susceptibility; Magnetic moment; spin orbit coupling; Ferromagnetism and antiferromagnetism; Anomalous magnetic moment; Thermal effects; Single molecular magnets.

Structure and Stability: Geometry of coordination complexes; Isomerism; Optical activity; Thermodynamic and kinetic stability; Chelate effect; Asymmetric synthesis.

Reactions of Metal Complexes: Substitution reactions in in square planar and octahedral complexes; Stereochemical reactions; Electron transfer reactions; Photochemical reactions.

TEXTBOOKS/REFERENCES

1. *Molecular Orbitals of Transition Metal Complexes*, Yves Jean, Oxford University Press, 2005.
2. *Coordination Chemistry*, Joan Ribas Gispert, Wiley-VCH Electronic Absorption Spectroscopy and Related Techniques,
3. D. N. Sathyanarayana, Universities Press, 2001.
4. *Elements of Magnetochemistry*, R. L. Dutta and A. Syamal, Affiliated East-West PVT Ltd, 1993.

CHY 312 Stereochemistry: Principles and Applications [3003]

Molecular symmetry and chirality axis, plane, center and alternative axis of symmetry, atropisomerism, helicity.

Difference between configurations and conformations, factors affecting the stability of conformers, dipole interaction, strain. Conformations, stereochemistry of simple and substituted cyclopentane, cyclohexane, and Decalin.

Diastereoselectivity: Stereoselective reactions, prochirality, diastereoselective addition to carbonyl groups, chelation controlled stereoselectivity, stereoselective reactions of acyclic alkenes.

Stereoselective synthesis of alkenes: Julia olefination, Peterson elimination, Wittig reaction, HWE reaction, Still-Gennari modification, Shapiro reaction, Mcmurry reaction. Metal-mediated alkene synthesis [Tebbe olefination, Petasis reaction, Heck reaction, Suzuki reaction, metathesis (cross metathesis, enyne metathesis, RCM)], stereoselective addition to alkynes (Birch reduction and Lindlar's O_2 reduction).

TEXTBOOKS/REFERENCES

1. E. L. Eliel, *Stereochemistry of Carbon Compounds*, Tata McGraw-Hill Edition 1975, 38th reprint 2008.
2. D. Nasipuri, *Stereochemistry of Organic Compounds-Principle and Applications*, 2nd Ed., New Age International Publishers, 2007.
3. F. A. Carey and R. J. Sundberg, *Advanced organic chemistry*.
4. J. Clayden, N. Greeves, S. Warren and P. Wothers, *Organic chemistry*.
5. R. Bruckner, *Advanced organic chemistry, Reaction mechanisms*, Academic Press.
6. Carruthers W.S. *Modern Methods of Organic Synthesis* 3rd edition, Cambridge University Press, 1986.

CHY 313 Quantum Chemistry [3003]

Fundamental Background: Blackbody radiation, photoelectric effect, spectral emissions from atoms, dual nature of light and matter, Schrodinger equation and its analogy with the classical wave equation, postulates of quantum mechanics, wave functions and requirements for an acceptable wave function, operator formalism, eigenfunctions and eigenvalues, expectation values, Hermitian operators, measurement, superposition of states, commuting operators, uncertainty principle.

Exactly Solvable Problems: free particle, quasi-free particle (1-D, 2-D and 3-D box problems), concepts of quantum numbers and degeneracies, Quantum wells and dots, quantum tunneling and scattering, simple harmonic oscillator, particle on a ring, particle on a sphere, angular momentum, hydrogen atom problem, atomic orbitals.

The Variation Method: Rayleigh-Ritz method, application to the solution of helium atom problem, independent electron approximation, Slater determinants, Pauli principle, LCAO-MO, the H^{2+} molecule-ion, molecular orbitals for diatomic molecules, Huckel theory.

Time-Independent Perturbation Theory: Formal development of non-degenerate perturbation theory upto second order, perturbation treatment of the ground state of helium atom, comparison with the variation treatment, excited states of helium atom.

TEXTBOOKS/REFERENCES

1. J. P. Lowe and K. A. Peterson, *Quantum Chemistry*, Elsevier publishers.
2. I. N. Levine, *Quantum Chemistry*, Prentice Hall.
3. Atkins and Friedman, *Molecular Quantum Mechanics*, Oxford University Press.
4. F. L. Pilar, *Elementary Quantum Chemistry*, Dover Publications.
5. Henry Eyring, John Walter and G E Kimball, *Quantum Chemistry*, John Wiley and Sons.
6. Thomas Engel and Reid, *Quantum Chemistry and Spectroscopy*, Prentice Hall.

CHY 314 Group Theory in chemistry [3003]

1. Definition of symmetry and symmetry elements. Definition of Group. Symmetry elements and symmetry operations in Molecules. Classes of operations and similarity transformations.
2. Point group classification . Systematic procedure to determine symmetry point group of molecules.
3. Matrix representation of symmetry operations. Basis vectors. Reducible and Irreducible representations. Characters Representations. Theorems on characters.
4. Construction of Character Tables for point groups.

5. Group theory of molecular vibrations. Application in Infrared and Raman spectroscopy.
6. Group theory of Chemical bonding. Hybridisation in molecules.
7. Group theory of Molecular orbitals. Application to Electronic spectra.
8. Preservation of symmetry in Chemical Reactions. Woodward-Hoffmann Rules.
9. Group theory and Molecular Complexes. Ligand Field Theory.
10. Symmetry of Crystals. International Notations. Crystallographic Point Groups. Bravais Lattices.

TEXTBOOKS/REFERENCES

1. *Chemical application of group theory*, F.A. Cotton
2. *Group theory in chemistry*, Ramakrishnan V. & M.S. Gopinathan

CHY 315 Chemical Kinetics [3003]

Introductory kinetics: Determination of order of reaction, complex reactions, integration of rate equations, opposing reactions, parallel reactions, and consecutive reactions, methods of analysis, measurement of rates, replacement of time with area variable, the steady state approximation.

Theory of chemical kinetics: Kinetic theory of collisions, macroscopic reaction rates from microscopic properties, collision cross section, potential energy surfaces for various reactive and nonreactive scattering processes, conventional transition state theory, Eyring equation, elementary gas phase reactions, Lindemann-Hinshelwood mechanism and the Rice-Ramsperger-Kassel-Marcus (RRKM) theory for unimolecular reactions, Kramers' theory, Marcus' electron transfer theory, and information theory.

Reactions in solution: Nature of liquids, effect of pressure, dielectric constant and ionic strength, state-to-state dynamics, molecular beams. Chain reactions: normal and branched chains, explosion reactions, Rice-Herzfeld mechanism.

Fast reaction kinetics: relaxation methods, large perturbation, flash photolysis, lasers photolysis, pulsed radiolysis, small perturbation. Kinetics in the excited electronic states: Jablonskii diagram, kinetics of unimolec-

ular photophysical and photochemical processes, photoisomerisation, bimolecular photophysical and photochemical processes, excimers, exciplexes and sensitisation; Time scales of photophysical processes, primary quantum yield, photostationary states, mechanism of the decay of singlet excited state and Stern-Volmer equation, resonance energy transfer, light induced electron transfer and Marcus equation; Laser photochemistry including pulsed laser and multiphoton excitation, laser flash photolysis in various time scales. Kinetics of natural light induced processes including photosynthesis and vision, designing of light induced systems and tuning of their rates, light induced processes and environment.

Surface reaction kinetics: Physical and chemical adsorption, adsorption isotherms, Langmuir-Hinshelwood and Eley-Rideal mechanism, heat of adsorption, kinetics of solid state reactions.

TEXTBOOKS/REFERENCES

1. K. J. Laidler, *Chemical Kinetics*, 3rd Ed., Pearson Education (Indian Ed.).
2. M. R. Wright, *An Introduction to Chemical Kinetics*.
3. J. Rajaram and J. C. Kuriacose, *Kinetics and mechanism of chemical transformation*, Macmillan India.
4. S. K. Upadhyay, *Chemical Kinetics and Reaction Dynamics*, Springer.
5. G. D. Billing and K. V. Mikkelsen, *Introduction to Molecular Dynamics and Chemical Kinetics*.
6. P. Atkins, *Physical Chemistry*, 8th Ed., Oxford University Press.
7. N. J. Turrro, V. Ramamurthy and J. C. Scaiano, University Science Books.
8. J. R. Lakowicz, *Principles of Fluorescence Spectroscopy*, 3rd Ed., Springer.

CHY 321 Organometallics and Bioinorganic Chemistry [3003]

Introduction: Definition of organometallic compounds; Historical perspective; Significance of valence electron count.

Organo-Transition Metal Chemistry: Synthesis structure and reactivity of organometallic compounds bearing Carbon monoxide, phosphines, alkyls, aryls, conjugated hydrocarbons, carbenes and hydrides.

Organometallic Catalysis: Alkene metathesis; Olefin hydrogenation; Olefin polymerization; Olefin oxidation; Hydroformylation; Fischer-Tropsch

process; Carbon-carbon bond forming reactions; Methanol carbonylation.

Biological functions of inorganic elements in organisms: Occurrence, availability, Biological ligands for metal ions; Function and transport of K^+, Na^+, Ca^{2+} and Mg^{2+} ions in biological systems; Complexes of alkali and alkaline earth metal ions with macrocycles; Ion channels; Ion pumps.

Photosynthesis and O_2 Transport: Tetrapyrrole ligands and other macrocycles; Metals in the centre of photosynthesis-Mg and Mn; Photosynthetic process; Mn-catalysed oxidation of water to O_2; Cobalamines including vitamin and coenzyme B_{12}; Haemoglobin and myoglobin and their functions; Cooperative effect in haemoglobin; Perutz mechanism; Haemerythrin and haemocyanin.

Cytochromes, Fe and Cu-containing proteins: Cytochrome P-450 and oxygen transfer from O_2 to non-activated substrates; Catalases and peroxidases; Generation and function of organic free radicals; Uptake, transport and storage of iron, Fe-S and other non-heme iron proteins; Ferredoxins, transferrin, ferritin; Type 1 blue copper centres; Type 2 and type 3 copper centres in O_2-activating proteins.

TEXTBOOKS/REFERENCES

1. *Basic Organometallic Chemistry: Concepts, Syntheses and Applications* B.D. Gupta, Anil J. Elias, Universities Press (2013)
2. *Organometallics*, Christoph Elschenbroich, Wiley-VCH (2006)
3. *Organotransition Metal Chemistry: From Bonding to Catalysis*, John Hartwig, University Science Books (2010)
4. B. Douglas, D. McDaniel and J. Alexander, *Concepts and Models if Inorganic Chemistry*, 3rd Ed., Wiley (1994).
5. W. Kaim and B. Schwederski, *Bioinorganic chemistry: Inorganic Elements in the Chemistry of Life*, Wiley (2006).
6. S. J. Lippard and J.M. Berg, *Priniciples of Bioinorganic Chemistry*.

CHY 322 Methods in Structure Determination [3003]

Nuclear Magnetic Resonance spectroscopy: Principle of NMR, common spin 1/2 nuclei, Zeeman splitting, Boltzmann distribution, effect of magnetic field strength on sensitivity and resolution, ^{1}H-NMR, chemical

shift, anisotropic effects, chemical and magnetic equivalence, coupling constants, applications: Karplus relationship of J on dihedral angle, first order J splitting patterns and structure correlation, strong coupling effects, ^{13}C satellites, ^{13}C-NMR, natural abundance, sensitivity, ^{13}C chemical shifts and structure correlations. DEPT pulse sequences, 2D NMR; ^{1}H COSY, one-bond (HSQC) and multiple-bond (HMBC) ^{1}H–^{13}C correlations. Defining molecular stereochemistry using the Nuclear Overhauser effect (NOE), dynamic processes by NMR, restricted rotation, cyclohexane ring inversion.

Infrared and UV spectroscopy: Review of basic principles, instrumentation, classification of UV absorption bands, examples of UV chromophores, vibrational modes, general features of IR spectra, group frequencies of organic systems, factors affecting the group frequencies, study of hydrogen bonding effects, vibrational spectra of ionic, coordination and metal carbonyl compounds.

Mass Spectrometry: Ionization methods, mass analyzers, fragmentation patterns (Mclafferty rearrangement), interpretation of EI mass spectra. Qualitative mass spectrometry analysis: Chemical formulae calculation; nitrogen rule; high resolution analysis of isotopes signatures. Illustrative examples of structure elucidation from spectra.

TEXTBOOKS/REFERENCES

1. R. M. Silverstein, G. C. Bassler and T. C. Morril, *Spectrometric identification of organic compounds*, John Wiley, 1991.
2. W. Kemp, *Organic spectroscopy*, 2nd Ed., ELBS, Hongkong, 1987.
3. L.D.Field, S. Sternhelland, J.R. Kalmann, *Organic structures from spectra*, John Wiley, 2007.
4. M. H. Levitt, *Spin Dynamics*, 2nd Ed., John Wiley, 2007.
5. S.Braun, H.O.Kalinowski and S.Berger, *100 and more basic NMR experiments*, VCH, Weinheim, 1996.
6. D.Neuhaus and M.Williamson, *The Nuclear Overhauser effect in structural and conformational analysis*, VCH, New York, 1989.

CHY 323 Pericyclic Reactions and Reactive intermediates [3003]

Pericyclic reactions: Four classes of pericyclic reactions, Woodward-Hoffmann rules in (i) cycloaddition (thermal and photochemical condition

4+2, 2+2) (ii) electrocyclic reactions (iii) sigmatropic reactions (iv) group transfer reactions with examples. Woodward-Hoffmann rules, frontier orbitals, and orbital symmetry correlation diagrams examples. Diels-Alder reaction-endo/exo-regioselectivity, effect of Lewis acid on Diels-Alder reaction; electrocyclic reactions-Claisen, Cope with stereochemistry; group transfer reactions-ene reaction; and, 1,3 dipolar cycloaddition including ozonolysis and reaction of ketene with alkenes.

Photochemical reactions: Paterno-Buchi reaction, photodimerization of alkenes. Photochemical reactions of carbonyl compounds: Norrish type I and II reactions, di-pi methane rearrangement.

Carbenes and Nitrenes: Structure of carbenes, generation-addition and insertion reactions, carbene based rearrangements. Structure of nitrene generation and reaction-electron deficient nitrogen intermediates, and rearrangements (Curtius, Schmidt and Beckmann).

Radicals: Generation of radical intermediates-addition to alkenes, alkynes (inter and intramolecular) to form C–C bonds-Baldwin's rules-fragmentation and rearrangements. Named reactions involving radical intermediate–Barton deoxygenation and decarboxylation–Ketyl radicals-synthesis of pinacol.

TEXTBOOKS/REFERENCES

1. I. Fleming, *Molecular orbitals and Organic chemical reactions*. Student Ed., Wiley VCH.
2. R. Bruckner, *Advanced organic chemistry, Reaction mechanisms*, Academic Press.
3. J. Clayden, N. Greeves, S. Warren and P. Wothers, *Organic chemistry*, Oxford University Press.
4. F. A. Carey and R. J. Sundberg, *Advanced organic chemistry*.

CHY 324 Theoretical Spectroscopy [3003]

Interaction of radiation with matter: Electromagnetic radiation, radiation density and intensity, theory of blackbody radiation, correlation to the Einstein coefficients of absorption and emission, time dependent perturbation theory, Fermi golden rule, lineshape functions, homogeneous and

inhomogeneous broadening, lasers.

Introduction to Molecular Spectroscopy: Molecular Hamiltonian, Born-Oppenheimer approximation. Rotational spectroscopy: Nuclear motion in diatomics, separation of translational and relative motion, rotation of rigid bodies, moment of inertia, linear molecules, spherical, symmetric and asymmetric tops, selection rules, rotational spectra and line intensities, molecule and space fixed coordinate systems, structure determination from rotational constants, isotopic effects.

Vibrational Spectroscopy: Review of vibrational motion in diatomics, vibrational selection rules, dissociation energies, vibration-rotation transitions in diatomics, Beyond the rigid rotor-harmonic oscillator approximation using perturbation theory, anharmonicity and Morse oscillator, centrifugal distortion, nuclear spin and the Pauli principle, ortho and para modifications of homonuclear diatomics, vibrational motion of polyatomics, internal coordinates, symmetry coordinates, normal coordinates, The Wilson F and G matrices, group theoretical treatment of vibrations.

Raman Spectroscopy: Review of light scattering and Raman effect, classical and quantum models for scattering, polarizability tensor, selection rules, mutual exclusion rule for centrosymmetric molecules, Rayleigh and Raman intensities, resonance Raman scattering.

Electronic Spectroscopy of molecules: Molecular orbitals as LCAOs, electronic spectroscopy of diatomics, orbitals and states, term symbols, parity of diatomic energy levels, selection rules, vibrational and rotational structures, Frank-Condon principle, photoelectron spectroscopy, dissociation, photodissociation and predissociation, electronic spectroscopy of polyatomic molecules, Walsh;s rules, Huckel molecular orbital theory, vibronic coupling.

NMR & EPR: Expression for Hamiltonian/Energy - Zeeman interaction, torque exerted by a magnetic field on spins, equation, its solution and the physical picture of precession. Thermal equilibrium, Curie susceptibility. Expressions for MR spectral sensitivity. Approach to equilibrium, Bloch equations, the rotating frame, pulsed) experiments, solutions of classical

master equation.

Density matrix approach and product operator formalism for NMR. The spin Hamiltonian, isotropic and anisotropic interactions. Vector description of simple NMR experiments like INEPT, DEPT.

The EPR Hamiltonian. Theory of g-factors in EPR, Theory of hyperfine interactions in π-type free radicals.

TEXTBOOKS/REFERENCES

1. P. F. Bernath, *Spectra of Atoms and Molecules*, Oxford University Press.
2. J. L. McHale *Molecular Spectroscopy*, Pearson Education.
3. I. N. Levine, *Molecular Spectroscopy*, John Wiley & Sons.
4. J. M. Hollas, *Modern Spectroscopy*, John Wiley & Sons.
5. W. W. Parson, *Modern Optical Spectroscopy*, Springer-Verlag.

CHY 411 Chemistry of Solids and Materials [3003]

Structures of Solids: Crystal structures-Symmetry in crystals: Crystallographic point groups, space groups, lattices, one and two dimensional unit cells, translational symmetry elements, three dimensional unit cells, Miller indices, inter-planar spacings, packing diagrams. Close packing, body centered and primitive structures.

Ionic Solids: Ionic solids with formula MX (CsCl, NaCl, NiAs, Zinc Blende and Wurtzite Structures), MX_2 (Fluorite and Antfluorite Structures, Cadmium Halides, Rutile, Anti-rutile, beta -cristobalite), other crystal systems (Bismuth tri-iodide, Corundum, Rhenium Trioxide etc.), Mixed oxides (Spinel, Perovskite, Ilmenite).

Non Ionic Solids: Covalent solids, molecular solids and dispersion interactions, Pauling rules, silicates, phosphates, arsenates and related extended systems, zeolites, mesoporous materials, clay, metal-organic (MOF) and related open framework materials, hybrid materials.

Defects and Dislocations in Solids: Point defects, dislocations, geometrical representation of various types, grain boundary, phase boundary, ex-

amples in alloys and materials.

Synthesis of Solids: Theory of nucleation and crystal growth, Phase transitions. Gas to Solid Synthesis: Vapour deposition, chemical vapour deposition (CVD/MOCVD), sputtering. Liquid to Solid Synthesis: Crystal growth from melt, liquid quenching, sol-gel methods, ion-exchange and intercalation. Solid to Solid Synthesis: Solid state reactions, high pressure synthesis, glass, ceramics. Other Methods: Microwave reactions, combustion synthesis, hydrothermal methods and high temperature superconductors.

Electronic Structure of Solids: Free electron theory, Drude model, concept of Fermi level, density of states, band structure, direct and indirect band gaps, the Hall effect, band structure for some simple solids, electronic structure of metals and alloys, Fermi Surface, Analysis of Bands, Partial density of states (PDOS) and crystal orbital overlap population (COOP). Intrinsic, extrinsic semiconductors. Basic ideas of superconductivity.

Magnetic Properties of Solids: Magnetization, types of magnetic materials, Langevin diamagnetism, order-disorder transitions, mean field approximation, Curie law and Curie-Weiss law, band electron theory for magnetism, Pauli paramagnetism, exchange coupling, spin-up and spin-down half bands, band model for transition metal alloys, the localized electron model for magnetism (lanthanides), mean field approximation, giant, tunneling and colossal magnetoresistance.

Dielectric Properties of Solids: Electrical polarization, dielectric constant, piezoelectric crystal, quartz, ferroelectric effect, multilayer ceramic capacitor, photovoltaics.

Other novel materials: Carbon nanostructures (Fullerenes, carbon nanotubes and graphenes) Structure and properties. Glasses and amorphous solids, Thin films, Polymers, Nanomaterials, Ionic-superionic conductors and high Tc Superconductors.

TEXTBOOKS/REFERENCES

1. A. R. West, *Solid State Chemistry*, Wiley Student Ed., (2014) (Indian Ed.).
2. C. N. R. Rao and J. Gopalakrishnan, *New Directions in Solid State Chemistry*, 2nd Ed., Cambridge University Press (1987).
3. L. E. Smart and E. A. Moore, *Solid State Chemistry: An introduction*, 3rd Ed., Taylor and Francis, 2010 (Indian Ed.)
4. P. A. Cox, *The Electronic Structure and Chemistry of Solids*, Oxford Science Publications (1987).
5. D. Jiles, *Introduction to the Electronic Properties of Materials*, 2nd Ed., (2010), Nelson Thornes Ltd. (Indian Ed.)
6. G. Gottstein, *Physical Foundations of Materials Science*, Springer (2004).
7. R. Hoffmann, *Solids and Surfaces: A chemist?s view of bonding in extended structures*, Wiley-VCH, 1988.
8. N. W. Ashcroft and N. D. Mermin, *Solid State Physics*, Brooks-Cole (1976).
9. S. Elliot, *The Physics and Chemistry of Solids*, Wiley India (1998).

CHY 412 Chemistry of C–C and C–X Bonds [3003]

Keto-enol tautomerism: formation of enols by proton transfer, enolization catalysed by acids and bases.

Alkylations of metal enolates including boron. Alkylation of carbonyl compounds, alkylation of active methylene compounds, C-alkylation vs O-alkylation, generation of thermodynamic vs kinetically controlled enolates. Alkylation via dianion. Generation and reactions of enamine.

Aldol reaction; diastereoselective aldol reaction, Mukaiyama aldol reaction. Intramolecular aldol reactions, and Robinson annulation. Crossed Claisen ester condensations, Dieckmann condensation, Knoevenegal, Stobbe, Darzen, Acyloin condensations, Henry reaction, Mannich reaction.

Michael addition; 1,2 *vs* 1,4-addition, conjugate addition followed by alkylation, conjugate substitution reactions (Baylis-Hilmann reaction, nucleophilic epoxidation), conjugate addition of organometallic reagents.

TEXTBOOKS/REFERENCES

1. F. A. Carey and R. J. Sundberg, *Advanced organic chemistry*.
2. J. Clayden, N. Greeves, S. Warren and P. Wothers, *Organic chemistry*.
3. R. Bruckner, *Advanced organic chemistry, Reaction mechanisms*, Academic Press.

CHY 413 Instrumental Methods [4004]

Basics of measurement: Separation Techniques: Separation based on increasing number of factors (volatility, solubility, interactions with stationary phase, size, electrical field), gas and liquid chromatography, electrophoresis (plates and capillary).

Analytical Techniques: Elemental analysis, index of refraction, Flame photometry, Infrared absorption, static and dynamic light scattering techniques, thermoanalytical techniques, techniques in nuclear and radiochemistry (GM counter, ionizing chamber etc.).

Spectroscopic Techniques: review of optical spectroscopic techniques, linear and circular dichroism, optical rotatory dispersion, emission spectroscopy; Microscopic Techniques: Diffraction limit, optical microscopy (bright field, dark field and confocal), electron microscopy (SEM and TEM), scanning probe microscopy (STM and AFM).

Principles of X-ray Crystallography, concepts of Symmetry, point groups and space groups; crystal lattices

Elements of scattering theory, diffraction principles, structure factor, fourier transform, phase problem in crystallography, reciprocal lattice

Powder diffraction: Single crystal methods; Data collection and processing strategies; Patterson and direct methods; Refinement techniques, Rietveld refinement in powder diffraction, particle size determination from powder X-ray data, Synchrotron radiations usage, Small angle X-ray scattering, Basics of neutron diffraction, electron diffraction.

TEXTBOOKS/REFERENCES

1. C. Giacavazzo (Ed.) *Fundamentals of crystallography*.
2. J. D. Dunitz, *X-ray analysis and the structure of organic molecules*.
3. G.H. Stout and L.H. Jensen, *X-ray structure determination: A practical guide*.
4. A. R. West, *Solid State Chemistry*, Wiley Student Edition, 2003.
5. R. S. Drago, *Physical Methods in Inorganic Chemistry*.
6. D. A. Skoog, F. J. Holler and T. A. Nieman, *Principles of Instrumental Analysis*, 5th Ed., Brooks Cole.

7. H. Willard, L. Merritt and J. Dean, I *nstrumental Methods of Analysis*, 7th Ed., Wadsworth Publishing Company.
8. Banwell, *Fundamental of Molecular Spectroscopy*.

CHY 421 Chemistry of s, p and f-block elements [3003]

s-block elements: Dinitrogen compounds; Metallic hydrides; Compounds of alkali metals; Alkali metal solutions in liquid ammonia, Zintl compounds, Crown ether and cryptand complexes; Organolithium compounds, Compounds of alkaline earth metals; Anomalous properties of beryllium; reactivity of s-block elements.

p-block elements
Group 13 elements: Boron halides; Diborane-electron deficient compounds; Boranes and boron clusters; Wade's rules, Carboranes and metalloboranes; Borazines and boron nitride, organoboron and organoaluminium compounds.

Group 14 elements: Carbides; Silicates; Aluminosilicates; Organo compounds of silicon, tin and lead.

Pnictogens: Nitrogen activation; Oxides of nitrogen and phosphorus; Pnictogen halides; Phosphazenes, rings and clusters.

Chalcogens: Oxo-acids of sulphur, Polyanions of sulfur, selenium, and tellurium; sulphur-nitrogen & phosphorus based compounds.

Halogens: Pseudohalogens; Polyhalides; Structure and bonding in interhalogen compounds; Oxoacids and oxoanions of halogens; Fluorocarbons; CFC's and ozone layer.

Nobel Gases: Structure and bonding in halides and oxo-halides of xenon compounds.

f-block elements: Lanthanide contraction; Occurrence and recovery; Separation of Lanthanides; electronic spectra and MRI contrast agents.

TEXTBOOKS/REFERENCES

1. *Advanced Inorganic Chemistry*: F.A. Cotton, G. Wilkinson, C.A. Murillo and M. Bochmann (1999) 6th edition, Wiley-Interscience
2. *Inorganic Chemistry*: D. Shriver and P. Atkins (2006) International Student Edition, 4th edition, Oxford University Press
3. *Basic Inorganic Chemistry*, F. A. Cotton, G. Wilkinson and P. L. Gaus, 3rd Ed. (1995).
4. *Concepts and Models in Inorganic Chemistry*, B. Douglas, D. McDaniel and J. Alexander, 3rd Ed., Wiley (1994).
5. *Chemistry of Elements*, N. N. Greenwood and Alan Earnshaw, 2nd Ed, Elsevier 1997.

CHY 422 Physical Organic Chemistry [3003]

Molecular Structure and Thermodynamics: Introduction to Structure and Models of Bonding, Strain and Stability, Solutions and Non-Covalent Binding Forces, Molecular Recognition and Supramolecular Chemistry.

Acid Base Chemistry, Stereochemistry; Reactivity, Kinetics, and Mechanisms: Energy Surfaces and Kinetic Analyses, Experiments Related to Thermodynamics and Kinetics, Catalysis, Organic Reaction Mechanisms, Hammett Plot-LFET, QSAR, Organotransition Metal Reaction Mechanisms and Catalysis, Organic Polymer and Materials Chemistry; Electronic Structure, Theory and Applications: Advanced Concepts in Electronic Structure Theory, Electronic Organic Materials.

TEXTBOOKS/REFERENCES

1. Anslyn and Dougherty, *Modern Physical Organic Chemistry*.

SUPPLEMENTARY READING:

1. Carey and Sundberg?s, *Advanced Organic Chemistry*, part A, 5th Ed.
2. E. L. Eliel, *Stereochemistry of carbon compounds*.
3. J. March, *Advanced Organic Chemistry*, 4th Ed. or 5th Ed.
4. Carpenter, *Determination of Organic Reaction Mechanisms*.
5. N. Isaacs, *Physical Organic Chemistry*.
6. Lowry and Richardson, *Mechanism and Theory in Organic Chemistry*, 3rd Ed.
7. F. A. Caroll, *Structure and Mechanism in Organic Chemistry*.
8. B. Miller, *Advanced Organic Chemistry: Reactions and Mechanisms (chapters 1 & 5)*.

CHY 423 Advanced Organic Chemistry [3003]

Heteroatoms in organic synthesis: Sulfur: Sulfur stabilized anions, sulfonium salts, sulfonium ylides, sulfur stabilized cations, sulfoxides, oxidations using selenium. Boron: organoboron reagents and reactions; Silicon: Organosilicon compounds and their reactions, organotin compounds and their applications. Important catalyzed reactions such as palladium catalyzed reactions including Heck, Stille, Sonogashira, Kumada, Suzuki & Negishi, alkene metathesis, enyne metathesis.

Metal mediated oxidations: Non-metal mediated oxidations: eg. Swern oxidation, IBX, Stereo- and enantioselective oxidation reactions: Reduction with metal hydrides: Dissolved metal based reduction: eg. Birch reduction. Catalytic hydrogenation reactions: Stereo-and enantioselective reductions: Functional group interconversion, common catalysts and reagents (organic, inorganic, organometallic and enzymatic, chemoselectivity. Use of protecting groups in multi-step synthesis: Different protection and deprotection methods.

Retrosynthetic analysis: Synthesis backwards, disconnections, synthons, choosing disconnections, functional group interconversion, two group disconnections, C–C disconnections, donor-acceptor synthons, natural reactivity and umpolung. Synthesis: Illustrative synthesis of complex natural products with relevant examples.

TEXTBOOKS/REFERENCES

1. F. A. Carey and R. J. Sundberg, *Advanced organic chemistry*.
2. J. Clayden, N. Greeves, S. Warren and P. Wothers, *Organic chemistry*.
3. Warren S. *Organic Synthesis: The Disconnection Approach*, Wiley, NY, 1982.
4. Wyatt P. and Warren S, *Organic Synthesis*, Strategy and Control; Wiley 2007.
5. Carruthers W. S., *Modern Methods of Organic Synthesis* 3rd edition, Cambridge University Press, 1986.
6. House, *Modern Synthetic Reactions*, 1972.?
7. *Greene's Protective Groups in Organic Synthesis*, A John Wiley & Sons publications, 2007.
8. L. Kurti and B. Czako, *Strategic Applications of Named Reactions in Organic Synthesis*, Elsevier Academic Press, 2005.

9. R. Bruckner, *Advanced organic chemistry, Reaction mechanisms*, Academic Press.

CHY 424 Electrochemistry and Statistical thermodynamics [3003]

Electrochemistry as interdisciplinary Science, Electrochemistry and Battery Technology, Electrochemical approaches to environmental problems.

Ionics: True and potential electrolytes, ion-solvent interactions –solvation of salts, size and structure of solvation shell, solvation number, IR, NMR, X-ray and neutron diffraction methods to study hydration of salts.

Ion-Ion interactions, Debye-Hckel (or Ion-Cloud) theory, activity coefficients, theoretical estimation of activity coefficients, Triumphs and limitations of Deby-Hckel law, Extended Deby-Hckel law based on finite size ion model, Bjerrum ion-pair formation, ion pairs to triplet ions to cluster of ions.

Electrodics: Overpotentials, Exchange current density, Derivation of Butler-Volmer equation and its implications, Tafel plot, Multistep electrode reactions, Determination of multistep electrode reactions, Mass transfer by diffusion, Charge transfer at electrode-solution interfaces, Quantization of charge transfer, Tunneling, Structure of double layer at semiconductor-solution Interface.

Electrochemical Methods: Controlled potential and current techniques, Hydrodynamic techniques, Electrochemical instrumentations, Scanning probe techniques.

Statistical Thermodynamics: Concepts of statistical thermodynamics. Micro canonical, canonical and grand canonical ensembles. Ensemble averages. Most probable distribution. Boltzmann statistics, Fermi-Dirac statistics and Bose-Einstein statistics.

Ideal monatomic, diatomic and polyatomic gas. Partition functions.

Equilibrium constant in terms of partition functions, Debye-Huckel theory. Statistical mechanics of ionic solutions. Flory-Higgins theory of poly-

mer solutions. Specific heats of solids- Einstein and Debye models.

Virial equation of state and virial coefficients. The law of corresponding states.

TEXTBOOKS/REFERENCES

1. A. J. Bard and L. R. Faulkner, *Electrochemical Methods Fundamentals and Applications*, 2nd Ed.

SUPPLEMENTARY READING:

1. R. Holze, *Experimental Electrochemistry: A Laboratory Textbook*.
2. Sawyer, Sobkowiak, and Roberts, *Electrochemistry for Chemists*, 2nd Ed.
3. S. Glasstone, *An Introduction To Electrochemistry*.

Syllabi of Selected Electives

Bioinorganic Chemistry [2002]

The reactivity of coordination complexes of metal ions will be discussed in the context of the reaction mechanisms of specific metalloenzymes. A portion of the course will be devoted to the toxicity of metals and also their utility in drugs and in diagnostic agents.

Cytochromes: Cytochrome P-450 and oxygen transfer from O_2 to non-activated substrates. Catalases and peroxidases. Generation and function of organic free radicals. Nitrogen fixation.

Mo and Zn-containing proteins: Mo-containing enzymes. Zinc in biological systems, metalloenzymes. Zinc-finger and other gene regulatory Zn-proteins.

Biomimetic chemistry: Model compounds. Metalloporphyrins, picket-fence porphyrins, capped porphyrins.

Bio-mineralization. Biological functions of the non-metallic inorganic elements. Bioinorganic chemistry of the quintessentially toxic metals. Chemotherapy with compounds of some non-essential elements. Cis platin

and its mode of action. Gold-containing drugs. Photodynamic therapy.

ESR and Mossbauer spectroscopy. Characterization of biological systems with these techniques.

TEXTBOOKS/REFERENCES

1. J. E. Huheey, E. A. Keiter, R. L. Keiter and O. K. Medhi, *Inorganic Chemistry: Principles and Reactivity*, 4th Ed., Pearson Education, (2008).
2. P. Atkins, T. Overton, J. Rourke, M. Weller and F. Armstrong, Shriver and Atkins *Inorganic Chemistry*, 4th Ed., Oxford University Press (2008).
3. J. D. Atwood, *Inorganic and Organometallic Reaction Mechanism*, 2nd Ed., Wiley-VCH (1997).
4. W. Kaim and B. Schwederski, *Bioinorganic chemistry: Inorganic Elements in the Chemistry of Life*, Wiley (2006).
5. I. Bertini, H.B. Gray, J.S. Valentine and J. Lippard, *Bioinorganic Chemistry*, South Asian Edition, (2007) Viva Books Private Ltd.
6. H.B. Gray, E.I. Stiefel, J.S. Valentine and I. Bertini, *Biological Inorganic Chemistry*: Eds: (2006) University Science Books.

Laboratory Courses

CHY 316 Organic Chemistry Laboratory [0093]

1. Separation and quantification of ternary mixtures. Determination of purity by melting points and TLC. Mixtures No. 1-4
2. S_N1 and S_N2 reactions
3. (a) Determination of moisture content in the organic solvents using Karl-Fischer titration
   (b) Drying of organic solvents
4. Estimation of nitrogen in the given organic compound by Kjeldahl's method
5. Extraction of eugenol from cloves by steam distillation
6. Cycloaddition reaction: (Diels- Alder reaction) Diels-Alder reaction of furan and N-phenylmaleimide, preference for endo or exo-product formation
7. (a) Claisen-Schimidt reaction- Preparation of benzal acetophenone
   (b)Malonic ester synthesis- cyclobutane carboxylic acid

8. Multistage preparations and spectroscopic characterization
   (a) Conversion of bromobenzene to triphenyl carbinol and then to tritylchloride
   (b) Preparation of vanilline and its derivatives from p-hydroxybezaldehyde
   (c) Benzaldehyde to methylstyrene and to 1-phenyl 1,2-dihydroxypropane
   (d) Preparation of benzotriazole from o-nitroaniline
   (e) Preparation of sys-tribromobenzene from aniline
   (f) Validity of Huckel's 4n+2 rule: Synthesis of triphenyl methyl fluoroborate and tropyllium iodide
   (a) Chemiluminesence: Synthesis of cyalume and chemiluminescence

9. Molecular rearrangement
   (a) Green photochemical reaction (Photoreduction of benzophenone to benzopinacol and then to benzopinacolone)
   (b) Rearrangement of diazoaminobenzene to p-aminoazobenzene
   (c) Benzil Benzilic acid rearrangement
   (d) Preparation of caprolactum from cyclohexanone and nylon-6

10. Ionic liquids
    Preparation of tetrabutylammonium tribromide (TBATB) and Bromination of Chalcone
    Preparation of 1-pentyl-3-methylimidazolium bromide (pmIm) and Preparation of 2-phenylbenzothiazoles catalyzed by ionic liquid.

11. Phase transfer catalyst
    Wittig reaction: The preparation and purification of trans-stilbenes

12. Microwave oven assisted organic syntheses
13. Multi-step synthesis coenzyme catalyzed synthesis of Benzoin and derivatives
    Part 1: Synthesis of Benzoin
    Part 2: Synthesis of Benzil
    Part 3: Synthesis of Benzilic Acid
    Part 4: Synthesis of Benzoic acid from Benzaldehyde

CHY 325 Inorganic Chemistry Laboratory [0093]

1. Synthesis and magnetic properties of tetragonal Ni(II) complexes
2. Synthesis of Co(III) complexes and characterization
3. Microwave assisted synthesis of 5,10,15,20 - tetraphenylporphyrin
4. Synthesis and characterization of an oxygen-carrying Cobalt complex which mimics Haemoglobin
5. Binding of a small molecule to a Metalloprotein: Determination of the Equilibrium Binding Constant
6. Reduction potential of cytochrome C
7. Common geometries of pentacoordinate complexes: preparation of acetylacetonate complexes
8. Determination of spectrochemical order of a series of ligands in Ni(II) coordination compounds using electronic spectroscopy.
9. Probing ligand symmetry and coordination modes using IR spectroscopy.
10. Probing the fluxional behaviour in coordination compounds using NMR spectroscopy.
11. Isomerism in coordination chemistry (cis-trans, linkage, optical, etc, kinetics of isomerisation) in Co(II) coordination compounds, effect of ligands and coordination number on the spin states of the transition metal ions in the coordination compounds - measuring the magnetic susceptibility using Gouy's method.
12. Organometallic synthesis of double decker complexes, preparation of Ferrocene and its reactions.
13. Catalysis using polyoxometalates, Probing the redox reactions of multivalent transition metal coordination compounds using electrochemical probes and magnetism.
14. Synthesis and characterization of High Tc superconductor materials.
15. Understanding the structure of simple cubic metal organic frameworks using PXRD.

CHY 414 Physical Chemistry Laboratory [0093]

1. Determination of molecular weights by cryoscopic method
   (a) using water (b) benzene and (c) Camphor as the solvents

2. Viscosity measurements
   (a) Determination of coefficient of viscosity using Ostwald's viscome-

ter
(b) Variation of viscosity of a liquid with temperature
(c) Verification of J. Kendall's equation and determination of the composition of a mixture of two liquids
(d) Determination of radius of glycerol molecule
(e) Determination of molecular weight of polymers

3. Surface tension
(a) Determination of surface tension of the liquid by drop weight and drop number method
(b) Determination of the composition of two liquids by surface tension measurements
(c) Determination of limiting cross sectional area by surface tension method
(d) Determination of atomic parachor

4. Thermochemistry
(a) Determination of heat of neutralization of strong acid against strong base
(b) Determination of heat of neutralization of weak acid and hence its heat of ionization
(c) Determination of calorific value of fuels using bomb calorimeter

5. Refractometry
(a) Determination of refractive index of liquids and hence specific and molar refraction
(b) Determination of molar refractivity of liquids and hence refraction equivalents of C, H and Cl atoms and refraction equivalent of -CH_2 group
(c) Determination of molar refraction of solid by dissolving in a liquid

6. Spectrophotometry
(a) Test the validity of Beer-Lambert's law
(b) Determination of composition of binary mixture of $KMnO_4$ and $K_2Cr_2O_7$
(c) Determination of dissociation constant of weak acid/ weak base
(d) Study the complex formation between Fe(III) and salicylic acid, and find the formula and stability constant of the complex

(e) Investigate the complex formation of (a) Fe(III) and thiocyanate (b) Ni(II) and ethylenediamine by Job's method

7. Dipole measurement
   (a) Determination of dipole moment of liquids and variation of dipole moment with temperature

8. Equilibrium and dissociation constant
   (a) Determination of equilibrium constant of keto-enol tautomerisation of ethyl acetoacetate
   (b) Determination of equilibrium constant of esterification reaction between acetic acid and ethanol.
   (c) Determine the equilibrium constant of the reversible reaction

   $2Ag(I) + CaSO_4) \Rightarrow Ag_2SO_4 + Ca^{2+}$

9. Chemical Kinetics
   (a) Study the kinetics of iodination of acetone by (a) Visual (b) Titrimetric and (c) Spectrophotometric methods
   (b) Electrochemistry

10. Electrolytic conductance
    (a) Determination of dissociation constant of weak acid (b) Determination of solubility of sparingly soluble salt (c) Verification of Onsagar equation.

11. Transport number
    Determination of transport number by moving boundary and Hitroff methods

12. Electromotive force
    (a) Single electrode potential and verification of Nernst equation (b) Thermodynamics of electrochemical cells
    (c) Determination of equilibrium constant (d) Determination of solubility of sparingly soluble salt.

13. Surface Chemistry
    Adsorption of oxalic acid/ acetic acid on charcoal and verification of

Freundlich and Langmuir's adsorption isotherms

14. Fuel Cells
    Determination of Faraday efficiency and Energy efficiency

15. Corrosion
    Determination of rate of corrosion of a material at different conditions

16. Concept of particle in a box
    Determination of C = C length from absorption spectra of conjugated dienes.

17. Electronic potential energy surfaces
    Absorption spectra of molecular iodine, calculation of vibrational frequencies, anharmonicities and bond energies.

18. Polarimetry
    (a) Rate constant of hydrolysis of cane sugar
    (b) Determine the percentage of two optically active substances in a given solution

19. Dissociation equilibria of ampholites and determination of isoelectric point

Mathematics Syllabus

MAT 311 Real Analysis [3003]

Zorn's lemma, Axiom of choice, Metric spaces: Properties and examples, supremum, infimum, neighbourhood, open sets, limit points, Bolzano-Weierstrass theorem, derived sets, closed sets, adherent points, closure of a set, nested intervals, Cantor intersection theorem, cover, open cover, subcover, Heine-Borel theorem, converse of Heine-Borel theorem, compact sets, connected sets, convergent sequences, subsequences, Cauchy sequences, completeness, continuous functions, continuity and compactness, continuity and connectedness.

The Riemann-Stieltjes integral: Functions of bounded variation, total variation, bounded variation functions as difference of monotone functions, continuous functions of bounded variations, partitions, definition of Riemann-Stieltjes integral, refinement, existence of the integral, properties of the integral, fundamental theorems of integral calculus, mean value theorems, integration by parts.

Sequences and series of functions: Pointwise and uniform convergence, uniform convergence and continuity, uniform convergence and integration, uniform convergence and differentiation, sufficient condition for uniform convergence of a series, power series and convegence, equicontinuity, Ascoli's theorem, Stone-Weierstrass theorem.

TEXTBOOKS/REFERENCES

1. T. M. Apostol, *Mathematical Analysis*, 2nd Edition, Addison Wesley, 1974.
2. R. G. Bartle and D. R. Sherbert, *Introduction to Real Analysis*, 4th Edition, Wiley, 2011.
3. R. M. Dudley, *Real Analysis and Probability*, Cambridge University Press, 2002.
4. S. R. Ghorpade and B. V. Limaye, *A Course in Calculus and Real Analysis*, Springer, 2006.
5. R. R. Goldberg, *Methods of Real Analysis*, 2nd Edition, Wiley, 1976.
6. S. Lang, *Undergraduate Analysis*, 2nd Edition, Springer, 1996.
7. W. Rudin, *Principles of Mathematical Analysis*, 3rd Edition, McGraw- Hill, 1976.

8. T. Tao, *Analysis I*, Hindustan Book Agency, 2006.
9. H. L. Royden, *Real Analysis, 3rd Edition,* Phi Learning, 2009.

MAT 312 Abstract Algebra [3003]

Groups, subgroups and homomorphisms, isomorphism theorems of Noether, cyclic groups, cosets and quotient groups, theorems of Lagrange and Cauchy, normal subgroups, group action on a set, symmetric and dihedral groups, direct products. Sylow theorems, nilpotent and solvable groups, Jordan-Holder theorem.

Rings, ideals and homomorphisms, polynomial rings and formal power series, UFDs and Euclidean rings, PIDs, Gauss' theorem on UFDs, Eisenstein's criterion for irreducibility.

Modules, homomorphisms and exact sequences, finitely generated modules over a PID, fundamental theorem of finitely generated abelian groups, Rational canonical form and Jordan canonical form. Projective, injective and free modules (if time permits).

TEXTBOOKS/REFERENCES

1. Michael Artin, *Algebra*, Phi Learning Pvt. Ltd., New Delhi, 2011.
2. I.N. Herstein, *Topics in Algebra*, 2nd Edition, Wiley, 1975.
3. D.S. Dummit and R.M. Foote, *Abstract Algebra*, 3rd Edition, Wiley India, 2011.
4. J.B. Fraleigh, *A First Course in Abstract Algebra*, 7th Edition, Addison Wesley, 2002.
5. N.S. Gopalakrishnan, *University Algebra*, 2nd Edition, New Age International, 1986.
6. N. Jacobson, *Basic Algebra, Vol-1*, 2nd Edition, Freeman, 1985.

MAT 313 Linear Algebra [3003]

Vector spaces, subspaces, quotient spaces, basis, change of basis, linear functional, dual space, projection, eigenvalues and eigenvectors, Cayley-Hamilton theorem, elementary canonical forms, annihilating polynomials, invariant subspaces, simultaneous diagonalization, direct sum decomposition, invariant direct sum, the primary decomposition theorem, Jordan form, inner product spaces, orthonormal basis, Gram-Schmidt process;

adjoint operators, normal and unitary operators, self adjoint operators, spectral theorem for self adjoint operators.

LU decomposition, cyclic decomposition, Matrix norms, positive definite matrices, Cholesky decomposition, condition numbers; orthogonal matrices, Householder transformation, Givens rotations, QR factorization, stability of QR factorization, singular value decomposition, sensitivity analysis of singular values and singular vectors, least square problems, Sylvester's law of inertia, Sylvester's criterion for positive definite matrices, Tensor products, Bilinear forms.

TEXTBOOKS/REFERENCES

1. S. Axler, *Linear Algebra Done Right*, Springer, 1997.
2. W. H. Greub, *Linear Algebra*, 4th ed., Springer, 1981.
3. W. H. Greub, *Multilinear Algebra*, 2nd ed., Springer, 2013.
4. I. N. Herstein, *Topics in Algebra*, 2nd Edition, Wiley and Sons, 1996.
5. K. Hoffman and R. Kunze, *Linear Algebra*, 2nd edition, Pearson Education, New Delhi, 2006.
6. C. D. Meyer, *Matrix Analysis and Applied Linear Algebra*, SIAM, 2001.

MAT 314 Numerical Analysis [3003]

Roundoff Errors and Computer Arithmetic. Interpolation: Lagrange Interpolation, Divided Differences, Hermite Interpolation, Splines. Numerical Differentiation, Richardson Extrapolation. Numerical Integration: Trapezoidal, Simpsons, Newton-Cotes, Gauss quadrature, Romberg integration, Multiple integrals.

Solutions of Linear Algebraic Equations: Direct Methods, Gauss Elimination, Pivoting, Matrix factorizations. Iterative Methods: Matrix Norms, Jacobi and Gauss-Siedel Methods, Relaxation Methods. Computation of eigenvalues and eigenvectors: Power method, Householder's method, QR algorithm. Numerical solutions of nonlinear algebraic equations: Bisection, Secant and Newton's method, Zeroes of polynomials, Horner and Muller methods, Equations in higher dimensions.
Ordinary Differential Equations, Initial Value Problems: Euler method, Higher order methods of Runge- Kutta type. Multi-step method, Adams-Bashforth, Adams-Moulton methods, System of ODEs. Ordinary Differ-

ential Equations, Boundary Value Problems: Shooting methods, Finite differences.

TEXTBOOKS/REFERENCES

1. K. E. Atkinson, *An Introduction to Numerical Analysis*, 2nd Edn., John Wiley, 1989.
2. E. K. Blum, *Numerical Analysis and Computation, Theory and Practice*, Addison Wesley Publishing Co., 1972.
3. R.L. Burden and J. D. Faires, *Numerical Analysis*, 7th Edn., Brookes/Cole, 2011.
4. S. D. Conte and C. deBoor, *Elementary Numerical Analysis - an algorithmic approach*, 3rd Edn., McGraw Hill, 1980.
5. J. W. Dummel, *Applied Numerical Linear Algebra*, SIAM 1997.
6. C. F. Gerald and P. O. Wheately, *Applied Numerical Analysis*, 5th Edn., Addison Wesley, 1994.
7. G. H. Golub and C. F. vanLoan, *Matrix Computations*, John Hopkins University Press, 1996.
8. F. B. Hildebrand, *Introduction to Numerical Analysis*, McGraw Hill, New York, 1974.
9. E. Süli and F. D. Mayers, *An introduction to Numerical Analysis*, Cambridge University Press, 2003.
10. L. N. Trefethen and D. Bau, *Numerical Algebra*, SIAM, 1997.
11. D. S. Watkins, *Fundamentals of Matrix Computations*, Wiley, 1991.

MAT 315 Number Theory and Cryptography [3003]

Divisibility, greatest common divisor, Euclid's algorithm, Linear diophantine equations, prime numbers, fundamental theorem of arithmetic, prime number theorem, Bertrand's postulate. Congruences, complete and reduced residue systems, Chinese remainder theorem, Wilson's theorem, Fermat's little theorem, pseudo- primes, Euler's theorem, primitive roots. Quadratic residues, Legendre symbol, law of quadratic reciprocity, Jacobi symbol, binary quadratic forms.

Arithmetic functions, Euler's totient function, perfect numbers, Möbius inversion formula. Pythagorean triples, Fermat's Last Theorem, Lagrange's theorem, Waring's problem, Hardy- Littlewood circle method. Irrationality of e and π, continued fractions, best approximations, quadratic irrationals, Pell's equation.

Classical cryptography, block ciphers, public key cryptography, RSA crypto-system, discrete logarithm problem, Diffie-Hellman key exchange, Elliptic curve crypto-systems, zero knowledge protocols. Algorithms for primality testing, Fermat's factorisation, Pollard's rho method, quadratic sieve.

TEXTBOOKS/REFERENCES

1. I. Niven, H. S. Zuckerman and H. L. Montgomery, *An Introduction to the Theory of Numbers*, 5th Edition, Wiley, 1991.
2. Neal Koblitz, *A Course in Number Theory and Cryptography*, 2nd Edition, Springer, 1994.
3. G. H. Hardy and E. M. Wright, *An Introduction to the Theory of Numbers*, 6th Edition, Oxford University Press, 2008.
4. Kenneth Ireland and Michael Rosen, *A Classical Introduction to Modern Number Theory*, 2nd Edition, Springer, 1990.
5. James K. Strayer, *Elementary Number Theory*, Waveland Press, 2001.

MAT 321 Complex Analysis [3003]

PREREQUISITE

1. MAT 311 Real Analysis

Geometric representation of complex numbers, Analytic functions: limits, derivatives, Cauchy-Riemann equations, sufficient conditions, Cauchy Riemann equations in polar form, harmonic conjugate.

Mapping by elementary functions: Linear functions, the function $1/z$, linear fractional transformations, the functions $w = z^n, w = e^z$, the logarithmic function and its branches, special fractional transformations.

Cauchy's theorem and Cauchy's integral formula for convex regions, Morera's Theorem, power series representation of analytic functions, zeros of analytic functions, open mapping theorem, maximum modulus theorem, Schwarz lemma, Weierstrass theorem on limits of analytic functions.

Laurent's theorem, classification of singularities, residue theorem, the principal part of a function, poles, quotient of analytic functions, evaluation of improper real integrals, improper integrals involving trigonometric functions, argument principle, Rouche's theorem.

TEXTBOOKS/REFERENCES

1. L. V. Ahlfors, *Complex Analysis*, Mcgraw-Hill, 1980.
2. J. Bak and D. J. Newman, *Complex Analysis*, 3rd Edition, UTM, Springer, 2010.
3. J. W. Churchill and R. V. Brown, *Complex Analysis*, Mcgraw-Hill, 2009.
4. T. W. Gamelin, *Complex Analysis*, Springer-Verlag, 2001.
5. R. Greene and S. G. Krantz, *Function Theory of One Complex Variable*, 3rd Edition, GSM, Vol. 40, AMS, 2006.
6. E. M. Stein and R. Shakarchi, *Complex Analysis*, Princeton University Press, 2003.

MAT 322 Measure Theory and Integration [3003]

PREREQUISITE

1. MAT 311 Real Analysis

Outer measure, σ-algebra of measurable sets and its properties, Lebesgue measure and its properties, a non-measurable set, measurable functions.

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.

Differentiation and integration: Differentiation of monotone functions, functions of bounded variation, differentiation of an integral, absolute continuity.

L^p-spaces: Definition and properties, Minkowski's inequality and Holder's inequality, convergence and completeness of L^p, approximation in L^p, bounded linear functionals on L^p spaces.

TEXTBOOKS/REFERENCES

1. K. B. Athreya and S. N. Lahiri, *Measure Theory*, Hindustan Book Agency, 2006.
2. G. Debarra, *Measure Theory and Integration*, New Age International, 1981.
3. G. B. Folland, *Real Analysis: Modern Techniques and Their Applications*, 2nd Edition, John Wiley and Sons, 1999.
4. P. R. Halmos, *Measure Theory*, Springer, 2009.

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

MAT 323 Galois Theory and Commutative Algebra [3003]

PREREQUISITE

1. MAT 312 Abstract Algebra

Field extensions, algebraic closure, splitting fields, separable and inseparable extensions, normal extensions, finite fields, The Chevalley-Warning theorem, Galois extensions, fundamental Theorem of Galois theory, cyclic and cyclotomic extensions, solving equations by radicals, ruler and compass constructions, construction of regular polygons.

Noetherian rings and Noetherian modules, Hilbert's basis theorem, integral extensions, Hilbert zero theorem, localization, discrete valuation fields.

TEXTBOOKS/REFERENCES

1. M. Artin, *Algebra*, Phi Learning Pvt. Ltd., New Delhi, 2011.
2. M. F. Atiyah and I. G. McDonald, *Introduction to Commutative Algebra*, Westview Press, 1994.
3. B. Singh, *Basic Commutative Algebra*,World Scientific, 2011.
4. D. S. Dummit and R. M. Foote, *Abstract Algebra*, 3rd Edition, Wiley India, 2011.
5. S. Lang, *Algebra*, 4th ed., Springer 2005.
6. Thomas Hungerford, *Algebra*, Graduate Texts in Mathematics, Springer, 2005.

MAT 324 Theory of Ordinary Differential Equations [3003]

PREREQUISITE

1. MAT 311 Real Analysis

Review of various solving techniques: integrating factor method, separation of variables, variation of parameters, method of undetermined coefficients.

Existence and uniqueness of initial value problems: Picard-Lindelöf theorem, Peano's existence theorem, Cauchy-Peano existence theorem, Gronwall's inequality, maximal and minimal solutions, right derivates, differential inequalities, uniqueness theorems, dependence on initial conditions and parameters.

Linear systems: existence and uniqueness of solutions of systems, general properties of linear systems, fundamental matrix solution, systems with constant coefficients, periodic linear systems, asymptotic behaviour of solutions of linear systems.

Stability theory: stability of quasi-linear systems, two-dimensional autonomous systems, limit cycles and periodic solutions, Poincaré-Bendixson theory in two-dimension, Lyapunov's direct method for autonomous systems.

Boundary value problems: Linear BVP, Green's function, maximum principles, Sturm-Liouville theory, comparison principle, eigenfunction expansion.

TEXTBOOKS/REFERENCES

1. Philip Hartman, *Ordinary Differential Equations*, 2nd Edn., SIAM, 2002.
2. E.A. Coddington and N. Levinson, *Theory of Ordinary Differential Equations*, McGraw-Hill, 1984.
3. Lawrence Perko, *Differential Equations and Dynamical Systems*, 3rd Edn., Springer, 2006.
4. Ravi P. Agarwal and Donal O'Regan, *An Introduction to Ordinary Differential Equations*, Springer, 2008.
5. G.F. Simmons, *Differential Equations with Applications and Historical Notes*, 2nd Edn., McGraw-Hill, 1991.
6. Hirsch and Smale, *Differential Equations, Dynamical Systems and Linear Algebra*, Academic Press, 1974.
7. Ivar Stakgold, *Green's Functions and Boundary Value Problems*, Wiley, New York, 1979.
8. G. Birkhoff and G-C Rota, *Ordinary Differential Equations*, 4th Edn., Wiley, 2004.

MAT 325 General Topology [3003]

PREREQUISITE

1. MAT 311 Real Analysis

Topological Spaces and Continuous Functions: Topological spaces, Basis for a topology, The order topology, The product topology, The subspace topology, Closed sets and limit points, Continuous functions, The metric topology, The quotient topology.

Connectedness and Compactness: Connected spaces, connected sets in the real line, Components and path components, Local Connectedness, Compact spaces, Limit point compactness, Local compactness. Tychonoff's theorem for finite products.

Countability and Separation Axioms: The countability axioms, The separation axioms, The Urysohn lemma.

The Tychonoff theorem, Completely regular spaces, one-point compactification.

Homotopy, Fundamental Groups, examples and computations.

TEXTBOOKS/REFERENCES

1. J.R. Munkres, *Topology*, 2nd Edition, Prentice Hall, 2000.
2. G.F. Simmons, *Introduction to Topology and Modern Analysis*, McGraw-Hill, 1963.
3. J.Dugundji, *Topology*, Prentice Hall, 1965.
4. I.M. Singer and J.A. Thorpe, *Lecture Notes on Elementary Topology and Geometry*, Springer, 1976.

MAT 411 Functional Analysis [3003]

PREREQUISITES

1. MAT 321 Complex Analysis
2. MAT 322 Measure Theory and Integration

Normed linear spaces, Riesz lemma, characterization of finite dimensional spaces, Banach spaces. Operator norm, continuity and boundedness of lin-

ear maps on a normed linear space.

Fundamental theorems: Hahn-Banach theorems, uniform boundedness principle, divergence of Fourier series, closed graph theorem, open mapping theorem and some applications.

Dual spaces and adjoint of an operator: Duals of classical spaces, weak and weak* convergence, adjoint of an operator.

Hilbert spaces: Inner product spaces, orthonormal set, Gram-Schmidt ortho-normalization, Bessel's inequality, orthonormal basis, separable Hilbert spaces. Projection and Riesz representation theorems: Orthonormal complements, orthogonal projections, projection theorem, Riesz representation theorem.

Bounded operators on Hilbert spaces: Adjoint, normal, unitary, self-adjoint operators, compact operators.

Spectral theorem: Spectral theorem for compact self adjoint operators, statement of spectral theorem for bounded self adjoint operators.

TEXTBOOKS/REFERENCES

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. Martin Schechter, *Principles of Functional Analysis*, AMS (Indian Edition, Uni. Press), 2009.
7. Peter D. Lax, *Functional Analysis*, Wiley-InterScience, 2002.
8. M. Reed and B. Simon, *Functional Analysis (Methods of Modern Mathematical Physics - Volume 1)*, Academic Press, 1981.
9. Y. Eidelman, V. Milman and A. Tsolomitis, *Functional Analysis: An Introduction*, GSM, Vol. 66, AMS, 2004.
10. B. Bollabas, *LinearAnalysis*, CambridgeUniversityPress(IndianEdition), 1999.
11. E. Kreyeszig, *Introduction to Functional Analysis with Applications*, Wiley, 1989.

MAT 412 Analysis on Manifolds [3003]

PREREQUISITES

1. MAT 311 Real Analysis
2. MAT 313 Advanced Linear Algebra

Functions of several Variables: Differentiation, Directional derivatives, Chain rule, Inverse function theorem and implicit function theorem.

Integration: Integration over a rectangle, surface and volume integrals, Fubini's theorem, Change of variables formula, Partitions of unity.

Submanifolds in $\mathbb{R}^n$, tangent spaces.

Differential forms: Multilinear algebra, tensors, tensor products, alternating tensors, wedge product, tangent vectors, differential forms, orientation, Stoke's theorem, derivations of the classical formulations.

TEXTBOOKS/REFERENCES

1. J. R. Munkres, *Analysis on Manifolds*, Westview Press, 1997.
2. W. H. Flemming, *Functions of severable Variables*, Springer, 1987.
3. Michael 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 413 Partial Differential Equations [3003]

PREREQUISITE

1. MAT 324 Theory of Ordinary Differential Equations

Second order linear partial differential equations: Laplace's equation, fundamental solution, mean value formulas, Green's function, maximum principle, energy methods; Heat equation, fundamental solution, mean value formulas, energy methods; Wave equation, solution by spherical means, non-homogeneous problem, energy methods.

First order partial differential equations: semilinear equations, quasilinear equations, solution of a Cauchy problem; first order nonlinear equations, Charpit's equations, Cauchy problem, the complete integral; Hamilton-Jacobi equations, calculus of variations, Hopf-Lax Formula.

TEXTBOOKS/REFERENCES

1. Lawrence C. Evans, *Partial Differential Equations*, 2nd Edition, American Mathematical Society, 2010.
2. R. McOwen, *Partial Differential Equations: Methods and Applications*, 2nd Edition, Pearson, 2002.
3. Gerald B. Folland, *Introduction to Partial Differential Equations*, 2nd Edition, Princeton University Press, 1995.
4. Fritz John, *Partial Differential Equations*, 4th Edition, Springer, 1981.
5. Michael E. Taylor, *Partial Differential Equations I*, 2nd Edition, Springer, 2010.
6. S. Kesavan, *Topics in Functional Analysis and Applications*, Wiley, 1989.

MAT414 Rings, Modules and Algebras [3003]

PREREQUISITE

1. MAT 312 Abstract Algebra

Basics of Module theory, fundamental theorem of finitely generated modules over a PID, Jordan and Rational Canonical forms, Tensor products, Free, projective, injective and flat modules, Localization, primary decomposition theorem, integral extensions, Noetherian and Artinian modules, Wedderburn's structure theorem, Going Up, Going down theorems, Krulls Intersection and Principal Ideal theorems, Completion, Dimension theory.

TEXTBOOKS/REFERENCES

1. M. F. Atiyah and I. G. McDonald, *Introduction to Commutative Algebra*, Westview Press, 1994.
2. S. Lang, *Algebra*, 4th ed., Springer 2005.
3. D. S. Dummit and R. M. Foote, *Abstract Algebra*, 3rd Edition, Wiley India, 2011.

MAT 421 Probability Theory and Stochastic Processes [3003]

PREREQUISITE

1. MAT 322 Measure Theory and Integration

Review of measure theory: measure spaces, Lebesgue measure, integration, transformations, product spaces.

Random variables: distributions and expectations.

Weak convergence: characteristic functions, moment generating functions, weak convergence.

Sum of independent random variables: independence and convolution, Khintchine's weak law of large numbers, strong limit theorems, series of independent random variables, Kolmogorov's strong law of large numbers.

The central limit theorems: tight families of probability distributions, Prokhorov's theorem, Skorohod's theorem, compact support functions, the central limit theorem.

Dependent random variables: conditioning, conditional expectation and conditional probability, Markov chains.

Basics of continuous time stochastic process, Poisson process and Brownian motion.

TEXTBOOKS/REFERENCES

1. K. B. Athreya and S. N. Lahiri, *Measure Theory and Probability Theory*, Hindustan Book Agency, 2006.
2. R. M. Dudley, *Real Analysis and Probability*, Cambridge University Press, 2002.
3. S. R. S. Varadhan, *Probability Theory*, Courant Institute of Mathematical Sciences, 2001.
4. Rick Durrett, *Probability: Theory and Examples*, 4th Edition, Cambridge University Press, 2010.
5. D. W. Stroock, *Probability Theory, An Analytic View*, 2nd Edition, Cambridge University Press, 2010.
6. A. N. Shiryaev, *Probability*, 2nd Edition, Springer, 1995.
7. Jean Jacod and Philip Protter, *Probability Essentials*, 2nd Edition, Springer, 2004.
8. Leo Breiman, *Probability*, Society for Industrial and Applied Mathematics, 1992.
9. P. Billingsley, *Probability and Measure*, 3rd Edition, Wiley (India), 2008.
10. O. Kallenberg, *Foundations of Modern Probability*, 2nd Edition, Springer, 2010.
11. K. R. Parthasarathy, *Introduction to Probability and Measure*, Hindustan Book Agency, 2005.

Partial List of Electives

1. Algebraic Geometry
2. Algebraic Number Theory
3. Algebraic Topology
4. Rings, Modules and Algebras
5. Lie Groups and Lie Algebras
6. Representation Theory
7. Category Theory
8. Nonnegative Matrices and Applications
9. Operator Algebras
10. C^* Algebras
11. Graph Theory
12. Diophantine Approximations
13. Harmonic Analysis
14. Topics in Analysis
15. Topics in Applied Mathematics
16. Advanced Partial Differential Equations
17. Stochastic Analysis
18. Control Theory
19. Mathematical Finance
20. Financial Engineering
21. Mathematical Fluid Dynamics
22. Calculus of Variations
23. Operations Research
24. Discrete Mathematics
25. Programming and Data Structures
26. Finite Element Methods
27. Operator Theory
28. Ergodic Theory
29. Category Theory and Applications
30. Complex Geometry
31. Topics in Group Theory and Number Theory
32. Geometry of Schemes
33. Class Field Theory
34. Introduction to Nonnegative Matrices
35. Elliptic Curves and Modular Forms
36. Topics in Matrix Analysis
37. An Introduction to Stochastic Calculus and its Applications
38. Fourier Analysis
39. Matrix Analysis
40. Topics in Number Theory
41. Complex Dynamics
42. Mathematical Biology
43. Infinite Dimensional Stochastic Analysis
44. Wavelets and Frames
45. Research Methodology

Physics Syllabus

Theory Courses

PHY 311 Mathematical Methods in Physics [3003]

Ordinary differential equations [10]:
Linear equations: Solution space, linear independence, Wronskians. Eigenvalue problems: Boundary conditions, self-adjointness, completeness of Eigen functions, Fourier series, continuous spectra and Fourier integrals. Series solution; Green Functions for ordinary differential operators.

Partial Differential equations [10]:
Preliminaries, important partial differential equations (e.g. heat and wave equations, Poissons and Laplace equations, Helmholtz equation), Solution by separation of variables in cartesian and spherical polar coordinate systems; Greens function for partial differential operators.

Special functions and Applications [2].

Complex Analysis [9]:
Functions of complex variable, limits and continuity, derivatives, analyticity, Cauchy-Riemann conditions, Types of singularities with examples, Contour integrals, Cauchys theorem, Cauchys integral formula, Moreras theorem, Taylor series, Laurent series, Calculus of residues: Residue theorem, Definite real integrals using residue theorem, Cauchys principal value.

Group theory [3]:
Basic concepts: definition, cosets, conjugacy classes, invariant subgroup, factor group, direct product; Representation of groups: definition, unitary representation, reducible and irreducible representation.

TEXTBOOKS/REFERENCES

1. G. B. Arfken and H. J. Weber, *Mathematical methods for physicists*, Academic press.
2. Murray Spiegel, Seymour Lipschutz, John Schiller and Dennis Spellman, *Schaum's Outline of Complex Variables*, 2ed (Schaum's Outline Series).
3. Tulsi Dass and Satish K Sharma, *Mathematical methods in classical and quantum physics*, Universities Press.

4. Dennery and Andre Krzywicki, *Mathematics for Physicists*, Dover.

PHY 312 Classical Mechanics [3003]

Review of Newtonian mechanics, Generalized coordinates, The principle of least action, Lagrange's equation, The Lagrangian for a free particle and for a system of particles;Symmetries, Conservation laws and Noethers theorem, Conservation of energy, momentum and angular momentum; Integrating the equations of motion: motion in one dimension, Central force motion and Kepler's problem, Collisions: elastic collisions, scattering and Rutherfords formula.

Motion of a rigid body, Angular velocity, Moment of inertia, Angular momentum, Euler angles, Euler's equations. Motion in a non-inertial frame; Small oscillations: simple harmonic, forced, damped and anharmonic oscillations; The Hamilton equations of motion, Legendre transformations, Cyclic coordinates, Routhian; Invariance properties of the Lagrangian and Hamiltonian descriptions, Poisson and Lagrange brackets, Canonical transformations, Group properties and methods of constructing canonical transformations; Hamilton-Jacobi theory and action-angle variables, The harmonic oscillator as an example, The Kepler problem in action angle variables.

TEXTBOOKS/REFERENCES

1. H. Goldstein, C. Poole and J. Safko, *Classical Mechanics*, 3$^{\text{rd}}$ Ed. Addison-Wesley, 2005.
2. L. D. Landau and E. M. Lifshitz, *Mechanics*, Vol. 1 of course of Theoretical Physics, Pergamon Press, 2000.

PHY 313 Electronics I [3003]

Introduction to conductors, semiconductors and insulators. Band structure, mechanism of conduction, doping and PN junction formation. Basic semiconductor devices: PN junctions, bipolar transistors and operation.

Norton and Thevnin's Theorem rectifiers and filters: L, C, RC, LC and LCR filters.

AC and DC analysis of transistor circuits amplifiers and differential amplifiers.

Operating principles of FET, MOSFET and Operational amplifiers.

TEXTBOOKS/REFERENCES

1. A. Malvino and D. J. Bates, *Electronic principles*, Mcgraw-hill, 2006.
2. J. Millman, C. C. Halkias and S. Jit, *Electronic devices and circuits*, Tata Macgraw Hill, 2007.
3. S. M. Sze, *Semiconductor Devices, Physics and Technology* (2^{nd} Ed.), Wiley India, 2008.
4. T. L. Floyd and R. P. Jain, *Digital Fundamentals* (8^{th} Ed.), Pearson Education, 2005.

PHY 314 Quantum Mechanics I [3003]

Quantum kinematics: The state vector, Dirac Bra and Ket notation, the principle of superposition, the Stern-Gerlach experiment. Hilbert space and some general properties of linear vector spaces, Rays and vectors in Hilbert space, Normalization, Basis vectors. Non commutating operators and observables, the uncertainty principle, Operators, eigenvalues, eigenvectors, observables and expectation values (a bit of linear algebra), Quantum amplitudes, probabilities and the Born rule. A basis labeled by a continuous parameter and the wave function, The position and momentum bases, Fourier transforms, Delta function normalization, Function spaces, The uncertainty principle revisited, The probability current and the continuity equation.

Quantum Dynamics: The Schrödinger equation: The Hamiltonian and the idea of generators, finite time evolution and unitary transformations, properties of unitary transformations, time evolution of expectation values. The Heisenberg picture, Commutation relations; The time independent Schrödinger equation, Stationary states, Stationary states, Examples: particle in an infinite square well and particle in a finite square well, scattering off a potential barrier. quantum tunneling, the quantum harmonic oscillator.

The Schrödinger equation in three dimensions: The Schrödinger equation in spherical coordinates, Separation of variables, The radial equation and energy quantization, the angular equation, spherical harmonics and introduction to quantized angular momentum. Spin, The Hydrogen atom; Charged Particle in a Magnetic Field: Oscillator algebra; Energy spectrum and Eigenstates; Landau levels, Wave functions.

TEXTBOOKS/REFERENCES

1. D. J. Griffiths, *Introduction to quantum mechanics*, Benjamin-Cummins, 2004.
2. J. J. Sakurai, *Modern quantum mechanics*, Addison-Wesley, 1994.
3. R. Shankar, *Principles of quantum mechanics*, Plenum Publishers, 1994.

PHY 321 Statistical Mechanics [3003]

Review of thermodynamics and Probability theory: The Laws of Thermodynamics. Interactions The Conditions for Equilibrium, Thermal Interaction Temperature, Volume change Pressure, Particle interchange chemical potential. Random variable, Distribution function, Central limit theorem; Statistical Picture of Mechanics: Statistical description of a classical particle, Dynamics in Phase space, Ergodicity, Stationary states and Liouville theorem, Microcanonical and Canonical states.

Methadology 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; Thermodynamic Averages: The Partition Function, Generalised 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).

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 Einsten Condensation and Fermi gas at low temperatures. Weakly interacting Systems: Cluster Expansion, Van der Waal's 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.

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.

TEXTBOOKS/REFERENCES

1. F. Reif, *Statistical Physics: Berkeley Physics Course Vol. 5*, Tata Mcgraw-hill, 2011.
2. F. Mandl, *Statistical Physics* (2^{nd} Ed.), John Wiley & Sons, 1991.
3. H. B. Callen, *Thermodynamics and an Introduction To Thermostatistics*, Wiley, 2006.
4. R. K. Pathria, *Statistical Mechanics* (2^{nd} Ed.), Elsevier, 2002.

PHY 322 Condensed Matter Physics I [3003]

Crystal structure: Bravais lattice, two and three dimensional lattices, primitive cells, symmetry, space group and point groups, classification of lattices by symmetry; Experimental determination of crystal structure: Scattering from crystals, Laue method, rotating crystal method, powder method, interaction of X-rays with matter, deciphering the structure; Electronic structure: The single electron model, free electron model, specific heat of noninteracting electrons; The Schrödinger equation and symmetry: Blochs theorem, Fermi surface, density of levels, van Hove singularities, Kronig-Penny model, band structure, rotational symmetry and group representations.

Models: Nearly free electrons, Brillouin zones, tightly bound electrons,Wannier functions, tight binding model, electron-electron interactions, Hartree-Fock equations, density functional theory; Mechanical properties: elasticity, liquid crystals, phonons, Einstein and Debye models, inelastic scattering from phonons; Electron transport: Drude theory, semiclassical electron dynamics, noninteracting electrons in an electric field, Zener tunneling.

TEXTBOOKS/REFERENCES

1. Michael P. Marder, *Condensed matter physics*, John Wiley, 2000.
2. N. W. Ashcroft, N. David Mermin, *Solid state physics*, Harcourt, 1976.
3. C. Kittel, *Introduction to solid state physics*, 7^{th} edition, John Wiley, 2004.
4. A. J. Dekker, *Solid state physics*, Macmillan India , 2005.

PHY 323 Electronics II [3003]

Heterojunction Properties, Special purpose diodes: Zener, Varactor diode, Tunnel diode, Diac, Triac, LED, PV cell, Photodetectors, SCR, UJT, IGBT. Oscillators design and applications. Power amplifiers.

Advanced Electronic Materials: Optoelectronic properties and applications.

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.

TEXTBOOKS/REFERENCES

1. A. Malvino and D. J. Bates, *Electronic principles*, Mcgraw-hill, 2006.
2. J. Millman, C. C. Halkias and S. Jit, *Electronic devices and circuits*, Tata Macgraw Hill, 2007.
3. J. Millman, and C. C. Halkias, *Integrated electronics*, Tata Macgraw Hill, 2008.
4. S. M. Sze, *Semiconductor Devices, Physics and Technology* (2^{nd} Ed.), Wiley India, 2008.
5. T. L. Floyd and R. P. Jain, *Digital Fundamentals* (8^{th} Ed.), Pearson Education, 2005.

PHY 324 Electrodynamics and Special Theory of Relativity [3003]

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; Quadropole and magnetic dipole radiation; radiation from rapidly moving charge; near and far field solutions and properties of radiation.

TEXTBOOKS

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.

REFERENCES

1. David J. Griffiths, *Introduction to Electrodynamics*, Prentice Hall, 1999.
2. Frank S. Crawford Jr., *Waves*, Berkeley Physics Vol 3.
3. A. P. French, *Special Theory of Relativity*.
4. Bernard F. Schutz, *A first course in General Relativity*, Cambridge, 2009.

PHY 411 Experimental Methods [3003]

Electrical characterization 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); AC + DC mixing and application in directly obtaining various harmonics of the primary signal; Application of above in designing and measuring resistance vs temperature or voltage vs temperature (at constant current) of a diode. Fitting bare data by linearization techniques, obtaining best fit; Introduce calibration curve of a sensor and its predictive value. Error Analysis.

Vacuum Techniques: Introduction to the concept of low pressure with examples and measurement scales; Production and measurement of high and ultra high vacuum. Various pumping methods (rotary/diffusion/turbo molecular/ion/cryo pump) and their area of application; Design of a vacuum chamber, pumping impedance and pumping speed; Comparison of different gauges used in measurement (pirani/penning/ion/capacitance) operating principles and ranges of application; Working principle of a residual gas analyser; Vapour pressure and choice of materials in a vacuum system.

Cryogenics: Introduction to low and high temperature applications and its importance; Relevant temperature ranges vis-a-vis practical applications (examples from real systems). Temperature scales vs energy scales in physical systems; Room temperature to mK ($300 - 77$K, $77 - 4.2$K, $4.2 - 1.6$K, < 1.6K); Production and Measurement: Introduction to cryogens liquid nitrogen and helium, pumping on cryogens to attain lower temperatures. Types of thermometers, comparative study and application ranges and conditions (Pt100, diode, cernox, capacitance, carbon, thermocouple). T measurement in high magnetic field and low temperatures (<1.6K, >5T). Introduction to attaining high magnetic field in lab. Piecewise curve fitting for a cernox thermometer. Temperature control, negative feedback and zeroing of a PID controller. (Electrical and thermal properties of common materials at low T. Cu, Al, Pt, Si, Rubber, Silicone, PTFE, Sapphire, Carbon, Glass, Macor, Paper).

Sample deposition Techniques: Thermal, electron beam, Knudsen Cell, RF/DC sputtering, applications and limitations. Thickness measurement, profilometer etc. Selected Characterisation techniques:-Principle of pulse NMR, measurements of NMR spectra, spin-lattice relaxation time (T1) and spin-spin relaxation time (T2); Basic principles of Electron Spin Resonance (ESR) and its application; Magnetic measurement, principle of Vibrating Sample Magnetometer (VSM) and SQUID magnetometer; Measurement of heat capacities.

TEXTBOOKS/REFERENCES

1. Charles P. Slichter, *Principles of Magnetic Resonance*, Springer, 1989.
2. R. A. Dunlap, *Experimental Physics - Modern Methods*, Oxford University Press, 1988.
3. JH. Moore, C C. Davis, M A Coplan, S C. Greer, *Building Scientific Apparatus* , Cambridge University Press, (4th Ed) 2009.

4. Low Level Measurements Handbook (6/7th Ed) Keithley Instruments Publication (available online).
5. G. L. Weissler, R W Carlson, *Methods of Experimental Physics Volume 14 : Vacuum Physics and Technology* , Academic Press, 1990.
6. G K. White, P. Meeson, *Experimental Techniques in Low Temperature Physics* (3rd/4th Ed) , Oxford University Press, 1979.
7. C. J. Chen, *Introduction to Scanning Tunnelling Microscopy* (2nd Ed), Oxford University Press, 2008.
8. Vacuum Technology Know How, Pfeiffer Vacuum, 2011 (available online)

PHY 412 Condensed Matter Physics II [3003]

PREREQUISITE

1. PHY 322: Condensed Matter Physics I

Semiconductors: intrinsic and extrinsic semiconductors, hole, effective mass, laws of mass action, electron and hole mobilities, impurity band conduction , p-n junction , Shottky barrier , quantum Hall effect ; Crystal defects: Schottky vacancies, Frenkel defects, F-center etc; Optical Processes: Optical reflectance, Kramers-Kronig relations, Electronic interband transitions, Frenkel excitons, Mott-Wannier excitons, Raman effect in crystals etc.

Magnetism: dia-, para-magnetism, Curie-Weiss law, Van-Vleck and Pauli paramagnetism, ferro-, anti- and ferrimagnetism. Classical and quantum theories, Hunds rule, Exchange interaction, Heisenberg model, mean field theory, spin wave.

Superconductivity: Experimental survey, Thermodynamics of superconductors, Meissner effect, Londons equation, BCS theory, Ginzburg-Landau theory, flux quantization, coherence length, Type-I and Type-II superconductors, Superconducting tunneling, DC and AC Josephson effects, SQUIDs, High-T superconductivity: structure and transport properties.

Dielectric and Ferroelectrics: General concept, dielectric constant and polarizability, Structural phase transitions, Ferroelectric crystals, Displacive transitions: Soft phonon modes, Landau theory of the phase transition, first and second order phase transitions, Ferroelectric domains, Piezoelectricity, and Ferroelasticity; Magnetic resonance.

TEXTBOOKS/REFERENCES

1. Michael P. Marder, *Condensed matter physics*, John Wiley, 2000.

2. N. W. Ashcroft, N. David Mermin, *Solid state physics*, Harcourt, 1976.
3. C. Kittel, *Introduction to solid state physics*, 7^{th} edition, John Wiley, 2004.
4. A. J. Dekker, *Solid state physics*, Macmillan India, 2005.

PHY 413 Quantum Mechanics II [3003]

PREREQUISITES

1. PHY 314: Quantum Mechanics I
2. PHY 312: Classical Mechanics

Angular Momentum: Angular Momentum algebra; Eigenvalues and Eigenstates of Angular Momentum; SU(2) Representations; Addition of Angular Momentum; Schwinger's Oscillator Model of angular momentum; Motion in Central Potential, Spherical waves, Resolution of a plane wave, Asymptotic properties of Radial wave-functions, Coulomb potential, Accidental degeneracy.

Approximation methods: Time-independent Perturbation Theory (non-degenerate case, degenerate case), and Applications (Fine structure of hydrogen, relativistic and spin-orbital effects, Zeeman effect, Stark effect, Van der Waals interaction); Variational Methods and Applications (Ground and Excited states of Helium). Semi-classical (WKB) Approximation and Applications (Bohr-Sommerfeld quantization rule, Tunneling, Transition Probabilities, Bound-state energies etc).

Time-dependent Potentials and the Interaction Picture: Time-dependent Perturbation Theory, Applications to Interactions with the Classical Radiation Field, Fermi's Golden rule; Transition rates, Spontaneous emission, Energy Shift and Decay Width. The Adiabatic Approximation and Geometrical Phase: Adiabatic theorem, Berry's phase, Application to spin in a time-varying Magnetic Field, Born-Oppenheimer approximation.

Identical particles, Permutation Symmetry, Symmetrization Postulate, Two electron system, The Helium Atom, Permutation symmetry and Young Tableau.

Scattering theory: Scattering cross-section; Lippmann-Schwinger Equation; Born Approximation and application to scattering from various spherically symmetric potentials, including Yukawa and Coulomb; Optical theorem; Eikonal approximation; Free-Particle states (plane waves, spherical waves); Method of Partial Waves; Low-Energy Scattering and Bound States; Resonance Scattering; Identical Particles and Scattering;

Symmetry considerations in Scattering; Time-dependent formulation of Scattering; Inelastic Electron-Atom Scattering.

TEXTBOOKS/REFERENCES

1. J. J. Sakurai, *Modern quantum mechanics*, Addison-Wesley, 1994.
2. R. Shankar, *Principles of quantum mechanics*, Plenum Publishers, 1994.
3. Cohen-Tannoudji and Diu-Laloë, *Quantum Mechanics* (2 volumes), Wiley, 2000.
4. L. D. Landau and E. M. Liftshitz, *Quantum Mechanics* Vol-3 of course of theoretical physics, Butterworth-Heinmann, 2000.

List of Electives in Physics

Sl. No.	Experimental/Applied Courses	Sl. No.	Theory Courses
1.	Atomic and Molecular Physics (PHY-422) Prerequisites: Quantum Mechanics-II	1.	High Energy Physics (PHY-421) Prerequisites: Quantum Mechanics-II
2.	Semiconductor Physics and Technology (PHYxxxx) Prerequisites: Electronics-I	2.	Computational Techniques & Programming Language (PHY-423)
3.	Quantum Transport (PHYxxxx) Prerequisites: CMP-I and QM-I	3.	Quantum Field Theory (PHYxxx) Prerequisites: QM-II, ED and STR
4.	Principles of Digital Imaging (PHYxxxx) Prerequisites: Numerical Methods (familiarity with MATLAB)	4.	Quantum Information Theory (PHYxxxx) Prerequisites: QM-I
5.	Nanoscale Physics (PHYxxxx) Prerequisites: CMP-I and QM-I	5.	Non-linear Dynamics (PHYxxxx) Prerequisites: Mathematical Methods in Physics
6.	Non-linear Optics and Photonics Prerequisites: Mathematical Methods in Physics	6.	Numerical Simulation Techniques in Physics (PHYxxxx)
7.	Lasers and Fiber Optics (PHYxxxx) Prerequisites: QM-I and Mathematical Methods in Physics	7.	General Relativity and Cosmology (PHYxxxx) Prerequisites: Classical Mechanics, ED and STR
8.	Organic Semiconductors: Fundamentals and Applications (PHYxxxx)	8.	Astrophysics (PHYxxxx) Prerequisites: ED and STR, Classical Mechanics, Statistical Mechanics
9.	Sensor Technology (PHYxxxx) Prerequisites: CMP-I and Electronics-I	9.	Quantum Many-body Theory (PHYxxxx) Prerequisites: QM-II
10.	Low Temperature Physics (PHYxxxx)	10.	Fluid Dynamics (PHYxxxx) Prerequisites: Classical Mechanics, ED and STR, Statistical Mechanics
11.	Probes in Condensed Matter Physics (PHYxxxx)	11.	Advanced Statistical Physics (PHYxxxx) Prerequisites: Statistical Mechanics
12.	Research Methodology	12.	Research Methodology

Laboratory Courses

PHY 315 Advanced Physics Experiments I [0093]

1. Viscosity of a liquid - Oscillating disc method
2. Young's modulus: Cornu's method
3. Spectrometer- $i - i'$ curve
4. Spectrometer- Hartmann's constant
5. Young's modulus- Optic lever method
6. Surface tension- Capillary method
7. Beam profile of laser
8. Diffraction by ultrasonic waves- velocity of sound in liquid
9. e/m - Thomson's method
10. Fabrey-Perot interferometer
11. Michelson's interferometer
12. LCR circuit (series and parallel)- Frequency response and the value of unknown L
13. Transistor characteristics and transistor as an amplifier
14. Phase shift oscillators

PHY 325 Advanced Physics Experiments II [0093]

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 Tunnelling Microscope - Topography

PHY 414 Advanced Physics Experiments III [0093]

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