Courses of Study

IISER Mohali

July 2019

Contents

Chapter 1

Course Structure

1.1 BS-MS Programme Core Semesters

Semester 1

Number	Title	Credits
BIO101	Cellular basis of life	3
BIO111	Biology Lab I	1
CHM101	Chemistry of elements and chemical transformations	3
CHM111	Chemistry Lab I	1
HSS101	Language skills-A *or* B	2
IDC101	Introduction to computers	2
MTH101	Symmetry	3
PHY101	Mechanics	3
PHY111	Physics Laboratory I	1

Semester 2

Number	Title	Credits
BIO102	Gene expression and development	3
BIO112	Biology Lab II	1
CHM102	Atoms molecules and symmetry	3
CHM112	Chemistry Lab II	1
HSS102	History of science	2
IDC102	Hands-on electronics	2
MTH102	Analysis in one variable	3
PHY102	Electromagnetism	3
PHY112	Physics Laboratory II	1

Semester 3

Number	Title	Credits
BIO201	Genetics and evolution	3
BIO211	Biology Lab III	1
CHM201	Spectroscopic and other physical methods	3
CHM211	Chemistry Lab III	1
IDC211	Workshop Training	1
IDC2**	Core Elective I	2
MTH201	Curves and surfaces	3
PHY201	Waves and optics	3
PHY211	Physics Laboratory III	1

Semester 4

Number	Title	Credits
BIO202	Behaviour and ecology	3
BIO212	Biology Lab IV	1
CHM202	Energetics and dynamics of chemical reactions	3
CHM212	Chemistry Lab IV	1
HSS202	Philosophy of science	2
IDC2**	Core Elective II	2
MTH202	Probability and statistics	3
PHY202	Thermodynamics and statistical physics	3
PHY212	Physics Laboratory IV	1

1.2 BS-MS Programme Majors

Biology

Semester 5

Number	Title	Credits
BIO301	Animals: Form and Function	4
BIO302	Advanced cell biology	4
BIO303	Experimental design and hypothesis testing	4
BIO311	Molecular methods in biology lab	4
******	Open Elective I	4
IDC351	Seminar (attending)	1

Semester 6

Number	Title	Credits
BIO304	Essential biochemistry	4
BIO305	Advanced developmental biology	4
BIO306	Plants: form and function	4
BIO312	Development and physiology lab	4
******	Open Elective II	4
IDC352	Seminar (attending)	1

Semester 7

Number	Title	Credits
BIO401	Structure and function of genomes	4
BIO402	Microbial physiology and microbial genertics	4
BIO411	Bioinformatics lab	4
BIO***	Biology Elective I	4
******	Open Elective III	4
******	Open Elective IV	4
IDC451	Seminar (delivering)	1

Semester 8

Number	Title	Credits
BIO403	Advanced evolutionary biology	4
BIO404	Cellular & molecular basis of immune response	4
BIO412	Lab on biophysical and spectroscopic tools	4
BIO***	Biology Elective II	4
******	Open Elective V	4
IDC452	Seminar (delivering)	1

Chemistry

Semester 5

Number	Title	Credits
CHM301	Quantum Chemistry	4
CHM302	Organic Reactions	4
CHM303	Main group chemistry	4
CHM311	Organic chemistry lab	4
******	Open Elective I	4
IDC351	Seminar (attending)	1

Semester 6

Number	Title	Credits
CHM304	Symmetry in chemistry	4
CHM305	Physical organic chemistry	4
CHM306	Transition metal chemistry	4
CHM312	Inorganic chemistry lab	4
******	Open Elective II	4
IDC352	Seminar (attending)	1

Semester 7

Number	Title	Credits
CHM401	Molecular spectroscopy	4
CHM402	Chemistry of materials	4
CHM411	Physical chemistry lab	4
CHM***	Chemistry Elective I	4
******	Open Elective III	4
******	Open Elective IV	4
IDC451	Seminar (delivering)	1

Semester 8

Number	Title	Credits
CHM403	Analytical chemistry	4
CHM404	Statistical thermodynamics	4
CHM412	Analytical chemistry lab	4
CHM***	Chemistry Elective II	4
******	Open Elective V	4
IDC452	Seminar (delivering)	1

Mathematics

Semester 5

Number	Title	Credits
MTH301	Analysis in $\mathbf{R}^n$	4
MTH302	Integers, polynomials and matrices	4
MTH303	Ordinary & partial differential equations	4
MTH304	Topology	4
******	Open Elective I	4
IDC351	Seminar (attending)	1

Semester 6

Number	Title	Credits
MTH305	Complex analysis	4
MTH307	Discrete mathematics	4
MTH308	Groups and fields	4
MTH309	Measure and probability	4
******	Open Elective II	4
IDC352	Seminar (attending)	1

Semester 7

Number	Title	Credits
MTH402	Functional analysis	4
MTH403	Manifolds	4
MTH***	Maths elective I	4
MTH***	Maths elective II	4
******	Open Elective III	4
******	Open Elective IV	4
IDC451	Seminar (delivering)	1

Semester 8

Number	Title	Credits
MTH***	Maths elective III	4
MTH***	Maths elective IV	4
MTH***	Maths elective V	4
MTH***	Maths elective VI	4
******	Open Elective V	4
IDC452	Seminar (delivering)	1

Physics

Semester 5

Number	Title	Credits
PHY301	Classical mechanics	4
PHY302	Quantum mechanics	4
PHY303	Electrodynamics	4
PHY310	Mathematical methods for Physicists I	4
PHY311	Advanced optics and spectroscopy lab	4
IDC351	Seminar (attending)	1

Semester 6

Number	Title	Credits
PHY304	Statistical mechanics	4
PHY306	Advanced quantum mechanics	4
PHY312	Advanced electronics & instrumentation lab	4
PHY***	Physics elective I	4
******	Open elective I	4
IDC352	Seminar (attending)	1

Semester 7

Number	Title	Credits
PHY401	Nuclear and particle physics	4
PHY402	Solid state physics	4
PHY403	Atomic and molecular physics	4
PHY411	Nuclear physics lab	4
******	Open elective II	4
******	Open elective III	4
IDC451	Seminar (delivering)	1

Semester 8

Number	Title	Credits
PHY412	Condensed matter physics lab	4
PHY***	Physics elective II	4
PHY***	Physics elective III	4
******	Open elective IV	4
******	Open elective V	4
IDC452	Seminar (delivering)	1

1.3 BS-MS Programme Research Year

Semester 9

Number	Title	Credits
******	Open Elective VI	4
PRJ501	Thesis Research I	16

Semester 10

Number	Title	Credits
******	Open Elective VII	4
PRJ502	Thesis Research II	16

1.4 Integrated PhD Programme

Biology

Semester 1

Number	Title	Credits
BIO**	Biology elective I	4
BIO**	Biology elective II	4
BIO303	Experimental design and hypothesis testing	4
BIO411	Bioinformatics lab	4
******	Open Elective I	4
IDC451	Seminar (delivering)	1

Semester 2

Number	Title	Credits
BIO**	Biology elective III	4
BIO**	Biology elective IV	4
BIO313	Experimental biology lab	4
******	Open Elective II	4
******	Open Elective III	4
IDC452	Seminar (delivering)	1

Semester 3

Number	Title	Credits
BIO**	Biology elective V	4
BIO**	Biology elective VI	4
BIO**	Biology elective VII	4
******	Open Elective IV	4
PRJ406	One semester project	6

Semester 4

Number	Title	Credits
BIO***	Biology Elective VIII	4

plus

******	Open Elective V	4
PRJ416	One semester Project	16

or

BIO412	Lab on biophysical and spectroscopic tools	4
PRJ416	One semester Project	16

Chemistry

Semester 1

Number	Title	Credits
CHM301	Quantum Chemistry	4
CHM311	Organic chemistry lab	4
CHM401	Molecular spectroscopy	4
IDC451	Seminar (delivering)	1
CHM601	Advanced inorganic chemistry	4
CHM6**	Chemistry Elective I	4

Semester 2

Number	Title	Credits
CHM304	Symmetry in chemistry	4
CHM305	Physical organic chemistry	4
CHM312	Inorganic chemistry lab	4
CHM404	Statistical thermodynamics	4
IDC452	Seminar (delivering)	1
CHM604	Advanced organic chemistry	4

Semester 3

Number	Title	Credits
CHM402	Chemistry of materials	4
CHM411	Physical chemistry lab	4
******	Open Elective I	4
******	Open Elective II	4

plus

PRJ406	One semester Project	6

or

*******	Open Elective III	4
PRJ401	One semester project	2

Semester 4

Number	Title	Credits
CHM403	Analytical chemistry	4
CHM412	Analytical chemistry lab	4
******	Open Elective IV	4
******	Open Elective V	4
PRJ408	One semester Project	8

Mathematics

Semester 1

Number	Title	Credits
MTH301	Analysis in $\mathbf{R}^n$	4
MTH302	Integers, polynomials and matrices	4
MTH303	Ordinary & partial differential equations	4
MTH304	Toplogy	4
******	Open Elective I	4
IDC451	Seminar (delivering)	1

Semester 2

Number	Title	Credits
MTH305	Complex analysis	4
MTH307	Discrete mathematics	4
MTH308	Groups and fields	4
MTH309	Measure and probability	4
******	Open Elective II	4
IDC452	Seminar (delivering)	1

Semester 3

Number	Title	Credits
MTH402	Functional analysis	4
MTH403	Manifolds	4
MTH***	Maths elective I	4
MTH***	Maths elective II	4
******	Open Elective III	4
******	Open Elective IV	4

Semester 4

Number	Title	Credits
MTH***	Maths elective III	4
MTH***	Maths elective IV	4
MTH***	Maths elective V	4
MTH***	Maths elective VI	4

plus

******	Open Elective V	4
PRJ401	One semester Project	2

or

PRJ406	One semester Project	6

Physics

Semester 1

Number	Title	Credits
PHY301	Classical mechanics	4
PHY302	Quantum mechanics	4
PHY303	Electrodynamics	4
PHY311	Advanced optics and spectroscopy lab	4
PHY***	Physics elective I	4
IDC451	Seminar (delivering)	1

Semester 2

Number	Title	Credits
PHY304	Statistical mechanics	4
PHY306	Advanced quantum mechanics	4
PHY312	Advanced electronics & instrumentation lab	4
PHY***	Physics elective II	4
******	Open elective I	4
IDC452	Seminar (delivering)	1

Semester 3

Number	Title	Credits
PHY401	Nuclear and particle physics	4
PHY402	Solid state physics	4
PHY403	Atomic and molecular physics	4
PHY411	Nuclear physics lab	4
******	Open elective II	4

plus

******	Open elective III	4

or

PRJ404	One semester project	4

Semester 4

Number	Title	Credits
PHY412	Condensed matter physics lab	4
PHY***	Physics elective III	4
PHY***	Physics elective IV	4
******	Open elective IV	4

plus

******	Open elective V	4
PRJ401	One semester project	2

or

PRJ406	One semester project	6

Chapter 2

BS-MS Programme Core Courses

In what follows a line such as

[Cr:*a*, Lc:*b*, Tt:*c*, Lb:*d*]

indicates a course having a credits with b lecture hours, c tutorial hours and d lab hours. For more details on how the credit system is used for calculations please consult the "Rules, Procedures and Guidelines for Academics at IISER Mohali."

2.1 Biology Core Courses

BIO101: Cellular basis of life

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- Diversity of Life forms and the evolution of body plans. Properties of life. Darwins voyage and the theory of natural selection- an introduction.
- Molecules of Life: pH and Buffers in Biology. Chemistry of water. The chemistry of carbon. Proteins. Functions of proteins. Amino acids as building blocks of proteins. How proteins fold and unfold. Nucleic acids as information molecules. DNA and RNA Carbohydrates. Simple sugars, polysaccharides. Lipids and Vitamins
- Origin of Life: Origin of cells. Cell Theory What is life? Theories about the origin of life. The Miller-Urey experiment. Theories about the origin of cells
- Cell structure and cell processes: Prokaryotic cells and eukaryotic cells Organelles of eukaryotic cell: Nucleus, endoplasmic reticulum, Golgi apparatus, vesicles, peroxisomes, hydrogenosomes, Organelles that contain DNA. The evolution of eukaryotic organelles
- Membranes as fluid layers of lipid: The phospholipids bilayer. The fluid mosaic model. Model Membranes Membrane proteins. Passive transport across membranes: Diffusion, facilitated diffusion, Osmosis. Active transport

- Cell-cell interactions: Receptor proteins and signaling between cells. Types of cell signaling. Intracellular receptors Cell-surface receptors. Second messengers to transmit signals. Cell-surface proteins mediate cell-cell interactions. Intercellular adhesion. Tight junctions. Anchoring junctions. Communicating junctions.

- Energy and metabolism: The law of thermodynamics in living things. Free energy. Activation energy. Enzymes as biological catalysts. Mechanisms of enzyme action. Enzymes take many forms-multienzyme complexes, Ribozymes and Abzymes Factors affecting enzyme action. ATP as the energy currency of life. Metabolism as the chemical life of a cell.

- How cells harvest energy: Chemical energy to drive metabolism. Energy-rich intermediates. Mitochondria. Harvesting energy by extracting electrons. The chemiosmotic hypothesis. Summarizing aerobic respiration. Regulating aerobic respiration. Catabolism of proteins and fats as a source of energy. Fermentation. Metabolism of food without oxygen
  Chloroplasts-photosynthetic electron transport, Calvin cycle.

Recommended Reading

- D. Sadava, W. K. Purves, G. H. Orians, and H. C. Heller, *Life: the science of biology*, 8th Edn., Sinauer Assoc. & Freeman & Co. (2008).

- N. A. Campbell, J. B. Reece, R. B. Jackson, M. L. Cain, L. A. Urry, S. A. Wasserman, P. V. Minorsky, *Biology*, 8th Edn. Benjamin-Cummings Pub Co. (2007).

BIO111: Biology Lab I

[Cr:1, Lc:0, Tt:0, Lb:3]

Course Outline

- This laboratory is designed to study cells as the fundamental functional units of life and their diversity. The lab will introduce students to major techniques used to study cells and sub-cellular compartments. Students will learn the use of microscopy, cell culture, molecular biology tools, biochemical and physiological analysis to understand the structure and function of cells.

BIO102: Gene expression and development

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- Cell division: Cell division in bacteria and eukaryotes. Discovery of chromosomes. Mitosis and cytokinesis. Cell cycle control.

- Meiosis: Meiosis produces haploid cells from diploid cells. Discovery of reductional division. Features of meiosis: synapsis, homologous recombination, reductional division. Chromosomal basis of inheritance

- The transplantation experiments. The Griffith experiments. The Avery-Chase experiments. The structure of DNA. DNA replication. The Meselson-Stahl experiment. The replication process. Eukaryotic DNA replication.
- The central dogma in biology: The genetic code. Discovery of the genetic code. Organization of prokaryotic and eukaryotic genes and chromosomes. Transcription. Translation. Differences between prokaryotic and eukaryotic gene expression.
- Control of Gene expression: Transcriptional regulation in bacteria. The operon. Repressors, promoters and activators. Transcriptional regulation in eukaryotes. Effect of chromosome structure. Post-transcriptional control in eukaryotes.
- Cellular mechanisms of Development: Overview of development. Vertebrate development,Insect development, Plant development. Multicellular organisms employ the same mechanism of development. Cell movement and induction.Determination. Pattern formation. Expression of homeotic genes. Programmed cell death.
- Gene Technology. Recombinant DNA technology. Restriction endoncleases. Gene cloning, techniques, Plasmids, Vectors, Expression vectors, cloning vectors, cDNA libraries, genomic libraries, DNA sequencing, PCR.
- Genomics: Genome sequencing projects. The history of the human genome sequencing project. Strategies for genome sequencing. Uses and challenges in genomics.

Recommended Reading

- D. Sadava, W. K. Purves, G. H. Orians, and H. C. Heller, *Life: the science of biology*, 8th Edn., Sinauer Assoc. & Freeman & Co. (2008).
- N. A. Campbell, J. B. Reece, R. B. Jackson, M. L. Cain, L. A. Urry, S. A. Wasserman, P. V. Minorsky, *Biology*, 8th Edn. Benjamin-Cummings Pub Co. (2007).

BIO112: Biology Lab II

[Cr:1, Lc:0, Tt:0, Lb:3]

Course Outline

- This laboratory is designed to train students in major techniques used to study gene expression as well as to expose students to important concepts in Developmental Biology. Students will learn basic molecular biology tools such as cloning, PCR, electrophoresis and isolation and quantification of DNA, RNA and proteins. Students will also study developmental processes in various model organisms such as *Drosophila, Caenorhabditis*, Chick, *Planaria* etc.

BIO201: Genetics and evolution

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- Transmission genetics of families: Mendel's laws, Mendelian mutants, monohybrid and dihybrid crosses, epistasis, pleiotropy and penetrance, recombination and genetic linkage. Recombination frequency. Genetic mapping.
- Natural selection: Basic idea of selection as "differential heritable reproductive success". Life-history as the timing of reproductive output and its central role in mediating selection. Field examples: The beaks of Darwin's finches. Peppered moths and industrial melanism. Laboratory examples: Evolution of lifespan/developmental rates in Drosophila, evolution of antibiotic resistance.
- Transmission genetics of populations: Gene variation as the raw material of evolution. Mutations. types of mutations. Genetic characterization of populations: genotype and allele frequencies. The Hardy-Weinberg Principle. Linkage disequilibrium. Agents of evolutionary change: One-locus two-allele models of selection, genetic drift, mutation, migration and inbreeding.
- Quantitative Genetics: Metric traits or continuous traits. Partitioning of phenotypic variance. Breeding value. Additive variation. Heritability. Artifical selection. Trade-offs. Quantititative Trait loci.
- The origin of species: Species concepts. Reproductive isolation. Allopatric and sympatric speciation. The geography of speciation.
- Systematics and Phylogeny: How we classify organisms. The taxonomic hierarchy. Convergent and divergent evolution. Evolutonary classifications and phylogeny. The molecular signatures of evolution. The molecular clock hypothesis.

Recommended Reading

- D. Sadava, W. K. Purves, G. H. Orians, and H. C. Heller, *Life: the science of biology*, 8th Edn., Sinauer Assoc. & Freeman & Co. (2008).
- N. A. Campbell, J. B. Reece, R. B. Jackson, M. L. Cain, L. A. Urry, S. A. Wasserman, P. V. Minorsky, *Biology*, 8th Edn. Benjamin-Cummings Pub Co. (2007).

BIO211: Biology Lab III

[Cr:1, Lc:0, Tt:0, Lb:3]

Course Outline

- This laboratory is designed to let students explore the basic principles and consequences of transmission genetics of families and populations. The lab will introduce students to major concepts in Mendelian, Population, Quantitative and Evolutionary genetics using laboratory and field studies. Emphasis will be laid on developing and/or testing mathematical models, experimental design, data collection, analysis, interpretation and scientific writing. Some of the issues to be addressed in the course include genetic variation, heredity, partitioning of phenotypic variance and natural selection

BIO202: Behaviour and ecology

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- Animal Behaviour: Ethology. Approaches to the study of behaviour. Learning and instinct. Development of behaviour. Communication as a key element in many animal behaviours. Circadian rhythms.
- Behavioural ecology: Evolution forces shape behaviour. Foraging behaviour. Territorial behaviour. Reproductive behaviour. Competition and sexual selection. Mating systems. Evolution of social behaviour. Examples of kin selection. Group living and the evolution of social systems.
- Population ecology: Single population growth models in continuous and discrete time Importance of time lags. Stable points, cycles and chaos. Effects of perturbations. Metapopulation dynamics.
- Community Ecology: Species interactions Lotka-Volterra models of competition and predation. Competitive exclusion, resource partitioning and other outcomes of competition.
- Conservation biology: Quantifying biodiversity. Overview of biodiversity crisis. Accelarating extinction rates. Why conservation is important. Speices endemism and hotspots. Vulnerable species. Factors responsible fore extinction: overexploitation, introduced species, disruption of ecological relationships, loss of genetic variation, Habitat loss and fragmentation. Approaches for preserving endangered species.

Recommended Reading

- D. Sadava, W. K. Purves, G. H. Orians, and H. C. Heller, *Life: the science of biology*, 8th Edn., Sinauer Assoc. & Freeman & Co. (2008).
- N. A. Campbell, J. B. Reece, R. B. Jackson, M. L. Cain, L. A. Urry, S. A. Wasserman, P. V. Minorsky, *Biology*, 8th Edn. Benjamin-Cummings Pub Co. (2007).

BIO212: Biology Lab IV

[Cr:1, Lc:0, Tt:0, Lb:3]

Course Outline

- This laboratory is designed to help the students to appreciate the interplay between organisms and their environment. This lab will introduce students to concepts and rigorous quantitative methods of research in Ecology and Behaviour including experimental design, data collection, analysis, interpretation and scientific writing using field and laboratory studies. The course will majorly focus on local ecosystems, plants and animals to address major concepts in population growth, predation, competition, migration, social behaviour, communication, Biodiversity etc.

2.2 Chemistry Core Courses

CHM101: Chemistry of elements and chemical transformations

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- Periodic table and periodicity of properties (atomic & ionic radius, electronegativity, electron affinity, ionization energy). Concept of effective nuclear charge. Electronic configuration of main group elements, transition metals, lanthanides & actenides.
- Main group elements: (i) Discussion of physical parameters & chemical properties (hydrides, oxides, halides) and their periodicity. (ii) Some unusual properties of heavy post-transition elements and their rationalization. (iii) Group-wise discussion of s-block and p-block elements covering their oxides, oxoacids, halides, hydrides, silicates, silicones, borazine, P-N & S-N compounds, polyhalides, pseudo-halogens, interhalogens and halogen cations.
- Transition elements: Nomenclature and isomerism of coordination compounds. Theories of bonding (VBT & CFT of octahedral, tetrahedral & square planar geometries). Electronic transitions (intraligand, d-d & charge transfer) & magnetic behaviour.
- Nomenclature of organic compounds. Reaction mechanism (concept of electronic and steric effects). Stereochemistry: Conformational analysis of acyclic (ethane & butane) and cyclic (cyclohexane) systems. Energies of differently substituted dimethylcyclohexanes. Chirality R & S assignment. Molecules with two stereogenic centers: eryhtro, threo, meso and d,l-racemates.
- Reaction types:
    1. Substitution reactions: Nucleophilic substitution at sp^3 carbon and its mechanism Addition reactions: Addition of X_2, HX, boranes and hydroxylation to C=C systems.
    2. Elimination reactions: Elimination reactions leading to C=C bond formation and their mechanisms. Hoffman and Saytzeff elimination.

Recommended Reading

- J. D. Lee: *Concise Inorganic Chemistry*, Indian Edition, 5th Ed, Blackwell Science Ltd, Oxford (1996).
- F. A. Cotton, G. Wilkinson, P. L. Gaus, *Basic Inorganic Chemistry*, Wiley Indian Edition, 3rd Ed, John Wiley & Sons Inc, Singapore (1995)..
- R. T. Morrison, R. N. Boyd, *Organic Chemistry*, Indian Edition, 6th Ed, Pearson Education, New Delhi (2007).
- J. E. Huheey, E. A. Keiter, R. L. Keiter, O. K. Medhi, *Inorganic Chemistry: Principles of Structure and Reactivity*, Indian Edition, 4th Ed, Pearson Education, India (2007).

- G. L. Miesler, D. A. Tars, *Inorganic Chemistry*, Indian Edition, 3rd Ed, Pearson Education, New Delhi (2007)
- P. Sykes, *A Guidebook to Mechanism in Organic Chemistry*, Indian Edition, 6th Ed, Pearson Education, New Delhi (2006).

CHM111: Chemistry Lab I

[Cr:1, Lc:0, Tt:0, Lb:3]

Course Outline

- Calibration of thermometer and determination of melting point.
- Handling of common laboratory glasswares and reagents.
- Qualitative analysis of organic compounds: Element detection and characteristic chemical reactions of organic functional groups.
- Qualitative analysis of inorganic mixture of acid and basic radicals without interfering radicals.

Recommended Reading

- B. S. Furniss, A. J. Hannaford, P. W. G. Smith, A. R. Tatchell, *Vogel's Textbook of Practical Organic Chemistry*, Indian Edition, 5th Ed, Pearson Education, New Delhi (2008).
- G. Svehla, *Vogel's Quantitative Inorganic Analysis*, Indian Edition, 7th Ed, Pearson Education, New Delhi (2006).
- F. G. Mann, B. C. Saunders, *Practical Organic Chemistry*, Indian Edition, 4th Ed, Orient Longman, Noida (2007).
- J. S. Nimitz, *Experiments in Organic Chemistry: From Microscale to Macroscale*, Prentice Hall, New Jersey (1990).

CHM102: Atoms molecules and symmetry

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- Atomic structure, spectrum of hydrogen atom, Stark effect, Zeeman effect, wave-mechanical description of matter, photoelectric effect, de Broglie hypothesis, uncertainty principle, the need for quantum theory.
- Postulates of quantum mechanics, state of a system, probability amplitude, probability density, operators and observables, Hermitian operators, commutators, expectation value.
- The wave equation, Schröinger equation and its significance, particle in a 1D, 2D and 3D-box, introduction to polar and spherical coordinates, hydrogen atom, the concept of orbitals, quantum numbers, helium atom, term symbols.

- Symmetry, symmetry elements and symmetry operations, properties of reducible and irreducible representations, construction of character tables.
- Chemical bonding, symmetry and properties of orbitals, linear combination of atomic orbitals, valence-bond theory, molecular orbital theory, comparison between valence bond and molecular orbital theories, examples of homonuclear and heteronuclear systems, electronic configuration of molecules in terms of MO theory.

Recommended Reading

- D. A. McQuarrie, J. D. Simon, *Physical Chemistry: A Molecular Approach*, Indian Edition, 1st Ed, University Science Books, California (1997).
- P. Atkins, J de Paula, *Physical Chemistry*, 8th Ed, Oxford University Press, New Delhi (2006).
- I. N. Levine, *Physical Chemistry*, 5th Ed, Tata McGraw-Hill, New Delhi (2007).

CHM112: Chemistry Lab II

[Cr:1, Lc:0, Tt:0, Lb:3]

Course Outline

- Familiarization with glasswares: burette, pipette, and volumetric flasks.
- Quantitative analysis using complexometric, titrimetric, gravimetric, and pHmetric methods.
- Determination of the composition of a mixture containing sodium bicarbonate and sodium carbonate by titrating against a standard aqueous hydrochloric acid solution.
- Synthesis and crystallization of potash alum from scrap aluminum; estimation of sulphate ions as barium sulphate.
- Synthesis and crystallization of potassium tris(oxalato)ferrate trihydrate; estimation of oxalate and ferric ions.
- Gravimetric estimation of chloride ions as silver chloride.
- Iodometric titrations.

Recommended Reading

- J. Mendham, R. C. Denney, J. Barnes, M. J. K. Thomas, *Vogel's Textbook of Quantitaive Chemical Analysis*, Indian Edition, 6th Ed, Pearson Education, New Delhi (2008).
- A. J. Elias, *A collection of Interesting General Chemistry Experiments*, 2nd Ed, Universities Press, Hyderabad (2007).
- R. A. Day, Jr., A. L. Underwood, *Quantitative Analysis*, Indian Edition, 6th Ed, Prentice-Hall of India, New Delhi (2006).

- D. A. Skoog, D. M. West, F. J. Holler, S. R. Crouch, *Fundamentals of Analytical Chemistry*, Indian Edition, 8th Ed, Thomson Brooks/Cole, Singapore (2004).
- H. W. Roesky, K. Möckel, *Chemical Curiosities*, Wiley-VCH, Weinheim (1996).

CHM201: Spectroscopic and other physical methods

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- Introduction to spectroscopy: Electromagnetic spectrum, representation of spectra, resolution and sensitivity, width and intensity of spectral transitions, fourier transform spectroscopy.
- Microwave spectroscopy: Interaction of radiation with a rotating molecule, rotational spectra of rigid diatomic molecules, isotope effect, intensity of rotational lines, non-rigid rotor.
- Infrared spectroscopy: The vibrating diatomic molecule, diatomic vibrating rotor, vibration-rotation spectrum of polyatomic molecules.
- Raman spectroscopy: Theory of Raman scattering, rotational Raman spectra, vibrational Raman spectra, mutual exclusion principle, structure determination using Raman and IR spectroscopy.
- Electronic spectroscopy of atoms and diatomic molecules. Photoelectron spectroscopy, Auger spectroscopy, and ESCA. Zeeman effect, the influence of nuclear spin.
- Magnetic resonance spectroscopy: NMR & EPR, the concept of spin, principles of nuclear magnetic resonance spectroscopy, principles of electron spin resonance spectroscopy.
- Types of magnetic behavior, magnetic moment and molar susceptibility, volume susceptibility measurement. High-spin low-spin crossover with examples and applications.
- Principles and applications of diffraction methods in chemistry. Single crystal and powder samples. Space lattice, unit cell, Laue symmetry, point groups and space groups, Bravais lattices, Bragg's equation. Miller indices and their relationship with diffraction angle and unit cell parameters. Reciprocal space lattice. Brief discussion on selection of a single crystal, data collection and structure solution.

Recommended Reading

- C. N. Banwell, E. M. McCash, *Fundamentals of Molecular Spectroscopy*, 4th Ed, Tata McGraw-Hill, New Delhi (1995).
- D. L. Pavia, G. M. Lampman, G. S. Kriz, *Introduction to Spectroscopy*, 3rd Ed, Cengage, India Edition (2001).
- W. Kemp, *Organic Spectroscopy*, 3rd Ed, Palgrave, New York (1991).
- I. N. Levine, *Physical Chemistry*, 5th Ed, Tata McGraw-Hill, New Delhi (2007).

CHM211: Chemistry Lab III

[Cr:1, Lc:0, Tt:0, Lb:3]

Course Outline

- Depression of freezing point and determination of molecular weight.
- Verification of Beer-Lambert's law and concentration of a sample using a calibration curve.
- Estimation of cholesterol using UV-vis spectrophotometer.
- Infrared spectra of common organic compounds and their interpretation.
- Polarimetry: Optical activity of glucose and sucrose; muta-rotation.
- CD measurements and Cotton effect.
- Proton NMR spectra of common organic compounds and their interpretation.
- Fluorescence spectroscopy.

Recommended Reading

- J. Tanaka, S. L. Suib, *Experimental Methods in Inorganic Chemistry*, Prentice Hall, New Jersey (1999).
- M. A. Malati, *Experimental Inorganic/Physical Chemistry: An Investigative, Integrated Approach to Practical Project Work*, Horwood Publishing Ltd, England (1999).
- D. L. Pavia, G. M. Lampman, G. S. Kriz, *Introduction to Spectroscopy*, Indian Edition, 3rd Ed, Cengage (2001).
- B. D. Khosla, V. C. Garg, A. Gulati, *Senior Practical Physical Chemistry*, R. Chand & Co, New Delhi, (2008).

CHM202: Energetics and dynamics of chemical reactions

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- Laws of thermodynamics; First law: Machinery and concepts, work done in reversible and irreversible processes, heat capacity at constant volume and pressure, zeroth law, the need for second law.
- Second law: Machinery and concepts, entropy, Clausius inequality, statistical interpretation of entropy, Boltzmann entropy equation, Gibbs and Helmholtz free energy, Maxwell's relations, molar properties, chemical potential, Gibbs-Helmholtz equation, Gibbs-Duhem equation.
- The concept of equilibrium in chemistry: Equilibrium and non-equilibrium states, equilibrium in heterogeneous systems and chemical reactions.

- Phase equilibrium, phase transitions and boundaries, solid-liquid, liquid-vapor and solid-vapor systems, Clausius-Clapeyron equation, phase rule and its derivation, phase diagrams of one and two-component systems.
- Chemical equilibrium: Equilibrium constant, reaction quotient, standard Gibbs free energy, temperature and pressure dependence of equilibrium constant, Van't Hoff equation.
- Elementary chemical kinetics and catalysis: Rate laws, chain reactions, explosions, acid-base catalysis, examples of homogeneous and heterogeneous catalysis, enzyme catalysis.
- Theory of reaction rates and reaction dynamics, activated complex, potential energy surface and reaction dynamics, Arrhenius theory, collision theory, transition-state theory, unimolecular and bimolecular reactions.

Recommended Reading

- D. A. McQuarrie, J. D. Simon, *Molecular Thermodynamics*, 1st Ed, Viva Books, New Delhi (2004).
- P. Atkins, J de Paula, *Physical Chemistry*, 8th Ed, Oxford University Press, New Delhi (2006).
- D. A. McQuarrie, J. D. Simon, *Physical Chemistry: A Molecular Approach*, 1st Ed, University Science Books, California (1997).

CHM212: Chemistry Lab IV

[Cr:1, Lc:0, Tt:0, Lb:3]

Course Outline

- Use of thin layer chromatography (TLC) and column chromatography for checking the purity of, and separation of organic compounds, respectively.
- Purification of a mixture containing (i) a solid in a liquid, (ii) two miscible liquids *via* simple distillation.
- Purification of a mixture of liquids *via* fractional distillation.
- Extraction of (i) solids in a solvent, and (ii) two miscible liquids.
- Purification of compounds *via* crystallization and sublimation.
- Purification of compounds *via* formation of derivatives.

Recommended Reading

- C. F. Most, Jr, *Experimental Organic Chemistry*, John Wiley & Sons Inc.
- G. S. Girolami, T. B. Rauchfuss, R. J. Angelici, *Synthesis and Technique in Inorganic Chemistry: A Laboratory Manual*, 3rd Ed, University Science Books, California (1998).
- J. D. Woollins, *Inorganic Experiments*, 2nd Ed, Wiley-VCH, Weinheim (2003).

- B. S. Furniss, A. J. Hannaford, P. W. G. Smith, A. R. Tatchell, *Vogel's Textbook of Practical Organic Chemistry*, Indian Edition, 5th Ed, Pearson Education, New Delhi (2008).

2.3 Humanities Core Courses

HSS101A: Language skills-A

[Cr:2, Lc:2, Tt:0, Lb:0]

Course Outline

- This course is designed to be an introductory program in reading, writing, listening and speaking for undergraduate students. It aims at improving the communication and comprehension skills of students who come from a vernacular background or who are not well-versed in science communication in English.
- Reading Module: The God of Small Things by Arundhati Roy (Novel), The Flies by Jean Paul Sartre (Drama) Selected Poems by John Keats.
- Writing Module: Fundamentals of Grammar, Semantics, Syntax, Basics of Public Communication.
- Speaking Module: Basics of Phonetics and Phonology. Some exercises based on the above-topics. Activities such as Debate, Elocution and Group Discussions, to help students to hone speech proficiency.
- Cinematic Appreciation: A module on movies as texts, which aims at improving reading, writing and speaking skills.
  - A documentary on the Holocaust, Bhopal Gas Tragedy, 9/11 or any such event that interrogates basic ideas about humans, humans as social beings, human behavior and human nature.
  - A movie based on a fine sensory experience (such as Mohsen Makhmalbaf's The Silence) where students can be sensitized toward their own senses and which should ideally make them enjoy more of aesthetics in their lives.
  - A movie based on a biography of a genius whose life and achievements are and achievements are important and relevant to other people.
  - A movie based on India, its issues, its past or its wonderful paradoxes.

Recommended Reading

- A. Roy, *The God of small things*, Random House (2008).
- J-P. Sartre, *No Exit and three other plays*, Vintage (1989).
- J. Keats, *Selected poems*, Penguin Classics (2007).

HSS101B: Language skills-B

[Cr:2, Lc:2, Tt:0, Lb:0]

Course Outline

- This course aims at making students better readers, writers and speakers. It will also try to inject in them a sense of understanding for other areas of knowledge other than science. The aim is to make it more than just a course in composition or English as a foreign language. The course will cover three parts, which are critically thinking about science and non-science areas like literature, film, art and music, functional grammar and writing skills which include components in research, academic writing and presentation.
- Figurative Language: Discussion on Simile, Metaphor, Symbol, etonymy, Synecdoche, Apostrophe, Personification, Parable, and Irony. (with examples) reading from Alfred Tennyson's "Crossing the Bar".
- Exercise: XVIII- A poem by Pablo Neruda Ode to Nightingale by John Keats Literature Reading
- Novel: Little Women by Louisa May Alcott
- Short stories: The grief by Anton Chekhov The Model Millionaire by Oscar Wilde A few passages for comprehension.
- Drama: Shakespeare: excerpts from Merchant of Venice Marlowe: excerpts from Dr. Faustus
- Movie Text: Children of Heaven' by Majid Majidi Little Women by Gillian Armstrong
- Elocution, Debate, Group Discussion
- Poetry Reading List: Crossing the Bar by Alfred Tennyson Ode to Nightingale by John Keats Prayer for Marilyn Monroe by Ernesto Cardenal From Sofia by Nizam Hikmet Santa Claus by Dunya Mikhael Twelve Roses in Balqis bun by Nizar Qabbani

Recommended Reading

- P. Neruda, *The essential Neruda: Selected poems*, City Lights Publishers (2004).
- A. Tennyson, *Selected Poems*, Penguin Classics (2008).
- T. S. Eliot, *T. S. Eliot:Collected poems, 1909-1962*, Harcourt Brace Jovanovich (1991).
- E. Cardenal, *Marilyn Monroe and other poems*, New Directions (2009).
- C. Marlowe, *Dr. Faustus*, Dover Publications (1994).
- W. Shakespeare, *The complete works of Shakespeare*, Longman (2008).
- A. Chekhov, *The complete plays*, W. W. Noron and Company (2007).
- O. Wilde, *Complete works of Oscar Wilde*, HarperCollins UK (2003).
- L. M. Alcott, *Little Women*, Signet Classics (2004).

HSS102: History of science

[Cr:2, Lc:2, Tt:0, Lb:0]

Course Outline

- Definitions of science, rational enquiry, history of ideas. The historicity of the concepts of space, time, number, infinity, perception. Paradoxes and paradigms. Calendars through the ages and the concept of time-keeping. The search for infinity.
- Science & Society: the emergence of twentieth-century science as a dominant societal force and how science came to have such authority over human progress. Examples of evolution of scientific thought. The crisis in physics in the twentieth century and the paradigm shift from the classical to the quantum domain. Scientists and the nuclear debate. The social context of Darwin's theory of evolution. A gendered perspective of science.
- Science in ancient civilizations. Historic periodizations:Babylon, Egypt, Greece, India, China. Early Greek Science: Thales to Plato. Pythagoras. Greek astronomy. Greek mathematics. Greek medicine. Aristotelian science. Islamic science.
- The emergence of modern science: The Scientific Revolution: Copernicus, Brahe,Kepler,Galileo. Galilean Relativity. Atomism and Empiricism. Boyle, Hooke, Lavoisier Newton.
- The Method of Science: Bacon, Descartes,logical positivism. Thomas Kuhn and the theory of scientific revolutions.
- Indian Science: positioning science in a non-Eurocentric, post-modernist world. Critique of the history of science from a non-Western perspective.

Recommended Reading

- T. S. Kuhn, *The structure of scientific revolutions*, University of Chicago Press (1996).
- T. S. Kuhn, *The Copernican revolution*, Harvard University Press (1992).
- D. C. Lindberg, *The beginnings of western science*, University of Chicago Press (1992).
- S. Shapin, *The scientific revolution*, University of Chicago Press (1998).
- A. Bala, *The dialogue of civilizations in the birth of modern science*, Palgrave Macmillan (2006).
- I. Habib and D. Raina, *Social history of science in colonial India*, Oxford University Press USA (2007).

HSS202: Philosophy of science

[Cr:2, Lc:2, Tt:0, Lb:0]

Course Outline

- Introduction to philosophy. The questions that philosophers ask: what is the true nature of reality? what is the foundation of knowledge? what is the nature of the self? can morality and ethics be objectively defined? Brief overview of different philosophical schools of thought. Indian philosophical schools of thought. The tools of rational enquiry.
- Rationality, realism and the philosophy of nature. An examination of scientific knowledge: how is it reached, what it reveals about the world we live in and what implications it has for human life and culture.
- Introduction to classic issues in the philosophy of science. The nature of scientific explanation. Popper's critique of narrow inductivism and positivism. Hume's problem of induction. Confirmation of scientific theories. Empiricism and realism.
- Brief introduction to epistemology. The nature of scientific truth:realism, skepticism, idealism and holism. Observation and cognition.Distinction between science and metaphysics. The "unity of science" thesis. The falsifiability of a scientific hypothesis.
- Is science a search for truth or for consensus? Is science a search for causes or for satisfying explanations? Scientific revolutions:relativity, space/time and evolution. The received view and the sociology of knowledge - Kuhn's legacy.
- Topics in the philosophy of biology. Evolutionary vs teleological explanations, natural selection,random mutation. The philosophy of psychology. Bioethics.

Recommended Reading

- M. H. Salmon et. al., *Introduction to the philosophy of science*, Prentice Hall (1992).
- M. Curd and J .A. Cover, *Philosophy of science:the central issues*, W. W. Norton and Company (1998).
- D. Gilles, *Philosophy of science in the twentieth century:four central themes*, Blackwell Publishers Oxford (1993).
- J. Kourany, *Scientific knowledge: basic issues in the philosophy of science*, 02nd edition, Wadsworth Publishing (1997).
- B.C.van Fraassen, *Introduction to the philosophy of time and space*, Columbia university press (1992).

2.4 Mathematics Core Courses

MTH101: Symmetry

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- Basic operations, row reduction, determinant and trace, Cramer's rule.
- Basic notions of groups, permutation groups.
- Group actions, prime-power groups.
- Finite Abelian groups.
- Matrix groups, $SO(3)$ and rotations.
- Groups of symmetries of real plane and Platonic solids.
- Vector spaces and linear transformations, eigen values and eigen vectors, diagonalization.

Recommended Reading

- M. A. Armstrong, *Groups and Symmetry*, Springer (1988).
- M. Artin, *Algebra*, Prentice-Hall of India, New Delhi (1994).
- I. S. Luthar and I. B. S. Passi, *Algebra* Vol. I, Narosa Publishing House, New Delhi (1996).
- J. A. Gallian, *Contemporary Abstract Algebra*, D. C. Heath Canada (1986).

MTH102: Analysis in one variable

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- The real number system, completeness axiom, complex numbers.
- Sequences, limits, convergence, series.
- Polynomials, rational functions, continuous functions.
- Trigonometric, exponential, logarithmic and hyperbolic functions.
- Differentiation, mean value theorem, Taylor's theorem.
- Uniform convergence, power series.
- Riemann integral, fundamental theorem of calculus.
- Fourier series.

Recommended Reading

- R. R. Goldberg, *Methods of Real Analysis*, Wiley (1970).
- K. A. Ross, *Elementary Analysis, The Theory of Calculus*, Springer (2004).
- T. M. Apostol, *Calculus*, Blaisdell Publishing Company, 1961.
- S. Shirali and H. L. Vasudeva, *Mathematical Analysis*, Alpha Science International Ltd. (2006).

MTH201: Curves and surfaces

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- Differentiation of vectors.
- Curves in the plane and in space, arc length, reparametrization.
- Curvature, torsion, Serret-Frenet formulae.
- Fundamental theorem of curves in plane and space.
- Surfaces in three dimension (2-manifolds), smooth surfaces.
- Tangents, normals, quadratic surfaces.
- Change of variable formula, surfaces of revolution.
- First and second fundamental forms, isometries, conformal mappings.
- Normal and principal curvatures, Gaussian curvature and the Gauss map.
- Geodesics, geodesic curvature, Gauss' theorema egregium.

Additional Topics

- Isoperimetric inequality, four vertex theorem.
- Area and volume integrals, surface area.

Recommended Reading

- L. Brand, *Vector Analysis*, Dover Publications (2006).
- A. Pressley, *Elementary Differential Geometry*, SUMS, Springer (2001).

MTH202: Probability and statistics

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- Recapitulation: Counting (urn, coins, cards).
- Axiomatic approach to probability, conditional probability, independence of events.
- Discrete random variables, probability mass function, some standard discrete distributions and examples.
- Continuous random variables, probability density function, some standard continuous distributions and examples.
- Bivariate distributions (discrete and continuous), marginal and conditional distributions, covariance, correlation coefficient.
- Moments, Markov's inequality, Chebychev's inequality.

- Sums of independent random variables, law of large numbers, central limit theorem
- A glimpse into estimation theory (maximum likelihood estimation, method of moments) and testing of hypothesis.

Recommended Reading

- K. L. Chung and F. AitSahila, *Elementary Probability Theory*, Springer (2004).
- R. Isaac, *The Pleasures of Probability*, Springer (Undergraduate Texts in Mathematics) (1995).
- S. Ross, *A First Course in Probability*, Pearson Education Inc. (2006).

2.5 Physics Core Courses

PHY101: Mechanics

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- Review of calculus, vectors, rotations, polar co-ordinates. Velocity and acceleration in polar co-ordinates. Newton's laws of motion. Configuration space and phase space. Notion of system Hamiltonian.
- Frames of reference. Inertial and accelerated frames. Centrifugal and Coriolis forces. Foucault's pendulum. Galilean transformations.
- Conservation laws. Conservation of energy, momentum and angular momentum. Their connection with symmetry principles.
- Central Force problem. Inverse-square law force. Derivation of orbit equation. Kepler's laws.
- Oscillations. Harmonic oscillator. Damped oscillations. Driven damped oscillations. Coupled oscillations and normal modes of motion.
- Motion of rigid bodies. Angular momentum, angular velocity, moment of inertia, product of inertia, principal axes. Euler's equations. Examples with fixed axis of rotation.
- Special theory of relativity. Relativistic kinematics. Lorentz transformations. Length contraction, time dilation. Velocity addition. Four-vectors. Doppler effect.

Recommended Reading

- C. Kittel et.al., *Mechanics Volume 1 Berkeley Physics Course*, 02nd edition(Special Indian Edition), Tata-McGraw Hill Ltd New Delhi (2008).
- D. Kleppner and R. Kolenkow, *An Introduction to Mechanics*, McGraw Hill Inc USA (1973).

- R. Resnick, D. Halliday and K. S. Krane, *Physics Vol 1*, 4th edition, John Wiley, (1991).
- A. P. French, *Newtonian Mechanics (M.I.T. Introductory Physics Series)*, CBS Publishers and distributers, New Delhi (1987).

PHY111: Physics Laboratory I

[Cr:1, Lc:0, Tt:0, Lb:3]

Course Outline

- This lab is designed to serve as an introductory course on hands-on physics experiments, built around the theme of Mechanics. The lab proceeds in tandem with the Mechanics course offered in the same semester. Experiments in this course include: exploring simple harmonic motion through different pendulum setups such as Kater's pendulum, compound pendulum and torsion pendulum, measuring g by free fall, estimating Young's modulus by Searle's method and bending of beam method, gyroscope motion. Concepts taught in this course include measurements, quantitative estimation of physical quantities, the different types of error that can arise in an experiment.

PHY102: Electromagnetism

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- Electrostatics: charges and fields. Charge distributions. Gauss's Law.
- The electric potential, the physical meaning of the divergence and the curl. Work and energy in electrostatics.
- Electric fields around conductors. Capacitors and capacitance. The Uniqueness Theorem. The Boundary-value problem.
- Electric fields in matter. Polarization. Bound charges. Field inside a dielectric. Linear dielectrics. Boundary value problems.
- Electric currents. Charge transport and current density. Electrical conductivity and Ohm's law. Energy dissipation.
- Fields of moving charges: From Oersted to Einstein. Magnetic forces. Electric field measured in different frames of reference. Force on a moving charge. The Magnetic field. Vector potential. How fields transform.
- Magnetic fields in matter. Diamagnets, paramagnets and ferromagnets. Torques and forces on magnetic dipoles. Bound currents. Auxiliary field. Linear and nonlinear media. Ferromagnetism, susceptibility and permeability.
- Electrodynamics: Electromagnetic induction and Faraday's law. Energy and momentum in electrodynamics. The Displacement Current. Maxwell's equations.

Recommended Reading

- E. M. Purcell, *Electricity and Magnetism (Berkeley Physics Course Vol 2)*, 02nd edition, Tata-McGrawHill (2008).
- R. P. Feynman, R.B. Leighton, and M. Sands, *The Feynman Lectures of Physics Vol 2*, Narosa Publishing House (2008).
- D. J. Griffiths, *Introduction to Electrodynamics*, 03rd edition, Dorling Kindersley (2007).

PHY112: Physics Laboratory II

[Cr:1, Lc:0, Tt:0, Lb:3]

Course Outline

- This lab course is designed to help students understand the physics of everyday electromagnetic phenomena. The lab proceeds in tandem with the Electromagnetism course offered in the same semester. The experiments in this course include: parallel plate capacitor, random sampling of an AC source, thermistor, em induction in a coil, characteristics of an AC and DC motor, eddy currents in a pipe, measurement of torque on a current carrying conductor in a magnetic field etc.

PHY201: Waves and optics

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- Mechanical Waves. Review of oscillators and systems of coupled oscillators. Waves on a string and membrane. Waves in an elastic medium: Pressure waves and shear waves. Acoustic resonators. Speed of a wave and wave impedance, shock waves.
- Electromagnetic waves: Review of Maxwell's equations. Wave solutions to Maxwell's equations. Energy and momentum of electromagnetic radiation. Poynting theorem and conservation laws.
- Reflection and refraction of waves from interfaces. Fresnel Coefficients. Interference of light: interferometers and devices based on two-beam interference.
- Diffraction of light: Scalar wave approximation. Kirchoff integral, Kirchoff-Fresnel boundary conditions. Fraunhoffer diffraction, Babinet principle, diffraction gratings.
- Lorentz model for dispersive media. Pulse propagation in a dispersive medium.
- Coherence theory: basic ideas of coherence. Temporal coherence, bandwidth of light. Spatial coherence, basic ideas of intensity correlations.

Recommended Reading

- A. P. French, *Vibrations and Waves (The M.I.T. Introductory Physics series)*, CBS Publishers and distributers, New Delhi (1987).
- H. J. Pain, *The physics of vibration and waves*, 6th edition, Wiley and Sons Ltd. New Delhi (2005).
- E. Hecht, *Optics*, 4th edition, Pearson Education Inc., New Delhi (2007).
- F. S. Crawford Jr., *Waves (Berkeley Physics Course Vol. 3)*, Special Indian Ed., Tata McGraw Hill Co. New Delhi (2008).
- M. V. Klein and T. E. Furtak *Optics*, 2nd edition, Wiley (1986).

PHY211: Physics Laboratory III

[Cr:1, Lc:0, Tt:0, Lb:3]

Course Outline

- This lab course is designed to encourage students to explore the physics behind waves and optics phenomena. The lab proceeds in tandem with the Waves & Optics course offered in the same semester. The experiments in this course include: measuring fundamental modes in a vibrating string using a sonometer, exploring the physics of sound and music on a CRO, Melde's setup for standing waves, prism spectrometer, constant deviation spectrometer, Newton's rings setup, polarimeter to measure specific rotation, Fresnel's biprism, diffraction grating using a laser source and measuring the wavelength of sodium source using interference observed with a Michelson interferometer setup.

PHY202: Thermodynamics and statistical physics

[Cr:3, Lc:2, Tt:1, Lb:0]

Course Outline

- Macroscopic and microscopic point of view, scope of thermodynamics, thermal equilibrium and zeroth law, equation of state. Hydrostatic systems. Examples.
- Intensive and extensive coordinates, Quasi-static process, work for hydrostatic systems, PV diagrams, path dependence of work, exact differentials.
- Work and heat, internal energy function, First law, differential form, heat capacity, heat reservoirs.
- Second law, Carnot cycle, Carnot theorem, Kelvin-Planck statement, Clausius statement, entropy and second law, entropy of ideal gas, principle of increase of entropy.
- Entropy maximum principle, energy minimum principle, Legendre transforms, thermodynamic potentials.
- Physical interpretation of entropy, two-level systems, deviation from most probable state, canonical formalism.

Recommended Reading

- H. B. Callen, *Thermodynamics and introduction to thermostatistics*, 2nd edition, Wiley & Sons (1985).
- C. Kittel and H. Kroemer, *Thermal Physics*, 2nd edition, W. H. Freeman Inc. (1980).
- M. W. Zemansky and R.H.Dittman, *Heat and Thermodynamics*, 7th edition, McGraw-Hill Inc. (1997).

PHY212: Physics Laboratory IV

[Cr:1, Lc:0, Tt:0, Lb:3]

Course Outline

- This lab course is designed to expose students to concepts in Modern Physics and also get them to perform certain famous physics experiments of the twentieth century. The experiments in this course include: Franks & Hertz tube for quantization of atomic levels, Planck's constant, photoelectric effect, Stefan's law, heat conduction, measurement of e/m etc.

2.6 Inter-disciplinary Core Courses and Core Electives

IDC101: Introduction to computers

[Cr:2, Lc:1, Tt:0, Lb:3]

Course Outline

- Overview of scientific computing and the role of computers in solving scientific problems.
- Linux Essentials. Operating System concepts and features. Basic commands (file, directory and disk related commands). File system and attributes. I/O devices. Shell and elements of shell programming.
- Editors (Vi and Emacs)
- Number representation in computers and roundoff error. Implications for numerical computing.
- Python programming. Basics and flowcharts. Data types and building blocks. Control statement. Functions. Arrays. Input/Output.
- Data visualisation and analysis, statistical analysis, curve fitting using the least square fit approach.
- Series summation, numerical integration.
- Pseudo random numbers, applications of random sequences in scientific computing, simulating data and experiments, estimating errors in experiments using simulations.

- Solutions of algebraic equations, iterative solutions. Recursion relations, logistics map. Brief overview of fractals resulting from simple maps. Bisection method. Newton-Raphson method.
- Ordinary differential equations, coupled equations, second order equations. Applications in evolution of population, reaction rates, mechanics.
- Systems of linear equations, matrices, row reduction, diagonalisation. Two dimensional arrays. Cellular automata.

Recommended Reading

- Richard Peterson, *Linux: The Complete Reference* 6th edition, Tata McGraw (2008).
- The online material available at `http://docs.python.org/`

IDC102: Hands-on electronics

[Cr:2, Lc:1, Tt:0, Lb:3]

Course Outline

- In this course the emphasis will be on practical knowledge and not on teaching electronics as a theory subject. The topics below provide a framework from which the instructor can choose experiments:
- Electronic Devices: Basic concepts of AC & DC current and voltage. Signals(sinusoidal and other) and signal sources. Voltage and current relationships in lumped circuit elements(Resistor, Capacitor and Inductor). Reactance and Impedance. Voltage current sources.
- Passive components. Device principle. Device characteristics(Semiconductor Diode and diac, power diode, signal diode, zener diode, LED photo diode varicap). Electromechanical devices, Indicators, variable components
- Active components: BJT, FET & MOSFET (Device principles, Characteristics, Comparison and applications). Amplifier. Switching. Current source.
- Negative resistance Devices: Unijunction Transistor, SCR, TRIAC.
- Power supply principles: Introduction to Linear and SMPS power supplies, basic principles and differences. Introduction to three terminal regulators (78XX, 79xx and LM317).
- Device applications. Diode applications (Rectification, Voltage regulation, Clipping, Clamping, voltage multipliers). Transistor applications (Amplification, oscillator, current source and Switch). Configurations(pushpull, Darlington, Bootstrapping, Differential amplifier).
- Integrated Circuits. Operational amplifier basics. Applications: Offset null, inverting amplifier, noninverting amplifier, logarithmic amplifier, integrator, differentiator, comparator, active rectifier, current to voltage convertion. Timer IC 555 basics , application as astable, monostable, bistable multivibrator.

- Digital Electronics: Introduction to Boolean Algebra, Number systems, Logic gates. Short project on a design/simulation application involving one of the devices studied using circuit simulator and realise the design on a PCB.

Recommended Reading

- P. Horowitz & Winfield Hill, *The Art of Electronics*, 02nd edition, Cambridge University Press (1989).
- R. L. Boylestad and L. Nashelsky, *Electronics devices and circuit theory*, 09th edition, Prentice Hall (2005).
- A. P. Malvino, *Electronic principles*, 06th edition, Career Education (1998).

IDC201: Astronomy and astrophysics

[Cr:2, Lc:2, Tt:0, Lb:0]

Course Outline

- Celestial coordinates, time measurement, rising, setting, meridian crossing of sources. circumpolar objects.
- Quantifying fluxes, magnitudes, absolute magnitudes, colour. Extinction, estimation of extinction.
- Distance measurements: parallax, moving cluster method, HR-Diagram method, Cepheid variables, Supernovae of type Ia.
- Two body systems, orbits, the effect of radiation pressure on orbits and cometary tails. Using observations of binary stars to infer physical properties of stars. Discovering exo-planets. Röche limit. Lagrange points.
- Stars: observed properties of stars, main sequence. Central pressure and temperature in stars. Nuclear reactions and generation of energy. Relation between mass, radius and luminosity of main sequence stars. Life time on main sequence, variation with mass of stars. Evolution of stars beyond the main sequence.
- Stellar remnants: white dwarfs, Chandrasekhar limit, Neutron stars, Black holes.
- Gravitational waves and other probes of compact binaries.
- Inter-stellar medium (ISM), Jeans length. phases of ISM, estimation using pressure equilibrium. photo-ionization equilibrium.
- Galaxies. Properties of galaxies, morphological classification. Structure and dynamics of spiral galaxies. Oort's constants, rotation curves. Structure and dynamics of elliptical galaxies. Groups and Clusters of galaxies.
- Expansion of the universe, Hubble's law. Newtonian cosmology. Estimating cosmological parameters from observations. Thermal and expansion history of the universe.

Recommended Reading

- H. Karttunen, P. Kröger, H. Oja, M. Poutanen and K. J. Donner, *Fundamental Astronomy*, 5th edition, Springer (2007).
- A. E. Roy and D. Clarke, *Astronomy: Principles and Practice*, 4th edition, CRC Press (2003).
- Bradley W. Carroll and Dale A. Ostlie, *Introduction to Modern Astrophysics*, IInd Edition, Addison Wesley (2006)

IDC202: Chemical biology

[Cr:2, Lc:2, Tt:0, Lb:0]

Course Outline

- An introduction to biological molecules and chemical biology
- Physicochemical interactions, water structure, molecular symmetry and chirality
- The molecules of life: Carbohydrates, steroids, vitamins, coenzymes, hormones, lipids and nucleic acids, amino acids, peptides, and proteins
- Protein structure, function, conformation, folding and misfolding
- Enzyme catalysis, inhibition and drug design
- Chemical and biological synthesis
- Molecular recognition, binding, supramolecular assemblies and conformational dynamics
- Molecular selection, evolution and chemical genetics
- Techniques in Chemical Biology: Fluorescence, IR, CD, NMR, X-ray, microscopy, mass spectrometry, light scattering, ultrafast spectroscopy and single molecule biophysics

Recommended Reading

- R. J. Simmonds, *Chemistry of Biomolecules*, RSC (1992).
- Berg, Tymoczko and Stryer, *Biochemistry* W. H Freeman, 6th edition (2006).
- A. D. Miller, J. Tanner *Essentails of Chemical Biology* Wiley (2008).
- Editors: B. Larijani, C. A. Rosser, R. Woscholski, *Chemical Biology: Techniques and Applications* Wiley (2006).

IDC203: Introduction to earth sciences

[Cr:2, Lc:2, Tt:0, Lb:0]

Course Outline

- Earth Sciences: Interfaces; Early Earth; Surface Processes, Formation of rocks, minerals, crystal structure; Time and its Measurement; Stratigraphy and the role of Fossils; Plate Tectonics and Internal Earth Processes; Earth Sciences and Societal benefits: Environmental concerns, Climate change and Economic Resources.

Recommended Reading

- J. Grotzinger, T. H. Jordan, F. Press and R. Siever, *Understanding Earth*, 05th edition, W.H. Freeman and Co. N.Y. USA (2007).
- E. J. Tarbuck, F. K. Lutgens and D. Tasa, *Earth: An introduction to physical geology*, 09th edition, Pearson Prentice Hall, USA (2008).
- R. Wikander and J. S. Monroe, *Historical Geology*, 04th edition, Thomson/Brooks/Cole (2004).

IDC204: Theory of computation

[Cr:2, Lc:2, Tt:0, Lb:0]

Course Outline

- Mathematical notions: Sets, Functions, Sequences, Graphs, Boolean Logic, Proofs and types of proofs.
- Languages: Context free grammar, Examples, Ambiguity, Chomsky normal forms.
- Computability: Origin of Computability Theory, Gödel and the discovery of incomputability, Church-Turing thesis, Turing machines and their variants, Examples, Decidability, Reducibility, Recursion Theorem, Self referencing, Russell's Paradox.
- Time Complexity: Big-O and small-o notation, Analysing algorithms, P and NP problems, Vertex cover problem, Hamiltonian path problem, Subset sum problem.
- Space Complexity: Savitch's problem, The class PSPACE, Classes L and NL.
- Computing time and space complexity for various algorithms.

Recommended Reading

- Michael Sipser, *Introduction to the Theory of computation*, Course Technology Publishers (1996).
- S. Barry Cooper, *Computability Theory*, CRC Press (2003).

IDC205: Differential equations for scientists

[Cr:2, Lc:2, Tt:0, Lb:0]

Course Outline

- Meaning of a differential equation and its solution, examples, families of curves, orthogonal trajectories.
- First order equations: Homogeneous, exact, linear, Bernoulli, Riccati and Clairaut equations, equations reducible to first order equations.
- Second and higher order linear equations, linear equations with constant coefficients, general solution of homogeneous equations, operator method for finding a particular solution, vibra- tions in mechanical and electrical systems. Power series method: Legendre, Hermite, Bessel and hypergeometric equation.
- Special functions: Legendre, Hermite and Chebychev polynomials, Bessel functions and appli- cations.

Recommended Reading

- Earl A. Coddington, *An Introduction to Ordinary Differential Equations*, Dover Publications (1989).
- Ravi P. Agarwal and Donal O'Regan, *Ordinary and Partial Differential Equations*, Springer (2008).
- Shepley L. Ross, *Differential Equations*, Wiley (1984).
- George F. Simmons, *Differential Equations with Applications and Historical Notes*, Tata McGraw-Hill Publishing Company (1978).

IDC206: Quantum physics for scientists

[Cr:2, Lc:2, Tt:0, Lb:0]

Course Outline

- This course is meant to provide a full overview of quantum physics and its impact on our understanding of the physical world. The course will cover aspects of modern physics for non-physics majors who will most probably not encounter these concepts in their major years, and will cover introductory quantum mechanics for physics majors, who will do more specialized courses later on.
- The birth of quantum theory will be explored from a historical point of view. Black body radiation, Photoelectric effect, photons, Compton scattering, Franck-Hertz experiment, Bohr atom and electron diffraction, deBroglie waves and the Wave particle duality of matter and light. An introduction to wave mechanics and Schroedinger's equation in one, two and three dimensions.
- An appreciation of the quantum world at an informal level will be taken up across systems and across scales. Examples from particle physics, collective quantum phenomena, possibilities of building quantum computers etc will be discussed at a non-technical level.

Recommended Reading

- R. M. Eisberg and R. Resnick, *Quantum physics of atoms, molecules, solids, nuclei and particles*, Wiley (1974).
- R. P. Feynman, R. B. Leighton and M. L. Sands, *The Feynman Lectures on Physics Vol. 3* Addison-Wesley (1989).
- S Gasiorowicz, *Quantum Physics* , Wiley (2003).
- A. P. French and E. F. Taylor, *Introduction to quantum physics*, Norton Publishing (1978).

IDC207: Number theory and cryptography

[Cr:2, Lc:2, Tt:0, Lb:0]

Course Outline

- *Number Theory*: Diophantine equations, primes and their distribution, cryptography, divisibility, Euclidean algorithm, linear Diophantine equations, Fermat and Mersenne numbers, fundamental theorem of arithmetic, Pythagorean triples, differences of squares, prime factorization of factorials, Riemann-zeta function, congruences, Chinese remainder theorem, Fermats little theorem, Eulers theorem, Wilsons theorem.
- *Cryptographic applications*: Shift and affine ciphers, secret sharing, RSA algorithm
- *Congruences*: Polynomials mod primes, solutions modulo prime powers, composite moduli.
- *Primitive roots*: Orders of elements, primitive roots, discrete log problem, existence of primitive roots, Diffie-Hellman key exchange, ElGamal public key cryptosystem, digital dignatures.
- *Quadratic reciprocity*: Squares and square roots mod primes, Legendre symbol, quadratic reciprocity, applications to cryptography.

Recommended Reading

- James S. Kraft, Lawrence C. Washington *An Introduction to Number Theory with Cryptography*,Chapman and Hall/CRC.
- Neal Koblitz, *A Course in Number Theory and Cryptography* (Graduate Texts in Mathematics), Springer. ISBN-10: 0387942939 ISBN-13: 978-0387942933.
- V. V. Yaschenko, *Cryptography: An Introduction*, Student Mathematical Library, AMS, Universities Press India (2009).

IDC211: Workshop Training

[Cr:1, Lc:0, Tt:0, Lb:3]

Course Outline

- In this course the students undertake workshop training in various fields including machine shop, woodwork, welding, glass blowing etc. The idea is to equip them with basic workshop training so that they are able to build things and fabricate equipment required for their research projects.

Chapter 3

Major Mandatory Courses

3.1 Biology Major Courses

BIO301: Animals: Form and function

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Animals origins and the Evolution of body plans: Evolutionary relationships among animals, salient features of Animal body plans, symmetry.
- Introduction to Animal Diversity: Body Cavity, Segmentation, Cephalization, Germ layers
- Invertebrates: i Life without a backbone, Origin and evolution of different organ systems .Sponges, Cnidarians, Lophotrochozoans, Ecdysozoans, Echinoderms and Hemichordates.
- Vertebrates: Origin and evolution of different organ system, Tetrapods, Amniotes, Mammals and Humans.
- Animal Nutrition: i Essential Nutrients, Main stages of food processing like Ingestion, Digestion, absorption and assimilation of food.
- Circulation and Gas exchange: Gaseous exchange through respiratory membranes and tissues, respiratory control centers, Basal metabolic rate, High altitude respiration physiology Blood, Haemopoiesis, Haemostasis, Haemoglobin, Lymph, Cardiac cycle, origin and conduction of cardiac impulse.
- Osmoregulation and Excretion: Glomerular filtration, Tubular re-absorption and secretion, counter current mechanism, hormonal regulations.
- Nervous System, Sensory and Motor Mechanisms: Neuron structure and functions, Genesis of membrane potential and conduction of action potentials, Sodium- potassium pump, calcium pump, Transmission at synapse, Neurotransmitters. Eye-retinal components and photo-receptors. Ear-cochlea, basilar membrane, organ of cortigenesis of action potential. Vertebrate skeletal muscle, other types of muscles,Energetics of muscle contraction, sequence of events in contraction & relaxation.

- Hormones and Reproduction: Asexual reproduction, parthenogenesis, Sexual reproduction: an evolutionary enigma,Sex hormones, male and female reproductive physiology, fertilization, pregnancy and child birth. AIDS, contraceptives.

Recommended Reading

- N. A. Campbell, J. B. Reece, R. B. Jackson, M. L. Cain, L. A. Urry, S. A. Wasserman and P. V. Minorsky, *Biology*, 8th Edn. Benjamin-Cummings Pub Co. (2007).
- C. Hickman Jr, L. Roberts, S. Keen, A. Larson, H. I'Anson and D. Eisenhour, *Integrated Principles of Zoology*, 14th Edn., McGraw-Hill (2007).
- R. W. Hill, G. A. Wyse and M. Anderson, *Animal Physiology*, 2nd Edn., Sinauer Associates Inc. (2008).

BIO302: Advanced cell biology

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Cell membrane Structure and Function: Lipid bilayer and membrane protein diffusion, principles of transport across the membrane, transporters and mechanism of active transport, ion channels, ion pumps and membrane potentials.
- Intra-cellular compartments and Membrane trafficking: Overview of the endomembrane system, molecular mechanism of membrane transport and maintenance of compartments diversity, types of vesicle transport and their functions, posttranslational u7 Lecturesptake of proteins by peroxisomes, mitochondria and chloroplast, endocytosis and exocytosis.
- Mechanisms of Cell signaling: Basic elements of the cell signaling system, signaling through G-protein-coupled receptors and intra-cellular mediators, signaling through enzyme coupled cell surface receptors, intra-cellular receptors and signaling, convergence, signaling by regulated proteolysis of latent gene regulatory proteins, divergence and crosstalk among different signaling pathways, signaling in plants.
- The extracellular Matrix and cell interactions: Extracellular matrix and interaction of cells with extracellular materials, cadherins and cell-cell adhesion, tight junctions, gap junctions and plasmodesmata, basal lamina, plant cell wall, integrins and adhesion molecules in cell signaling.
- Cytoskeleton: Self-assembly and dynamic structure of cytoskeletal filaments, regulation of cytoskeletal filaments, molecular motors, cytoskeleton and cell behavior.
- Organization of Genes and Chromosomes: Chromosomal DNA and its packaging in Chromatin fiber, regulation of chromatin structure, global structures of chromosomes, unique and repetitive DNA, heterochromatin, euchromatin, transposons.
- Cell Division: Molecular basis of cell cycle checkpoints, regulation of cell division and cell growth, causes and genetics of cancer.

Recommended Reading

- B. Alberts, A. Johnson, J. Lewis, M. Raff, K. Roberts and P. Walter, *Molecular Biology of the Cell*, 5th Edn., Garland Science (2008).
- G. Karp, *Cell Biology*, 6th Edn., John Wiley and Sons Inc.(2010).
- H. Lodish, A. Berk, C. A. Kaiser, M. Krieger, M. P. Scott, A. Bretscher, H. Ploegh and P. Matsudaira, *Molecular Cell Biology* 6th Edn., W. H. Freeman (2007).

BIO303: Experimental design and hypothesis testing

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Review of basic results from probability; random variables and expectations; binomial, Poisson and normal distributions
- Populations and samples; estimators and parameters; properties of estimators – efficiency, unbiasedness and efficiency; maximum likelihood and least squares approaches to estimation.
- The sampling distribution of an estimator, using the mean as an example; standard errors and confidence intervals; testing hypotheses about one and two means (t-test); type 1 and type 2 errors.
- Comparing two means using a paired t-test; concept of accounting for sources of variation; comparing two means using the within-sample and among-sample mean variation.
- Comparison-wise and family type 1 error rates; single-factor ANOVA
- Two-factor ANOVA; main effects, interactions and their interpretation; experimental design – random and fixed factors; blocks; nested factors; multiple comparisons; multiple factor ANOVA
- Introduction to non-parametric approaches to hypothesis testing.
- Linear regression and correlation.

Recommended Reading

- J. H. Zar, *Biostatistical analysis*, 4th Edn., Prentice Hall (1998).
- J. Norman and D. Steiner, *Biostatistics: The Bare Essentials*, 3rd Edn., B C Decker Inc. (2008).

BIO304: Essential biochemistry

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Biochemistry: A historical perspective Review of thermodynamic principles relevant to biochemistry: Laws of thermodynamics. Free energy. Chemical equilibrium.
- Structural aspects of biomolecules:
    1. Amino acids and proteins. Covalent structures of proteins. Protein three dimensional structures. Domains and Motifs Protein structure-function mechanisms- overview of protein families and superfamilies. A case study on Hemoglobin.
    2. Nucleic acids and their structures.
    3. Sugars and polysaccharides.
    4. Lipids and membranes.
- Enzymes and their mechanisms of action:
    1. Introduction to enzymes.
    2. Rates of enzymatic reactions.
    3. Enzymatic catalytic mechanisms: lysozyme and serine proteases.
- Metabolism:
    1. Carbohydrate metabolism.
    2. Electron transport and oxidative phosphorylation.
    3. Photosynthesis
    4. Lipid metabolism.
    5. Amino acid metabolism.
    6. Nucleotide metabolism.
    7. Integration of metabolic pathways and metabolic disorders.

Recommended Reading

- D. Voet and J. G. Voet, *Biochemistry*, 4th Edn., Wiley (2010).
- D. L. Nelson and M. M. Cox, *Lehninger Principles of Biochemistry*, 5th Edn., W. H. Freeman (2008).

BIO305: Advanced developmental biology

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Introduction: What is developmental biology? History and Basic Concepts
- From Sperm and Egg to Embryo: 1. Beginning the Developmental Program: Gametogenesis, Structure of eggs and sperm, Comparing oogenesis and spermatogenesis 2. Fertilization: Beginning a New Organism- Gamete recognition, Gamete fusion and prevention of polyspermy, Activation of egg metabolism, Fusion of the genetic material
- Early Embryogenesis: Cleavage: Generating a Multicellular Embryo (a) Overview of Cleavage Amphibians/Birds/Mammals, Gastrulation and cell movement and types of movement, Sea urchin/Chick/Amphibia, Germ layers (b) Cellular basis of morphogenesis, cell motility and the molecular players
- Body Patterning: Animal-Vegetal Axis, Rotation of Fertilization and the Dorso-Ventral Axis Organizer in Amphibia, Development of Body plan in Drosophila, Maternal genes, Zygotic genes, Segment Identity genes. Segment identity and Hox genes.
- Differential gene expression during development: Genomic Constancy during Cell Differentiation, Differential Gene Activity Regulation of Gene Expression in Early Development Transition from maternal to zygotic control. Models of Cell Differentiation Introduction to developmental genetics (techniques and concepts)
- Completing the Life Cycle, and New Beginnings— Sex determination, Dosage compensation, Imprinting Introduction to concepts in stem cell biology (renewal, potency, etc.)
- Development and Evolution: Developmental mechanisms of evolutionary change Evolution of morphological novelty

Recommended Reading

- S. F. Gilbert, *Developmental Biology*, 8th Edn., Sinauer Associates Inc. (2006).
- L. Wolpert, J. Smith, T. Jessell, P. Lawrence, E. Robertson and E. Meyerowitz, *Principles of Development*, 3rd Edn., Oxford Univ Press (2006).

BIO306: Plants: Form and function

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Plant Kingdom: Evolutionary history and diversity of;Algae, Fungi, Bryophytes, Pteridophytes, Gymnosperms, Angiosperms. Morphology of Flowering Plants: Root, Stem, Leaf, Inflorescence, Flower, Fruit, Seed Anatomy of Flowering Plants: Cell wall, Parenchyma, Collenchyma, Sclerenchyma, Meristems, Sieve tubes, Fibres & Sclerides

- Transport in Plants: Plant water relations, long distance transport of water, Transpiration, Uptake and transport of mineral nutrients, xylem & phloem transport, Stomata Plant Nutrition: Mineral requirements, Essential mineral elements, mechanism of absorption of elements, translocation of solutes, soil as reservoir of essential elements, Nitrogen metabolism, carnivorous plants, parasitic plants, fertilizers

- Photosynthesis: Site and pigments, light reaction, electron transport, ATP and NADH, C4 pathway, photorespiration, factors influencing photosynthesis, photoreceptors. Respiration in plants: Respiration during photosynthesis, role of environmental factors on rate of respiration Regulation of Plant growth: Gibberlins, Auxins, Cytokines, Ethylene, Abscisic acid, Brassinosteroids Reproduction in flowering plants: transition from vegetative phase to flowering state.

- Plant protection: Plant defence against pathogens, insects and herbivores. Plant-plant interaction: Allelopathy

Recommended Reading

- N. A. Campbell, J. B. Reece, R. B. Jackson, M. L. Cain, L. A. Urry, S. A. Wasserman and P. V. Minorsky, *Biology*, 8th Edn. Benjamin-Cummings Pub Co. (2007).

- L. Taiz and E. Zeiger, *Plant Physiology*, 4th Edn., Sinauer Associates Inc. (2006).

BIO311: Molecular methods in biology lab

[Cr:4, Lc:0, Tt:0, Lb:12]

Course Outline

- Cloning of the DNA segment encoding the protein of interest into an expression vector: Knowing the online servers/software for DNA and protein analysis: Acquiring DNA sequence encoding the protein of interest (for example GFP) from online database like PUBMED and PDB. Analysis of DNA sequence for presence of internal restriction digestion sites etc. using software like 'Ape'. Primer designing: Designing of 5' forward and 3' reverse complementary primers containing appropriate restriction digestion sites, affinity tags (penta-His etc.). PCR amplification of the DNA segment of interest from a suitable source, purification of the PCR product, restriction digestion, and subsequent ligation into the suitable bacterial expression vector (also containing an antibiotic resistant marker) of interest. Transformation into suitable competent cells (BL21 etc.). (Students will learn how to prepare E. coli competent cells). Selection of the antibiotic resistant single colony. e.Plasmid isolation from the transformed cells and sequencing it to confirm the sequence of cloned DNA segment of interest. Testing of protein expression upon induction in presence of IPTG (SDS PAGE/Western Blotting).

- Large scale expression and purification of the protein: Bulk scale bacterial cell culture and IPTG induction for protein expression. Detection of the protein by western blotting in soluble and insoluble fraction after bacterial

cell lysis. Affinity purification of the protein from the soluble fraction of the bacterial cell lysate (for His-tagged protein, Ni-agarose matrix will be used).

- Biochemical and biophysical characterizations of the purified protein: Purified protein will be assayed for its biological activity. (Fluorescence from GFP). UV-VIS absorption and emission spectra resulting from intrinsic Tryptophan and GFP chromophores. Fluorescence quenching and polarization studies. Unfolding and refolding studies using CD and fluorescence methods.

Recommended Reading

- J. Sambrook, E. F. Fritsch, and T. Maniatis, *Molecular cloning: a laboratory manual*, 2nd Edn., Cold Spring Harbor Laboratory Press (1989).

BIO312: Development and physiology lab

[Cr:4, Lc:0, Tt:0, Lb:12]

Course Outline

- The students will develop the skill of designing and performing experiments that would help them understand some fundamental concepts in Developmental Biology and Physiology. The choice of model organisms to be used for these experiments is up to the discretion of the instructor.
- An outline of some of the aspects that can be explored is as follows:

  1. Cleavage patterns.
  2. Segmentation during embryonic development; Reporter gene expression; mutant phenotypes.
  3. Master regulators in cell fate specifications.
  4. Pattern formation in developing tissues Programmed.
  5. Cell Death and tissue sculpturing Role of niche and stem cells in tissue regeneration.
  6. Regulation of Skeletal/Cardiac Muscle Contraction.
  7. Generation of action potential; neuronal propagation and synaptic transmission.

BIO401: Structure and function of genomes

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Organization of the eukaryotic genome. Nucleosomes, histones, chromatids, centromeres, teleomeres. Repetitive content of eukaryotic genomes. Organization of prokaryotic genomes. Organization of genes, operons.
- Mapping of Genomes. Genetic maps. DNA markers: RFLP, SSR, SNP,. Linkage analysis as a basis of genetic analysis. Physical maps. Restriction maps, FISH, STS mapping

- Sequencing of genomes. Methods of DNA sequencing. Maxam and Gilbert method. Sanger method. Automated DNA sequencing. Pyrosequencing. An introduction to Next Generation sequencing strategies. Genome sequencing strategies. Assembly of contiguous DNA by hierarchial (clone contig) and shotgun strategies. BACs, YACs in genome sequencing strategies.
- The Human genome project and the history of genome sequencing. The mapping phase. Sequencing the human genome. Future implications and impact. Genome sequencing projects of model organisms.
- How genomes function: Chromatin modification and genome expression. Histone acetylation, deacetylation, nucleosome remodelling.
- Experimental approaches to genome-wide analysis. Genome-wide mutational strategies. Transcriptome analysis using microarray. ChIP on ChIP assays.
- Genome evolution and comparative genomics. Genome duplication, horizontal gene transfer. Orthologues,paralogues. Horizontal gene transfer. Organellar evolution.

Recommended Reading

- T. A. Brown, *Genomes 3*, 3rd Edn., Garland Science (2006).
- D. L. Hartl and E. W. Jones, *Genetics: Analysis of Genes and Genomes*, 7th Edn., Jones and Bartlett Publishers (2009).

BIO402: Microbial physiology and microbial genetics

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Introduction to microbial taxonomy /diversity
- Structure of the prokaryotic cell: cell surface structure, motility,internal genome architecture
- Bacterial growth and differentiation
- Mutations, mutants and genetic screens
- Reversion and Supression
- Genetics of Bacteria
- Transformation
- Plasmids
- Conjugation
- Bacteriophage genetics
- Phage transduction and mapping
- Transposable elements

- Life Cycle of yeasts
- Genetics of yeasts
- Molecular genetic tools in yeasts
- In vitro genetics
- Genetics in the era of Genomics

Recommended Reading

- S. Maloy, J. Cronan and D. Freifelder, *Microbial Genetics*, 2nd Edn., Jones and Bartlett Publishers Inc. (1994).
- C. Guthrie and G. R. Fink, *Guide to Yeast Genetics and Molecular and Cell Biology*, Academic Press (2004)
- D. L. Hartl and E. W. Jones, *Genetics: Analysis of Genes and Genomes*, 7th Edn., Jones and Bartlett Publishers (2009).

BIO403: Advanced evolutionary biology

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Review of Basic concepts of Evolution.
- Population genetics. Advanced topics in H-W principle- Infinite alleles, X-linkage, Models of selection (additivity, dominance, overdominance, underdominance), viability selection, gametic selection; Mutation, Gene flow, Genetic Drift, Effective population size.
- Molecular Population genetics Neutral Theory, Coalescence and genealogies. Molecular clock, tests of neutral theory. Molecular Phylogenetics, QTL mapping.
- Origin and Evolution of Sex. Linkage disequilibrium and recombination. Cost of sex and benefits. Sexual Conflict and Sexual Selection.
- Life History Evolution. Aging, Body Size and other life-history related traits. Leslie Matrices, Euler-Lotka eqn. and the growth of age-structured populations. Density dependent selection, frequency dependent selection, Game theory and ESS. Behavioural evolution.
- Evolution of Humans.
- Evolution, culture and health.

Recommended Reading

- B. K. Hall and B. Hallgrimsson, *Strickberger's Evolution*, 4th Edn., Jones and Bartlett (2008).
- S. Freeman and J. C. Herron, *Evolutionary Analysis*, 4th Edn., Benjamin-Cummings (2007).
- P. W. Hedrick, *Genetics of Populations*, 3rd Edn., Jones and Bartlett (2005).
- D. L. Hartl and A. G. Clark, *Principles of Population Genetics*, 4th Edn., Sinauer Associates (2006).

BIO404: Cellular and molecular basis of the immune response

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Basic concepts in immunology: Hematopoiesis. Cells of immune system. Basic concepts of Innate and Adaptive immunity.
- Innate Immunity: Pattern recognition. Complement system. Induced innate responses to infection.
- Antigen recognition by B-cell and T-cell receptors.
- Generation of lymphocyte antigen receptors: Immunoglobulin gene rearrangement. T-cell receptor gene rearrangement.
- Antigen presentation to T-cells: MHC complex: structure and function.
- Signaling through immune receptors: Immunological synapse. General principles of signal transduction through T-cell receptor activation. Costimulation. Cytokine receptors.
- Development and survival of lymphocytes: B-cell development. T-cell development. Positive and negative selection of T-cells. Survival and maturation of lymphocytes in peripheral lymphoid tissues.
- T-cell-mediated immunity.
- Humoral immunity.
- Dynamics of adaptive immunity: Immunological memory. Mucosal immunity.
- Immune system in health and disease: Failures of host immunity. Immunodeficiency. Allergy and hypersensitivity. Autoimmunity.
- Evolution of immune system.
- Techniques in immunology: ELISA. RIA. Immunofluorescence and immunohistochemistry. Immunoprecipitation. Immunoblotting. Flow cytometry. Elispot. Monoclonal antibody and Hybridoma technology. Isolation and characterization of lymphocytes.

Recommended Reading

- K. M. Murphy, P. Travers and M. Walport, *Janeway's Immunobiology*, 7th Edn., Garland Science (2008).
- T. J. Kindt, R. A. Goldsby and B. A. Osborne, *Kuby Immunology*, 6th Edn., W.H. Freeman (2006).

BIO411: Bioinformatics lab

[Cr:4, Lc:1, Tt:0, Lb:9]

Course Outline

- Biological databases. Nucleic acid and protein databases.ENTREZ. Genbank. Nucleotide and protein sequence data formats: FASTA, ASN.1, Genbank Flatfile
- Pairwise and Multiple alignment. Homology, Sequence Identity and Sequence similarity. Global alignment, Local alignment, Scoring functions. Gap penalty. Statistical significance. PAM and BLOSUM. Applications of Multiple sequence alignments: Consensus, motifs and Profiles. Position Specific Scoring Matrices. Clustal X.
- Methods for Database Searching BLAST and FASTA. Scoring matrices, Significance of alignments, E-values. BLAST programs: BLASTp, BLASTn, BLASTx, tBLASTn, tBLASTx. PSI BLAST.
- Phylogenetic analysis: Concept of phylogenetic trees – Branches, nodes, internal nodes, rooted and unrooted trees. Distance matrix methods; Maximum parsimony methods; Maximum likelihood methods.
- Gene prediction: Prokaryotes versus eukaryotes. Promoters,splice sites. RNA secondary structure prediction.
- Structural bioinformatics. Protein secondary structure prediction. Tertiary structure prediction: Homology modeling, Threading , Fold recognition, ab initio protein structure prediction. Protein structure visualization. Protein structure classification and databases.

Recommended Reading

- J. Xiong, *Essential Bioinformatics*, Cambridge University Press (2009).
- D. Mount, *Bioinformatics: Sequence and Genome Analysis*, 2nd Edn., Cold Spring Harbor Laboratory Press (2004).
- A. D. Baxevanis and B. F. F. Ouellette (eds), *Bioinformatics: A practical guide to the analysis of genes and proteins*, 3rd Edn., Wiley-Interscience (2004).
- D. E. Krane and M. L. Raymer, *Fundamental concepts of Bioinformatics*, 1st Edn., Pearson Education India (2003).

BIO412: Lab on biophysical and spectroscopic tools

[Cr:4, Lc:0, Tt:0, Lb:12]

Course Outline

- Introduction to molecular biophysics and spectroscopic techniques in biology (2 Lectures) Determination of the critical micellar concentration of a biological surfactant (bile salt) using fluorescence spectroscopy. (1 Lab session) Basic structural characterizations of a model protein using circular dichroism, fluorescence, Raman spectroscopy etc. (3 Lab sessions) Urea and pH denaturations of a model protein using circular dichroism and fluorescence spectroscopy. (2 Lab sessions) Thermal denaturation of a model protein using circular dichroism spectroscopy. (1 Lab session) Fluorescence correlation spectroscopy experiment to measure the protein diffusion and hydrodynamic size. (2 Lab sessions) Atomic force microscopy of plasmid DNA. (2 Lab sessions)

Recommended Reading

- K. E. van Holde, C. Johnson, P. S. Ho *Principles of Physical Biochemistry*, 2nd Edn., Prentice Hall (2005).
- C. R. Cantor and P. R. Schimmel, *Biophysical Chemistry* (Part 1-3), 2nd Edn., W. H. Freeman (2009).

3.2 Chemistry Major Courses

CHM301: Quantum chemistry

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Two spectroscopic models: The harmonic oscillator and the rigid rotor, description of a diatomic molecule, energy levels of a quantum-mechanical oscillator, Hermite polynomials. The rigid rotor, energy level of a rigid rotor, spherical harmonics, description of hydrogen atom, Schrödinger equation for the helium atom.
- Approximation methods: Time-independent perturbation theory, non-degenerate perturbation theory, degenerate perturbation theory, applications, variational method and its applications, description of helium atom using variational and perturbation method.
- Multi-electron atoms: Born-Oppenheimer approximation, symmetric and anti-symmetric wave functions, spin orbitals and spatial orbitals, Hartree products, Slater determinants, the Hartree-Fock approximation, configuration interaction, the Coulomb and exchange operators, spin adapted configurations, term symbol, description of electron configuration, description of atomic spectra using term symbols, Russell-Saunders coupling.

- Description of molecules: Valence bond treatment and stability of bonds, molecular orbital theory and its applications in simple systems, molecular orbital theory of polyatomic molecules, the concept of delocalization, conjugated systems, butadiene.

Recommended Reading

- D. A. McQuarrie, *Quantum Chemistry*, 1st Ed, Viva Books, New Delhi (2003).
- I. N. Levine, *Quantum Chemistry*, 5th Ed, Prentice Hall of India (2000).
- A. Szabo, N. S. Ostlund, *Modern Quantum Chemistry: Introduction to Advanced Electronic Structure Theory*, 1st Ed, Dover Publicatsions, New York (1996).
- G. C. Schatz, M. A. Ratner, *Quantum Mechanics in Chemistry*, 1st Ed, Dover Publications, New York, (2002).

CHM302: Organic chemistry

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Selectivity in organic reactions: Chemoselectivity, regioselectivity, enantio- and stereo-selectivity. Stereoaspects of the addition of X_2, HX, boranes and hydroxylation to C=C systems. *Cis*- and *trans*-hydroxylation of cycloalkenes. Atropisomerism. Racemisation, resolution, prostereoisomerism, stereotopicity and enantiomeric excess. Chirality-optical isomerism in biphenyls, allenes. Geometrical isomerism-acylic and cyclic compounds.
- Selected named reactions: Aldol, Arndt-Eistert, Bardhan-Sengupta, Baker-Venkataraman, Barbier, Barton, Baylis-Hillman, Benzoin, Birch, Cannizaro, Corey-Bakshi-Shibata, Corey-Seebach, Darzen, Dakin, Diels-Alder, Dieckmann, Fischer, Friedel-Crafts, Friedlander, Grignard, Fukuyama, Heck, Knoevnagel, Paal-Knorr, Mannich, Michael, Mukaiyama, Pictet-Spengler, Perkin, Prins, Reformatsky, Reimer-Tiemann, Robinson, Stork, Strecker, Vilsmeier, Wittig Wagner-Meerwein. Mitsonobu reaction. 1,3-dipolar cycloaddition in the construction of rings. Prevost and Woodward procedures.
- Oxidation and reduction chemistry. Metal hydrides as reagents. Aluminum/boron hydride reagents & hydroboration reaction. Baeyer-Villiger, Oppenauer, Dess-Martin, Swern, Jones oxidation reactions. Meerwein-Ponndorf-Verley, Wolff-Kishner, Rosenmund, Clemmensen reduction reactions.
- Selected reagents in organic synthesis: Barbier and Grignard, organolithium, organosilicon, organo zinc based organometallic reactions involving C-C bond formations. Selected functional group transformations organic synthesis.

Recommended Reading

- F. A. Carey, R. J. Sundberg, *Advanced Organic Chemistry Part A: Structure and Mechanism & Part B: Reactions and Synthesis*, 5th Ed, Springer, New York (2007).
- R. T. Morrison, R. N. Boyd, *Organic Chemistry*, Indian Edition, 6th Ed, Pearson Education, New Delhi (2007).
- W. Carruthers, I. Coldham, *Modern Methods of Organic Synthesis*, Indian Edition, 4th Ed, Cambridge (2004).
- J. Clayden, N. Greeves, S. Warren, P. Wothers, *Organic Chemistry*, Oxford University Press, New York (2006).
- L. G. Wade Jr., M. S. Singh, *Organic Chemistry*, Indian Edition, 6th Ed, Pearson Education, New Delhi (2008).
- E. L. Eliel, S. H. Wilen, L. N. Mander, *Stereochemistry of Organic Compounds*, Wiley, New York (2005).
- T. Laue, A. Plagens, *Named Organic Reactions*, 2nd Ed, John Wiley & Sons Inc, Hoboken, New Jersey (2005).

CHM303: Main group chemistry

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Coordination chemistry of *s*-block elements with an emphasis on structural features of their hydrides, halides, oxides and oxyacids.
- Boron and aluminium compounds: Structure and bonding of boranes, metallaboranes, carboranes, metallacarboranes; Organoaluminium and low-valent Al compounds.
- Main group complexes with CO, CN-, C_2H_4, Cp, Cp* ligands their chemistry, structure and bonding. Special topics in carbon chemistry: Fullerenes, etc.
- Silicon chemistry: Structure and bonding in silicates, silicones, silylenes. Selected examples of single, double, and triple bonded Si compounds.
- NS, NO and NP compounds with special focus on NP and NS compounds, organic and inorganic phosphates.
- Oxides and peroxides, Interhalogens, polycations of halogens and chalcogens.

Recommended Reading

- F. A. Cotton, G. Wilkinson, C. A. Murillo, M. Bochmann, *Advanced Inorganic Chemistry*, Indian Edition, 6th Ed, Wiley-India, Noida (2007).
- N. N. Greenwood, A. Earnshaw, *Chemistry of The Elements*, Indian Edition, 2nd Ed, Butterworth-Heinemann, Elsevier (2005).

- J. E. Huheey, E. A. Keiter, R. L. Keiter, O. K. Medhi, *Inorganic Chemistry: Principles of Structure and Reactivity*, Indian Edition, 4th Ed, Pearson Education, India (2007).
- H. J. Emeleus, A. G. Sharpe, *Modern Aspects of Inorganic Chemistry*, 4th Ed, ELBS and Routledge & Kegan Paul, London (1974).
- P. Atkins, T. Overton, J. Rourke, M. Weller, F. Armstrong, *Shriver & Atkins Inorganic Chemistry*, Indian Edition, 4th Ed, Oxford University Press, New Delhi (2008).

CHM304: Symmetry in chemistry

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Symmetry elements and operations, the algebra of symmetry operations, symmetry property of orbitals.
- Point groups and matrix representations: Determination of molecular point groups, group-multiplication tables, group-generating elements, the rearrangement theorem.
- Reducible and irreducible representations, character of a representation, the great orthogonality theorem, properties of irreducible representations, criterion for irreduciblity, character tables and their construction, the reduction of reducible representation.
- Free ion configurations, terms and states, configuration of free-ions, angular momentum of electrons, vector coupling of angular momentum, spin-orbit coupling, L-S coupling scheme, j-j coupling scheme, derivation of terms, symmetry of atomic orbitals, correlation tables.
- Applications in chemistry, molecular vibrations, normal coordinates, classification of normal coordinates, IR and Raman spectra, MO theory, LCAO MO approximation, HMO approach, hybrid orbitals.

Recommended Reading

- D. M. Bishop, *Group Theory and Chemistry*, 1st Ed, Dover Publications, New York (1993).
- F. A. Cotton, *Chemical Applications of Group Theory*, Indian Edition, 3rd Ed, Wiley-India, Noida (2003).
- H. H. Jaffe, M. Orchin, *Symmetry in Chemistry*, 1st Ed, Dover Publications, New York (2002).

CHM305: Physical organic chemistry

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Reactive intermediates and rearrangement reactions: Carbenes, nitrenes, isonitrenes, carbocations, carbanions, radical involved reactions and mechanisms. Selected rearrangement reactions: Beckmann, Benzilic acid, Benzidine, Cope, Curtius, Favorskii, Fries, Hofmann, Lossen, Pinacol, Wolf, Wagner-Meerwein, Schmidt, Sommelet-Hauser.
- Thermodynamic vs kinetic control. Curtin-Hammett principle, Hammonds postulates.
- Mechanism of organic transformations involving potential reactive intermediates, their generations, stability, and applications in reactions & rearrangements. Labeling and kinetic isotope effects, solvents and their effect on course of a reaction.
- Aromaticity and anti-aromaticity: Types Hückel and Craig's rules, homo, hetero (furan, thiophene and pyrrole) and nonbenzenoid aromatic systems. Aromaticity of annulenes. mesoionic compounds, metallocenes, cyclic carbocations and carbanions. Aromatic substitution reactions of aromatic systems and hetero aromatic compounds (electrophilic, nucleophilic and through benzynes)-radical substitution of arynes. Orientation effects of substituents in aromatic electrophilic substitutions. Hammett equation.
- Pericyclic reactions: Classification, mechanism, Conservation of orbital symmetry and stereo course of electrocyclic, cycloaddition and sigmatropic reactions. Woodward-Hoffmann rules. Claisen rearrangement. Stereo aspects of Diels-Alder reaction and Cope rearrangement. Sommelet-Hauser, Retro Diels-Alder, Ene, cheletropic and *cis* elimination reactions. Synthetic applications.
- Photochemical processes: Jablönski diagram and fluorescence emmission, singlet and triplet states and their reactivity. Energy transfer, sensitization and quenching. Photoreactions of carbonyl compounds, enes, dienes, and arenes. Norrish reactions. Patterno-Buchi, Barton, photo-Fries and Di-π-methane rearrangement reactions. Photoreactions of Vitamin D. Photochemistry of vision and photosynthesis. Singlet oxygen generation and reactions. Applications of photoreactions, The Photochemistry of nitrenes and azo compounds.

Recommended Reading

- P. Deslongchamps, *Stereoelectronic Effects in Organic Chemistry*, Elsevier (1983).
- N. J. Turro, *Modern molecular photochemistry*, University Science Books (1991).
- F. A. Carey, R. J. Sundberg, *Advanced Organic Chemistry Part A: Structure and Mechanism & Part B: Reactions and Synthesis*, 5th Ed, Springer, New York (2007).
- J. Clayden, N. Greeves, S. Warren, P. Wothers, *Organic Chemistry*, Oxford University Press, New York (2006).
- L. G. Wade Jr., M. S. Singh, *Organic Chemistry*, Indian Edition, 6th Ed, Pearson Education Inc, New Delhi (2008).

- D. Bethall, *Advances in Physical Organic Chemistry*, Volume 29, Academic Press (1994).
- J. Kagan, *Organic Photochemistry*, Academic Press (1993).

CHM306: Transition metal chemistry

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Coordination chemistry of 1st and 2nd row transition metals: Reaction mechanism in transition metal complexes, trans effect, inner & outer sphere mechanism, electronic spectra of transition metal complexes, Orgel and Tanabe Sugano diagrams. Types of magnetic behavior and its qualitative and quantitative discussion with respect to coordination complexes.
- Organometallic complexes of 1st and 2nd row transition elements and their application in catalysis. Silicon analogs of 1st and 2nd row transition metals will also be discussed. Fluxional organo transition metal compounds and stereochemical nonrigidity.
- Concept of isolobality in organometallic and metal cluster compounds and parallels between main group and organometallic chemistry.
- Polyhedral clusters with or without a metal-metal bond: structure, bonding and properties.

Recommended Reading

- F. A. Cotton, G. Wilkinson, C. A. Murillo, M. Bochmann, *Advanced Inorganic Chemistry*, Indian Edition, 6th Ed, Wiley-India, Noida (2007).
- N. N. Greenwood, A. Earnshaw, *Chemistry of The Elements*, Indian Edition, 2nd Ed, Butterworth-Heinemann, Elsevier (2005).
- R. H. Crabtree, *The Organometallic Chemistry of The Transition Metals*, 4th Ed, John Wiley & Sons Inc, New Jersey (2005).
- J. E. Huheey, E. A. Keiter, R. L. Keiter, O. K. Medhi, *Inorganic Chemistry: Principles of Structure and Reactivity*, Indian Edition, 4th Ed, Pearson Education, India (2007).
- L. M. Jackman, F. A. Cotton, *Dynamic Nuclear Magnetic Resonance Spectroscopy*,Academic Press Inc, New York (1975).

CHM311: Organic chemistry lab

[Cr:4, Lc:1, Tt:0, Lb:9]

Course Outline

- Analysis of organic binary mixtures: Separation and identification of organic binary mixtures containing substituents. (A student is expected to analyze atleast 8-10 different binary mixtures). Chemical reactions and derivatisations.
- Synthesis and purification of organic compounds involving one and two/three stages: Reactions involving nitration, halogenation, oxidation, reduction, alkylation/acylation, condensation, esterification and rearrangement etc will be covered. Examples will be selected from:
  - Preparation of benzydrol from benzophenone.
  - Prepration of menthone from menthol.
  - Preparation of dibenzylideneacetone.
  - Nitration of methyl benzoate to prepare methyl-3-nitrobenzoate.
  - Benzoylation of bromobenzene to prepare 4-bromobenzophenone.
  - Preparation of 2-aminobenzoic acid from phthalimide.
  - Preparation of *trans*-stilbene from benzyl halide and benzaldehyde.
  - Preparation of *p*-bromoaniline from aniline.
  - Preparation of *trans*-cyclohexane-1,2-diol from cyclohexene.
  - Preparation of E-3-phenylpropenoic acid (cinnamic acid) followed by esterification from benzaldehyde and malonic aicd.
  - Preparation of paracetamol.
  - Coumarine synthesis.
  - Extraction of caffeine from tea.
  - Extraction of nicotine from cigarettes.

Recommended Reading

- L. M. Harwood, C. J. Moody, J. M. Percy, *Experimental Organic Chemistry*, 2nd Ed, Blackwell Science, Oxford (1999).
- B. S. Furniss, A. J. Hannaford, P. W. G. Smith, A. R. Tatchell, *Vogel's Textbook of Practical Organic Chemistry*, Indian Edition, 5th Ed, Pearson Education, New Delhi (2008).
- J. S. Nimitz, *Experiments in Organic Chemistry: From Microscale to Macroscale*, Prentice Hall, New Jersey (1990).
- F. G. Mann, B. C. Saunders, *Practical Organic Chemistry*, Indian Edition, 4th Ed, Orient Longman, Noida (2007).

CHM312: Inorganic chemistry lab

[Cr:4, Lc:1, Tt:0, Lb:9]

Course Outline Familiarization with advanced techniques for syntheses and characterization of coordination compounds and organomatallic complexes including the use of standard Schlenk and vacuum line techniques. Crystallization, distillation and sublimation as purification methods will be practiced. Representative examples as:

- Synthesis and reactivities of organocobaloximes.
- Prepration of *tris*(acetylacetonato) iron(III).
- Preparation *tris*(ethylenediammine)cobalt(II) ion and its resolution into optical antipodes.
- Synthesis of hexaminecobalt(III) chloride and pentammineaquacobalt(III) chloride.
- Silicones-its preparation and characterization.
- Other silicone polymers and bouncing putty.
- Preparation of an iron (or nickel) nitrosyl complex.
- Synthesis of a cationic iodine complex.
- Synthesis of *bis*(cyclopentadienyl)iron(II) (ferrocene).
- Dilithiation of ferrocene and synthetic uses of the product in the preparation of acetyl ferrocene.
- Preparation of *bis*(cyclopentadienyl) nickel (nickelocene).
- Synthesis of a metal-metal bonded cyclopentadienyl complex of molybdenum, $Cp_2Mo_2(CO)_6$.
- Synthesis of an arenetricarbonyl chromium(0) complex.
- Preparation of boronic acid from Grignard reagents and trimethyl borate.
- Preparation of chiral salen based catalysts of Co, Cr derived from 3,5-di-*tert*-butylsalicylaldehdye and *trans*-1,2-diaminocyclohexane,

Recommended Reading

- J. D. Woollins, *Inorganic Experiments*, 2nd Ed, Wiley-VCH, Weinheim (2003).
- M. A. Malati, *Experimental Inorganic/Physical Chemistry: An Investigative, Integrated Approach to Practical Project Work*, Horwood Publishing Ltd, England (1999).
- J. Tanaka, S. L. Suib, *Experimental Methods in Inorganic Chemistry*, Prentice Hall, New Jersey (1999).

CHM401: Molecular spectroscopy

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Theory of emission and absorption of radiation, symmetry property of wave functions, the Boltzmann distribution, selection rules, induced emission and induced absorption, integrated absorption coefficient.
- Rotational spectroscopy: Linear polyatomic molecules, symmetric top molecules, asymmetric top molecules, Stark effect, quadrupole hyperfine interaction, rotational spectrum of polyatomic molecules, molecular rotation-nuclear-spin coupling, derivation of selection rules.
- Vibrational spectroscopy: Interaction of vibration and rotation, vibrations of polyatomic molecules, normal modes and normal coordinates, quantum-mechanical treatment of vibrations of polyatomic molecules.
- Rotational-vibrational spectroscopy: Influence of rotation on the spectra of polyatomic molecules, theoretical model for describing ro-vibrational spectra, selection rules and transitions, coupling of rotation and vibration, quantum-mechanical description.
- Electronic spectroscopy of diatomic molecules, the vibrational structure of electronic bands, rotational structure of electronic bands, electronic states of atoms, electron orbitals and electronic states in diatomic molecules, potential energy curves for electronic states of diatomic molecules
- Magnetic resonance spectroscopy: Nuclear spin interactions, quantum-mechanical description of NMR interactions, basic principles of pulse-NMR, description of simple experiments such as cross-polarization, INEPT and DEPT experiments, introduction to dynamic nuclear polarization (DNP) experiments.

Recommended Reading

- P. F. Bernath, *Spectra of Atoms and Molecules*, 2nd Ed, Oxford University Press, USA (1995). J. M. Hollas, *Modern Spectroscopy*, 4th Ed, John Wiley & Sons Inc, England (2004).
- D. C. Harris, M. D. Bertolucci, *Symmetry and Spectroscopy: An introduction to Vibrational and Electronic Spectroscopy*, 1st Ed, Dover Publications, New York (1989).

CHM402: Chemistry of materials

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Inorganic materials: metals, alloys, glass, anionic clays, zeolites, simple and complex oxide and non-oxide ceramic systems, crystal structure, properties, structure-property relationship, defect chemistry, synthesis and characterization.
- Organic and organometallic materials: Synthesis and properties of mono/multimetallic system, supramolecular and dendrimeric materials, polymers, electrical conduction, superconductivity and magnetism; charge

transfer salts; fullerides; thin films (Langmuir Blodgett films and self assembled monolayers); application as catalysts, nonlinear optical materials; organic LEDs; light harvesting and light emitting materials; spintronics.

- Conducting polymers: Band structure; mechanism of conduction; synthesis and characterization of polyacetylene, polythiophene, polyaniline, metallophthalocyanines and their chemical and electrochemical properties; applications in molecule-based devices.
- Porous, soft materials, inorganic-organic hybrid and nanostructured materials.

Recommended Reading

- B. D. Fahlman, *Materials Chemistry*, 1st Ed, Springer Verlag (2007).
- U. Schubert, N. Husing, *Synthesis of Inorganic Materials*, Wiley-VCH GmbH & Co. kGaA (2000).
- A. F. West, *Solid State Chemistry and Its Applications*, John Wiley, New York (1990).
- C. Hammond, *The Basics of Crystallography and Diffraction*, 2nd Ed, Oxford Science Publications (2001).
- C. N. R. Rao, J. Gopalakrishnan, *New Directions in Solid State Chemistry*, 2nd Ed, Cambridge University Press (1997).
- A. K. Cheetham, P. Day, *Solid State Chemistry-Compounds*, Oxford University Press (1992).
- A. K. Cheetham, P. Day, *Solid State Chemistry-Techniques*, Oxford University Press (1987).
- W. D. Kingery, H. K. Bowen, D. R. Uhlman, I*ntroduction to Ceramics*, 2nd Ed, New York (1976).

CHM403: Analytical chemistry

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Statistical methods in chemical analysis: Types of errors, propagation of errors, statistical treatment of random errors, sample and population, Normal distribution, Tests of Significance and Confidence Limits. Method of Least squares and weighted least squares formalism. Use of certified reference materials and procedures for interlaboratory comparisons. Definition of limits of detection and sensitivity, and concept of standard addition to assess matrix effects.
- Analytical Spectroscopy: Atomic Absorption Spectrometry (AAS); Flame AAS, Electrothermal AAS (ET-AAS). Atomic Emission Spectrometry (AES): With different excitation sources such as Flame AES, Inductively Coupled Plasma AES (ICP-AES), Glow Discharge AES (GD-AES) and Spark Source AES (SS-AES). Fluorescence Spectrometry, Laser Induced

Fluorescence (LIF), steady state and lifetime measurements, Single atom detection. UV-Visible Molecular Absorption Spectrometry. Sources and treatment of interferences and detection limits to be considered in each of the techniques.

- Mass and Electron Spectroscopy: Mass Spectrometry: Mass Analysers; Magnetic, Electrostatic, Double Focusing, Quadrupole, Time of Flight, Ion cyclotron resonance. Discussion on instrumentation, resolution and sensitivity. Detectors; Electron multipliers, Faraday cup and microchannel plates. Ion Sources, Electron Impact Ionization, Inductively Coupled Plasma, Glow Discharge, Thermal ionization, Laser Ionisation, Matrix Assisted Laser Desorption and Ionisation (MALDI) and SIMS. Applications to ultra-trace analysis, isotope ratio measurements and surface characterization. Electron Spectrometry: X-ray and UV Photoelectron Spectroscopy, Auger Electron Spectroscopy, Electron Energy Loss Spectroscopy (EELS)

- Microscopy: Scanning Electron Microscopy, SEM-EDX (Scanning Electron Microscopy-Energy Dispersive X-ray Spectroscopy), Scanning Tunneling Microscopy (STM), Atomic Force Microscopy (AFM), Transmission Electron Microscopy (TEM)

- X-ray Spectroscopy: X-ray fluorescence – Wavelength dispersive (WDXRF), Energy dispersive (EDXRF) XRF, Proton Induced X-ray Emission (PIXE), Extended X-ray Absorption Fine Structure (EXAFS), X-ray Absorption Near Edge Structure (XANES)

- Analytical Electrochemistry: Potentiometry – General principles, Calomel Electrodes, Ag-AgCl electrodes, Membrane electrodes – ion selective electrodes, glass electrodes, biosensors. Coulometry: Basic principles, constant current and constant potential coulometry. Voltammetry: different waveforms – linear scan, square scan and triangular scan, cyclic voltammetry.

- Separation techniques: Principles and applications of TLC, Gas chromatography (GC), High Performance Liquid Chromatography (HPLC), FPLC, Ion chromatography (IC), Supercritical Fluid Chromatography, Capillary Electrophoresis.

Recommended Reading

- D. A. Skoog, D. M. West, F. J. Holler, S. R. Crouch, *Fundamentals of Analytical Chemistry*, 8th Edition, Thomson (2004).

- D. A. Skoog, F. J. Holler, S. R. Crouch, *Instrumental Analysis*, 1st Edition, Brooks/Cole (Cengage Learning) (2007).

- H. H. Willard, L. L. Merritt Jr.,J. A. Dean, f. A. Settle Jr., *Instrumental Methods of Analysis*, CBS Publishers, New Delhi (1986).

- J. C. Miller, J. N. Miller, *Statistics for Analytical Chemistry*, 2nd Edition, Wiley (1998).

- D. C. Harris, W. H. Freeman *Quantitative Chemical Analysis*, 7th Edition (2006).

CHM404: Statistical thermodynamics

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Averaging and statistics, elements of probability theory, thermodynamics versus statistical mechanics, classical thermodynamics, statistical ensembles in classical mechanics, the concept of ensemble and phase space, Liouville's theorem, Ergodic hypothesis in statistical mechanics, equal *a priori* probabilities in phase space, the Maxwell-Boltzmann distribution law.
- Foundations of molecular thermodynamics, isolated assembly, assumptions in molecular thermodynamics, partition function, classical partition function, derivation of thermodynamic relations using partition functions.
- Molecular and assembly partition functions, localized and non-localized systems, the assembly of independent localized and non-localized systems, multiplication theorem for partition functions, the statistical interpretation of entropy.
- Molecular partition functions, classical molecular partition functions, the classical rotor, the classical harmonic oscillator, thermodynamic functions of the ideal assembly of localized and non-localized systems, applications in describing the behavior of gases, Maxwell-Boltzmann distribution law, velocity distributions, the pressure of an ideal gas.
- Chemical equilibrium, derivation of molecular thermodynamic equations from classical thermodynamics, the transition state theory, derivation, bimolecular collisions, rearrangements.

Recommended Reading

- D. A. McQuarrie, *Statistical Mechanics*, 1st Ed, Viva Books, India (2003).
- D. Chandler, *Introduction to Modern Statistical Mechanics*, 1st Ed, Oxford University Press, New York (1987).
- T. L. Hill, *An Introduction to Statistical Thermodynamics*, 1st Ed, Dover Publications, New York (1986).
- N. Laurendeau, *Statistical Thermodynamics: Fundamentals and Applications*, 1st Ed, Cambridge University Press, New York (2005).

CHM411: Physical chemistry lab

[Cr:4, Lc:1, Tt:0, Lb:9]

Course Outline

- Potentiometric titration of strong acid HCl by strong base NaOH.
- Potentiometric titration of weak acid CH_3COOH by strong base NaOH and determination of pK_a of the weak acid.

- Potentiometric titration of a weak dibasic acid using strong base NaOH,
- determination of the two pK_a values of the acid. Conductometric titration of strong acid HCl using strong base NaOH.
- Conductometric titration of weak acid CH_3COOH by strong base NaOH.
- Conductometric titration of a triple mixture of HCl, NH_4Cl and KCl by NaOH and $AgNO_3$.
- Determination of partition coefficient of I_2 in water and chloroform.
- Determination of the equilibrium constant of the reaction $KI+I_2=KI_3$ using the result from the previous experiment.
- Determination of solubility product of CH_3COOAg.
- Kinetic study of acid catalyzed hydrolysis of methyl acetate.
- Determination of viscosity of a solution of glycerol and determination of concentration of an unknown solution of glycerol.
- Determination of surface tension of soap water.
- Determination of hardness of water.
- Determination of the order of mutarotation of glucose using polarimetry.
- Kinetic study of acid catalyzed hydrolysis of sucrose and determination of the rate law.
- Construction of phenol-water phase diagram and determination of upper critical solution temperature.
- Construction of binary Eutectic phase diagram of naphthalene-biphenyl system and determination of Eutectic temperature and Eutectic composition.
- Enzyme catalyzed hydrolysis of methyl acetate.
- Determination of pK_a of an amino acid.

Recommended Reading

- B. Viswanathan, P. S. Raghavan, *Practical Physical Chemistry*, Viva Books Pvt. Ltd., New Delhi (2010).
- A. Ghosal, B. Mahapartra, A. K. Nad, *An Advanced Course in Practical Chemistry*, New Central Book Agency Pvt Ltd, Calcutta (2000).

CHM412: Analytical chemistry laboratory

[Cr:4, Lc:1, Tt:0, Lb:9]

Course Outline

- UV-Visible spectrophotometry: (a) Determination of concentrations of absorbing, and non-absorbing species using chromophoric reagents (such as the use of 1,10-phenanthroline for iron); (b) Method of continuous variation for determination of stoichiometry of complexes.
- Electrochemical methods: (a) Potentiometry-estimation of chloride and iodide in a mixture; use of ion-selective electrodes for the determination of chloride and fluoride – determination of fluoride in drinking water; (b) Electrogravimetry: Determination of Cu and Pb in brass, or determination of purity of a Cu piece; (c) Voltammetry and coulometry (may be included); (d) Fabrication of a screen printed SnO_2 sensor for the detection and measurement of NH_3.
- Separation techniques: (a) GC – separation of a mixture of organics f ollowed by identification using IR; (b) HPLC-separation of organics and comparison with GC, (c) separation of lanthanides using HPLC.
- Fluorescence spectroscopy: (a) Determination of fluorophore concentrations using emission and synchronous fluorescence methods. (b) Study of ligand sensitized fluorescence; (c) Effects of quenching – Stern Volmer equation.
- Microscopy: Raman Microscopy and AFM
- Atomic Absorption and Emission Spectroscopy – Preparation of standards at μg/mL concentrations (ppm) and use in the determination of trace levels using Atomic Absorption and Atomic Emission techniques, using flame and electrothermal vaporization techniques
- Determination of Ca, Mg and Cu in tap water, and waste water samples by Flame Atomic Absorption Spectroscopy
- Determination of total organic carbon chemical oxygen demand in water samples

Notes

- The lab course has been designed to accommodate a total of about 20 experiments. A student may be required to do about 15 of these experiments in the course.
- If AAS spectrometer and GC-MS are not available, the course may be conducted using experiments listed from 1-5, instruments for which are available or would become available, and which would account for 15 experiments.

Recommended Reading

- A. Ghosal, B. Mahapartra, A. K. Nad, *An Advanced Course in Practical Chemistry*, New Central Book Agency Pvt Ltd, Calcutta (2000).
- D. A. Skoog, F. J. Holler, S. R. Crouch,: *Principles of Instrumental Analysis*, 6th Ed, Brooks Cole, USA (2006).

3.3 Mathematics Major Courses

MTH301: Analysis in $\mathbb{R}^n$

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Functions of several variables.
- Continuity compactness and connectedness in $\mathbb{R}^n$, properties of continuous functions.
- Differentiation, inverse function and implicit function theorems, the rank theorem, Jacobian.
- Lebesgue measure, measurable sets, measurable functions.
- Integration, monotone convergence Theorem, Fatou's lemma, dominated convergence Theorem.
- Fubini's theorem through examples.
- L^p spaces, $1 \leq p \leq \infty$, completeness, dense subspaces of L^p spaces.

Recommended Reading

- G. de Barra, *Measure Theory and Integration*, New Age International Publishers, First Edition, Indian Edition reprint (2008).
- James R. Munkres, *Analysis on Manifolds*, Westview Press (1997).
- W. Rudin, *Principles of Mathematical Analysis*, McGraw-Hill Inc, Third Edition (1976).
- M. Spivak, *Calculus on Manifolds*, Westview Press (1971).

MTH302: Integers, polynomials and matrices

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Definitions and examples of Rings, integral domains, division rings and fields.
- Ideals, maximal and prime ideals, quotients.
- Homomorphisms and isomorphisms of rings.
- Factorization in domains, Euclidean domains, principal ideal domains, unique factorization domains.
- *Recapitulation of vector spaces and linear transformations, eigenvalues and eigenvectors, diagonalization.*
- Modules, direct sums, free modules.
- Quoteints and momomorphisms of modules, simple modules.

- Modules over principal ideal domains.
- Invariant subspaces for a linear transformation, simultaneous triangulation and diagonalization, Jordan decomposition of a linear transformation.
- Rational and Jordan canonical forms of matrices.
- Inner product spaces, The Gram-Schmidt orthogonalization. orthogonal complements.
- The adjoint of a linear operator, normal and self-adjoint operators, Unitary and orthogonal operators, orthogonal projections and spectral Theorem.

Recommended Reading

- M. Artin, *Algebra*, Prentice-Hall of India, New Delhi (1994).
- K. R. Hoffman and R. A. Kunze, *Linear Algebra*, Pearson Education (1971).
- C. Musili, *Introduction to Rings and Modules*, Narosa Publishing House (1994).
- N. S. Gopalakrishnan, *University Algebra*, New Age International (1986).
- Nathan Jacobson, *Basic Algebra* Vol. I, Dover Publications (2009).
- I. S. Luthar and I. B. S. Passi, *Algebra* Vol. II & III, Narosa Publishing House, New Delhi (2002).

MTH303: Ordinary and partial differential equations

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Fundamental existence and uniqueness theorem, dependence of solution on initial conditions and parameters.
- System of first order linear equations, general solution of homogeneous linear systems, fundamental matrix, non-homogeneous linear systems, linear systems with constant coefficients.
- Sturm theory, Comparison theorem, boundary value problems, Green's function, adjoint system, regular Sturm-Liouville systems, eigenvalues and eigenfunctions.
- First order partial differential equations (PDEs), linear and quasi-linear equations, general first order PDE for a function of two variables.
- Second order PDEs, characteristic for linear and quasi-linear second order equations.
- The Cauchy problem, Cauchy-Koualevski theorem.
- The method of separation of variables, the Laplace equation, the heat equation, the wave equation.

Recommended Reading

- Earl A. Coddington and Norman Levinson, *Theory of Ordinary Differential Equations*, Tata McGraw-Hill Publishing Company (1998).
- Shepley L. Ross, *Differential Equations*, Wiley (1984).
- Fritz John, *Partial Differential Equations*, Springer (1981).
- Yehuda Pinchover and Jacob Rubinstein, *An Introduction to Partial Differential Equations*, Cambridge University Press (2005).
- Ravi P. Agarwal and Donal O'Regan, *Ordinary and Partial Differential Equations*, Springer (2008).

MTH304: Topology

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Basic set theory, countable and uncountable sets, axiom of choice, well-ordering, Zorn's Lemma and their equivalence.
- Metric spaces, neighbourhoods and continuity.
- Topological spaces, open sets, closed sets, examples, order topology, subspace topology, product topology, quotient topology.
- Connectedness and compactness, compact and connected subspaces of $\mathbb{R}$, local connectedness and local compactness.
- Limit points, convergence of nets in topological spaces.
- Countability axioms, separation axioms, Urysohn's lemma, Tietz's extension theorem.
- Tychonoff theorem, one point compactification, Stone-Cech compactification.

Recommended Reading

- Paul R. Halmos, *Naive Set Theory*, Springer (UTM) (1998).
- J. R. Munkres, *Topology*, Pearson Education, Second Edition (2005).
- M. A. Armstrong, *Basic Topology*, Springer (1983).
- J. Dugundji, *Topology*, McGraw-Hill Companies, (1966).
- G. F. Simmons, *Introduction to Topology and Modern Analysis*, McGraw Hill (1963).

MTH305: Complex analysis

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- The field of complex numbers, extended complex plane, convergence, subsets.
- Complex differentiation, analytic functions, polynomials, power series, exponential and trigonometric functions.
- Cauchy- Riemann equations, analytic functions as mappings, exponential function, logarithm, harmonic functions.
- Complex integration, Cauchy's theorem and integral formulas, power series representation.
- Zeros of analytic functions, index of a closed curve.
- Morera's theorem, Liouville's theorem, open mapping theorem. argument principle, Rouche's theorem.
- Poles and essential singularities, Casorati-Weierstrass theorem. residues, Laurent series.
- Maximum modulus principle, Schwarz lemma, Phragmen-Lindelof theorems.
- Conformality of analytic maps, Möbius transformations.

Additional Topics

- Gamma function, Riemann zeta function, prime number theorem.
- Analytic continuation, spaces of analytic functions and of meromorphic functions.
- Riemann mapping theorem, infinite products, Weierstrass factorization Theorem.

Recommended Reading

- Lars V. Ahlfors, *Complex Analysis*, McGraw-Hill (1979).
- John B. Conway, *Functions of One Complex Variable*, Springer (Graduate Texts in Mathematics Vol. 11) (1978).
- Theodore W. Gamelin, *Complex Analysis*, Springer (2003).
- Reinhold Remmert, *Theory of Complex Functions*, Springer, (Graduate Texts in Mathematics/Reading in Mathematics Vol. 122) (1998).
- Elias Stein and Rami Shakarchi, *Complex Analysis*, Princeton University Press (Princeton Lectures in Analysis) (2003).
- W. Tutschke and H. L. Vasudeva, *An Introduction to Complex Analysis: Classical and Modern Approaches*, Chapman & Hall/CRC (2005).

MTH307: Discrete mathematics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Sets, relations, disjunctive and conjunctive normal forms, well-ordering principle, representation of sets, relations and numbers on the computer.
- Posets, trees, Boolean algebras, lattices, representation of relations as digraphs and Boolean matrices.
- Floors and ceilings, applications, recurrences, sums involving floor and ceiling functions, summation formula, polynomial functions with with integer values.
- Finite fields and mod p-arithmetic.
- Probability generating functions, flipping coins, hashing.
- Combinatorics: Counting principles, permutation groups and applications, Ramsey theory by examples, Recurrence relations, difference equations.

Additional Topics

- Graph Theory: Graphs, digraphs, trees; Euler's formula and graph colouring, transitive closure and connectedness, Warshall's algorithm, Eulerian and Hamiltonian circuits, Algorithms for tree traversing.
- Special Functions and Special Numbers

    1. Special Numbers: Stirling numbers, Eulerian numbers, harmonic numbers, harmonic summation, Bernoulli numbers, Fibonacci numbers.
    2. Generating Functions, Generating functions, solving recurrences, specific generating functions (from number theory and combinatorics), convolutions, exponential generating functions, Dirichlet generation functions.

Recommended Reading

- Ronald L. Graham, Donald E. Knuth and Oren Patashnik, *Concrete Mathematics, A Foundation for Computer Science*, Addison Wesley (1994).
- John Truss, *Discrete Mathematics for Computer Scientists*, Addison Wesley (1998).
- R. G. Dromey, *How to Solve it by Computer*, Prentice-Hall (1982).
- Kees Doets and Jan vak Eijck, *The Haskell Road to Logic, Maths and Programming*, College Publications (2004).
- John O'Donnell, *Discrete Mathematics Using a Computer*, Springer (2006).

MTH308: Groups and fields

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Recapitulation: Cayley's Theorem, Class equations, Group of prime power order.
- Sylow Theorems, Groups of order ≤ 8.
- Free groups, generators and relations, commutators, and derived and central series of subgroups.
- Free Abelian groups, further examples of groups of small order.
- Field extensions, algebraic extensions, perfect fields, separable and normal extensions.
- Finite fields, algebraically closed fields.
- Automorphisms of extensions, cyclotomic extensions.
- Galois extensions and Galois group, fundamental theorem of Galois theory.
- Solutions of polynomial equations by radicals, constructibile numbers.

Additional Topic

- Infinite Galois extensions.

Recommended Reading

- M. Artin, *Algebra*, Prentice-Hall of India, New Delhi (1994).
- Paul J McCarthy, *Algebraic Extensions of Fields*, Dover Publications Inc., New York (1991).
- S. Lang, *Algebra*, Third Edition, Springer (India) (2004).
- Thomas W. Hungerford, *Algebra*, Springer-Verlag, *Graduate Texts in Mathematics* 73 (1974).
- I. S. Luthar and I. B. S. Passi, *Algebra* Vol. I & IV, Narosa Publishing House, New Delhi (2004).

MTH309: Measure and probability

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Outer measures and Carathéodory extension, Lebesgue measure, Measurable function, Integration.
- Absolute continuous function on $\mathbb{R}$, fundamental theorem of integral calculus for Lebesgue Integral.
- Measure on product spaces and Fubini's theorem.
- Complex measures, Radon-Nikodyn theorem.
- Independence of events, Borel-Cantelli lemma.

- Random variables, distribution functions, moment generating functions.
- Conditional expectation, independence of random variables and Kolmogorov's zero-one law
- Joint distributions.
- Convergence of andom variables, law of large numbers.
- Characteristic function, central limit theorem.

Additional Topics

- Kolmogorov consistency theorem.
- Markov chains, Markov processes.
- Stationary distributions, limit theorems.

Recommended Reading

- S. R. Athreya and V. S. Sunder, *Measure and Probability*, CRC Press (2009).
- Kai Lai Chung, *A Course in Probability Theory*, Academic Press, San Diego (2001).
- Patrick Billingsley, *Probability and Measure*, John Wiley & Sons, Inc., New York (1995).
- Jacques Neveu, *Mathematical Foundations of the Calculus of Probability*, Holden-Day Inc., San Francisco (1965).
- K. R. Parthasarathy, *Introduction to Probability and Measure*, Hindustan Book Agency, New Delhi (2005).
- Walter Rudin, *Real and complex analysis*, McGraw-Hill Book Co., New York (1987).

MTH402: Functional analysis

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Normed linear spaces, Banach spaces, examples and interesting dense subspaces.
- Continuous linear functionals, duals.
- Hahn-Banach theorem, separation theorems.
- Duals of classical spaces ℓ^p, L^p.
- Bounded linear operators, open mapping and closed graph theorems, uniform boundedness principle and applications, spectrum of an operator.
- Hilbert spaces, orthogonality and geometric structure, projections, Reisz representation theorem.

- Fourier series — L^2 theory.
- The Banach space $\mathcal{B}(\mathcal{H})$
- Adjoint of an operator, self-adjoint, normal and unitary operators. spectral theorem for compact self-adjoint operators.

Additional Topics

- Weak and weak-* topologies, Banach Alaoglu theorem.
- Spectral theorem for general self-adjoint and normal operators. Reisz representation theorem, dual of $C_0(X)$, X a locally compact space, Gelfand theory.
- Unbounded operators: definition and examples.

Recommended Reading

- J. B. Conway, *A course in Functional Analysis*, Springer (Graduate Texts in Mathematics Vol. 96) (1990).
- G. F. Simmons, *Introduction to Topology and Modern Analysis*,Tata McGraw Hill (2004).
- B. Bollobás, *Linear Analysis: An Introductory Course*, Cambridge University Press, Cambridge (1999).
- B. V. Limaye, *Functional Analysis*, New Age International Publishers Limited, New Delhi (1996).

MTH403: Manifolds

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Topological and smooth manifolds, examples. manifolds with boundary. smooth functions, maps between manifolds. Lie groups. smooth partition of unity.
- Tangent vectors, tangent bundle of a manifold and vector fields. Lie brackets. The Lie algebra of a Lie group. covectors and cotangent bundle.
- Submersions, immersions and embeddings, inverse and implicit function theorem. embedded submanifolds. level sets.
- Vector and covector fields on submanifolds. Lie subgroups. Lie group actions, equivariant maps, proper action. quotients of manifolds by group action. Homogeneous spaces.

Additional Topics

- The Whitney embedding theorem. The Whitney approximation theorem.
- Connections, Chern classes.
- Universal connections

Recommended Reading

- John M. Lee, *Introduction to Smooth Manifolds*, Springer (Graduate Texts in Mathematics Vol. 218) (2003).
- Michael Spivak, *Calculus on Manifolds*, W. A. Benjamin, New York (1965).
- N. J. Hicks, *Notes on Differential Geometry*, Van Nostrand, Princeton N.J (1965).
- James R. Munkres, *Analysis on Manifolds*, Addison Wesley (1991).
- R. W. Sharpe, *Differential Geometry, CARTAN'S GENERALIZATION OF KLEIN'S ERLANGEN PROGRAM*, Springer-Verlag (Graduate Texts in Mathematics Vol. 166) (1997).
- I. M. Singer and J. A. Thorpe, *Lecture notes on Elementary Topology and Geometry* (Undergraduate Texts in Mathematics), Springer-Verlag (1967).

3.4 Physics Major Courses

PHY301: Classical mechanics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Lagrangian formulation of mechanics. Degrees of freedom and equations of motion. Constraints and Generalized coordinates. Principle of least action. Emphasis on the Variational principle. The Calculus of Variations. Euler-Lagrange equations. Constrained systems and Lagrange multipliers.
- Phase space formulation. Hamiltonian, phase space, Poisson brackets. Canonical transformations. Liouville's theorem and Poincare recurrence. Hamilton-Jacobi theory. Action-angle variables.
- Oscillators. Small fluctuations. Damped,forced and anharmonic. Eigenvalue equation and principle axis transformation, normal coordinates, forced oscillations and resonance, vibrations of molecules. Nonlinear oscillations and chaos.
- Motion in a central field. Equivalent one-body problem. first integrals, classification of orbits, virial theorem, Bertrand's theorem Kepler's law. Symmetries and conservations laws. Noether's theorem. Central forces in three dimensions. Scattering in a central force field, Rutherford scattering.
- Rigid bodies. Rotation. Orthogonal transformations, Euler angles, rigid body dynamics, spinning top.

Recommended Reading

- H. Goldstein, C. P. Poole and J. L. Safko, *Classical mechanics*, 03rd edition, Addison-Wesley (2001).
- L. D. Landau and E. M. Lifshitz, *Mechanics*, 03rd edition, Butterworth Heinemann (1976).

- N. C. Rana and P. S. Joag, *Classical Mechanics*, Tata McGrawHill (1992).
- V. I. Arnold, V. V. Kozlov and A. I. Neishtadt, *Mathematical aspects of classical and celestial mechanics*, 03rd edition, Springer (2006).
- J. V. Jose and E. J. Saletan, *Classical dynamics: a contemporary approach*, Cambridge University Press (1998).
- W. Greiner, *Classical Mechanics - Systems of Particles and Hamiltonian Dynamics*, Springer (2002).

PHY302: Quantum mechanics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Classical vs. quantum Mechanics, Simple 2-state QM system. Hilbert Spaces, Operators. Observables - Compatible Observables, Tensor Product Spaces, Uncertainty Relations. Position, Momentum and Translation. Eigenvalue Problems. Emphasis on Linear Vector Spaces from a mathematical point of view.
- Time Evolution (Quantum Dynamics). Schroedinger, Heisenberg and Interaction Pictures; Energy-time Uncertainty, Interpretation of Wavefunction. Quantum Particles in Potential. Harmonic oscillator.
- Angular Momentum. Rotation in Quantum mechanics. S$O(3)$ vs. S$U(2)$. Spherical Harmonics. Addition of Angular Momenta.
- Single electron atoms: Spherically symmetric potentials, spherical harmonics, Hydrogen atom problem, solution of Schroedinger equation, energy levels and eigenfunctions, orbital angular momentum, Hydrogenic atoms.

Recommended Reading

- L. I. Schiff, *Quantum mechanics*, 03rd edition, McGrawHill Publishers (1968).
- J. J. Sakurai, *Modern quantum mechanics*, Addison-Wesley (1993).
- C. Cohen-Tannoudji, *Quantum mechanics Vols 1 and 2*, Wiley-Interscience (2006).
- J. D. Bjorken and S. D. Drell, *Relativistic quantum mechanics*, McGrawHill (1998).
- R. Shankar, *Principles of quantum mechanics*, 02nd edition, Springer (1994).
- W. Greiner and B. Muller, *Quantum mechanics - Symmetries*, 02nd edition, Springer (2004).

PHY303: Electrodynamics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Electrostatics. Boundary value problems. Method of images. Green's functions. Eigenfunction expansions. Series solution of PDE. Laplace equation in spherical and cylindrical coordinates. Special functions. Legendre polynomials, Associated Legendre functions and Spherical harmonics, Bessel functions. Multipole expansion. Electric fields in dielectrics. Boundary value problems in dielectrics.
- Magnetostatics. Biot and Savart Law. Ampere's law vector potential. Magnetic field in matter. Boundary conditions. B and H fields. Magnetization. Faraday's law. Energy in the magnetic field.
- Electrodynamics. Maxwell equations. Displacement current. Scalar and vector potentials. Gauge transformations. Electromagnetic waves. Pointing vector. Electromagnetic waves in media.
- Relativistic formulation of electromagnetism. $F^{\mu,\nu}$ and its transformation properties.
- Dipole radiation. Fields or moving charges. Retarded potentials.

Recommended Reading

- J. D. Jackson, *Classical Electrodynamics*, 03rd edition, Wiley NY (1998).
- D. J. Griffiths, *Introduction to Electrodynamics*, 03rd edition, Prentice-Hall NJ (1999).
- L. D. Landau and E. M. Lifshitz, *The Classical theory of fields*, 04th edition, Pergamon Press (1994).
- W. K. H. Panofsky and M. Phillips, *Classical electricity and magnetism*, 02nd edition, Dover Publications (2005).
- J. Schwinger, L. L. DeRaad Jr., K. A. Milton, and W-Y. Tsai, *Classical Electrodynamics*, Perseus Book Group Massachusetts (1998).
- W. Greiner and J. Reinhardt, *Quantum electrodynamics*, 04th edition, Springer (2008).

PHY304: Statistical mechanics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Review of thermodynamics: Laws, processes, thermodynamic stability.
- Review of probability: one random variable, probability distributions, random walks, many random variables, central limit theorem, information, entropy and estimation.
- Kinetic Theory of gases: Liouville's theorem, Boltzmann transport equation.
- Classical statistical mechanics: Microcanonical, canonical, and grand canonical ensembles.

- Quantum statistical mechanics: Identical particles, Quantum microstates and macrostates, Bose-Einstein and Fermi-Dirac statistics, quantum ideal gases, example systems.
- Phase transitions: Cumulant expansion, van der Waals equation, variational methods, corresponding states, phase transitions, critical point behaviour.

Recommended Reading

- K. Huang, *Statistical Mechanics*, 02nd edition, Wiley (1987).
- F. Reif, *Fundamentals of Statistical and Thermal Physics*, McGraw-Hill International (1987).
- L. D. Landau & E. M. Lifshitz, *Statistical Physics*, 03rd edition, Butterworth-Heinemann (1980).
- Mehran Kardar, *Statistical Physics of particles*, Cambridge University Press (2007).
- W. Greiner, L. Neise, H. Stocker, and D. Rischke, *Thermodynamics and Statistical Mechanics*, Springer (2001).
- S.K. Ma, *Statistical Mechanics*, World Scientific (1985).

PHY306: Advanced quantum mechanics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Time independent and time dependent perturbation theory. Transitions under the action of a perturbation acting for a finite time, Transitions under the action of a periodic perturbation.
- Review of Hydrogen atom, Fine structure, Hyperfine structure as an application of perturbation theory to real systems. Zeeman effect, Stark effect.
- The semi-classical approach, WKB approaximation. Penetration through a potential barrier.
- The variational principle, applications.
- Scattering theory: Scattering cross-section, partial waves, Yukawa and Coulomb potentials, scattering by square well potential, reaction rates, mean free path, retarded potentials, Born approximation.
- Relativistic quantum mechanics: Klein-Gordon equation, negative probabilities. Dirac equation, relativistic free particle solutions, negative energy solutions, anti-particles. Zitterbewegung.

Recommended Reading

- B. H. Bransden and C. J. Joachain, *Physics of Atoms and Molecules*, 02nd edition, Pearson Education (2008).
- P. Atkins and J. De Paula, *Physical Chemistry*, 08th edition, Oxford University Press (2009).
- J. J. Sakurai, *Quantum Mechanics*, Addison Wesley Low Priced Edition (2008).
- L. I. Schiff, *Quantum Mechanics*, 03rd edition, McGraw-Hill (1968).
- W. Demtroder, *Atoms, Molecules and Photons*, Springer-Verlag Berlin (2006).
- J. B. Rajam, *Atomic Physics*, S. Chand & Company Ltd. (2007).

PHY310: Mathematical methods for physicists I

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Complex algebra: Functions of complex variables, Cauchy-Riemann conditions, Cauchys integral theorem, Laurent expansion, singularities, mapping, conformal mapping. Calculus of residues, Dispersion relations, method of steepest descent.
- Gamma and Beta functions: Gamma function, definition and properties, Stirlings series, Beta function, Incomplete Gamma function.
- Differential equations: Partial differential equations, First order differential equations, separation of variables, singular points, series solutions with Frobenius method, a second solution, nonhomogenneous equations, Greens function, Heat flow and diffusion equations.
- Sturm-Liouville theory: Self adjoint ordinary differential equations, Hermitian operators, Gram-Schmidt orthogonalization, completeness of eigenfunctions, Greens function eigenfunction expansion.
- Special functions: Bessel functions of the first kind, orthogonality, Neumann functions, Hankels functions, Asymptotic expansions, Spherical Bessel functions. Legendre functions, generating function, recurrence relations, orthogonality, alternate definitions, associated Legendre functions, spherical harmonics, Hermite functions, Laguerre functions.

Recommended Reading

- H. J. Weber and G. B. Arfken, *Essential Mathematical Methods for Physicists*, Academic Press (2004).
- D. A. McQuarrie, *Mathematical Methods for Scientists and Engineers*, Viva Books (2009).
- Mary L. Boas, *Mathematical Methods in the Physical Sciences*, Wiley (2005).

PHY311: Advanced optics and spectroscopy lab

[Cr:4, Lc:1, Tt:0, Lb:9]

Course Outline

- Advanced optics experiments involving study of coherence on Michelson interferometer and Fabry-Perot atelon.
- Spectroscopic experiments like Zeeman effect, IR spectroscopy and NMR spectroscopy will be used to study atomic, molecular and nuclear spin resonances.

PHY312: Advanced electronics and instrumentation lab

[Cr:4, Lc:1, Tt:0, Lb:9]

Course Outline

- Micro-controller: Architecture and design. Executing electronic circuits using the microcontroller. Logic Gates, Flip Flops, Registers and Counters. Basic digital I/O. Digital-to-Analog and Analog-to-Digital conversion. Counting and Timing. Timing Diagrams. Motor Control using the microcontroller. Servo motors and Stepper Motors.
- FPGA: Introduction to FPGA basic architecture. Programming with Verilog and VHDL. Building a function generator using FPGA board. Digital logic circuits.
- Automation: Data acquisition and interfacing with PC. Automation of physics laboratory experiments. Programming with Phoenix. Programming with LabView.
- Student Project: Individual project to be conceived and executed by each student, in any of the three areas outlined above.

Recommended Reading

- C. Steiner, *The 8051/8052 microcontroller: architecture, assembly language and hardware interfacing*, Universal (2005).
- D. W. Preston and E. R. Dietz, *The art of experimental physics*, Wiley (2009).
- S. Ghoshal, *Embedded systems and robots:projects using the 8051 microcontrollers*, Cengage learning Asia (2009).
- S. Brown and Z. Vranesic, *Fundamentals of digital logic with VHDL design*, McGraw Hill (2005).
- C. Maxfield, *The design warrior's guide to FPGAs*, Elsevier (2004).

PHY401: Nuclear and particle physics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Basic Ideas: History. Particle exchange, range of forces, units: length, mass and energy, review of special relativity, particle decay.
- Structure of Nuclei: The shell model: basic ideas. Spins, parities and magnetic moments in the shell model; excited states in the shell model. Fermi gas model. Collective model. β-Decay. Fermi theory.
- Nuclear Phenomenology: Notation; mass, spin and binding energies. Nuclear forces; shapes and sizes; Liquid drop model: semi-empirical mass formula. Nuclear stability. α-, β-, γ- decay.
- Fission and Fusion: Induced fission – fissile materials. Fission chain reactions. Power from nuclear fission: nuclear reactors. Nuclear fusion: Coulomb barrier. Stellar fusion. Fusion reactors.
- Experimental Methods: Overview, accelerators, beams, particle interactions with matter. Particle detectors (measurement of position, momentum, particle identification, energy measurements).
- Review of Dirac equation, covariant form of Dirac equation, relativity and anti-particles, bilinear covariants, zero mass Fermions.
- Elementary particles: Lepton multiplets. Lepton numbers. Neutrinos. Neutrino mixing and oscillations; numbers of neutrinos. Evidence for quarks; properties of quarks; hadrons. Flavour independence and hadron multiplets.
- Electroweak Interactions: Charged and neutral currents. Symmetries of the weak interaction. Spin structure of the interactions. Neutral kaons. K_0-K_0 mixing and CP violation. Strangeness oscillations. $W_{\tilde{A}_\pm}$ and Z_0 bosons. Weak interactions of hadrons. Neutral currents and the unified theory. The Higgs boson.

Recommended Reading

- L. D. Landau & E. M. Lifshitz, *Quantum Mechanics*, Volume 3 of A Course of Theoretical Physics, Pergamon Press (1965).
- B. Povh, K. Rith, C. Scholz and F. Zetsche, *Particles and Nuclei: An introduction to the physical concepts*, Springer, 6th edition (2008).
- B. R. Martin and G. Shaw, *Particle Physics*, 03rd edition, Wiley (2008).

PHY402: Solid state physics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Periodic Structure and Symmetry of Crystals. Fundamental types of lattices. Simple crystal structures. Diffraction, Bragg's Law, Reciprocal Lattice.
- Chemical Bonding (Ionic, covalent, hydrogen, metallic). Lattice Dynamics, Phonons. Brioullin zones. Group and phase velocity. Thermal Properties. Normal modes, density of states, Debye theory, Einstein model.

- Free Electron Gas in 1D, 2D, 3D. Heat capacity. Electrical conductivity. Hall effect. Thermal conductivity. Nearly Free Electron Approximation. Bloch Theorem and Band Structure. Kronig-Penney model. Tight Binding Method. Fermi Surface.
- Semiconductors: Band Gap, Electrons, Holes, Impurities. Band theory for semiconductors.
- Magnetic properties of materials. Concepts of Dia-, Para-, Ferro- and Antiferro- Magnetism. Introduction to Superconductivity & Superfluidity.

Recommended Reading

- C. Kittel, *Introduction to Solid State Physics*, 08th edition, John Wiley & Sons, Inc. (2004).
- N. W. Ashcroft & N. D. Mermin, *Solid State Physics*, Saunders College Publishing (1996).
- H. Ibach & H. Luth, *Solid State Physics*, Springer (2003).

PHY403: Atomic and molecular physics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Multielectron atoms: Schroedinger equation for He atom, spin wavefunction and Pauli's exclusion principle, ground state and first excited state, complete level schemes of He, Other multielectron atoms. Thomas-Fermi approach and Hartree-Fock approximation for studying multi-electron atoms.
- Molecules: Hydrogen molecular ion, Hydrogen molecule, Born-Oppenheimer approximation, Frank-Condon transition, molecular potential energy curves, Molecular orbitals, Morse potential formalism.
- Spectroscopy of atoms and molecules: Fine and Hyperfine structure of atoms, electronic, vibrational and rotational spectroscopy of molecules, selection rules, some experimental techniques of spectroscopy.
- Atom Radiation interactions: Semi-classical description of radiation. Absorption, spontaneous and stimulated emissions, Einstein's A and B coefficients, Coherent and Incoherent emissions, LASERs and MASERs, Line widths, various types of line broadening, two-level atoms in a radiation field.

Recommended Reading

- B. H. Bransden and C. J. Joachain, *Physics of Atoms and Molecules*, 02nd edition, Pearson Education (2008).
- P. Atkins and J. De Paula, *Physical Chemistry*, 08th edition, Oxford University Press (2009).
- J. J. Sakurai, *Quantum Mechanics*, Addison Wesley Low Priced Edition (2008).

- L. I. Schiff, *Quantum Mechanics*, 03rd edition, McGraw-Hill (1968).
- W. Demtroder, *Atoms, Molecules and Photons*, Springer-Verlag Berlin (2006).
- J. B. Rajam, *Atomic Physics*, S. Chand & Company Ltd. (2007).

PHY411: Nuclear physics lab

[Cr:4, Lc:1, Tt:0, Lb:9]

Course Outline

- Geiger-Muller (GM) Counter based experiments: To become acquainted with the operation and characteristics of the GM counter. To determine the best operating voltage and the resolving time of a GM counter. To determine the dead time of the GM counter. To investigate the Binomial, Poisson and Gaussian probability distributions by counting radiation events with a GM counter. To study the statistical fluctuations which occur in the disintegration rate of an essentially constant radioactive source. To use a GM detector to detect the gamma ray emitted by a short-lived excited isotope of Barium.
- Scintillation counter based experiments: To study the scattering of high-energy photons by electrons. Detection of scattered photons in a scintillation counter. Measuring energies of scattered photons and recoil electrons as function of scattering angle. Use a plastic scintillator as a target and record relative intensities of scattered photons at several scattering angles.

Recommended Reading

- G. F. Knoll, *Radiation detection and measurement*, 03rd edition, John Wiley and Sons (1999).
- William Leo, *Techniques for nuclear and particle physics experiments:A how-to approach*, 02nd edition, Springer Verlag (1994).
- A. Melissinos, *Experiments in modern physics*, Academic Press (1966).

PHY412: Condensed matter physics lab

[Cr:4, Lc:1, Tt:0, Lb:9]

Course Outline In this course students will perform two kinds of experiments.

- Measurements on various materials using standard equipment.
  - Hall effect to study carriers in semi-conductors.
  - Four-probe method for resistance measurement.
  - Magnetic hysteresis loop on various magnetic materials
  - Resistance and Magnetoresistance of some standard materials.

  - KCl Fluorescence. Study and color centers.

- Advanced and non-standard experiments

  - Meissner effect of YBCo
  - Design and fabricate a dip-stick to measure resistance versus temperature of a superconductor (YBCo) between nitrogen and room temperature.
  - Study of sand piles.

Recommended Reading

- C. Kittel, *Introduction to Solid State Physics*, 08th edition, John Wiley & Sons Inc. (2004).

- M. Tinkham, *Introduction to Superconductivity*, 02nd edition, Dover Publications (2004).

Chapter 4

Electives and PhD Courses

4.1 Biological Sciences

BIO307: Microbial technology

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Microbial Life and the Biosphere: Fossil evidence of microorganisms. Microbial life as the foundation of biosphere. Importance of microbiology in Astrobiology.
- The History, Scope, and Future of Microbiology.
- Microscopic techniques to study microbes.
- Nutrition, Cultivation and Isolation of Microorganisms.
- Basic Virology: Origin of viruses. General properties, structure, reproduction, cultivation, and purification of viruses. Bacterial and Eukaryotic viruses.
- Microbial Ecology: Microbial communities. Biogeochemical cycles. Beneficial symbiotic associations. Human host-microbe interaction.
- Role of microbes in human health, industry and environment :
  - Viral, Bacterial, and Fungal Diseases of Humans.
  - Microbes involved in industrial processes.
  - Major industrial products from microbes.
  - Microbes in wastewater treatment and bioremediation.

Suggested reading

- Willey, Sherwood, and Woolverton, Prescott, Harley and Kleins*Microbiology*, (Seventh Edition), McGraw-Hill International Edition (2008).
- Staley, Gunsalus, Lory, and Perry, *Microbial Life*, (Second Edition), Sinauer Associates (2007).

BIO308: Fundamentals of microbiology

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- **Introduction to the Microbial World**: Important events in the history and development of microbiology; Members of the microbial world; Scope and relevance of microbiology in medicine, ecology, agriculture, space research and industry (pharmaceutical, biotech, food & dairy industries); Perspectives and future scopes in microbiology.
- **Microbial Evolution and Diversity**: The origin of life, three domains of life (Archaea, Bacteria, and Eukarya);Evolutionary processes and the endosymbiotic origin of mitochondria and chloroplasts; Techniques for determining microbial taxonomy and diversity.
- **Cellular Architecture and Functions of Microorganisms**: Microscopic techniques to study prokaryotic and eukaryotic microorganisms;Cellular architectureand functions of bacteria, fungi and protists.
- **Microbial Growth**: DNA replication and cell division in bacteria; Techniques measuring bacterial growth.
- **Microbial Ecology**: Biogeochemical cycles; Biofilms and microbial mats; Microbial interactions; Microbiota of the human body.
- **Symbiosis**: Bacterial interactions with plants and animals; Endosymbionts;Mycorrhiza.
- Virus Structure and Function: General structural properties of animal, plant and bacterial viruses;Virus life cycle.

Suggested Reading

- J. Willey, L. Sherwood, and C. Woolverton, *Prescott, Harley, and Klein's Microbiology*, (Seventh Edition), McGraw-Hill International Edition (2008).
- J. T. Stanley , R. P. Gunsalus , S. Lory , and J. J. Perry *Microbial Life*, (Second Edition), Sinauer Associates (2007).

BIO405: Advanced biochemistry

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Prologue and a historical perspective.
- Review of thermodynamic principles relevant to biochemistry: Laws of thermodynamics. Free energy. Chemical equilibrium.
- Structural aspects of biomolecules:

1. Amino acids and proteins. Covalent structures of proteins. Protein 3-dimensional structures. Domains and Motifs. Protein structure-function mechanisms. Overview of protein families and superfamilies. A case study on Hemoglobin.
2. Nucleic acids and their structure.
3. Sugars and polysaccharides.
4. Lipids and membranes.

- Enzymes and their mechanisms of action: Introduction to enzymes. Rates of enzymatic reactions. Enzymatic catalytic mechanisms: lysozyme and serine proteases.
- Metabolism: Carbohydrate metabolism. Electron transport and oxidative phosphorylation. Photosynthesis. Lipid metabolism. Amino acid metabolism. Nucleotide metabolism. Integration of metabolic pathways and metabolic disorders.

Recommended Reading

- Voet and Voet, *Biochemistry* 4th Edn. Wiley (2011).
- Lehninger, *Principles of Biochemistry* 5th Edn. Freeman (2009).

BIO451: Microbial genetics

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- An overview of microbial genetics
- Mutations, mutants and genetic screens
- Reversion and Suppression
- Genetics of Bacteria
- Transformation
- Plasmids
- Conjugation
- Bacteriophage genetics
- Phage transduction and mapping
- Transposable elements
- Life Cycle of yeasts
- Genetics of yeasts
- Molecular genetic tools in yeasts
- In vitro genetics
- Genetics in the era of Genomics

Recommended Reading

- S. Maloy, J. Cronan and D. Freifelder, *Microbial Genetics*, 2nd Edn., Jones and Bartlett Publishers Inc. (1994).
- C. Guthrie and G. R. Fink, *Guide to Yeast Genetics and Molecular and Cell Biology*, Academic Press (2004)
- D. L. Hartl and E. W. Jones, *Genetics: Analysis of Genes and Genomes*, 7th Edn., Jones and Bartlett Publishers (2009).

BIO452: Infectious diseases and epidemiology

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Host-pathogen relationship, Overview of pathogenesis of viral diseases, Overview of bacterial pathogenesis.
- Discussion of Virulence Factors and toxins: Virulence factors, Exotoxins, Enterotoxins, Endotoxins.
- Host Factors in infection: Host risk factors for infection, Innate resistance to infection.
- Microbial mechanisms for escaping host defenses.
- Epidemiological terminology. Measuring frequency: the epidemiologist's tools.
- Recognition of an infectious disease in a population, Recognition of an epidemic.
- The infectious disease cycle. Cause, Source, Transmission, Susceptibility of the host, Excretion
- Epidemiology, Symptoms, Diagnosis and Treatment of important human diseases– Airborne transmission of Diseases-Tuberculosis, leprosy, Diphtheria, Colds and Influenza; Soilborne diseases-Tetanus; Waterborne diseases- Typhoid, cholera; Arthropod transmitted disease-Malaria; Animal transmitted diseases- Rabies Sexually transmitted diseases- AIDS
- Role of models in Epidemiology; Single species population growth models in discrete and continuous time; Two species interaction models; Epidemiological Rates and Risks; Models of Infectious and vector borne diseases; Models of parasite dynamics; Models of vaccine effects. Using open source equivalent of software like Stella which allow you to construct and analyse basic models using available data.

Recommended Reading

- J. Willey, L. Sherwood and C. Woolverton, *Prescott's Principles of Microbiology*, 1st Edn., McGraw-Hill Science (2008).
- J. G. Black, *Microbiology: Principles And Explorations*, 7th Edn., John Wiley and Sons Inc. (2008).
- F. Bauer and C. Castillo-Chavez, *Mathematical Models in Population Biology and Epidemiology*, 1st Edn., Springer (2001).

BIO453: Principles underlying instrumental biomacromolecular analyses

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Analyses of Macromolecular Composition, Separations-based analyses, Protein amino acid analysis, Protein N-terminal sequencing, DNA sequencing, Mass spectrometry-based analyses, Ionization and detection technologies, Peptide mass fingerprinting and identification, Protein sequence determination, Disulphide and epitope mapping, Confirmation of post-translational modifications, Quantitation of relative protein expression (I-TRAC).
- Analyses of Macromolecular Conformation (and Interactions), Separations-based analyses, Chromatography – principles and practice, Gel filtration chromatography, Ion exchange chromatography, Reverse-phase chromatography, Hydrophobic interaction chromatography, Affinity chromatography, Chromato-focusing, Electrophoresis – principles and practice, SDS-PAGE electrophoresis, Native-PAGE and Ferguson analyses, Isoelectric focusing to determine pI, Two-dimensional gel electrophoresis, Capillary electrophoresis, Agarose gel electrophoresis and its variants, Immuno-electrophoresis, Classical and novel applications, Mass spectrometry-based analyses, Hydrogen-deuterium amide labeling-accessibility (H-D exchange), Proteolytic-accessibility, Mass labeling-accessibility, Spectroscopy-based analyses, Normal and difference UV-visible absorption spectroscopy, Normal and difference Circular Dichroism (CD) spectroscopy, Fluorescence spectroscopy, Time-resolved fluorescence spectroscopy, Fluorescence polarization measurements, Fluroescence resonance energy transfer (FRET) measurements, FTIR spectroscopy, Fundamentals of 1-D NMR spectroscopy, Heteronuclear and multidimensional NMR methods, Electron paramagnetic resonance (EPR) methods, Fluorescence correlation spectroscopy (FCS), Calorimetry-based analyses, Differential scanning calorimetry (DSC), Isothermal titration calorimetry (ITC), Optical measurements-based analysis, Surface plasmon resonance (SPR), Dynamic light scattering (DLS) analyses , Microscopy-based analyses, Confocal microscopy – principles and practice, Fluorescence resonance energy transfer (FRET), Fluorescence lifetime imaging (FLIM) analysis, Fluorescence recovery after photobleaching (FRAP) analysis, Near field fluorescence imaging (SNOM/TIRF), Atomic force microscopy – principles and practice, Interaction force measurements, Chemical affinity imaging, Crystallography-based analysis, Structure-determination by molecular replacement, Structure-determination by multiple anomalous dispersion (MAD).

Recommended Reading

- T. G. Cooper, *The Tools of Biochemistry*, Wiley-Interscience (1977).
- D. A. Skoog, F. J. Holler and S. R. Crouch, *Principles of Instrumental Analysis*, 6th Edn., Brooks Cole (2006).
- M. L. Srivastava, *Bioanalytical Techniques*, Alpha Science International Ltd (2007).

BIO454: Neuroscience

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Introduction to the nervous systems of humans and other animals.
- Electrical properties of nerve cells and voltage dependent membrane permeability.
- Channels, transporter, neurotransmitters and their receptors.
- Synaptic transmission.
- Cellular and biochemical processes within neurons.
- The changing brain: Early brain development, construction of neural circuits, plasticity of synapses and circuits.
- Basics of sensation and sensory processing: Visual system, auditory system, olfactory system, somatosensory system and pain.
- Basics of complex brain functions and related disorders: Language and speech, sleep and wakefulness, emotions, memory, sex and sexuality.

Recommended Reading

- D. Purves, G. J. Augustine, D. Fitzpatrick, W. C. Hall, A. S. LaMantia, J. O. McNamara and L. E. White (eds), *Neuroscience* 4th Edn., Sinauer Associates, Inc. (2008).
- E. Kandel, J. Schwartz and T. Jessell (eds), *Principles of Neural Science*, 4th Edn., McGraw-Hill (2000).
- J. G. Nicholls, A. R. Martin, B. G. Wallace and P. A. Fuchs, *From Neuron to Brain*, 4th Edn., Sinauer Associates Inc. (2001).

BIO455: Computational structural biology

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Introduction to experimental methods (X-ray and NMR) of protein structure determination.
- Basic ideas on structure and conformations of proteins.
- Structural motifs and analysis of information from protein databank.
- Homology modeling and protein structure prediction.
- Aspects of biomolecular forces.
- Introduction to various molecular simulations methods.
- Molecular dynamics (GROMACS, VMD and NAMD).
- Molecular docking (protein ligand docking).

Recommended Texts

- Thomas E. Crieghton, *Proteins: Structures and Molecular Properties*
- Andrew Leach, *Molecular Modeling: Principles and Applications*
- Branden & Tooze, *Introduction to Protein Structure*
- Tamar Schlick, *Molecular Modeling and Simulation: An Interdisciplinary Guide*

BIO456: Cancer cell biology

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline The cancer cell biology course objective will be achieved through brief overview of biology of a cancer cell and through the in-depth discussion of two research papers each week. Initially, there will be lectures given on topics (mentioned below) which will be followed by extensive discussion of research articles that will be primarily driven by the course participants. The students will practice critical reading and discussion of scientific papers and learn to evaluate data and methodologies.

- History of Cancer.
- Brief overview of Cell cycle control and Genome stability.
- Genetic Pathways in Cancer: Tumor Suppresor, Oncogenes, Proto-oncogenes and their cellular functions.
- Cancer Stem cells.
- Metastasis and Angiogenesis.
- Cancer immunology.
- Future of Cancer Research.

Recommended Reading

- Siddhartha Mukherjee, *The Emperor of All Maladies: A Biography of Cancer*
- Bruce Alberts, *Molecular Biology of the Cell*, Fifth edition
- Vogelstein, B., E. R. Fearon, S. R. Hamilton, S. E. Kern, A. C. Preisinger, M. Leppert, Y. Nakamura, R. White, A. M. Smits & J. L. Bos., *Genetic alterations during colorectal-tumor development*, N Engl J Med. 319 (1988): 525-532.
- Goodrich, D. W., N. P. Wang, Y. W. Qian, E. Lee & W. H. Lee., *The retinoblastoma gene product regulates progression through the G1 phase of the cell cycle*, Cell 67 (1991): 293-302.
- Artandi, S. E., S. Chang, S. L. Lee, S. Alson, G. J. Gottlieb, L. Chin & R. A. DePinho., *Telomere dysfunction promotes non-reciprocal translocations and epithelial cancer in mice*, Nature 406 (2000):641-645.

- Al-Hajj, M., M. S. Wicha, A. Benito-Hernandez, S. J. Morrison & M. F Clarke. *Prospective identification of tumorigenic breast cancer cells*, Proc. Natl Acad. Sci. USA 100 (2003): 3983-3988.

- Clark, E. A., T. R. Golub, E. S. Lander & R. O. Hynes., *Genomic analysis of metastasis reveals an essential role for RhoC*, Nature 406 (2000): 532-535.

- Paez, J. G., P. A. Janne, J. C. Lee, S. Tracy, H. Greulich, S. Gabriel, P. Herman, F. J. Kaye, N. Lindeman, T. J. Boggon, K. Naoki, H. Sasaki, Y. Fujii, M. J. Eck, W. R. Sellers, B. E. Johnson & M. Meyerson., *EGFR mutations in lung cancer: correlation with clinical response to gefitinib therapy*, Science 304 (2004): 1497-1500.

BIO457: Ecosystem ecology

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Ecosystem concepts- Classic, Systems- and Thermodynamic Ecosystem properties : Openness, directionality, connectivity, emergent hierarchy, complex dynamics, self-regulation through feedbacks.

- Major biomes and ecosystems of the world : Major Biomes and their geographical distribution-relation with annual precipitation-temperature patterns; selected, well studied ecosystems- coral reefs, man-grove swamps, deep sea, lakes, streams, alpine, etc.

- Ecosystem components : Biotic components- autotroph, herbivore, primary carnivore, secondary carnivore, omnivore. And decomposer levels; Abiotic components- Important physic-chemical factors that influence the biotic components; human activities (Anthropocene concept).

- Energy Flow :Primary sources of energy- sun; deep sea hydrothermal vents; geography of solar radiation; factors influencing light energy reaching the plants (latitude; cloud cover, albedo; etc.); photosynthetic efficiency; Assimilation efficiency, Production efficiency and Consumption (exploitation efficiencies) at different trophic levels; Productivity/biomass ratios; detrital pathway and microbial loop; food pyramids.

- Materials cycling :Biogeochemistry; Nutrient cycling- C, N, P; respiration and decomposition; soil ecosystem; detritus, Nutrient limitation in terrestrial and aquatic environments and its consequences; eutrophication; anthropogenic sources of nutrients in to the ecosystem; ecological stoichiometry.

- Ecosystem development : Succession concepts; Primary and secondary succession; Changes in ecosystem functions during succession; Mechanism of succession-models; Concepts of climax.

- Biodiversity :Diversity at species and ecosystem levels; Patterns of species diversity- Latitudinal gradients, Factors contributing to tropical species richness; Species-area relationships; Components of diversity and Measurement and interpretation of diversity- Different indices of diversity; species-abundance relationships.

- Ecosystem regulation and stability :Top-down and bottom-up controls; Ecosystem-level response to perturbation- natural and man-made (alien species introductions, habitat fragmentation; anthro-pogenic climate change); Ecosystem resilience; diversity-stability relationships.
- Ecosystem health, Ecosystem services and their management :Major criteria for assessing ecosystem health (productivity, organization, resilience); Human perspectives and metrics of ecosystem health;Major ecosystem services important for human wellbeing; Economic value of ecosystem services; Relation with biodiversity conservation.
- Managed ecosystems- Agricultural and aquacultural ecosystems.
- Remediation of degraded ecosystems (restoration ecology) : Basic principles of restoration ecology;Role of Biotechnology in restoration of degraded ecosystems; Selected case studies.
- Ecosystem modeling and models :Analytical and simulation model; Multispecies interaction models; Whole ecosystem models; Network analysis.

Recommended Reading

- Chapin, F. S., P. A. Matson & P. Vitousek, 2012., *Principles of terrestrial ecosystem ecology*, 2nd ed. Springer, N.Y.
- Raffaelli, D. G. & C. L. J. Frid, 2010., *Ecosystem ecology: A new synthesis*, Cambridge Univ.Press, Cambridege
- Weathers, K., D. Strayer & G. Likens, 2012., *Fundamentals of ecosystem science*,Elsevier.

BIO458: Advances in plant cell and molecular biology

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- History of plant biology from crop origins to domestication, Genetics behind the crop domestication, Genetic improvement of plant architecture for agriculture.
- A humble beginning of plant life: From embryogenesis to flowering, Pattern formation and early development, Axis formation and radial patterning of root and shoot.
- Plant stem cells and the concept of totipotency: Stem cell niche organization, a comparison in animals and plants, Specification of stem cells in shoot apex, root apex and vascular bundles, Cell differentiation and the concept of lineage dependent development of plant.
- Maintenance of plant genome: Genome to epigenome Reprogramming of plant genome during gametogenesis and seed development, Role of DNA methyaltrasnferases and demethyalases in gene regulation, Characterization of plant epigenomes, Tools and techniques required to study epigenome.

- Plant-plant and plant environment interactions: Role of light in phenotypic plasticity, Shade avoidance vs. shade tolerance, Somatic competition, Root plasticity in response to nutrients, Role of fires in seed germination.
- Plant immunity: Organism that attacks plants, What kind of plant pathogen interaction leads in to disease, How do plants perceive pathogens and response to them, Role of FLS2 in bacterial pathogen perception, Systemic acquired resistance against the viruses, Cultural practices to protect plants from pathogens.
- Genetically modified food and sustainable agriculture: Plant breeding for improved health, Constrains in producing sufficient food, Enhancing plant productivity by generating drought and salt tolerant plants, Risks associated with GMOs, Are GMOs safe to eat?

Recommended Reading

- L. Taiz and E. Zeiger, *PlantPhysiology*, 6th Edn., Sinauer Associates Inc. (2015).
- R. Jones, H. Ougham, H. Thomas, *The Molecular Life Of Plants*, Wiley-Blackwell (2012)

BIO501: Topics in biology-I

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Genomes and Genome Analysis: In this series of lectures, genome organization, as well as the techniques and scientific approaches leading to the study and analysis of genomes will be discussed. Some of the topics that would be discussed include: Genome organization, Mapping genomes-genetic and physical maps, Seqeuncing genomes- methodology, assembly& genome sequencing projects, Genome-wide analysis methods and approaches
- Advanced Topics in Ecology: In this series of lectures, ecology will be covered in a set of advanced topics in ecology. For each of the topics listed below, the instructor's lecture will be supplemented by selected research papers and reviews on the topic which the students will read and discuss in the class. The advanced topics to be included in the Ecology component will be chosen from among the following: Metabolic Theory of Ecology, Prey-predator interactions , Reproductive strategies, Ecology of Social behavior, Patterns and processes in Biodiversity, Population growth and regulation, Communication in animals, Plant-animal interactions.
- Plant Biotechnology: In this series of lectures of plant biotechnology the following areas would be discussed : Maintenance of callus and suspension cultures; single cell clones,Totipotency, Organoganesis; somatic embryogenesis; transfer and establishment of whole plants in soil. Protoplast fusion, selection of hybrid cells. Production of haploid plants and their utilization, Molecular markers. Gene transfer in nuclear genome and chloroplasts; Agrobacterium-mediated gene transfer, direct gene transfer, antibiotic marker-free transgenics. Transgenic plants:insect resistance,virus

resistance,abiotic stress tolerance, enhanced nutrition (golden rice), edible vaccines.

- Topics in Applied Microbiology: A Series of lectures will be given to deal with the following topics in microbiology: Microbial systematics and diversity: bacteria, archaea, viruses and fungi; Microbial growth and metabolism; Fermentation. Bioprocess Technology & Engineering Medical Microbiology, Agricultural Microbiology, Food and Dairy Microbiology, Industrial microbiology: application of microbiology in different industrial processes.

Recommended Reading

- T. A. Brown, *Genomes 3*, Garland Sciences Publishers, (2007).
- S. B. Priomrose and R. M. Twyman, *Principles of Gene Manipulation and Genomics*, 7th Edn., Blackwell Publishing (2008).
- S. H. Mantell, J. W. Mathews and R. A. Mckee, *Principles of Plant Biotechnology- An Introduction of Genetic Engineering in Plants*, Blackwell Science Inc. (1985).
- A. Slater, N. W. Scott and M. R. Fowler, *Plant biotechnology: the genetic manipulation of plants*, 2nd Edn., Oxford University Press (2008).
- M. J. Pelczar, *Microbiology*, 5th Edn., McGraw Hill (2001).
- L. E. Casida Jr, *Industrial Microbiology*, New age International Pub. (2007).
- G. Reed, *Prescott and Dunn's Industrial Microbiology*, CBS Publishers and Distributors (2004).
- P. F. Stanbury, A. Whitaker and S. J. Hall, *Principles of Fermentation Technology*, 2nd Edn., Butterworth Heineman (1999).

BIO512: Topics in biology-II

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Systems Biology: Systems Biology attempts to integrate information available from the studyof the components that make up a biological system. Experimental studies have led to the accumulation of large amount of information in different areas of biology - on genetic and biochemical interaction networks, cell interactions during development, and organismal response to environmental stimuli, along with genome sequences and molecular understanding of diseases. Systems Biology investigates the behaviour and relationships of all of the elements in a particular biological system while it is functioning, and describes the information using mathematical, computational, and graphical techniques to find the underlying design and working principles. In this set of nine lectures, this emerging area will be introduced and basic methods elaborated. Few specific biological studies in this direction will be discussed.

- Animal Biotechnolgy: Somatic cells : cell lines, culture, handling, sorting, transfection Germ cells : extraction, micromanipulation, IVF, nuclear transfer, embryo cloning Transgenics, knockouts, knockdowns, xenografts Animal Health Biotechnolgy: (i) therapeutics : hormones, therapeutic proteins, DNA and protein vaccines, antibiotics, antibodies. (ii) host-pathogen interactions : viruses, microbial pathogens, parasites, prion Animal Product Biotechnology(i). leather : enzymatic dehairing, softening, dekeratinization (ii) milk : altering constituents of milk proteomes

- Single-molecule Biology: (i) Biology at single-molecule resolution: Advantages over traditional (bulk) ensemble measurements. (ii) Technological advances in single-molecule detection, interrogation, tracking, analysis and manipulation. (iii) Single-molecule methodologies and measuring of molecular properties at single-molecule resolution (iv) Applications in biology: Motor proteins (F1-ATPase, phage DNA-packaging motor, kinesin, helicases, RNA polymerase etc.). Protein folding, assembly and enzymology Cell biology (cell membranes, lipid rafts, cell-signalling, nuclear pore transport, vesicle trafficking, neuronal communication, viral infection pathways, gene transcription and translation etc.).

- Stem Cell Biology: Overview of Stem Cell Biology Stem cells in plants and other model organisms Embryonic stem cells: maintenance of pluripotency and early lineage specification in mouse and human ESCs. Adult stem cells: Types of adult stem cells, Stem cell niche and its role in stem cell maintenance, Cellular plasticity Induced pluripotent stem cells: Epigenetics and reprogramming in stem cell biology Metabolic regulation of pluripotency and early lineage specification Cancer stem cells Policies and Ethics in stem cell research

Recommended Reading

- Ideker T. et al. (2001) A new approach to decoding life: Systems Biology. Annu. Rev. Genomics Hum. Genet., 2: 343-372.

- Kitano H. (2002) Systems Biology: A Brief Overview. Science, 295: 1662-1664.

- L. Castilho, *Animal Cell Technology: From Biopharmaceuticals to Gene Therapy*, Taylor and Francis (2008).

- T. Cartright, *Animal Cells as Bioreactors*, Cambridge Studies in Biotechnology Series, Cambridge University Press (1994).

- M. Butler, *Animal Cell Culture and Technology : The Basics*, 2nd Edn., Taylor and Francis (2004).

- R. Portner (ed), *Animal Cell Biotechnology:Methods and protocols*, 2nd Edn., Humana Press (2007).

- Alexander Knight (Ed), *Single Molecule Biology*, Academic Press (2008).

- P. Hinterdorfer and A. van Oijen (Eds), *Handbook of Single-Molecule Biophysics*, Springer (2009).

- R. Lanza, J. Gearhart, B. Hogan, D. Melton, R. Pederson, E. D. Thomas, J. Thomson and I. Wilmuti, *Essentials of Stem Cell Biology*, 2nd Edn., (2009).

BIO601: Techniques in biology

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Strategies in gene cloning (Bacteria, Yeast, Drosophila, C.elegans, Mouse and Human), PCR and its application, Cloning vectors, Strategies in heterologous gene expression, Si-RNA technology, DNA-protein interaction, Protein-protein interaction, Gene knock-out and knock-in technology, Transgenic technology, Microarray technology, Proteomic technology.

Recommended Reading

- J. D. Watson, *Recombinant DNA: genes and genomes : a short course WH*, Freeman (2007).
- T. A. Brown, *Genomes 3*, Garland Science Pub. (2007)
- S. B. Primrose, R. M. Twyman, *Principles of gene manipulation and genomics* 7th edition (2006).

BIO602: Regulation of gene expression

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Basic concepts of transcription, Transcriptional regulation in bacteria, Promoters, enhancers and insulators, Transcription activators, co-activators, RNA splicing and alternative splicing, Chromatin remodeling, RNA stability and degradation, RNA transport and localization, Transcription repression in higher eukaryotes, RNA interference, Epigenetic regulation.

Recommended Reading

- J. E. Krebs, E. S. Goldstein, S. T. Kilpatrick, B. Lewin, *Lewin's essential genes*, Jones and Bartlett publishers, 2nd Edition (2009).
- J. E. Krebs, E. S. Goldsteini,B. Lewin, *Lewin's Genes X*, Jones and Bartlett publishers (2009).
- S. B. Primrose, R. M. Twyman, *Principles of genome analysis and genomics*, Blackwell publishing 7th Edn.(2006).

BIO606: Biostatistics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Review of Probability and statistics.
- Measures of central tendency and variability.
- Probability and probability distributions- review.
- Binomial Distributions , Normal Distribution, Poisson Distribution.
- Population and sampling, estimating means and confidence Intervals.
- Hypothesis testing, types of errors.
- Comparing means of two populations t Test.
- Contingency table and Chi-square test.
- Analysis of Variance, F test to compare variances of two populations.
- Two way analysis of variance, Random effects.
- Regression, least squares method, correlation, Spearmans rank order correlation.

Recommended Reading

- J. H. Zar., *Biostatistical Analysis (4th or 5th edition)*, Year: 2009. Publisher: Prentice Hall
- Geoffery R & Norman Steiner, *Biostatistics: The Bare Essentials 3rd Edition.*, Year: 2007 Publisher: B C Decker Inc.

BIO609: Immunology

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Overview of the immune system- Cells and organs of the immune system. Innate and adaptive immunity.
- Innate immunity & complement.
- Hematopoiesis.
- VDJ joining: T and B cells.
- B cell maturation & class switching.
- Somatic hypermutation.
- Dendritic cells.
- MHC: T cell-antigen presenting cell: interactions.
- T-B cells interactions.
- Chemokines & Adhesion molecules.

- Signal transduction in immune cells.
- T cell subsets, Regulatory T cells, Th17 cells.
- Clonal selection, central tolerance.
- Peripheral regulation.

Recommended Reading

- Mostly, current research reports and reviews will be used as study materials. Recent articles from Annual Review of Immunology, Current Opinion in Immunology, Nature Immunology etc. will be consulted.
- K. M. Murphy, P. Travers and M. Walport, *Janeway's Immunobiology*, 7th Edn., Garland Science (2008).
- T. J. Kindt, R. A. Goldsby and B. A. Osborne, *Kuby Immunology*, 6th Edn., W.H. Freeman (2006).

BIO610: Advanced topics in molecular genetics

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- In this course we would take a practical approach to understanding molecular tools used in genetic analysis. A special feature of this course would also be to address how Genomics and Next generation sequencing technologies have impacted the practice of genetics.
- The course would cover bacterial genetics (from mutant screen to clone) and the impact of the genomics era, yeast genetics and reverse genetics, human genetic mapping and the impact of next generation sequencing such as in exome sequencing. The course would also deal with phage display, in vitro genetics, and directed evolution.
- The course would be taught by discussing and analyzing published papers, and also will be supplemented with a few lectures.

Recommended Reading

- Mardis E. R. (2008) The impact of next-generation sequencing technology on genetics. Trends in Genetics, 24, 133-141, 2008.
- MacLean D., Jones J. D. G., and Studholme D. J. (2009) Application of next-generation sequencing technologies to microbial genetics, Nature Reviews in Microbiology. 287-296, 2009
- Majewski J. , Schwartzentruber J., Lalond E., Montpetit A. and Jabado N. (2011). What can exome sequencing do for you? . J.Med Genetics, July 2011.
- Shendure J. (2011). Next Generation Human genetics. Genome Biology 12, 408, 2011.
- A. J. F. Griffiths, S. R. Wessler, R. C. Lewontin and S. B. Carroll, *Introduction to Genetic Analysis*, 9th Edn., W. H. Freeman (2007).

BIO611: Fluorescence in biology

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- An introduction to biological fluorescence spectroscopy
- Basics of fluorescence spectroscopy: Absorption and emission photophysics
- Fluorescent probe chemistry
- Instrumentation in fluorescence spectroscopy
- Steady-state and time-resolved fluorescence
- Fluorescence quantum yield, lifetime, quenching, fluorescence resonance energy transfer, polarization anisotropy and solvent relaxation
- Fluorescence imaging: Epi-, confocal-, total-internal reflection- and near-field fluorescence microscopy
- Single-molecule fluorescence and fluorescence correlation spectroscopy
- Application of fluorescence in protein, nucleic acid and membrane research
- Fluorescent proteins
- Application of fluorescence in cell and molecular biology, immunology, developmental biology, genetics and neurobiology

Recommended Reading

- J. R. Lakowicz, *Principles of Fluorescence Spectroscopy*, 3rd Edn., Springer (2006).
- B. Alberts, A. Johnson, J. Lewis, M. Raff, K. Roberts and P. Walter, *Molecular Biology of the Cell*, 5th Edn., Garland Science (2008).

BIO612: RNA biology

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Evolution of RNA: RNA World Hypothesis
- RNA catalyst - Ribozymes
- Life Cycle of RNAs: Transcription, Export, Translation, Storage and Decay
- Structure, Function and Regulation of RNP (RNA - protein) Machineries
- Ribosome and Protein Synthesis
- Spliceosome, RNA Splicing and Alternative RNA Splicing
- Telomerase and Telomere Capping

- Function of small RNAs as Regulators of Gene Expression
- RNAi (RNA interference) Pathway
- Non coding RNAs: siRNAs, miRNAs and piRNAs
- Heterochromatin and X-Inactivation
- Overview of Tools and Techniques for RNA Research

Recommended Reading

- John F. Atkins et al (ed.), *RNA Worlds: From Life's Origins to Diversity in Gene Regulation* CSHL press (2011).
- Gunter Meister (ed.), *RNA Biology: An Introduction* Wiley press (2011).
- David Elliott and Michael Ladomery (ed.), *Molecular Biology of RNA* Oxford University Press (2011).
- James Darnell (ed.), *RNA: Life's Indispensable Molecule* CSHL press (2011).

BIO613: Developmental neurobiology

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline Understanding how the nervous system is formed. Aspects of nervous system development in various model organisms including worms, flies, frogs, chicks and mice. Relations of these to the development of the human brain. Diseases effecting normal brain development and function. Current research will also be analyzed and presented.

- Evolution of the nervous system
- Patterning of the Nervous system
- Neuronal determination, survival and death
- Axon guidance
- Synapse formation and developmental plasticity
- Brain mapping
- Behavioral Neurobiology

Recommended Reading

- D. Sanes et al., *Development of the Nervous System* 3rd Ed. Academic Press (2011).

BIO614: Topics in evolutionary biology

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Introduction to Evolutionary Biology: A brief history of Evolutionary Thought, Darwinism, The nature of Natural Selection.
- The Genetics of Populations: The Hardy-Weinberg Equilibrium, Forces of evolutionary Change- Selection, Mutation, Migration, Random Genetic Drift, Non-random Mating.
- Adaptation: What is adaptation? Approaches to studying adaptation-Comparative methods, Phenotypic manipulation, Experimental Evolution.
- Evolution of Life Histories: Evolution of Aging, Development, Fecundity and Body size. Trade-offs and constraints.
- Evolution of Sex: The Origin and maintenance of Sexual reproduction, Sexual Dimorphism and sex roles, Sexual selection, Sexual conflict. Evolution of Social Behaviour: Evolution of Altruism Eusociality Conflict and co-operation
- Evolution and Development: Homeotic genes, Pattern formation, Diversification Homology
- Evolution and Human life: Evolution of Humans, Evolution and Human Behaviour, Evolution and Human Health
- Evolutionary History of Life on Earth: Origin of Life, Pre-cambrian evolution, Cambrian Explosion and future radiation.

Recommended Reading

- S. Freeman and J. C. Herron, *Evolutionary Analysis*, 4th Edn., Benjamin-Cummings (2007).
- D. J. Futuyma, *Evolution*, 2nd Edn., Sinauer Associates Inc. (2009).

BIO615: Developmental biology

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Introduction: History and Basic Concepts.
- Organizing centers: activators and inhibitors. Role of organizers in neural induction and organizing the anteroposterior axis in vertebrate.
- Morphogens in action: Components of limb bud signaling. Morphogens and antero-posterior patterning of Drosophila embryo. Cellular basis of morphogenesis. Communication by extracellular signals.
- Symmetry breaking during development: Symmetry Breaking in AP and DV axis formation. Left/Right Symmetry. Mechanisms of symmetry breaking during axis formation. Examples from different model systems.
- Development in progress—Patterning in steps: Reading out the patterning information, localized transcriptional factors, regulatory modules. Role of the segmentation cascade in patterning in Drosphila.

- Axon guidance—wiring of the nervous system: Patterning of the brain, Neuronal cell fate determination, Neuronal differentiation, Axon pathfinding, Dendrite development, Map formation, Layer formation, Synaptogenesis, Synaptic competition, homeostasis, plasticity. Neural induction and Patterning.
- Organ development: Heart Development, morphogenesis, conduction, valves.
- Epicardium, second heart lineage, cardiac neural crest, tissue-tissue interactions & reciprocal signaling.
- Regeneration: Vertebrate limb and organ regeneration.
- The evo-devo saga of Development: How muticellular organism evolved from single cell ancestor. The evolutionary modification of embryonic development. Changes in the timing of developmental processes.
- Implications of Developmental Studies: Understanding aspects of Bio-medicine, Bio-diversity and Disease Mechanisms.

Recommended Reading

- Scott F. Gilbert, *Developmental Biology* 8th ed. Sinauer Assoc. Inc. (2006).
- L. Wolpert et al, *Principles of Development* 3rd ed. Oxford Univ. Press (2007).

BIO616: Animal behaviour: Proximate mechanism, ultimate causes

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- History Of Animal Behavior: Behaviorism and Ethology, Founders of Ethology, Learned vs Innate Behaviour, Instincts, Conditioning, Habituation, Reinforcement.
- Measuring Behaviour: States and Events, Measures of Behaviour, Sampling Methods, Constructing Ethograms.
- Animal Communication: Modes of Communication, Advantages and Disadvantages, Functions of Communication, Types of Signals.
- Finding Food: Foraging Strategies, Generalists vs Specialists, Marginal Value Theorem and Patch Residence Time, Economics of Diet Selection.
- Finding Shelter: Habitat Selection, Territoriality, Dispersal, Migration.
- Finding Mates: Mating Systems, Mating Behaviour, Male-Male Competition, Sexual Selection by Female Choice.
- Avoiding Predators: Antipredator Behaviour, Prey-predator Interactions, Red Queen Hypothesis.
- Parental Care: Adaptive Value, Asymmetry in Parental Investment, Offspring Recognition, Brood Parasitism, Parent-Offspring conflict.

- Social Behavior: Animal Societies, The Costs and Benefits of Group-living, Cooperation and Conflict, Kin-selection and Inclusive Fitness.
- Neuroethology And Behavioural Genetics: Development of Behaviour, Processing of Sensory Information, Hormonal control of behaviour, Learning, Memory and Cognition.

Recommended Reading

- Alcock J. 2005, *Animal Behaviour: An Evolutionary Approach*, 8th Edition, Sinauer Associates, Inc.
- Davies N. B., Krebs J. R., West S. A. 2012, *An Introduction to Behavioural Ecology*, 4th Edition, Wiley-Blackwell.

BIO623: Protein folding, misfolding and amyloid biology

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- The protein folding problem and the Levinthal paradox.
- The conformational description of polypeptide chains in good and poor solvents.
- The protein folding funnel and the energy landscape.
- Biophysical techniques in protein folding studies: CD, fluorescence, NMR, H/D exchange, Time-resolved spectroscopy, Laser T-jump and fast mixing.
- Unfolding and folding under equilibrium and kinetic conditions.
- Detection and characterizations of folding intermediates Case studies on two-state, multi-state and downhill folding.
- Intrinsically disordered proteins and new paradigm in protein folding.
- Single-molecule studies in protein folding.
- Molecular chaperones and protein folding in the context of cells.
- Protein misfolding and aggregation leading to amyloid formation.
- Protein misfolding diseases: Alzheimer's, Parkinson's, Huntington's and prion diseases.
- Prion biology: Self-replicating misfolded protein conformers and non-Mendelian genetics.

Recommended Reading

- V. Muñoz, *Protein Folding, Misfolding and Aggregation: Classical Themes and Novel Approaches*, 1st Edn., Springer (2008).
- A. R. Fersht, *Structure and Mechanism in Protein Science: A Guide to Enzyme Catalysis and Protein Folding*, 1st Edn., W. H. Freeman (1998).
- B. Nolting, *Protein Folding Kinetics: Biophysical Methods*, 2nd Edn., Springer (2005).

BIO624: Case studies in hypotheses-driven molecular and cellular biology

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Students will be exposed to twelve case-studies involving the formulation of hypotheses in different domains of molecular biology, and the design and execution of experiments shedding light on the correctness of these hypotheses. Topics covered will be chosen from the following:
  - Immune responses to protein aggregates.
  - Replication-driven transcription of bacterial genes.
  - Transcription-driven transcription of bacterial genes.
  - Chromatin remodeling and mid-blastula genome-wide activation of genes in animal development.
  - Helix/sheet architecture & topology in beta/alpha barrel protein folding.
  - Building mirror-imaged proteins using 'retro' and 'inverso' polypeptides.
  - Building ultra-stable protein structures through engineering of the cooperativity of global unfolding.
  - Protein skin grafting through remodelling of beta sheet surfaces.
  - Use of DNA sequencing to discover translation-inhibiting messenger RNA structures.
  - Molecular recognition in the formation of amyloid/amorphous protein aggregates.
  - Rational reengineering of protein surfaces to block aggregation.
  - Protein domain-swapping interactions and optically-useful biomaterials.

Recommended Reading

- P. Delves, S. Martin, D. Burton and I. Roitt, *Roitt's Essential Immunology*, 11th Edn., Wiley-Blackwell (2006).
- T. E. Creighton, *Proteins : Structure and Molecular Properties*, 2nd Edn., W. H. Freeman (1992).
- B. Alberts, A. Johnson, J. Lewis, M. Raff, K. Roberts and P. Walter, *Molecular Biology of the Cell*, 5th Edn., Garland Science (2008).
- S. F. Gilbert, *Developmental Biology*, 8th Edn., Sinauer Associates Inc. (2006).
- Klein et al. (1997) A crucial role for B cells in neuroinvasive scrapie. Nature 390, 687-690.
- Brewer (1988). When polymerases collide : Replication and the transcriptional organization of the E.coli chromosome. Cell 53, 679-686.

- Liu and Wang (1987). Supercoiling of the DNA template during transcription. Proc. Natl. Acad. Sci. USA 84, 7024-7027. Farber and Petsko (1990) The evolution of alpha/beta barrel enzymes. Trends Biochem. Sci. 15, 228–234. Guichard et al. (1994) Antigenic mimicry of natural L-peptides with retro-inverso-peptidomimetics. Proc. Natl. Acad. Sci. USA 91, 9765-9769.

- Tsou (1993) Conformational flexibility of enzyme active sites. Science 262, 380–381. D'Amico et al. (2003) Activity–stability relationships in extremophilic enzymes. J. Biol Chem. 278, 7891–7896. Sanger & Coulson (1975) A rapid method for determining sequences in DNA by primed synthesis with DNA polymerase. J. Mol. Biol. 94, 441–448.

- Fink (1998). Protein aggregation: folding aggregates, inclusion bodies and amyloid. Fold. Des. 3, R9-R23 Vassetzky et al. (2000) Rearrangement of chromatin domains during development in Xenopus. Genes Dev. 14, 1541–1552.

BIO625: Molecular evolution and phylogenetics

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Introduction: Revision of Natural Selection, Hardy-Weinberg Equilibrium, Random Genetic Drift and Effective Population Size.

- Manipulating sequences: Mutations; Rates of Mutations; Recombination; Indels; Aligning Sequences; Calculating Evolutionary Distances among Sequences; Corrections and Models of Sequence Evolution. and.

- Natural Selection: Rates, Clocks, and the Neutral Theory: Selection at the Molecular Level; The Neutral and Nearly-neutral Theories of Molecular Evolution; Molecular Clocks and the Relative Rates Test; Codon Bias; Variations in Substitution Rates and their Causes in Nuclear, Organellar, and Viral DNA; Tests of Positive Selection (McDonald Kreitman, Ka/Ks, Tajimas D Statistics, etc.).

- Genome Evolution: Genome Duplication in Eukaryotic Evolution; Evolution of Gene Families; Chro- mosome Evolution; Endosymbiosis and Lateral Gene Transfer.

- Introduction to Systematics and Phylogenetics: Taxonomy as the most Fundamental Biological Science; Nomenclature and Classification.

- Phylogenetic Trees: Kinds of Trees; Rooting; Clades; Reconstructing Character Evolution, Consensus Trees, Phylogenetic Hypothesis Testing; Gene Trees and Species Trees.

- Methods for Inferring Phylogenetic Trees: Parsimony, Minimum Distance, Maximum Likelihood and Bayesian Methods; Statistical Robustness of Trees; Introduction to some Software for Building Trees and Molecular Population Genetic Tests.

- Using Phylogenetic and Molecular Evolutionary Tools to Answer Biological Questions: Speciation; Phylogeography; Biogeography; Infectious Diseases.

Recommended Reading

- *Fundamentals of Molecular Evolution*, Dan Graur & Wen-Hsiung Li, Sinauer Associates, 2nd Edition, 1999.
- *Molecular Evolution: A Phylogenetic Approach*, Roderick D.M. Page, Wiley-Blackwell, 1998.
- *The Phylogenetic Handbook: A Practical Approach to Phylogenetic Analysis and Hypothesis Testing*, Philippe Lemey, Cambridge University Press, 2009.
- *Tree Thinking: An Introduction to Phylogenetic Biology*, David Baum & Stacey Smith, Roberts and Company Publishers, 2012.

BIO626: Immunological tools, techniques and technologies

[Cr:4, Lc:3, Tt:0, Lb:1]

Course Outline

- Part I: Purification and isolation and identification of immunoglobulins and their sub-units, Proteolytic cleavage of lg molecules by enzymes and their usage. Various serological tests (precipitation, aggluti- nation reaction-based tests), bedside or point-of-care immunodiagnostic tests, Immunoassays (ELISA, radioimmunoassay, Fluoroimmunoassay, immunohistochemistry, ELISPOT assay et), The use of flow cytometry in disease diagnosis and monitoring of treatment efficacy.
- Part II: Separation and enumeration of lymphocytes by conventional and flowcytometry based methods: Culturing of myeloid and lymphoid cells and determining their functional ability, In vitro and in vivo tests for phagocytosis, Apoptotic changes in lymphoid and non-lymphoid cells.
- Part III: Traditional and modern methods of production of antibodies: such as animal immunization, hybridoma and rDNA technologies including antibody display technologies, Multicolor flowcytometric analyses of lymphocytes and other cells, In vitro differentiation of helper T cells, Identifying immuno- genic epitopes of intracellular pathogens. Genesis and use of transgenics, transnuclear as well as Knock-in and knockout mice models for immunological investigations.

Recommended Reading

- Coligan JE, Kruisbeek AM, Margulies DH, Shevach EM & Strober W., *Current Protocols in Immunology*, 3rd Ed., John Wiley & Sons. 2003, (subsequent versions)
- Detrick B & Hamilton RG. (Eds)., *Manual of Molecular and Clinical Laboratory Immunology*, 7th Ed. American Society for Microbiology, 2006.
- Hay FC & Westwood OMR,
- Practical Immunology, 4th Ed. Blackwell, 2002.

BIO627: Origin, ecology and bioresources of Western Himalaya

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Origin of the Himalaya: Origin and expanse of the Himalayan range. Geology, Glaciology and Hydrology across the Himalayan range.
- Environmental attributes and Climate Regulation and Ecological Managemenet. The use of Remote sensing in monitoring environmental dynamics. Natural and Man made calamities in the Himalayas. Environmental Impact Assessment with particular reference to projects in the Himalayan region. Adaptation and Mitigation Strategies.
- Distribution and Organization of Flora Forest and Soil types, Landscape elements, (sub-tropical, semitemperate, temperate, alpine pastures and the trans-Himalayas). Altitudinal zonalization, and species adaptation and distribution. Foret types and their quality and expanse. Emphasis to be on Biosphere Reserves, National Parks and Wildlife Sanctuaries located in this region.
- Biodiverity and Bioresources Endemism and Himalayas, species richness and issues of biodiversity. Ornamentals, medicinal and aromatic plants and other minor forest produce. Bioprospection and Utilization of the Bioresources at the level of whole plants and organisms (microbes and viruses) proteins and enzymes, Genomes and gene sequences of unique traits.
- Plant adaptation and climate change in context of Himalayas. Assessing baseline parameters of soil, (depth, type, nutrient status, moisture retention, etc., weather features such as temperature CO2 content light intensity sunshine hours, precipitation wind speed and direction, and physical and environmental charecteristics of diverse ecological zones. Measuring and assessing the phonological and biochemical and chemical changes in the species complex in the background of above . Evolving Mathematical models to predict the change in face of an emerging scenario.
- Anthropogeny and Demography Tribal history of Himalayas, Traditional Knowledge, Herbal Remedies over the ages. Developmental patterns and impact analyses.(Roads dams canals and tunnels and town planning) Role of GIS and RS in impact analyses.

Recommended Reading

- Digital Himalaya (journal, maps, census and data), http://www.digitalhimalaya.com
- Rashid. I. et.al., 2012, *Geospatial modelling approach for identifying disturbance regimes and biodiversity rich areas in North Western Himalayas India Conserv Biodivers.*
- Singh J. S. & Singh S. P. 1987. *Forest Vegetation of Himalaya.*, The Botanical Review 53 : 80-192.

- Ray. P. S. et.al., *Indias plant diversity database at landscape level in geospatial plot foms : Prospects and utility in todays changing climate.*, Curr Sci 102(8) : 1136-1142.
- Negi, G. S., et al *Impact of Climate Change on Western Himalayan Mountain System : An overview* 2012 Tropical Ecology 53 (3) 345-356.
- Immerzeel, W. W. 2010., *Climate Change will affect the Asian Water Towers.*, Science 328 no. 5984 : 1382-1385.
- Yu H. et.al., 2010. *Winter and Spring Warming result in delayed Spring Phenology on the Tibetan Plateu.*, Proc Natl Acad Sc. USA 107 : 22151-22156.
- Shrestha, U. B. et. al., 2012. *Widespread Climate Change in the Himalayas and Associated Changes in Local Ecosystems.* PLOS ONE
- Mission Report : National Mission for Sustaining the Himalayan Ecosystem 2010, Department of Science and Technology Government of India.

BIO628: Synthetic biology

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Introduction to Synthetic Biology, Bacterial Promoters and Prokaryotic Gene regulation, Early Synthetic Biology Experiments based on gene regulation, Orthogonality of parts- context independance.
- Quantitative representation of gene regulation, Negative feedback loops Positive feedback loops, Simple synthetic networks, Reprissilator, Toggle switch Networks; Scale-free networks, Gene regulatory networks Response times; Robustness and Stochasticity.
- Directed Evolution in synthetic biology, Methods of generating diversity; Screening and selection in directed evolution.
- Allostery and Allosteric Switches, Engineering allostery: Protein Fusions and linkers, Combinatorial approaches, Domain insertions, Engineering GFP to make sensors.
- Oligonucleotide synthesis, Gene synthesis, Genome synthesis, Genome Assembly, Synthetic Genomes Synthetic Biology approach to Minimal Genomes, Extension of the Genetic code.
- Metabolic networks and Metabolic Engineering, Metabolic Flux analysis, 13C- Metabolic Flux Analysis Metabolic engineering for synthetic Biology.
- Recent Applications of Synthetic Biology, Quorum sensing and RNA riboswitches as a tool iGEM competitions.

Recommended Reading

- H. Zhao, *Synthetic Biology: Tools and Applications*, Academic Press, 2013.
- Campbell, A. M. and Heyer L., *Discovering Genomics, Proteomics and Bioinformatics*, Pearson, 2007.
- Voigt, C. *Synthetic Biology, Part A, Methods in Enzymology*, V 497, Academic Press, 2015.
- Voigt, C. *Synthetic Biology, Part B, Methods in Enzymology*, Vol, 498, Academic Press,2015.
- Gibson, D. G. et.al. Editors. *Synthetic Biology: Tools for Engineering Biological Systems*, Cold Spring Harbor Press, 2017.

BIO629: Bioinformatics

[Cr:4, Lc:1, Tt:0, Lb:6]

Course Outline

- Biological databases: Nucleic acid and protein databases such as ENTREZ, Genbank. File formats of nucleotide and protein sequences such as FASTA, ASN.1, Genbank flatfile.
- DNA and protein sequence analysis: Data storage and compression, DNA sequence composition, primer design, Motif and pattern search methods, Sequence alignments (Pairwise and multiple sequence alignment), Local and global sequence alignments, Scoring matrices such as PAM and BLOSUM. Consensus pattern, motifs and Profiles. Position Specific Scoring Matrices.
- Methods for Database Searching BLAST and FASTA. Significance of alignments, E-values. BLAST programs: BLASTp, BLASTn, BLASTx, tBLASTn, tBLASTx, PSI BLAST.
- Phylogenetic analysis: Concept of phylogenetic trees-Branches, nodes, internal nodes, rooted and unrooted trees. Distance matrix methods; Maximum parsimony methods; Maximum likelihood methods.
- Gene prediction: Prokaryotes versus eukaryotes. Promoters,splice sites. RNA secondary structure prediction.
- Structural bioinformatics: Introduction to protein tertirary structure analysis, Protein structure visualization, Protein structure classification and databases. Ramachandran map, Protein secondary structure prediction. Tertiary structure prediction: Homology modeling, Threading/Fold recognition, ab initio protein structure prediction.
- 4 to 6 weeks project on sequence or/and structure analysis.

Recommended Reading

- J. Xiong, *Essential Bioinformatics*, Cambridge University Press (2009).
- D. Mount, *Bioinformatics: Sequence and Genome Analysis*, 2nd Edn., Cold Spring Harbor Laboratory Press (2004).
- A. D. Baxevanis and B. F. F. Ouellette (eds),*Bioinformatics: A practical guide to the analysis of genes and proteins*, 3rd Edn., Wiley-Interscience (2004).
- D. E. Krane and M. L. Raymer, *Fundamental concepts of Bioinformatics*, 1st Edn., Pearson Education India (2003).

4.2 Chemical Sciences

CHM307: Electrochemistry and ionic equillibria

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline This course is an introduction to electrochemistry through theory and a few experiments to understand fundamental electrochemical processes. The course will cover the laws of electrolysis, Arrhenius theory of dissociation, transport number, Debye-Huckel theory, ionic mobility, degree of dissociation and dissociation constants, Debye-Huckel Limiting law and conductometric titrations. Special emphasis will be given on various types of electrochemical cells, standard electrode potentials, liquid junction potential, applications of emf measurements, polarization and overvoltage etc.

- The Laws of electrolysis, Arrhenius theory of electrolytic dissociation, strong and weak electrolytes. Migration of ions, the transport number, Hittorfs rule and determination of transport number Conductance in solution, specific conductance, equivalent conductance, determination of conductance, equivalent conductance at infinite dilution.
- Kohlrauschs Law and its applications, ionic mobilities, weak electrolytes, degree of dissociation.
- Various conductometeric titrations.
- Ionic strength, Debye-Huckel limiting law.
- Electrochemical cells, measurement of EMF, EMF and free energy, Nernst equation and equilibrium constant.
- Types of electrodes, construction of electrodes, EMF of cell and electrode potential, standard electrode potential, application of salt bridge, applications of different electrode systems and EMF measurements.
- Liquid junction potential, concentration cell, commercial cells, fuel cells.
- Polarization, decomposition potential and overvoltage.
- Solubility product and activity product, determination of solubility product from EMF.

- Dissociation constant of weak acid, applications of solubility and solubility product, measurement of pH, ionic product of water, isohydric solutions, salt hydrolysis and buffer solution, neutralization indicators and their practical applications.
- Voltametry Instrumentation, electrodes, voltamogram and its interpretation, Polarography and cyclic voltammetry.

Recommended Reading

- Thomas Engel and Philip Reid, *Physical Chemistry*, Pearson Publication 2006.
- P. W. Atkins, *Physical Chemistry*, 8 th Edition, Oxford University Press, 2005.
- S. Glasstone, *An Introduction to Electrochemistry*, Affiliated East West Press 1942.
- P. C. Rakshit, *Physical Chemistry*, 7 th Edition, Sarat Book Distributors, Kolkata, 2004.

CHM601: Advanced inorganic chemistry

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Brief discussion about coordination chemistry of s-block elements. Structural features of s-block hydrides, halides, oxides and oxyacids.
- Recent advances in chemistry of boranes, metallaboranes, carboranes, metallacarboranes. Organoaluminium compounds and low-valent aluminium compounds.
- Structure, bonding and applications of main group elements containing CO, CN-, C_2H_4, Cp, Cp* ligands.
- Discussion of Schrock and Fischer carbene complexes of transition metals; Carbyne and allyl complexes of transition metals: synthesis, structure, bonding and catalysis.
- Polyhedral clusters including M-M bonded complexes: synthesis, structure, bonding and properties. Polyhedral skeletal electron pair approach.
- Concept of isolobality and stereochemical nonrigidity
- Fluxional organo transition metal compounds

Recommended Reading

- F. A. Cotton, G. Wilkinson, C. A. Murillo, M. Bochmann, it Advanced Inorganic Chemistry, Indian Edition, 6th Ed, Wiley-India, Noida (2007).
- N. N. Greenwood, A. Earnshaw, it Chemistry of The Elements, Indian Edition, 2nd Ed, Butterworth-Heinemann, Elsevier, (2005).

- R. H. Crabtree, it The Organometallic Chemistry of The Transition Metals, 4th Ed, John Wiley & Sons Inc, New Jersey (2005).
- J. E. Huheey, E. A. Keiter, R. L. Keiter, O. K. Medhi, *Inorganic Chemistry: Principles of Structure and Reactivity*, Indian Edition, 4th Ed, Pearson Education, India (2007).
- D. M. P. Mingos, it Essential Trends in Inorganic Chemistry, Indian Edition, Oxford University Press, Kolkata (2004).

CHM602: Magnetic resonance

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Introduction to NMR: Spin and spin angular momentum, CW NMR, pulse NMR, sampling, bandwidth, detection and acquisition of NMR signals, time and frequency domain spectra, FT-NMR, resolution and sensitivity in NMR.
- Spin interactions in NMR, chemical shift, scalar or J-coupling, dipolar interaction and quadrupole interaction, quantum mechanical description of spin-interactions, spin interactions in the solution and solid-state.
- Pulse NMR experiments, describing pulse NMR experiment: The radio-frequency field, pulse, the concept of rotating frame, relaxation, spin-lattice relaxation, spin-spin relaxation, nuclear overhauser effect (NOE).
- Polarization transfer experiments and spectrum editing, selecting polarization transfer, INEPT experiment, implementation and its Characteristics, DEPT experiment, implementation and its characteristics, cross-polarization (CP) experiment and its variants.
- Fourier transform NMR, single-pulse experiment, signal averaging, multiple-pulse NMR experiments, NMR spectrum, NMR signal, line shapes in NMR, two-dimensional NMR spectroscopy, two-dimensional fourier transformation.

Recommended Reading

- R. S. Macomber, *A Complete introduction to modern NMR techniques*, 1st Ed, John Wiley & Sons, England (1998).
- M. H. Levitt, *Spin dynamics: Basics of Nuclear Magnetic Resonance*, 2nd Ed, John Wiley & Sons, England (2008).
- C. P. Slichter, *Principles of Magnetic Resonance*, 3rd Ed, Springer Verlag, Berlin (1996).

CHM603: Elements of NMR theory

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Rotations in quantum mechanics: Rotations in two and three dimensions, active and passive rotations, Euler angles, rotation operators, Wigner rotation matrices, properties of Wigner rotation matrices, the concept of tensors, reducible and irreducible tensors, Wigner-Eckart theorem, coupling of angular momentum, Clebsch-Gordon coefficients, 3-j, 6-j and 9-j symbols.
- Operator basis and spin dynamics in NMR: Basis states, basis operators, the product operator basis, fictitious spin operator basis, multipole operator basis, Floquet basis operators, irreducible Floquet tensor operator basis, operator basis for multiple spins, commutator relations, matrix representation of operators, direct method, indirect method, pure and mixed States, density matrix theory, Liouville-von-Neumann equation of motion, description of time-dependent hamiltonians, Magnus expansion, Baker Campbell Hausdorff expansion, average hamiltonian theory, Floquet theory
- Description of NMR experiments: Description of spin echo, double resonance, Carr-Purcell sequence, WAHUHA, solid echo experiments using density matrix theory. Description of MAS experiments, the concept of spin and spatial tensor operators, representation of spin hamiltonians in the solid-state.

Recommended Reading

- M. H. Levitt, *Spin Dynamics: Basics of Nuclear Magnetic Resonance*, John Wiley & Sons (2001).
- C. P. Slichter, *Principles of Magnetic Resonance*, 3rd Ed, Springer-Verlag, Berlin, (1990).
- R. R. Ernst, G. Bodenhausen, A. Wokaun, *Principles of Nuclear Magnetic Resonance in One and Two Dimensions*, Oxford Science Publications by Clarendon Press, (1987).
- A. E. Derome, *Modern NMR Techniques for Chemistry Research*, Pergamon Press, (1987).
- N. Chandrakumar, S. Subramanian, *Modern Techniques in High Resolution FT-NMR*, Springer-Verlag, New York Inc. (1987).

CHM604: Advanced organic chemistry

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Recent advances in selected metal-mediated coupling reactions and mechanisms: Buchwald-Hartwig, Suzuki, Sonogashira, Fukuyama, Heck, Tsuji-Trost, Hiyama, Kumada, Negishi, and Stille coupling reactions. Selected familiar named reactions and their recent advances with their mechanistic aspects.
- Reaction mechanisms, functional group transformation in synthetic organic chemistry and its importance.

- Selected transition metal-based catalytic reactions in modern organic synthesis. Selected important reagents in modern organic synthesis. Alpha-diazo ketones and their synthetic reactions for C-C bond formation.
- Recent trends in organometallic reactions involving C-C bond formations: Magnesium, Zinc, Indium-mediated stereoselective additions to carbonyl compounds.
- Lewis acids and Lewis acid-catalyzed reactions and their importance in modern organic synthesis.
- Stereo-, chemo-, and regio-selective reactions: Hydrogenation and addition to multiple bonds and elimination reactions and mechanisms.
- Protective groups and their importance in synthetic organic chemistry.

Recommended Reading

- W. Carruthers, I. Coldham, *Modern Methods of Organic Synthesis*, 4th Ed, Cambridge (2004).
- F. A. Carey, R. J. Sundberg, *Advanced Organic Chemistry Part A: Structure and Mechanism & Part B: Reactions and Synthesis*, 5th Ed, Springer, New York (2007).
- K. C. Nicolaou, T. Montagnon, *Molecules That Changed The World*, 1st Ed, Wiley-VCH, Weinheim, Germanyx, (2008).
- R. Mahrwald, *Modern Aldol Reactions, Volumes 1 & 2*, Wiley-VCH, Weinheim (2004).
- A. de Meijere, F. Diederich, *Metal-Catalyzed Cross-Coupling Reactions*, 2nd Ed, Wiley-VCH Verlag GmbH, Weinheim (2004).
- P. G. M. Wuts, T. W. Greene, *Greene's Protective Groups in Organic Synthesis*, 4th Ed, John Wiley & Sons, Inc. (2006).
- M. Nògrádi, *Stereoselective Synthesis*, VCH Verlagsgesellschaft GmbH, (2007).
- T. Laue, A. Plagens, *Named Organic Reactions*, 2nd Ed, John Wiley & Sons, Hoboken, New Jersey (2005).

CHM605: Advances in solid state NMR

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Magic angle spinning (MAS) NMR: Magic angle spinning experiments. Theoretical description of MAS via Wigner rotation matrices, the concept of powder averaging. Representation of spin interactions through second rank tensors.

- Recoupling experiments in SSNMR: Selective and broadband recoupling techniques. Gamma and non-gamma encoded sequences. Homonuclear and heteronuclear recoupling experiments and examples. Polarization transfer experiments in the solid sate, spectral assignment experiments, distance and torsion angle experiments.
- Decoupling experiments in SSNMR: Homonuclear and heteronuclear decoupling experiments, broadband and selective decoupling experiments and examples.

Recommended Reading

- K. Schmidt-Rohr, H. Spiess, *Multi-dimensional Solid-state NMR and Polymers*, 1st Ed, Academic Press, London (1996).
- M. Mehring, *High Resolution NMR of Solids*, 1st Ed, Springer, New York (1975).
- U. Haeberlen, *High Resolution NMR of Solids: Advances in Magnetic Resonances: Supplement I*, 1st Ed, Academic Press, San Diego (1976).
- B. C. Gerstein, C. R. Dybowski, *Transient Techniques in NMR of Solid*, 1st Ed, Academic Press, Orlando (1985).

CHM606: Bio-organic chemistry

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Bio-catalysis, enzyme-catalyzed reactions, principles, application of bio-catalysis in organic synthesis and industry.
- Bio-organic related heterocycles: Synthesis, properties, and application.
- Bio-organic molecules I: (a) Amino acids, (b) Peptides. Synthesis, properties, and application.
- Selected bio-organic molecules II: (a) Nucleosides, (b) Nucleotides. Synthesis, properties, and application.
- Bio-organic molecules III: Carbohydrate molecules and their chemistry.
- Selected name reactions, rearrangements and mechanisms related to bio-organic chemistry.

Recommended Reading

- J. Clayden, N. Greeves, S. Warren, P, Wothers, *Organic Chemistry*, Oxford University Press, New York 2006.
- G. M. Loudon, *Organic Chemistry*, 4th Ed, Oxford University Press, New York (2002).
- J. McMurry, *Organic Chemistry*, 5th Ed, Boroks/Cole (2006).

- H. D. Jakubke, N. Sewald, Peptides from A to Z, Wiley-VCH Verlag GmbH & Co. KgaA (2008).
- R. A. Sheldon, I. W. C. E. Arends, U. Hanefeld, *Green Chemistry and Catalysis*, Wiley-VCH Verlag GmbH & Co. KgaA (2007).
- T. Eicher, S. Hauptmann, A. Speicher, *The Chemistry of Heterocycles*, 2nd Ed, Wiley-VCH Verlag GmbH & Co. KgaA (2003).
- D. Voet, J. Voet, *Principles of Biochemisty*, 3rd Ed, Wiley (2005).

CHM607: Chemical crystallography

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline This course is useful for anyone interested in using X-ray diffractometry. It requires some knowledge in symmetry and algorithms.

- Concepts of symmetry, point groups and space groups; crystal lattices.
- Elements of scattering theory, diffraction principles, reciprocal lattice; crystals and their properties.
- Basics of the diffractometers; X-ray sources; image plate and CCD detectors.
- Single crystal methods; data collection and processing strategies; phase problem in crystallography; Patterson and direct methods.
- Refinement techniques; Molecular structure and crystal structure; intermolecular interactions and applications in solid state.
- Powder diffraction; Rietveld refinement in powder diffraction.
- Basics of electron density analysis from X-ray diffraction.
- Basics of neutron diffraction, electron diffraction, elements of electron microscopy.

Recommended Reading

- C. Giacavazzo, et al. (Editor): *Fundamentals of Crystallography*, 2nd Ed, Oxford University Press, USA (2002).
- G. H. Stout, L. H. Jensen, *X-Ray Structure Determination: A Practical Guide*, 2nd Ed, Wiley-Interscience, New York (1989).
- J. D. Dunitz, *X-Ray Analysis and The Structure of Organic Molecules*, 2nd Ed, Wiley-VCH, New York (1996).
- V. Pecharsky, P. Zavalij, *Fundamentals of Powder Diffraction and Structural Characterization of Materials*, 1st Ed, Springer, New York (2005).

CHM608: Advanced industrial chemistry

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline This course provides a non-traditional course work in chemistry preparing students with practical applied chemistry for numerous items in our day-to-day life. Some historical background for the innovation of products will be discussed. This bridges the gap between (a) the basic research and development, and (b) chemical engineering and chemical marketing. It will cover chemistries from bench top to scale up to manufacturing for a number of essential products in various industries as outlined below:

- Introduction to manufacturing industry with a special emphasis on chemical industry.
- Industrial gases, petrochemicals, detergents, fertilizers, agrochemicals.
- Food preservatives and beverage products.
- Textiles and dyes.
- Cosmetics and perfumes.
- Pharmaceuticals synthesis and production of top prescription drugs.
- Polymers plastics, fibers, nylons, and silicones.
- Chemical industry, pollution prevention and waste management.

Recommended Reading

- C. A. Heaton, *Introduction to Industrial Chemistry*, 3rd Ed, Springer, New York (2009).
- K. H. Bächel and others, *Industrial Inorganic Chemistry*, 3rd Ed, Wiley-VCH, New York (2005).
- K. Weissermel, Hans-Jrgen Arpe, *Industrial Organic Chemistry*, 3rd Ed, Wiley-VCH, New York (2003).

CHM609: Polymer chemistry

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Basic characteristics of polymers, melting point of polymers, glass transition temperature, molecular weight and molecular weight distribution.
- Organic polymers: Synthetic polymers and their syntheses *via* free radical polymerization, polymerization by ionic initiators, Ziegler-Natta type polymerization, atom transfer radical polymerization, ring opening polymerization, olefin metathesis and polymerization, group transfer polymerization, condensation polymerization.
- Inorganic polymers:

    1. Siloxanes and polysiloxanes: conformational flexibility and glass transition temperature, ring opening polymerization of cyclosiloxanes by ionic initiators, and crosslinking of polysiloxanes.

2. Preparation of polysilanes by - Wurtz-type reactions, -catalytic dehydrogenation, and -anionic initiators. Applications of polysilanes, NMR spectra, electronic spectra and optical activity of polysilanes. Polysilynes.
3. Cyclophosphazenes and polyphosphazenes. Cyclophosphazenes containing polymers and their applications. Polyheterophosphazenes (with hetero atom, such as C, B, and S), metallacyclophosphazenes, borazine based polymers.
4. Organometallic polymers: Ferrocene containing polymers, polygermanes and polystannanes.

Recommended Reading

- H. R. Allcock, F. W. Lampe, J. E. Mark, *Comtemporary Polymer Chemistry*, Indian Edition, 3rd Ed, Prentice-Hall, Englewood Cliffs, New Jersy (1980).
- V. Chandrasekhar, *Inorganic and Organometallic Polymers*, Springer (2005).
- I. M. Campbell, *Introduction to Synthetic Polymers*, 2nd Ed, Oxford University Press, New York (2000).

CHM610: Chemistry of natural products

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- This course will deal with the chemistry of important natural product molecules.
- Natural product molecules I: Chemistry of stereoids. Classification, synthesis and application of selected steroids.
- Natural product molecules II: Chemistry of alkaloids. Classification, synthesis and application of selected alkaloids.
- Natural product molecules III: Chemistry of terpenes and terpenoids. Classification, synthesis and application of selected terpenes and terepenoids.
- Natural product molecules IV: Classification and structure of lipids and their biofunctions.
- Natural product molecules V: Chemistry of antibiotics and vitamins. Synthesis and application of selected molecules as drug molelcules.
- Natural product molecules VI: Prostaglandins. Nomenclature and structure elucidation.

Recommended Reading

- J. Clayden, N. Greeves, S. Warren, P, Wothers, *Organic Chemistry*, Oxford University Press, New York (2006).
- J. Mann, J. Harborne, R. S. Davidson, *Natural Products: Their Chemistry and Biological Significance*, Longman (1994).

- I. L. Finar, *Orgnic Chemistry, Vol 1 and 2*, Indian Edition, 6th Ed, Pearson Education Inc, New Delhi (2008).
- G. M. Loudon, *Organic Chemistry*, 4th Ed, Oxford University Press, New York 2002.
- K. C. Nicolaou, T. Montagnon, *Molecules That Changed The World*, 1st Ed, Wiley-VCH, Weinheim, Germany (2008).
- D. Voet, J. Voet, *Principles of Biochemisty*, 3rd Ed, Wiley (2005).

CHM611: Frontiers of organometallic chemistry

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- General introduction, Structure and bonding, 18-electron rule, Wades rule, survey of organometallic complexes.
- Preparation, properties and bonding of metal carbonyl, nitrosyls, tertiary phosphines, hydrides, alkene, alkyne, cyclobutadiene, cyclopentadiene, arene compounds and their molecular orbital diagrams.
- Preparation and applications of organomagnesium compounds, organolithium compounds, organocopper reagents, organozinc compounds, organolead compounds, organoaluminum compounds, organosilanes and organoboranes towards organic tranformations.
- Metal-carbon multiple bonds; carbene and carbyne complexes including *N*-heterocyclic carbene complexes.
- Metal-metal bonded organometallic clusters.
- Fluxional organometallic compounds including allyl complexes and their characterization.
- Metallocycles, unsaturated nitrogen ligands including dinitrogen complexes.

Recommended Reading

- J. P. Collman, L. S. Hegedus, J. R. Norton (Author), R. G. Finke : *Principles and Applications of Organotransition Metal Chemistry*, 1st Ed, University Science Books, California (1987).
- D. Astruc: *Organometallic Chemistry and Catalysis*, 1st Ed, Springer, Berlin (2007).
- R. H. Crabtree: *The Organometallic Chemistry of The Transition Metals*, 4th Ed, Wiley, New Jersy (2005).

CHM612: Asymmetric synthesis and catalysis

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Asymmetric reductions and oxidations: Enantioselective hydrogenation of olefins and imines, asymmetric reduction of ketones and transfer hydrogenation. Enantioselective epoxidation of allylic alcohols and unactivated olefins, aziridination of olefins, oxidation of sulfides, dihydroxylation and aminohydroxylation of olefins. Industrial applications of asymmetric oxidation and reduction reactions.
- Asymmetric C-C bond forming reactions: Asymmetric aldol reactions, cyclo-addition reactions, Michael reactions, allylic substitution reactions, cyanation of carbonyl and imino groups, cross coupling reactions and symmetric amplifications. Industrial applications of asymmetric C-C bond forming reactions.
- Asymmetric organocatalysis: L-Proline and its derivatives catalyzed or mediated asymmetric transformations, chiral N-heterocyclic carbenes (NHCs) catalyzed organic transformations, chiral bases and asymmetric phase transfer catalysis. Large scale applications of organocatalysis.
- Kinetic and enzymatic resolutions: Kinetic resolution of alcohols, amines and acids. Enzymatic resolution of esters, aminoacid derivatives etc. Applications of biocatalysis in industry.

Recommended Reading

- I. Ojima, *Catalytic asymmetric synthesis*, 2nd Ed, John Wiley & Sons Inc. (2000).
- E. N. Jacobson, A. Pfaltz, Yamamoto, Y. (Editors), *Comprehensive asymmetric catalysis I - III*, Springer-Verlag, New York (1999).
- A. Berkessel, H. Groger, *Asymmetric Organocatalysis: From Biomimetic Concepts to Applications in Asymmetric Synthesis*, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim (2005).

CHM613: Supramolecular chemistry

[Cr:4, Lc:3, Tt:2, Lb:1]

Course Outline

- Terminologies and nomenclature in supramolecular chemistry. Chemical interactions leading to supramolecular assemblies.
- Molecular recognition and host-guest complementarity. Concept of molecular receptors and design principles including cryptands. Cation and anion receptors and coordination and inverse coordination.
- Transport processes and carrier design based on cation and anion carriers. Electron coupled transport in a redox gradient and proton coupled transport in a pH gradient.

- Molecular machines, molecular and supramolecular devices. Supramolecular photochemistry and photonic devices. Non-linear optical properties of supramolecular species. Molecular wires and rectifying devices. Ion responsive monolayers. Bouquet-type molecules and Chundle approach. Molecular protonics. Photoswitching devices and electroswitching devices. Logic devices.
- Supramolecular chirality and self-assembly. Self-assembly of organic motifs, self-assembly by hydrogen bonding. Supramolecular materials and nanochemistry.

Recommended Reading

- J. M. Lehn, *Supramolecular Chemistry: Concepts and Perspectives*, Wiley VCH, Weinheim (1995).
- V. Balzani (Editor), L. De Cola, *Supramolecular Chemistry*, Kluwer, Dordrecht (1992).
- H. Dodziuk, *Introduction to Supramolecular Chemistry*, Kluwer Academic Publishers, The Netherlands (2002).
- Y. Murakami (Editor), *Supramolecular Assemblies*, Mita Press, Tokyo, (1990).
- G. W. Gokel (Editor), *Advances in Supramolecular Chemistry, Vol 1 (1990), Vol 2 (1992), Vol 3 (1993)*, JAI Press, Greenwich.

CHM615: Kinetics and dynamics of chemical reactions

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Reaction rates, rate laws and mechanism
- Experimental methods
- Reaction Rate theories
- Unimolecular reactions and RRK and RRKM theories
- Potential energy surfaces
- Molecular reaction dynamics
- Interaction of light with matter: atomic, molecular and chemical lasers
- Optical control of chemical reactions

Recommended Reading

- J. I. Steinfeld, J. S. Francisco and W. L. Hase, *Chemical Kinetics and Dynamics*, 2nd edition, Prentice Hall, NJ, (1999).
- R. D. Levine and R. B. Bernstein, *Molecular Reaction Dynamics*, Oxford Univ. Press, New York, (1974).
- R. B. Bernstein, *Chemical Dynamics via Molecular Beam and Laser Techniques*, Oxford University Press, New York, (1982).
- A. H. Zewail, *The Chemical Bond: Structure and Dynamics*, Academic Press, San Diego, (1992).

CHM616: Computational chemistry

[Cr:4, Lc:3, Tt:0, Lb:1]

Course Outline

- Computational models and algorithms; Scaling of resources vs system size.
- Born-Oppenheimer approximation and concept of molecular geometry; Molecular Hamiltonian; Potential energy surfaces (PES) and their features; Transition states and reaction paths; Specification and optimization of geometries on ground state PES.
- The Hartree-Fock (HF) method; LCAO approach; Gaussian basis sets; Commonly used basis sets; The HF limit; Koopman's theorem; Population analysis; HF methods for open-shell molecules.
- Electron correlation and its importance; Dynamical electron correlation in ground states; Second-quantization representation; Moller-plesset perturbation and Configuraton Interaction methods; Size-extensivity and Size-consistency; Coupled-cluster methods; The CCSD(T) method; Computational scaling, basis-set convergence issues and possible remedies.
- Molecular properties and analytic gradients; Vibrational frequencies and gas-phase thermochemistry; Intermolecular interactions.
- Nature of excited states and problems with their computational treatment; Singly-excited states; Configuraton Interaction singles and Equation-of-Motion methods; Near- degeneracies and non-dynamical electron correlation; multi-reference methods.
- Density Functional Theory (DFT); Hohenberg-Kohn theorems and Kohn-Sham approach; Different types of exchange-correlation functionals; Comparison to HF method; Pure vs. hybrid functionals; Time-dependent DFT for excited states; Advantages and disadvantages of DFT.
- Solvent effects; Explicit and continuum solvation models; Self-consistent reaction-field and polarizable continuum models
- Semi-empirical and Molecular Mechanics (MM) methods; Components of Force-Field (FF) potential energy and their parameterization; Polarizable FFs.

- Simulating an assembly of molecules; Equilibrium properties as time and ensemble averages; Molecuar Dynamics and Monte-Carlo simulations; Combined QM/MM methods.

Recommended Reading

- C. J. Cramer, *Essentials of Computational Chemistry: Theories and Models*, 2nd Ed., Wiley 2004
- F. Jensen, *Introduction to Computational Chemistry*, 2nd Ed., Wiley 2006
- A. Szabo, and N. S. Ostlund, *Modern Quantum Chemistry*, Dover, 1999
- A. Hinchliffe, *Modelling Molecular Structures*, 2nd Ed., Wiley 2000
- A. Leach, *Molecular Modelling: Principles and Applications*, 2nd Ed., Pearson 2009

CHM617: Chemical dynamics and non-adiabatic interactions

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- The Born-Oppenheimer Approach - The Time Independent Framework: (a) The Adiabatic Representation; (b) The Diabatic Representation
- Mathematical Introduction: (a) The Hilbert Space and the Curl-Div Equations; (b) First Order Differential Equations along contours; (c) Abelian and non-Abelian Systems.
- The Adiabatic-Diabatic Transformation (ADT). On the Single-valuedness of the newly formed Diabatic Potentials and the Quantization of the Born-Oppenheimer (BO) non- adiabatic coupling (NAC) matrix.
- Singularities, Poles and Seams characterizing the BO-NAC terms.
- Molecular Fields as formed by Lorentz Wave-Equations.
- The Jahn-Teller Model, The Renner-Teller model, the mixed Jahn-Teller/Renner-Teller model. The Privileged ADT phase and the corresponding Topological (Berry/Longuet- Higgins) phase.
- The Extended Born-Oppenheimer Equation including Symmetry
- The Born-Oppenheimer Approach - The Time Dependent Framework (emphasizing Field-dependent non-Adiabatic Coupling terms).
- The interaction between molecular systems and electromagnetic fields: (a) The Classical treatment of the field (b) The Quantum treatment of the Field (based on Fock states).
- If time allows various subjects related to Quantum Reactive Scattering Theory will be introduced. Among other things the concept of arrangement channels and decoupling of arrangement channels employing Absorbing Boundary conditions will be discussed.

Recommended Reading

- M. Baer and C-Y. Ng, (eds), *State-Selected and State-to-State Ion-Molecule Reaction Dynamics*. Ser. Advances of Chemical Physics, Vol. 82, Part 2, John Wiley, Hoboken, N.J. (1992)
- M. Baer and G.D. Billing (eds), *The Role of Degenerate States in Chemistry*, Ser. Advances of Chemical Physics, Vol. 124; John Wiley, Hoboken, N.J. (2002)
- W. Domcke, D.R. Yarkony and H. Koeppel, *Conical Intersections*, Advances Series In Physical Chemistry Vol. 15 (World Scientific, Hong-Kong (2004).
- Farad. *Discussions, Non-Adiabatic Effects in Chemical Dynamics*, Vol. 127 (R.S.C.), University Oxford, (2004)
- M. Baer, *Beyond Born-Oppenheimer: Electronic Nonadiabatic Coupling Terms and Conical Intersections*, Wiley Interscience, Hoboken, N.J., (2006).

Suggested Reading

- G. C. Schatz and M. A. Ratner, *Quantum Mechanics in Chemistry*, Prentice-Hall, Englwood Cliffs (1993)
- J. D. Jackson, *Classical Electrodynamics*, 2nd Edition, John Wiley, New York (1975)
- J. Z. H. Zhang, *Theory and Application of Quantum Molecular Dynamics*, World Scientific, Hong-Kong (1999)

CHM618: Bioinorganic chemistry

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Metal ions in biology; Active-site structure and function of metallo-proteins and enzymes with Mg, Ca, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Mo and W ions.
- Heme and Nonheme systems with mono-, di- and multinuclear metal centers, such as Fe: Hb, Mb, Hr, P-450, MMO, ferridoxins, Fe-S clusters; Cu: hemocyanin, hemerythrin; Mn: SOD, Catalase; Co: vitamin B12; Zn: CPA, CA; Ni: urease. Metal environments (ligand type, coordination, geometry), electronic, magnetic and redox properties.
- Some biological processes, such as electron transfer, oxygen-binding, reduction of oxygen to peroxide and superoxide species; their utilization in hydroxylation and epoxidation.
- Further discussions on Nitrogenase and Oxygen Evolving Center in Photosystem II.

Recommended Reading

- S. J. Lippard, J. M. Berg, *Principles of Bioinorganic Chemistry.* 1st Ed, University Science Books, California, 1994.
- H. B. Gray, E. I. Stiefel, J. S. Valentine, I. Bertini, *Biological Inorganic Chemistry: Structure and Reactivity*, 1st Ed, University Science Books, California, 2006.
- L. Que (Editor), *Physical Methods in Bioinorganic Chemistry: Spectroscopy and Magnetism*, 1st Ed, University Science Books, California, 2000.

Suggested Reading

- R. H. Holm, E. I. Solomon (Guest Editors), Chemical Review, 1996, 96(7), 2237-3031. *Special Issue on Bioinorganic Enzymology.*
- R. H. Holm, E. I. Solomon (Guest Editors), Chemical Review, 2004, 104(2), 347-1200. *Special issue on Biomimetic Inorgnaic Chemistry.*

CHM619: Numerical methods in chemistry

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Significant digits, precision, accuracy, number representation, errors (roundoff errors, experimental errors, truncation, error propagation).
- Introduction to numerical libraries,Fortran, Matlab and Mathematica.
- Linear algebra: Matrices and determinants, eigenvalues and eigenvectors, simultaneous equations (Gauss elimination, LU factorization), diagonalization methods (Jacobi, Hausholder and Davidson), matrix exponential. (Connectivity matrices, Hckel matrices, charge density bond order matrix, Normal modes of polyatomic molecules, standard orientations of molecules, Orthogonalization of nonorthogonal basis sets, Rotation matrices, Euler angles, symmetry operations of point groups, coordinate transformations).
- Numerical interpolation and extrapolation,splines, 2D plotting. (The problems will be chosen from experimental data, involving spectra, potential energy curves of diatomic molecules, heat capacities of etc.)
- Numerical differentiation and integration. (Integration of spectra.)
- Infinite series, power series, convergence, LHospitals rule.
- Complex numbers.
- Vector analysis and multivariate calculus, plotting in 3D.
- Calculus of variations and optimization methods. (Least squares fitting, nonlinear least squares optimization).
- Fourier transform and fast Fourier transform methods, convolution. (analysis of spectral data).

- Differential equations: First-Order ODE, Second-Order Linear ODEs,Higher Order Linear ODEs,Systems of ODEs,Phase Plane, Series Solutions of ODEs, Special Functions,Laplace Transforms. (Kinetics of chemical reactions, diffusion equation).
- Difference methods, discrete variable representation (DVR). (Vibrational and rovibrational states of diatomic molecules from a numerical potential) Probability and statistics.

Recommended Reading

- Erwin Kreyzig, *Advanced Engineering Mathematics*
- Numerical Recipes in Fortran 90 (second edition)., *Numerical Recipes in C*
- Mary L. Boas, *Mathematical Methods In the Physical sciences*
- M. P. Hobson & K. F. Riley, *Essential Mathematical Methods for the Physical Sciences*
- George B. Arfken, Hans J. Weber & Frank E. Harris, *Mathematical methods for physicists*

CHM620: Energetics and dynamics of chemical reactions-2

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Thermodynamics: Review of classical thermodynamics (CHM202), Equilibrium in non-electrolyte solution, Equilibrium in electrolyte solution: Debye-Huckle theory, Onsager limiting law, NernstSimon theorem (third law of thermodynamics).
- Electrochemical phenomena: Types of electrochemical cells, Standard electrode potential, Nernst equation, Liquid junction potential, Electrical polarization: Dipole moment and Electrical double-layer, Colloids: Lyophobic and lyophilic colloids, Electrokinetic phenomena, Sedimentation, Flocculation and coagulation (Introduction to DLVO theory), Stability of colloids, Light scattering.
- Surface/Interface phenomena: Surface energy and surface tension, Capillary action, Gibbs adsorption isotherm, Physisorption and Chemisorption, Langmuir adsorption isotherm, Langmuir-Blodgett technique, Surface films and Langmuir balance, Multilayer adsorption (BET isotherm), Introduction to mesophase: Micelles, Biological membranes & Liquid crystals, Surfactants: Critical micellar concentration, Introduction to Rheology.
- Transport phenomena: Review of kinetic theory of gases, Mean free path, Viscosity, Diffusion (Ficks laws), Introduction to electrical conductivity.
- Reaction kinetics: Review of basic concepts in chemical kinetics (CHM202), Kinetic measurements, Reaction mechanism, Introduction to Atmospheric chemistry.

- Reaction dynamics: Collision theory, Introduction to potential energy surface, Transition state theory, Unimolecular reactions (Lindemann-Christiansen model (Introductory discussion on Hinshelwood and RRK/RRKM models).

Recommended Reading

- Gilbert W. Castellan, *Physical Chemistry*, 3rd Ed, Narosa, New Delhi (2002).
- Ira N. Levine, *Physical Chemistry*, 6th Ed, McGraw-Hill, New York, 2009.
- Herbert B. Callen, *Thermodynamics and an Introduction to Thermostatistics*, 1st Ed, John Wiley & Sons (1985).
- D. A. McQuarrie, J. D. Simon, *Physical Chemistry: A Molecular Approach*, 1st Ed, University Science Books, California (1997).
- P. Atkins, J de Paula, *Physical Chemistry*, 8th Ed, Oxford University Press, New Delhi (2006).

CHM621: Advances in X-ray crystallography and its applications

[Cr:4, Lc:3, Tt:0, Lb:1]

Course Outline This course covers advanced topics in X-ray crystallography emphasizing the modern methods of structure determination and refinement, handling of X-ay diffraction data for charge density analysis, basics of experimental and theoretical charge density analysis, using the packages for charge density analysis (theoretical and experimental). The aspects of crystal growth, polymorphism, intermolecular interactions, multi-component crystals, in situ crystallization, crystal engineering, synthon approach, MOF and COF etc. will be covered under Crystal Engineering.

- Basics of X-ray crystallography (recap): Crystallographic symmetry, point groups and space groups, Braggs law for X-day diffraction, data collection, data processing, structure solution and refinement, fixing of H atom and structure completion.
- Scope of structure analysis from routine data and need for high resolution X-ray crystallography Introduction to experimental charge density study, breakdown of independent atom model, improved scattering model, Kappa formalism, multipole refinement methods, residual density, deformation density.
- Topological analysis of charge density data.
- Data collection and data processing strategies for charge density analysis through hands-on using a diffractometer.
- Introduction to XD and MoPro packages for experimental charge density analysis.
- Introduction to Crystal14 theoretical charge density analysis.

- Introduction to Crystal Engineering, organic solid state chemistry, modern aspects of crystal engineering.
- Intermolecular interactions and their applications in designing desired crystalline supramolecular architecture.
- Polymorphism, origin and thermodynamics of polymorphism, properties and applications of polymorphs.
- Multi-component crystals, pharmaceutical and non-pharmaceutical co-crystals, their importance and applications.
- Metal-organic framework and covalent-organic framework materials and their applications Quasicrystals.
- Introduction to macromolecular crystallography: Basics, choice of radiation, MIR, SAD and MAD phasing in protein crystallography, structure refinement.

Recommended Reading

- G. H. Stout and L. H. Jensen, *X-ray Structure Determination A Practical Guide*, 2^{nd} Ed, Wiley Interscience, 1989.
- C. Hammond, *The Basics of Crystallography and Diffraction*, IUCr Texts on Crystallography 12, 3^{rd} Ed, Oxford Science Publications.
- P. Müller et. al., Ed. By P. Müller, *Crystal Structure Refinement A Crystallographers Guide to SHELXL*, IUCr Texts on Crystallography, Oxford Science Publications.
- P. Coppens, *X-ray Charge Densities and Chemical Bonding*, IUCr Texts on Crystallography 4, Oxford Science Publications.
- G. R. Desiraju, *Crystal Engineering: A Textbook*, World Scientific, 2011.
- J. Bernstein, *Polymorphism in Molecular Crystals*, IUCr Monograph on Crystallography 14, Oxford Science Publications.
- Jan Drenth, *Principles of Protein X-Ray Crystallography*, Springer; 3rd ed. 2007.

CHM622: Chemistry, energy and environment

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Energy classifications, global and national energy scenario;
- Scope of chemistry and material design in energy harvesting and environmental remediation, renewable energy sources: advantages and challenges;
- Solar energy: fundamentals of photovoltaic conversions, types and design of solar cells;

- Hydrogen energy: scope, and status; H_2 production and storage;
- Principles of artificial photosynthesis and photocatalytic water splitting; electronic band structure engineering and characterization of carrier dynamics for these applications;
- Photoelectrochemical and thermal water splitting,
- Introduction to the principles of fuel cells, their types and material design; electrochemistry, kinetics and thermodynamics of fuel cell;
- Biofuel: chemical conversion processes;
- Energy storage strategies: batteries and supercapacitors;
- Thermoelectrics fundamentals and material design;
- Introduction to nuclear energy and its scope in India;
- Green house effect and global warming; principles of CO_2 capture, storage and conversion.

Recommended Reading

- B. E. Conway, *Electrochemical Supercapacitors: Fundamentals and Applications*, (Kluwer) 1999.
- R. M. Dell, *Understanding Batteries/*, D. A. J. Rand (RSC), 2003.
- Sammes Nigel, *Fuel Cell Technology*,(Springer) 2006.
- Godfrey Boyle, *Renewable energy*, (Oxford University Press) 2004.
- Ying Wu, *Carbon Dioxide Sequestration and Related Technologies*, (Wiley) 2011.
- Wang, Xiaodong, *High-efficiency solar cells: physics, materials and devices*, (Springer) 2014.

CHM623: Concepts in nanomaterials and chemical applications

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Nanomaterials: 0D, 1D and 2D nanocrystals, multi-component nanocrystals (core-shell and hetero-nanostructures, nanocomposites). Size dependent electronic and optical properties of nanomaterials, properties of core-shell nanocrystals;
- Size dependent mechanical and thermal properties of nanomaterials; nanoscale magnetic properties;
- Metallic vs. semiconducting nanomaterials; phase transformations in nanoparticles.

- Key synthetic strategies: top down and bottom up approach, synthesis of carbon nanomaterials, intrinsic and induced shape anisotropy, examples of important growth mechanisms such as exfoliation, Ostwald ripening, oriented attachment, VLS growth mechanism, vapour solid growth mechanism etc.
- Characterization techniques: nanoscale diffraction and scattering based techniques (electron and X-ray diffraction, small angle X-ray and dynamic light scattering), transmission and scanning electron microscopy: instrument design, working principle, chemical analysis using electron microscopy: EDS and EELS, energy filtered TEM, electron tomography;
- Atomic force and scanning tunnelling microscopy, nanointendation.
- Reactivity of metal and inorganic nanocrystals, applications of nanomaterials in chemical analysis: surface enhanced Raman spectroscopy, nanomaterials for chemical sensing; radical scavenging, antibacterial properties of nanomaterials; nanomaterials for photocatalysis and electrocatalysis applications; heterogenous catalysis; strategies for renewable energy harvesting and removal of pollutants by using nanomaterials; nanohazards.

Recommended Reading

- Dieter Vollath, *Nanomaterials: An Introduction to Synthesis, Properties and Applications*, 2nd Edition, ISBN: 978-3-527-33379-0
- C. N. R. Rao (Editor), Achim Muller (Editor), Anthony K. Cheetham (Editor), *The Chemistry of Nanomaterials: Synthesis, Properties and Applications*, 2 Volumes, ISBN: 978-3-527-30686-2
- Nanomaterials and Nanochemitry: C. Brchignac, P. Houdy, M. Lahmani, Springer Science & Business Media

CHM624: Soft matter, colloids and interfacial phenomena

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Definition of soft matter; self-assembly and the key interaction mechanisms.
- Principles of Colloids and Interface Science: Viscosity, Diffusion, Brownian motion, Forces between colloidal particles, Sedimentation, Surface tension, Contact angle, Adsorption, Association colloids, Particle interactions, Electro-kinetics, Electrostatics and colloidal stability, Glass formation, Jamming & gelation, Percolation.
- Complex fluids: Liquid Crystals, Structures and physical properties, Order parameter, Defects, Effect of confinement, Textures of phases with orientation & partial translational order, Dynamics of phase transitions. Self-assembly of polymeric soft matter, Gels, Liquid crystal gels, Surface patterning of gels, Functional polyelectrolytes, Reactive polymers, Biological soft matter, Nucleic acids & their self- assembled structures.

- Surfactants and Amphiphiles: Self-assembly; Phase behaviour; Lyotropic liquid crystals, Formation and properties of micelles, cylinders, bilayers, vesicles and tubules, Langmuir films, Micro-emulsions, Foams, Microfluidics, Membranes.
- Instrumentation and characterization techniques: Polarizing light microscopy, Dynamic light & X-ray scattering, Rheology & Probe microscopy, Optical tweezers.
- Applications in Technology: Liquid crystals in display technology, Chemical & biological sensing, Reverse micelles in transport catalysis and others.

Recommended Reading

- P. C. Hiemenz and R. Rajagopalan, *Principles of Colloid and Surface Chemistry*, 3rd edition, Marcel-Dekker, New York (1997).
- Linda S. Hirst *Fundamentals of Soft Matter Science*, CRC Press (2012).
- Peter Collings and M. Hird,I*Introduction to Liquid Crystals: Chemistry and Physics*,Taylor and Francis Ltd. (1997).

CHM625: Molecular dynamics simulations

[Cr:4, Lc:3, Tt:0, Lb:1]

Course Outline

Theory:

- Foundations of Molecular mechanics and Classical description of molecules.
- Potential Energy surfaces and optimization methods.
- Potentials for bonded and non-bonded interactions: classical and polarizable forcefields.
- Tackling electrostatics and long-range interactions.
- Monte carlo simulations.
- Statistical mechanics application to macroscopic ensembles.
- Algorithms to integrate equations of motion with use of thermostats and barostats.
- Measuring thermodynamic, structural and dynamical properties of equilibrium systems: transport coefficients; space-dependent and time-dependent correlation coefficients.
- Advanced practices of MD:
  - Coarse-grained models for molecule description.
  - Free energy calculations: alchemical transformation, Thermodynamic Integration methods.

- Enhanced sampling techniques: Umbrella sampling, Steered MD, Targeted MD, replica.
- exchange sampling.
- Metadynamics and Adaptive biasing forces (ABF).
- Extending to QM-MM hybrid simulation and first principle ab-initio simulation.

Lab:

- Familiarity with basic LINUX commands.
- Setting up and running conventional MD simulation with different ensembles and barostats.
- Analysis of trajectories.
- Setting up and running free energy calculations via perturbation methods.
- Analyzing the FEP results.
- Setting up and running enhanced MD simulations eg Steered MD, umbrella sampling, ABF simulations.
- Setting up and running small QM-MM and Ab-initio simulations.
- MD Softwares: NAMD, CPMD, AMBER, CHARMM, MMTSB.
- Visualization Softwares: VMD, Pymol.
- lotting Softwares: Gnuplot, R.

Recommended Reading

- M. P. Allen and D. J. Tildesley, *Computer Simulations of Liquids*, Oxford Clarendon Press (1989).
- A. R. Leach, *Molecular Modelling, Principles and Applications*, 2nd edition, Pearson Education Ltd. UK (2001).
- D. Frenkel and B. Smit, *Understanding Molecular Simulation: From Algorithms to Applications*, 2nd edition, Academic Press UK (2001).
- D. C. Rapaport, *The Art of Molecular Dynamics Simulations*, 2nd edition,Cambridge University UK (2004).
- T. Schlick, *Molecular Modeling and Simulations. An Interdisciplinary Guide*, 2nd edition, Springer Verlag, New York (2010).

CHM626: Photochemistry - concepts, techniques and applications

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Fundamentals of Photochemistry: Introduction to photochemistry, Photophysical and photochemical Processes, Internal Conversion, Intersystem Crossing, El Sayed rules, Quantum Yield, Kasha and Vavilov rules, Kashas Exciton models: H and J molecular aggregates, selection rules, optical properties, Excimer and exciplexes, Photophysics of aromatics, Terms and definitions associated with photochemistry.

- Conceptual and Theoretical Aspects: Energy transfer (Forster and Dexter), Electron transfer, Proton transfer, Twisted intramolecular charge transfer (TICT), Aggregate induced emission (AIE), Thermally activated delayed fluorescence (TADF), upconversion, triplet-triplet annihilation, phosphorescence, Chemiluminescence and bioluminescence, Sensitization and quenching, Stern-Volmer analysis, Chemistry of excited molecules and photochemical intermediates, Radical ions, Radical pairs, Biradicals, Predicting ground state spin multiplicity, Classification of photochemical pathways, State energy diagrams, Correlation diagrams, Diabatic and Adiabatic reactions, Concerted and non-concerted photochemical reactions, Mechanistic aspects in photochemical reactions, Potential energy surfaces, Hot reactions, Conical intersections, Excitations in metals and semiconductors, Frenkel and Wannier-mot excitons, Photophysics of quantum dots and metal nanoparticles.

- Techniques: Light Sources, Filters, Detectors, LASERs, Steady state photolysis, Photoreactors, Flow reactors, Flash photolysis and time resolved spectroscopic techniques, Organic glasses and low temperature trapping techniques, Pump-probe techniques, Two photon and single molecular spectroscopy, Quantum yield determination using different techniques (Relative methods and absolute method, Solution phase and solid phase), Actinometers.

- Light in Organic Chemistry: Photoisomerization , Photodissociation, Rearrangement, Photooxidation reactions, Photochromism, Photochemical reactions and asymmetric synthesis, Photocatalysis, Photoremovable protecting groups in chemistry and biology, Photoredox chemistry and its application in organic synthesis, Photochemistry in cages or confined area, medium, Photochemistry of biomolecules, Photochemistry in atmosphere.

- Applications: Photoswitchable functional materials and molecular machines, Photoaffinity labeling, Photodynamic therapy, Phototherapy, Photochemotherapy, Phototoxicity, Organic light emitting diodes (OLED) (link to concepts of Phosphorescence, upconversion, AIE), Organic photovoltaics (link to concept of photoinduced electron transfer), Artificial photosynthesis (link to concept of PET and EET), Artificial photosynthesis, Photoconductivity, Photolithography and UV curing.

Recommended Reading

- Petr Klán, Jacob Wirz, Wiley, *Photochemistry of organic compounds: From Concepts to Practice*, 2009.

- Nicholas J. Turro, V. Ramamurthy, Juan Sciano,Casebound, *Modern Molecular Photochemistry of Organic Molecules*, 2010.

- Martin Klessinger, Josef Michl, *Excited States and Photochemistry of Organic Molecules*, VCH, 1st Edition, 1995.
- Joseph R. Lakowicz, Springer, *Principles of Fluorescence Spectroscopy*, Third Edition, 2006.
- B. Wieb Van Der Meer, George Coker, S. Y. Simon Chen, *Resonance Energy Transfer: Theory and Data*, VCH Publishers, 1994.

Suggested Reading

- Axel Griesbeck, Michael Oelgemöller, Francesco Ghetti, *CRC Handbook of Organic Photochemistry and Photobiology*, Two volumes, CRC Press, 2012.
- John B. Birks, *Photophysics of Aromatic Molecules*, Wiley monographs in chemical physics, 1970.
- Charles Kittel, *Introduction to Solid State Physics*, 8th Edition, John Wiley and Sons, 2005.
- Bernard Valeur *Molecular Fluorescence: Principles and Applications*, 2nd Edition, Mario Nuno Berberan-Santos, Wiley-VCH, 2002.
- Vincenzo Balzani, Paola Ceroni, Alberto Juris,*Photochemistry and Photophysics: Concepts, Research, Applications*, Wiley-VCH, 2014.

4.3 Earth and Environmental Sciences

EES301: Sedimentology and concepts in Stratigraphy

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Development of Concepts in Sedimentology; The context of sedimentology; Weathering; erosion; transportation; Sedimentation in the backdrop of the interaction of plate tectonics and hydrological cycle; Soil formation and sediment production; regolith; chemical index of alteration.
- Textural Properties of Sediments and Sedimentary Rock; Grain Size and scale; grain size distributions; Porosity and permeability; Grain orientation and fabric.
- Fluid Flow and Sediment Transport: Fluid gravity flows Classification; velocity distribution in turbulent flows; Sediment transport under unidirectional flows; Hjulstroms diagram; Shields criterion; Bedforms and structures under unidirectional flow Flow regime concept; bedform stability diagrams.
- Primary structures and their directional significance; biogenic sedimentary structures - Stromatolites and Ichnofossils; Penecontemporaneous Deformation Structures (PCD).
- Depositional Sedimentary Environments; Classification; methods and data integration for environmental reconstruction - vertical facies associations.

- Facies: Walthers Law of correlation of sedimentary facies; migration of facies tracts; Facies models and interpretation of depositional environments.
- Terrigenous Clastic Sediments; Sediment connectivity and transport systems; compositional versus textural maturity of sediments; Sedimentology of mudstones.
- Carbonate Rocks; Importance of limestone; carbonate continuum and carbonate minerals; carbonate geochemistry; controls on carbonate deposition; Carbonate sediment factories; bio- and organo-mineralisation; warm and cool water carbonates; pelagic carbonates; reefs and build-ups; Carbonate diagenesis.
- Biogenic Sedimentary Rocks; Chert and siliceous sediment; phosphates; and organic-rich sediments; Chemical and non-epiclastic sedimentary rocks Iron-rich sedimentary rocks and evaporates; Volcanoclastic sedimentary rocks fragmentation; eruption column characteristics non-genetic classification of pyroclastic rocks.
- Siliciclastic Diagenesis: Compaction and cementation; Authigenesis; recrystallization and replacement; Diagenesis and porosity.
- Tectonics of Sedimentary Basins; Basin classification intraplate (pre- and post- rift); Divergent and convergent margin basins; collision and post collision basins; strike slip basins; mechanisms of basin formation; the uniform stretching model.
- Concepts in Lithostratigraphy and Biostratigraphy; Index fossils; FAD/LAD; bio stratigraphic zonation and correlation; time significance of biostratigraphic events; Geophysical and chemostratigraphic correlation - well logging; seismic stratigraphy; chemostratigraphy; Magnetostratigraphy and Geochronology: Principles of magnetostratigraphy and development of GPTS (Global Polarity Time Scale); Geochronological techniques applied to the Quaternary and pre- Quaternary record.

Recommended Reading

- *Principles of Sedimentology and Stratigraphy*, 3rd edition, Boggs (2000)
- D. R. Prothero, F. L. Schwab, *Sedimentary geology: an introduction to sedimentary rocks and stratigraphy*, London: W. H. Freeman, 2004
- G. Nichols, *Sedimentology and Stratigraphy*, 2nd Edition, Wiley-Blackwell, 2009

EES401: Quantitative data analysis in earth and environmental sciences

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Data types binary data (absence present data), integer data (abundance data), univariate and multivariate measurement data, geospatially data, time series data, spatio-temporal data.
- Uncertainty and error propagation.
- Univariate Data analysis: Descriptive statistics (Mean, Variance, Standard deviation), Robust statistics (Median, Quarter values, Median Median Deviation), Skewness, Kurtosis.
- Testing datasets for normality (Shapiro-Wilk test, Jarque-Bera test, Chi-square test, Anderson-Darling test).
- Statistical tests for normal distributed datasets (F test, t-test, Welch test), Tests for paired data (t, sign, Wilcoxon), tests for equal coefficient of variation.
- Statistical tests for environmental datasets that are not normal distributed (Mann-Whitney test and Friedman test for equality of median, Kolmogorov-Smirnov for equal distribution.
- Multivariate Data analysis: ANOVA and Kruskal-Wallis test, Levene's test for homogeneity of variance, unequalvariance (Welch) version of ANOVA, ANCOVA (Analysis of covariance), ANOSIM (Analysis of Similarity), Principle Component Analysis, Principle Coordinate Analysis, Positive Matrix Factorisation, Chemical Mass Balance Modelling, Correspondence Analysis, detrended correspondence analysis, canonical correspondence analysis, Cluster Analysis, Regression analysis (Linear, Polynomial, Sinosoidal).
- Diversity indices, taxonomic distinctness, diversity t-test, SHE analysis, diversity curves, spindle diagram.
- Seriation, Unitary Associations, Appearance event ordination.
- Time series analysis, spectral analysis, autocorrelation, cross correlation, autoassociation, wavelet transform, diel and seasonal cycles, Intervention analysis, trend analysis of cyclic data.
- Analysis of Geospatial data, Direction data, polar plots, rose plots, nearest neighbour point pattern, spatial autocorrelation and spatial interpolation, splines and warps.
- Receptor modelling in atmospheric sciences: back trajectory analysis, conditional probability and concentration weighted trajectories, wind roses and pollution roses.
- Spatio-temporal data: polar annulus plots.

Recommended Reading

- Ronald E. Walpole and Raymond H. Myers, *Probability and Statistics for Engineers and Scientists (9th Edition).*
- Hammer, O. & D. Harper. 2006. *Paleontological Data Analysis* Wiley.

- Software tools
  - PAST
  - R
  - Openair
  - PanMap

EES402: Geomorphology and earth surface processes

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction to Geomorphology; types of geomorphic studies, models and systems; materials and geomorphic processes.
- Process, landforms and landscape: Weathering and paedogenesis, Hill slopes, Fluvial, Glacial, Periglacial, Aeolian, Coastal, Karst, and volcanic landforms.
- Tools in Geomorphology: Surficial geologic tools, dating of landforms; remote sensing and GIS, analysis of channel form, geomorphic indices and longitudinal profile analysis.
- Quaternary landform evolution - Geomorphic markers, estimation of erosion and uplift rates, climate-tectonic coupling and deconvolutions.

Recommended Reading *(Additional material may be suggested during the course)*

- Hugget R. J., *Fundamentals of Geomorphology*, Routledge Fundamentals of Physical Geography Series, 2nd Edition, 2007.
- Kale V. and Gupta A.,*Introduction to Geomorphology*, Orient BlackSwan, 2001.
- Kondolf, G. M. and Pigay H., *Tools in fluvial Geomorphology*, Wiley. 2003.
- Anderson D. W. and Anderson, R. S., *Tectonic Geomorphology*, Blackwell Science, 2008.
- W. D. Thornbury, *Principles of Geomorphology*, 2nd edition, CBS, 2004.

EES403: Remote sensing and GIS

[Cr:4, Lc:2, Tt:1, Lb:1]

Course Outline

Remote Sensing

- Concepts and foundation: Electromagnetic radiation principles, Energy-atmosphere-terrain interactions, data acquisition, interpretation, and referencing.
- Earth observation; Aerial platforms and sensors, aerial photography, photogrammatery.
- Fundamentals of visual interpretation.
- Multi-spectral, thermal and hydperspectral systems: basic concepts, analyses and interpretation of the imageries.
- Active and passive microwave remote sensing; LIDAR.

Geographic Information System (GIS)

- Introduction to GIS.
- Maps and GIS.
- Spatial data, models, data quality assessment.
- Raster and Vector data processing in GIS.
- Digital Terrain modelling, spatial analyses.
  Practical:

  Image interpretation and application of remote sensing and GIS in vegetaion, water, geomorphology, geology, hazards and landuse/cover.
  Software tools
- ARC-GIS, ERDAS, ENVI

Textbooks and Recommended Reading

- Hugget R. J., *Fundamentals of Geomorphology*, Routledge Fundamentals of Physical Geography Series, 2nd Edition, 2007.
- Lillesand, Kiefer & Chipman (2015) Remote sensing and image interpretation (7th Edition) Wiley & Sons.
- Jensen (2006) Remote sensing of the environment: an earth resource perspective (2nd Edition) Prentice Hall.
- Lo and Yenug (2006) Concepts and Techniques of GIS, Prentice Hall (Eastern Economy Edition).

EES404: Basic meteorology

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction to earth's atmosphere, definition of weather and climate, fundamental atmospheric radiation, Heat exchange processes; radiation laws - absorption, emission and scattering in the atmosphere, atmospheric boundary layer.
- Atmospheric Dynamics: Basic laws of conservation; Fundamental Forces - Pressure Gradient Forces, Gravitational Force, Friction or Viscous Force; Apparent forces- Centrifugal Force, Coriolis force, Momentum Equations; Scale analysis of momentum equations; Hydrostatic approximation; Inertial Flow; Balanced motion, Geostrophic Wind, Gradient wind, Thermal Wind
- Atmospheric thermodynamics: thermodynamic laws, specific heats of a gas, moisture parameters, adiabatic processes, lapse rates, potential temperature, virtual temperature, adiabatic processes, water vapour in air, static stability.
- Introduction to the boundary layer, definition, convective, neutral and stable boundary layers, surface boundary layer characteristics, temporal evolution and vertical structure; surface energy balance, Reynolds number, Richardson number
- Elementary concepts of General Circulation of the Atmosphere, Jet streams - Definition and characteristics, regional circulation systems-Tropical Easterly jet, Subtropical Westerly jet, Somali jet.
- Overview of Clouds: types of clouds; cloud formation; warm cloud microphysics: diffusional growth, droplet population, collisioncoalescence, cold cloud microphysics: nucleation, ice multiplication, growth of ice particles by accretion and ice particle melting; hydrometeors.
- Indian summer monsoon: definition of monsoon driving forces of the monsoon, synoptic features associated with onset, withdrawal, active and break cycles of monsoon, rainfall distribution and rain bearing systems.

Recommended Reading

- J. M. Wallace and P. V. Hobbs, *Atmospheric science - An Introductory Survey*, 2nd Edition, Academic Press, London, 2006.
- Holton J. R., *An Introduction to Dynamical Meteorology*s, Academic Press
- The Monsoons by P. K. Das, *National Book Trust*, India
- Ahrens, C. D., *Meteorology Today*, 11th editions, Cengage, 2015
- Roland B. Stull, *An Introduction to Boundary Layer Meteorology*, Springer, 1988

EES636: The quarternary period-environments, animals adaptations during the last 2.5 million years

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Pleistocene and Holocene; geological and environmental change; major climatic oscillations (e.g. Milankovitch cycles; glacial interglacials; monsoons)
- Vertebrate speciation events including the genus Homo; subsequent dispersals and adaptations
- Environmental reconstructions using proxy data (e.g. pollen records, deep sea core records, fossil records, stable isotope (carbon, oxygen, nitrogen)
- Multidisciplinary case studies (e.g. aridity, sea level changes, floods)
- Ecological roles in the rise and decline of complex societies (e.g. Harappans, Mayans, Mesopotamians); advent of agriculture and domestication
- Methods in Quaternary studies (e.g. stratigraphy, geomorphology, geochronology, paleontology, palaeobotany)
- Major debates in Quaternary studies (e.g. faunal overkill; Toba super-eruption)

  Additional course activities

- Geological fieldtrips to show examples of Quaternary change and associated proxy records

Recommended Reading

- *Dunkerely et al. Quaternary Environments.* Routledge Press. (1998)
- Book chapters and journal articles, *(e.g. Quaternary International, Journal of Quaternary Studies, Quaternary Geochronology, Quaternary Research, Quaternary Science Reviews, Paleo3)*

EES637: Introduction to aeronomy

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- *N*eutral atmosphere
  Structure of the atmosphere Physics and Chemistry of the mesosphere and thermosphere Airglow Winds and waves Formation of the ionosphere
- *I*onosphere
  Layering into the D, E and F regions Topside ionosphere Conductivities Current systems: EEJ, Sq and AEJ Equatorial ionization anomaly Ionospheric instabilities in the E-region instabilities in the F-region Midnight temperature maximum and F-region collapse
- *M*agnetosphere
  Magnetosphere above the ionosphere Magnetopause Geomagnetic tail Plasma and neutral sheets Radiation belts Plasmasphere Reconnection and interaction of solar wind plasma Geomagnetic disturbances Aurorae Disturbance effects in the ionosphere-thermosphere system
- *B*road perspective
  Overview of ionospheres and magnetospheres of other planets

Recommended Reading

- J. K. Hargreaves, *The Solar-Terrestrial Environment*, Cambridge University Press
- R. Schunk, A. Nagy, *Ionospheres*, Cambridge University Press
- M. G. Kivelson, C. T. Russell, *Introduction to Space Physics*, Cambridge University Press
- M. C. Kelley, *The Earths Ionosphere*, Academic Press
- H. Rishbeth, O. K. Garriot, *Introduction to Ionospheric Physics*, Academic Press
- M. H. Rees, *Physics and Chemistry of the Upper Atmosphere*, Cambridge University Press
- Y. Kamide, A. Chian (Eds), *Handbook of Solar-Terrestrial Environment*, Springer-Verlag

EES638: Paleoclimatology

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Components of the earth's climate system; causes, controls and feedback mechanisms of the climate system.
- The Indian monsoon; monsoon and global teleconnections; decadal and interannual variability of the Indian monsoon.
- Introduction to paleoclimatology; terrestrial and marine archives of past climate change; dating paleoclimatic archives; methodological approaches and proxies used in climate research.
- Overview of Earths long-term climate history; Climate change hypotheses & major climatic events starting with formation of the atmosphere; Oceans and climate change.
- Orbital Changes & Ice Age climates; Quaternary and Holocene climates; Climate change during the last millennium; Insolation control of monsoons and ice sheets.
- Human civilizations and climate change; projections for future climate change.

Recommended Reading

- W. F. Ruddiman. *Earth's Climate: past and future*, W.H. Freeman & Son, 2nd edition (2008).
- T. M Cronin,*Paleoclimates: understanding climate change past and present*, Columbia University Press (2009).
- B. Wang,*The Asian monsoon*, Springer Science & Business Media (2006).

EES639: Space weather

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- *Solar activity*: Solar interior - solar atmosphere - corona - solar wind - solar rotation - sunspots and solar cycle - interplanetary magnetic field - heliosphere prominences, filaments and plages - solar flares - coronal mass ejections - coronal holes.
- *Geospace*: Structure of earth - atmosphere - atmospheric waves - ionosphere - geomagnetic field - ionospheric conductivity and currents - important features of ionosphere - plasmasphere - radiation belts - bowshock - magnetopause - magnetosheath - cusp - magnetotail - plasma and neutral sheets - magnetospheric current systems.
- *Solar-terrestrial interactions*: Solar cycle impacts on atmosphere and ionosphere - magnetic reconnections - geomagnetic storms substorms and aurorae - thermospheric disturbances - ionospheric storms and disturbances - effects in the middle atmosphere.
- *Societal impacts and prediction*: Satellite lifetimes - satellite charging - energetic particle impacts and implications for space travel - radio propagation hindrances - ground induced currents and effects on electrical lines - induction effects in oil pipelines - probable effects on living beings - prediction capabilities.

Recommended Reading

- W. H. Campbell, *Introduction to Geomagnetic Fields*, Cambridge University Press, 2003.
- J. K. Hargreaves, *The Solar-Terrestrial Environment*, Cambridge University Press, 1992.
- M. Moldwin, *An introduction to Space Weather*, Cambridge University Press, 2008.
- Y. Kamide, A. Chian (Eds), *Handbook of Solar-Terrestrial Environment*, Springer-Verlag, 2007.
- M. G. Kivelson, C. T. Russell, *Introduction to Space Physics*, Cambridge University Press, 1995.
- G. K. Parks, *Physics of Space Plasmas An Introduction*, Westview Press, 2004.
- A. S. Jursa (Ed), *Handbook of Geophysics and the Space Environment*, Air Force Geophysics Laboratory, 1985.
- W. Baumjohann, R. A. Treumann, *Basic Space Plasma Physics*, Imperial College Press, 1997.

EES640: Global tectonics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction: Earth and its early history. Differentiation of earth into crust, mantle and core, Internal structure of the Earth.
- Plate Tectonics: Development of theory of plate tectonics. Mechanism of plate-tectonics: Mantle convection, The forces acting on plates.
- Plate boundary processes: Spreading centers, subduction zones, collision zones and transform faults. Physiography, structure, magmatism, metamorphism and sedimentation along plate boundaries.
- Origin and evolution of land: Origin and evolution of continental-crust. Supercontinent cycles.

Recommended Reading

- Kearey, P., Klepeis, K.A. and Vine, F.J. *Global Tectonics*, (Third Edition). Wiley-Blackwell, John Wiley and Sons Ltd., UK (2007).
- Windley, B.F., *The evolving continents*, John Wiley & Sons (1995).
- Molnar, P., *Plate Tectonics, A very short introduction*, Oxford University Press (2015).
- Condie, K.C., *Plate Tectonics and Continental Evolution*, Pergamom Press Inc (1989).

EES641: Radiogenic isotope geology

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction and basis of radiogenic isotope geology: Scope of radiogenic isotope geology. Discovery of radioactivity and historical development of the subject. Nuclear structure. Theory and mechanism of decay, particles emitted, growth and retention of daughter isotopes in earth systems. Mass spectrometery and laboratory methods.
- Geochronology: Methods of dating. Radio Isotope systematic- K-Ar, ^{40}Ar-^{39}Ar, Rb-Sr, Sm-Nd, Lu-Hf, Re-Os, U-Th-Pb and others. Cosmogenic radio-nuclides. Short-lived and extinct radio-nuclides and early Earth and Solar system processes.
- Geological processes: Radioactive and radiogenic elements as major, minor and trace elements and their geochemical behaviour. Applications of radio-isotope systematic in geochemistry. Petrogenesis of Igneous, Metamorphic, and Sedimentary Rocks. surface processes.

Recommended Reading

- Dickin, A.P., *Radiogenic Isotope Geology*, (Second Edition). Cambridge University Press (2005).
- Allegre, C. J., *Isotope Geology*, Cambridge University Press (2008).
- Faure, G. and Teresa M. Mensing, *Isotopes: Principles and Applications*, (Third Edition) John Wiley & sons (2005).

EES642: Environmental microbiology

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Introduction to Environmental Microbiology.
- Metabolic classification of microorganisms; Bacterial growth under aerobic and anaerobic conditions.
- Microbial ecology and diversity in various environments such as earth (surface soils and subsurface zones), air (aeromicrobiology), aquatic (freshwater and marine), and extreme environments (e.g., deep-sea hydrothermal vents, hot springs, acid mine drainage systems)
- Role of microorganisms in geochemical cycling of carbon, nitrogen, phosphorous, sulphur and iron.
- Microbiological aspects of drinking water and water distribution systems: Drinking water quality parameters and regulations; Groundwater and surface water contamination; Indicator microorganisms; Waterborne pathogens; Drinking water treatment; Disinfection.
- Microbiology of wastewater treatment: municipal/sewage wastewater treatment; aerobic and anaerobic processes; Microorganisms for metal removal and oil spill remediation.
- Role of microorganisms in green-house gas emissions.

Recommended Reading

- Ian L. Pepper, C. P. Gerba and T. J. Gentry, *Environmental Microbiology*, 3rd edition, Elsevier Academic press (2014).
- G. Bitton, *Wastewater Microbiology*, 3rd edition, Willey (2005).
- D. Mara and N. Horan, *Handbook of Water and Wastewater Microbiology*, Academic press (2003).

EES643: Environmental biotechnology

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction to Environmental Biotechnology.
- Biological treatment of waste streams; Resource recovery from wastewaters; e.g., of nitrogen, sulphur, phosphorous and critical metals; Microbial electro-biotechnology (microbial fuel cells and electrolysis cells) for wastewater treatment; Strategies for future sustainability of water sources and water re-use.

- Bioremediation of polluted terrestrial and aquatic environments: current practice and applications; Factors influencing bioremediation; Soil bioremediation approaches such as biostimulation and bioaugmentation; Application of genetically engineered microorganisms for hazardous waste management; Microbial cleaning of gases (biofiltration and bioscrubbing) and acid mine drainage; Phytoremediation: practice and applications, pros and cons; Emerging approaches such as microbial electro-bioremediation; In situ and ex situ bioremediation technologies.

- Biocatalysis and bioelectrocatalysis for cleaner production: Production of value-added products from wastes, agricultural residues and industrial side-streams, e.g., biofuels and bioenergy (such as biohydrogen, biogas, bioethanol, biobutanol, biodiesel and bioelectricity), biosurfactants and bioplastics; Desulphurization of fossil fuels; Bioleaching of metals, Production of biofertilizers and biopesticides; Microbial enhanced oil recovery, Microbial carbon dioxide conversion into chemicals and fuels; Biomass and waste-based biorefineries: state-of-the-art, technical and commercial challenges.

- Environmental monitoring: bio-indicators, biomarkers and biosensors.

- Biocorrosion: mechanisms, prevention and control.

- Public perception and future of the Environmental Biotechnology.

Texts/References

- Gareth M. Evans and Judith C. Furlong, *Environmental Biotechnology: theory and application*, 2nd edition, Wiley-Blackwell, 2010. ISBN: 978-0-470-68418-4

- Lawrence K. Wang, Volodymyr Ivanov, Joo-Hwa Tay, and Yung-Tse Hung, *Environmental Biotechnology*, Humana Press, USA, 2010. ISBN 978-1-58829-166-0

- Metcalf and Eddy, George Tchobanoglous, H. David Stensel, Ryujiro Tsuchihashi and Franklin L. Burton, *Wastewater engineering: Treatment and Resource Recovery*, 5th edition, McGraw-Hill Education/Asia, 2014. ISBN-13: 978-1259010798

- Rittmann B. E. and McCarty P. L., *Environmental Biotechnology: principles and applications*, McGraw-Hill, New York, USA, 2001. ISBN-13: 978-0071181846

Suggested Reading

- Daniel Vallero, *Environmental Biotechnology: A Biosystems Approach*, 2nd Edition, Academic Press, 2015. ISBN: 9780124077768

- Kumar Raman, Sharma Anil Kumar, and Ahluwalia Sarabjeet Singh (Eds.), *Advances in Environmental Biotechnology*, Springer, 2017. ISBN 978-981-10-4041-2

- Ansari, A. A., Gill, S. S., Gill, R., Lanza, G. R. and Newman, L. (Eds.), *Phytoremediation: Management of Environmental Contaminants*, Volume 1, Springer, 2015. ISBN 978-3-319-10395-2

- J. M. Lema and S. S. Martinez, *Innovative Wastewater Treatment & Resource Recovery Technologies: Impacts on Energy, Economy and Environment*, IWA Publishing, 2017. ISBN13: 9781780407869

4.4 Humanities and Social Sciences

HSS301: Construction of identity and knowledge

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline The course explores how identities are constructed and how these constructions intersect with the construction of knowledge. Through scholarly readings, fiction and films we will explore the mutual constitution of identities and the nature of knowledge. Readings will range from Focauldian perspectives on the birth of society and the archeology of knowledge, to subaltern studies discussion on colonial and postcolonial knowledge(s), to Donna Harraway's manifesto of the Cyborg.

- Theories on social construction, construction of individual identity, construction of group identity, Gender, class, caste and other forms of difference
- Panopticon, the birth of society, modes of embodiment Nationalism, national identity, Orientalism, memory and identity, transnational identity
- Colonial constructions of the colonized, postcolonial identities
- The politics of reality, subject formation, Structure and agency, humanism, positivism, environmental determinism
- The archeology of knowledge, power-knowledge, discourse, dialectics
- Relationship of identity to place and environment
- Indigenous knowledge(s), feminist critique of scientific knowledge, feminist science, subaltern knowledge(s)

Recommended Reading

- M. Frye, *The Politics of Reality: Essays in Feminist Theory*, The Crossing Press, Berkeley (1983).
- M. Foucault. *The Archaeology of Knowledge*, translated from 1969 version by A. M.S. Smith. Routledge (2002).
- P. Chatterjee, *The Nation and Its Fragments: Colonial and Postcolonial Histories*, Princeton University Press (1993).
- M. Foucault, *Discipline and Punish: the birth of the prison*, Translated from 1979 version by A. M. Sheridan, Random House, New York 2nd edition (1995).
- D. Haraway, *Simians, Cyborgs and Women: The Reinvention of Nature*, Routledge (1991).
- E. Said, *Orientalism*, Vintage, New York (1979).

- U. Narayan, *Dislocating culture: Identities, traditions and Third World Feminisms*, Routledge (1997).
- Other materials will include journal articles and films.

HSS302: Concepts of space and time in the humanities and social sciences

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Spatial analysis of social structuring , economic patterns and political groupings: commodity chain analysis, public-private domains, shifts from nomadic groupings to nation-states, international organizations and regional blocks. Spatial implications of the Internet and emerging communications technologies.
- Temporal analysis of contemporary political-economy and social struggles: Partition of British India, Consolidation of the states, history of identity struggles. Temporal implications of the Internet.
- Methods of analysis: qualitative, quantitative, archival: introductions to basic research tools of the humanities and social sciences.
- Space and time in built form and human-environment relationships: spatial and temporal diffusion of disease, historical and spatial ordering of urban and rural settlements.
- Theoretical dimensions: Space as productive. Time as non-linear. Time-space compression. World-systems theory. Actor-network theory.

Recommended Reading

- P. Hubbard; R, Kitchin; and G, Valentine (Eds.) *Key thinkers on Space and Place*, Sage (2004).
- R. Guha, *India after Gandhi: a history of the world's largest democracy*, Harper Collins (2007).
- T. Friedman *The World is Flat: a brief history of the 21st century.* Thomas. Farrar, Straus and Giroux Publications (2005).

HSS304: Visual art: Studio practice and theory

[Cr:4, Lc:1, Tt:0, Lb:6]

Course Outline

- The course intends to introduce students to the different mediums of artistic expression as well as to theoretical and historical contexts for art appreciation. The course also includes visits to galleries and art museums. A major emphasis of the course is studio art and therefore the course will essentially be like a lab with some lectures.

- Topics: contemporary debates in art, elements of art and design ((line, shape, value, texture, color, and space), principles of art and design (unity & variety, balance, emphasis & subordination, scale & proportion, rhythm), visual arts in everyday life, 2-D art (painting, collage, printmaking, photography), 3-D art (sculpture, environmental art, installation art), clay and stoneware pottery and glazing, multimedia and art, digital arts, fabric art, making natural dyes and colors, glass (slumping and fusion).

Recommended Reading

- Mirzoeff, *The Visual Culture Reader*, Routeledge (2002).
- Barrett, *Interpreting art: reflecting, wondering and responding*, McGraw hill, London (2002).
- Other material: art material (such as paints (water colours, acrylic, oil), charcoal pencils, clay)

HSS402: Introduction to linguistics

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Communication: biological and philosophical perspectives, elements of linguistic form: morphology, phonetics, phonology; syntax, semantics, pragmatics, socio-linguistics, language and gender, linguistic form in art, ritual and play; language production and perception; brain and language; language acquisition; language change, psycholinguistics, bilingualism.

Recommended Reading

- S. Pinker, *The Language Instinct: The New Science of Language and Mind*, Penguin (1994).
- O'Gardy; Dorovolsky; Katamba *Contemporary Linguistics: an introduction*, Longman (1997).

HSS601: Identity, power and place

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Theoretical perspectives on space and place: Introduction to concepts of space and place, construction of place, Topophilia, Space as productive of social relations, Time-space compression, How power acts spatially: panopticon, surveillance and the spaces of everyday life, Rhizomatics and/or postmodernist constructions of space as a network, relationship between power, knowledge and the construction of space, representations of space and place, space and place as contested.

- Theoretical perspectives on identity: Identity as constructed: construction of identity, spatialized identity, Concepts of otherness, orientalism, gender, race, class, caste, linguistic identity and intersectionality, theorizing colonialism and national identity, performance of identity, theorizing globalization and construction of diasporic idenitities, non-places and places of flows, migration and identity, notion of scale and identity (home, local, national, global), postcolonial identity, politics of nature and identity, claiming subaltern identities, introduction to dalit studies, identity and exclusion; consumption, capitalism and glocal identities.

- Contextualizing theory: Regional, linguistic identity and the history of Indian states, case studies of identity struggles and politics in the contemporary world, Analysis of one's own identity (gendered/class/national/caste etc.) and how it is constructed and contested in public and private spaces of everyday life.

Recommended Reading

- H. Lefebvre, *The production of Space*, Wiley-Blackwell (1992).
- D. Massey, *For Space*, Sage (2005).
- P. Hubbard, R. Kitchin and G. Valentine (Eds.) *Key Thinkers on Space and Place*, Sage (2004).
- E. Said, *Orientalism*, Vintage, New York (1979).
- B. Anderson, *Imagined Communities: Reflections on the Origin and Spread of Nationalism*, Verso, New York (1991).
- J. Butler, *Gender Trouble: Feminism and the Subversion of Identity*, Routledge (1999).
- R. Guha, *A Subaltern Studies Reader, 1986-1995*, Oxford University Press, India (2000).
- J. C. Scott, *Seeing Like a State: How Certain schemes to Improve the Human Condition Have Failed*, Yale University Press (1998).
- R. Ray and S. Qayum, *Cultures Of Servitude: Modernity, Domesticity, and Class in India*, Stanford University Press (2009).

HSS602: Social theory: concepts and debates

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Historical roots of social theory: Theorizing social relations; relations between individual biographies and social structures; the tradition of social theory with its roots in 19th century political economy; religion, ritual and emergence of social order.

- Classical social theory and modernity: Durkheim's writings on the conscience collective and the moral order, division of labor and suicide; Marx's writings on historical materialism, human nature, labor, class conflict and alienation, Frankfurt school (Habermas), relationship between state and society, understanding social cohesion, collective action, social stratification; Weber on the protestant ethic and the spirit of capitalism, bureaucracy, rationalization and the roots of social domination;

- Modernity and Late modernity: Conflict Theory: (Weber, Dahrendorf, & Collins), Dependency theory, symbolic interactionism (Meal, Blumer, Goffman), Rational choice theory, Exchange network theory, Phenomelogy and the social world(Schutz), structures of the life world, ethnomethodology, Social construction of reality (Berger and Luckman), social construction of inequality (Bourdieu), structure of scientific revolutions(Kuhn).

- Postmodernity, poststructuralism and beyond: Feminist critique of social theory, standpoint theory, The production of modern society and the body discourse (Focault) , Neomarxists and critique of marxism, network society(Castells), world-systems theory (Wallerstein), the problem of intersubjectivity, relationship between technology, culture and politics, understanding scales from the body, family, community, national to global; power and resistance, global terror and the modern nation-state.

Recommended Reading

- A. Giddens, *Social Theory and Modern Sociology*, Stanford University Press (1987).

- N. Crossly, *Key Concepts in Critical Social Theory*, Sage (2005).

- M. Dhillon, *Introduction to Sociological theory*, Wiley Blackwell (2010).

- D. Harvey, *Limits to Capital*, Verso (2006).

- K. Marx, *Capital: A Critique of Political Economy - Vol. I: The Process of Capitalist Production*, Cosimo (2007).

- H. Arendt, *The Human Condition*,University of Chicago Press, Second edition (1998).

- M. Foucault, *Discipline and Punish: the birth of the prison*, Translated from 1979 version by A. M. Sheridan, Random House, New York 2nd edition (1995).

- Grewal and Kaplan, *An Introduction to Women's Studies: Gender in a Transnational World*, McGraw-Hill (2001).

- J. Farganis, *Readings In Social Theory: The classic tradition to postmodernism*, McGraw-Hill (2003).

HSS603: Advanced qualitative research design and methods

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Research design: formulating viable research questions, theory/model building in social sciences and humanities, relationship of epistemology to methodology, mixed methods approach, triangulation, planning data collection and data analysis, exploring bias and rigour in qualitative research, history of qualitative inquiry
- Theoretical basis of qualitative inquiry: positivism, realism, hermeneutics, critical theory, grounded theory, ethnography, semiology, discourse analysis, narrative, memoirs, psychoanalysis, critical arts- based inquiry, participatory action research, oral history, autoethnography, visual methodologies, feminist research, transformative research and critical pedagogy
- Data collection and analysis methods: case studies, interviews, oral histories, participant-observation, survey techniques, archival data collection, focus groups, data transcription, photo-voice and film- making as research tools, content analysis, coding, comparative analysis, longitudinal analysis, online inquiry, multimedia analysis, Nvivo software
- Ethics in social research: subject and object of study, research regulations, disclosure and consent, reflexivity, research in difficult situations such as in violent zones or with emotionally troubled subjects, insider/outsider subjectivities

Recommended Reading

- Denzin and Lincoln, *Sage handbook of qualitative research*, Sage (2011).
- R. Gillian, *Visual methodologies: an introduction to the interpretation of visual methodologies*, Sage (2007).
- V. Amit(Ed.), *Constructing the field: Ethnographic fieldwork in the contemporary world*, Routledge (2000).
- A. Grimshaw, *The ethnographer's eye: Ways of seeing in modern anthropology*, Cambridge University Press, (2001).
- Other material: voice recorder, transcriber, digital still and video cameras.

HSS611: Literary appreciation

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Imaginative works drawn from the first and second half of twentieth century: Focus on both male and female writers: Joseph Conrad's Heart of Darkness (1902), W. B. Yeats' "The Second Coming," (1920), Jorge L. Borges' "The Garden of Forking Paths" (1942), Boris Leonidovich Pasternak's Doctor Zhivago (1957), Lorraine Hansberry's Raisin in the Sun (1959), Rachel Carlson's Silent Spring (1962), Jean Rhys's Wide Sargasso Sea (1966), Ursula K. Guin's The Dispossessed (1974), J. M Coetzee Foe's (1986), Susie Tharu and K. Lalitha's "Introduction" in Women Writing in India (1991), Salman Rushdie's Imaginary Homelands (1991), Rabindranath Tagore's

Gitanjali (1913). Representative literary pieces drawn from British, Latin-American, Russian, African-American, American, South-African, Indian, and Caribbean literatures, a broader picture of the major themes and trends in World Literature

- Interpreting literary texts: Develop the skill of reading literary texts, reader as the literary interpreter of meaning, interpreting socio-cultural issues outlined in the text, interpretation as an active activity leading to the appreciation of literary texts
- Critical Perspectives: Psychological, ecological, modernist, postmodernist, feminist, diaspora, minority studies, science fiction studies, appreciation of literary texts from various theoretical standpoints, cultural and social phenomenon as the objects of reading, focus on the multiple dimensions inherent in the textual space
- Literary genres: Formal features of literary texts, types or classes of literary productions, the emergence of literary genres, the criteria of classification, classes and subclasses to which literary works have been assigned: novel, novella, drama, poetry, essay, short story

Recommended Reading

- B. Ashcroft, G. Griffiths et.al, *The Empire Writes Back: Theory and Practice in Postcolonial Literatures*, Routledge(2002).
- J. L. Borges, *Fictions*, Translated by A. Hurley, Penguin (2000).
- J. Barth, *The Literature of Exhaustion and the Literature of Replenishment*, Lord John Press (1982).
- P. Barry,*Beginning Theory. An Introduction to Literary and Cultural Theory*, Manchester University Press (1995).
- R. Carlson, *Silent Spring*, Penguin (2000).
- J. M. Coetzee, *Foe*, Penguin, (1987).
- J. Conrad, *The Heart of Darkness and the Secret Sharer*, Signet Classics (1902).
- D. Daiches, *A Study of Literature: For Readers and Critics*, W. W. Norton & Company (1964).
- C. Glotfelty and H. Fromm, *Ecocriticism Reader*, University Of Georgia Press, (1996).
- G. Wilfred et al. *A Handbook of Critical Approaches to Literature*, Oxford University Press (1992).
- U. K. Guin, *The Dispossessed*, Harper Perennial (2003).
- A. Fowler, *Kinds of Literature: An Introduction to the Theory of Genres and Modes*, Harvard University Press (1982).
- L. Hansberry, *Raisin in the Sun*, Knopf Doubleday (2006).
- U. K. Heise, *Sense of Place and Sense of Planet*, Oxford University Press (2008).

- B. L. Pasternak, *Doctor Zhivago*, Translated by M. Hayward and M. Harari, Knopf Doubleday, (1958).
- J. Rhys, *Wide Sargasso Sea*, W. W. Norton & Company (1992).
- R. Salman, *Imaginary Homelands*, Random House (2001).
- D. Suvin, *Metamorphoses of Science Fiction: On the Poetics and History of a Literary Genre*, Yale University Press (1979).
- R. Tagore, *Gitanjali*, Scribner Book Company (1997).
- S. Tharu and K. Lalitha, *Women Writing in India Vol. 1*, Oxford University Press (2000).
- M. Walters, *Feminism: A Very Short Introduction*, Oxford University Press (2005).
- V. Woolf, *A Room of One's Own*, Harcourt Brace & Co. (1989).
- W. B. Yeats, *The Collected Poetry of William Butler Yeats*, Digireads.com (2010).

HSS612: The idea of evolution: Before and after Darwin

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline This course will look at the genesis, the historical development and the social, cultural and religious impact of Darwin's theory of evolution by natural selection. Starting from pre-Darwinian ideas about creation of the earth and life upon it, this course will trace the historical development of Darwinism. We will try to place Darwin's contribution in his social context of 19th century England, the center of the industrial revolution, capitalism and imperialism. Along with an examination of the scientific debates over adaptation and natural selection, we will look at the social and religious implications of Darwinism. Debates over sociobiology and creationism will be examined. We will also look at the reception of Darwinism in India, including the attempts to reconcile it with a Hindu worldview.

Selected Readings

- Bowler, Peter, *Evolution: The History of an Idea*, University of California, (2009).
- Brown, Mackenzie, *Hindu Perspectives on Evolution: Darwin, Dharam and Design*, Routledge, (2012).
- Darwin, Charles, *Collected works*, edited by E.O. Wilson, *From so Small a Beginning* Norton, (2006).
- Dawkins, Richard, *The Blind Watchmaker*, Norton, (1986),
- Gould, Stephen J., *Ever Since Darwin*, Norton, (1977).
- Mayer, Ernst, *One Long Argument.: Charles Darwin and the Genesis of Modern Evolutionary Thought*, Harvard University Press, (1991).
- Ruse, Michael, *Taking Darwin Seriously*, Prometheus Press, (1998).

HSS613: The social history of science in modern India, 1780-1950

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline This course will deal the social history of, and the historiographical debates surrounding, science in Modern India.

- Colonialism, Imperialism and the emergence of modern western science in India.
- Policies of the colonial state and scientific institutions.
- The origin, development and institutionalisation of scientific disciplines: Geology, Geography, Cartography, Mathematics, Physics, Chemistry and Biology.
- Science in the Age of Nationalism and Indian scientific community.
- Science on the eve of Indian Independence.
- Science and Industry: A historical overview.
- Historiography of Science in India.

Recommended Reading

- Deepak Kumar, *Science and the Raj, 1857-1905*, Oxford University Press, New Delhi, 1995.
- Zaheer Baber, *The Science of Empire: Scientific Knowledge, Civilization and Colonial Rule in India*, Oxford University Press, New Delhi, 1998.
- Dhruv Raina and S. Irfan Habib, *Domesticating Modern Science: A Social History of Science and Culture in Colonial India*, Tulika Books, New Delhi, 2004.
- S. Irfan Habib and Dhruv Raina (eds)., *Social History of Science in Colonial India*, Oxford University Press, New Delhi, 2007.
- Shiv Visvanathan, *Organizing for Science: The Making of an Industrial Research Laboratory*, Oxford University Press, New Delhi, 1985.
- Kapil Raj, *Relocating Modern Science: Circulation and the Construction of Knowledge in South Asia and Europe, 1650-1900*, Palgrave Macmillan, 2010.
- David Arnold, *Science, Technology and Medicine in Colonial India,* Cambridge University Press, Cambridge, 2004.
- Robert Kanigel, *The Man Who Knew Infinity: A Life of the Genius Ramanujan*, Abacus, 1991.
- Meera Nanda, *Prophets Facing Backward: Postmodernism, Science and Hindu Nationalism*, Permanent Black, New Delhi, 2004.

Suggested Readings

- S. Irfan Habib and Dhruv Raina (eds)., *Social History of Science in Colonial India*, Oxford University Press, New Delhi, 2007.
- Shiv Visvanathan, *Organizing for Science: The Making of an Industrial Research Laboratory*, Oxford University Press, New Delhi, 1985.
- Kapil Raj, *Relocating Modern Science: Circulation and the Construction of Knowledge in South Asia and Europe, 1650-1900*, Palgrave Macmillan, 2010.
- David Arnold, *Science, Technology and Medicine in Colonial India*,Cambridge University Press, Cambridge, 2004.

HSS614: Women's history of science

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline This course will examine history of science, both in the West and in India, from a womens perspective.
Women have been conspicuous in the enterprise of science by their absence: a handful of notable exceptions prove the rule of their exclusion from the professional world of science.
The course will ask the question: Why? Why has the world of science been a world without women, for most of its history? What is the extent of progress that women have made over the last 100 years of so? And what structural obstacles still remain?

- The historical question: Through their work as care-givers and producers of food, fabric and other sources of sustenance, women have been knowledge-producers from the very beginning of history. Why, then, we dont find them within the ranks of astronomers, mathematicians, engineers and medical doctors whose work we acknowledge as milestones in science? What kinds of barriers patriarchy created against the recognition of womens work and their inclusion in the circle of knowledge-producers and intellectuals?
- The contemporary situation: What is the situation today? Where does India stand with respect to the rest of the world when it comes to the womens question in science? What kinds of structural barriers still prevent a full flowering of womens potential?
- The philosophical question: Is there is a womens way of knowing? Are men and womens style of scholarship different, or are their research interests, priorities and ways of looking at problems interchangeable with those of men? This issue has been a subject of a lot of debate within the feminist philosophy of science and we will look at the central issues.

Recommended Reading

- Fox Keller, Evelyn., *Reflections on Gender and Science*, Yale University Press., 1985.
- Harding, Sandra., *The Science Question in Feminism*, Cornell University Press, 1989.

- Haraway, Donna. , *Primate Visions: Gender, Race and Nature in the World of Modern Science*, Routdedge, 1989.
- Merchant, Carolyn., *The Death of Nature: Women, Ecology and the Scientific Revolution*, Harper and Row, 1980
- Schiebinger, Londa, *Has Feminism changed Science?* , Harvard University Press. 2001.
- Shiebinger, Londa, *The Mind has no Sex? Women in the Origins of Modern Science.*, Harvard University Press, 1989.
- Woolf, Virgina, *A Room of Ones Own.* (a classic novel)

HSS615: Introduction to archeology with special reference to the Indian subcontinent

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Introduction to the basics of archaeology: Definition of archaeology within anthropology including various terminologies, excavation and analytical methods, subject aims and its close links with science in general. Multidisciplinary uses of various hard sciences and social sciences. Study of ancient material culture starting from about 2.6 million years ago up to the Iron Age. Geochronological methods. The three phases of humanity (prehistory, proto-history and historical times) and their various sources of knowledge (physical cultural remains including artifacts and architecture, the human fossil evidence, various sources of ancient literature, modern ethnography and other related sources.)
- Global examples and case studies: Key artifacts, sites and site-complexes, and multiple data and examples from Africa, Eurasia, Australasia, the Americas, Indian Subcontinent or South Asia (India, Nepal, Pakistan, Afghanistan, Bhutan, Bangladesh and Sri Lanka). History of Indian archaeology. Theoretical perspectives vs. empirical data. Key conceptual perspectives: human evolution, tool invention, agriculture, domestication and the rise of civilization and urbanization.
- Roots of human culture and cultural identity, stability and change: Examples of both indigenous developments of culture, and external influences on regional cultures through human dispersals, economic/cultural interactions etc. Viewing archaeology as human ecology. Current debates and controversies in global and Indian archaeology. Relevance of archaeology in modern society and the scope of the discipline in India.
- Related activities: Few field trips to local and regional museums and archaeological and geological sites in its original cultural and geological contexts. Handling of artifacts, registration and documentation of artifacts, presentations and discussions.

Recommended Reading

- Allchin, B., F. R. Allchin., *The Rise of Civilization in India and Pakistan*, Cambridge: Cambridge University Press (1982).
- Barry, L., R. Jurmain, L. Kilgore., *Understanding Physical Anthropology and Archaeology*, London: Thomson Wadsworth (2007).
- Binford L. R., *In Pursuit of Past*, London: Thames and Hudson (1983).
- Brothwell D., E. S. Higgs., *Science in Archaeology*, London: Thames and Hudson (1970).
- Chang, K. C., *The Archaeology of Ancient China*, Yale: Yale University Press (1968).
- Clarke, D. L., *Analytical Archaeology*, London: Methuen (1968).
- Daniel G., *Hundred and Fifty Years of Archaeology*, London: Dockworth (1975).
- Dennell, R. W., *The Palaeolithic Settlement of Asia*, Cambridge: Cambridge University Press (2009).
- Fagan, B. M., *In the Beginning- an Introduction to Archaeology*, New York: Harper Collins (1991).
- Harris, D. R., *The Origins and Spread of Agriculture and Pastoralism in Eurasia*, London: UCL Press/Washington, D.C.: Smithsonian Institution Press (1996).
- Hodder I., *Reading the Past: Current Approaches to Interpretation in Archaeology*, Cambridge: Cambridge University Press (1991).
- Klein, R. G., *The Human Career: Human Biological and Cultural Origins*, Chicago: The University of Chicago Press (1999).
- Leute, U., *Archaeometry: An Introduction to Physical Methods in Archaeology and the History of Art.*, New York: VCH (1987).
- Newmayer, E., *Lines on Stone: Prehistoric Rock Art of India*, New Delhi: Manohar (1993).
- Paddayya, K., *The New Archaeology and its aftermath*, a view from outside the Anglo-American world, Pune: Ravish (1990).
- Phillipson, D. W., *African Archaeology*, Cambridge: Cambridge University Press (1988).
- Possehl, G. L., *The Indus Civilization: A Contemporary Perspective.*, New Delhi: Vistar Publication (2003).
- Sankalia, H. D., *Prehistory and Protohistory of India and Pakistan.*, Pune: DCPGRI (1974).
- Schiffer, M. B., *Behavioral Archaeology*, New York: Academic Press (1976).
- Settar, S., R. Korisettar., *Indian Archaeology in Retrospect: Volumes 1 to 4.*, ICHR, Delhi: Manohar (2002).

- Sinopoli, C., *Approaches to Archaeological Ceramics*, New York: Springer (1991).
- Trigger, B. G., *Towards A History of Archaeological Thought*, Cambridge: Cambridge University Press (1989).

HSS616: Bones, stones & chromosomes: The story of our evolution

[Cr:4, Lc:3, Tt:0, Lb:1]

Course Outline

- The study of human evolution is one of the most important and popular subjects in academics. Not only does it attempt to explain our biological origins and place in the global evolutionary chain but is also now helping to understand the role of genetics in unraveling the history of behavior and various illnesses. This course essentially presents multidisciplinary scientific evidences broadly related to human evolution and systematically covers three main scientific datasets: human paleontology, archaeology and genetics.
- Following a broad introduction to fundamental evolutionary principles, the empirical data will be presented in chronological fashion starting from the earliest evidences from Africa where the earliest bipedal hominins appeared at about 7 million years ago. This will be followed by the biological and adaptive traits of the various Australopithecine species and the earliest Homo species. The combined roles of stone tools, control of fire, and diverse subsistence strategies will be taught using specific case studies from well-studied paleoanthropological sites across the Old World. Following the time after 3 million years ago, the biological, behavioral and technological evidences will discussed through integrated multidisciplinary perspectives.
- Key conceptual issues will be taught and discussed based on the latest discoveries and associated published and online resources. These issues include the hunting vs. scavenging debate, the role of climate on animal and human evolution, the number and context of hominin dispersals, the art of naming a new hominin species, technological innovations and social exchange networks, animal overkill hypothesis, and so forth.
- Key historical milestones in human origins studies will be discussed including various intellectual figures (e.g. the Leakeys, J.D. Clark, T. White, S. Paabo) and their contributions to the discipline.
- The third component of the course will address the growing role of genetics in human evolutionary studies in the context of recent discoveries and interpretations. These include the discovery of new hominin species in Asia, complex biological relationships between various species in time and space, and the issue of interbreeding between Neanderthals and modern humans in Eurasia. Besides a basic introduction to genetics and different analytical methods to study DNA, students will be presented with specific case studies that reflect the molecular evolution at varying scales and associated mutation events. The role of DNA in identifying diseases and the evolutionary history of specific illnesses will also be included as a part of this course component.
- Laboratory component: museums and field visits; and making/using stone tools.

Recommended Reading

- Klein, R., *The Human Career: Human Biological and Cultural Origins*, University of Chicago Press. (2009)
- Jobling, M. et al., *Human Evolutionary Genetics*, Garland Science. (2013)
- Selected PDFs addressing specific paleoanthropological sites and genetic studies from Africa, Europe and Asia.

HSS617: From Plassey to partition: A history of modern India

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- 18th Century India: characterization, general features and in particular the historiographical implications of the notion of dark age, the implication of the characterisation of the 18th century on the origins of colonialism in India.
- Brief introduction to colonialism, capitalism and imperialism: definitions. British revenue policies: origins and consequences, types of revenue/tenurial systems; three stages of colonialism; deindustrialization, commercialisation of agriculture and their impact in the rural economy, and the mode of production debate on India.
- Formation of all India community of English educated intellectuals and the educational policies of the British; 19th century socio-religious reform movements: an assessment; Ideas on caste and the growth of caste reform movements in India.
- Civil rebellions in the early 19th century and the Revolt of 1857: historiographical perspectives.
- Emergence and Growth of Indian nationalism: origin and growth during the 19th Century; History of anti-colonial struggles: 1885-1905, 1905-11, 1920-22, 1930-34, and 1942.
- History of peasant and tribal movements; formation of working class in India, the history of trade union movements, anti-caste movements and the attitude of Indian National Congress towards these movements.
- Science and Industrialization: Private Investments in India, New Industrial Policy, Discourse on Science in late 19th and early 20th century India, National Planning Committee.
- Towards partition: ideology, history and players.

Recommended Reading

- Bipan Chandra, Aditya Mukherjee, K. N. Panikkar, Mridula Mukherjee & Suchetem Sumit Sarkar, *Modern India, 1885-1947*, Macmillan India, 2002.
- Sekhar Bandopadhyaya, *From Plassey to Partition: A History of Modern India*, Orient Blackswan, 2004.

- K. N. Panikkar, *Culture, Ideology, Hegemony: Intellectuals and Social Consciousness In Colonial India*, Tulika Books, Delhi, 1998.
- Perry Anderson, *The Indian Ideology*, Three Essays Collective, New Delhi, 2012.
- Bipan Chandra, *Essays on Colonialism*, Orient Blackswan, New Delhi, 2009.
- Sugata Bose & Ayesha Jalal, *Modern South Asia: History, Culture and Political Economy*, Routledge, London, 1998.
- Thomas R. Metcalf, *Ideologies of the Raj*, Cambridge University Press, Cambridge, 1994.

HSS618: India from prehistory to early history

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Lower Paleolithic (Oldowan, Acheulean), Middle Paleolithic (Levallois, modern humans) and Upper Paleolithic (modern human evolution); multidisciplinary evidence including contextual, geochronological and archaeological data; Various human dispersals and ecological adaptations.
- Mesolithic cultures and associated symbolic behaviors (e.g. rock art);
- Neolithic cultures and the beginning of agriculture; regional variations (e.g. Kashmir Neolithic; ashmound sites); the Neolithic problem in India.
- Regional Chalcolithic cultures (e.g. Ahar-Banas, Malwa, Jorwe, Savalda) and the Harappans (their rise, maturation and decline); the Aryan debate.
- Early Iron Age cultures: Black and Red Ware (BRW), Painted Grey Ware (PGW) cultures, Vedic life, social organization and religious life.
- Urbanization in the Gangetic Valley: Transformation of territories into kingdoms, Northern Black Polished Ware (NBPW) culture, agrarian order, trade, social organization, rise of Sramanic religions, social base of Buddhism and Jainism.
- Competing States to Empire: Magadha from city-state to empire, Mauryas, political outline, sphere of influence, nature of administration, internal and foreign trade, agrarian base, social organization and decline.
- South India: Early Iron Age cultures, Chera, Chola and Pandyas, Sangam literature, social formation, nature of polity, socio-economic organization, nature of trade and urbanization.
- From Mauryan Empire to Secondary State Formations: Satavahanas and Kalinga, nature of secondary state formations, agrarian base, social organization, trade and religious life.
- Indo-Greeks, Shakas, Parthians, Kushanas and Kshatrapas and the Rise of Mercantile Communities.
- Guptas: Political outline, nature of polity, administration, social organization, agriculture, trade, art and literature, golden age for whom?

Recommended Reading

- D. N. Jha, *Early India: A Concise History*, Manohar, 2004.
- Romila Thapar, *The Penguin History of Early India: From the Origins to AD 1300*, Penguin,2003.
- Upinder Singh, *A History of Ancient and Early Medieval India: From the Stone Age to the 12th Century*, Pearson Longman, 2009.
- Kennedy, K. A. R. 2001., *God-Apes and Fossil-Men. Paleoanthroplogy in South Asia*, Michigan University Press.
- Nayanjot Lahiri, (Ed), *The Decline and Fall of the Indus Civilization*, Permanent Black, 2000.
- Brajadulal Chattopadhyaya, *Studying Early India: Archaeology, Texts and Historical Issues*, Permanent Black, 2005.
- Rajan Gurukkal, *Social Formations of Early South India*, Oxford University Press, 2010.

HSS619: Ancient greek theatre: Aeschylus, Sophocles and Euripides

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Tragedy as a dramatic genre is central to ancient Greek theatre. A compound of two Greek words tragos (goat) and ode (song or to sing), tragedy is a theatrical form performed in honour of the Greek mythological figure of Dionysus. The greatest exponents of Attic tragedyAeschylus, Sophocles, and Euripidesdrew their characters and themes primarily from Greek myths. Focusing on in-depth analyses of representative Greek tragediesAeschylus The Oresteia trilogy and Prometheus Bound, Sophocles The Theban Plays, and Euripides Medea, Bacchae, and The Trojan Womanthis course attempts to unveil the enduring legacy of ancient Greek theatre.

Recommended Reading

- *Aristotle, Poetics*, (Trans. Malcolm Heath), Penguin (1996).
- Aeschylus, *The Oresteia: Agamemnon, The Libation Bearers*, The Eu menides (Trans. Robert Fagles), Penguin Books (1979).
- Bloom, Harold, *Greek Drama*, Chelsea House Publishers (2004).
- Euripides, *The Trojan Woman* (Trans. Gilbert Murray), Watchmaker (1980).
- Gregory, Justina, *A Companion to Greek Tragedy*, Blackwell Publishing (2005).
- Kitto, H. D. F., *Greek Tragedy*, Routledge (2011).

- McLeish, K., *A Guide to Greek Theatre and Drama*, Bloomsbury (2003).
- Nietzsche, Friedrich, *The Birth of Tragedy. Out of the Spirit of Music* (Trans. Shaun Whiteside), Penguin (1993).
- Poole, Adrian, *Tragedy: A Very Short Introduction*, Oxford Press (2005).
- Sophocles, *The Theban Plays: Antigone, Oedipus the King, Oedipus at Colonus* (Trans. Robert Fagles), Penguin (1980).
- Sophocles, Euripides, and Aeschylus,*Five Great Greek Tragedies: Prometheus Bound, Oedipus Rex, Electra, Medea, Bacchae*, Dover Publishing (2004).

HSS620: Imagining India: An intellectual history of orientalism

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- This course will introduce the select writings on India by European scholars during the eighteenth and nineteenth century and the interpretative essays on this intellectual tradition. Conscious of the internal diversity and ideological orientation of European intellectuals and their writings on India, this course focuses on imagining India whose themes range from language and literature, caste, religion, kingship, history, architecture to visual representations like paintings and photography. The framework of the course is not to equate Orientalism with the exercise of power (although this aspect is evident in a few case studies) but to emphasise on the certain enduring intellectual breakthrough that has come to stay on studies related to South Asian history and culture. The course intends to survey the select writings of William Jones, Abbe Dubois, James Mill, Friedrich Max Muller, Robert Caldwell, Francis Whyte Ellis, W W Hunter, H H Risley, Edgar Thurston, William Simpson and James Fergusson.

Recommended Reading

- Archer, Mildred, *Early Views of India: The Picturesque Journeys of Thomas and William Daniel*, Thames and Hudson (1980).
- Ballantyne, Tony, *Orientalism and Race: Aryanism in the British Empire*, Palgrave (2002).
- Cohn, Bernard,*Colonialism and Its Forms of Knowledge*, Oxford University Press (1998).
- Dalmia, Vasudha, *Orienting India: European Knowledge Formations in the Eighteenth and Nineteenth Century*, Three Essays Collective (2003).
- Dodson, Michael, *Orientalism, Empire and National Culture, India 1770-1880*, Cambridge Press (2010).
- Inden, Ronald, *Imagining India*, Blackwell (1990).

- Mackenzie, John, *Orientalism: History, Theory and the Arts*, Manchester University Press (1995).
- Mitter, Partha, *Much Maligned Monsters: A History of European Reactions to India Art*, Oxford University Press (1977)
- Majeed, Javed, *Ungoverened Imaginings: James Mills The History of British India and Orientalism*, Clarendon Press (1992).
- Talbott, Cynthia, (ed), *Knowing India: Colonial and Modern Constructions of the Past*, Yoda Press (2011).
- *Thakurta, Tapati-Guha, Monuments, Objects, Histories: Institutions of Art in Colonial and Post- colonial India*, Permanent Black (2004). Trautmann, Thomas, Aryans and British India, Yoda Press (2004).
- Schwab, Raymond, *The Oriental Renaissance: Europes Rediscovery of India and the East*, 1680 to 1880, Cambridge University Press (1984)

HSS621: Intellectual and cultural sources of modernity

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline This course is aimed at answering the question: What is modernity? What makes a society modern? How does the Indian experience of modernity differ from societies in Europe and North America and from its neighbors in Asia?
This course will start with the assumption that the transition from traditional to modern societies results from the interaction of a number of deeply structural processes of change taking place over a long period of time. These processes include the political, the economic, the social and the cultural. While the political (the rise of the nation state) and the economic (the rise of industrial capitalism) will not be ignored, the emphasis will be on the social and cultural/intellectual factors in the emergence of modernity.
We will focus on the following cultural and intellectual movements that have shaped the modern consciousness:

- The Scientific Revolution: We will focus on the dis-enchantment of nature, and the growing respect for experimental and inductive reasoning brought about by the Scientific Revolution through 1500-1700 CE.
- The Enlightenment: We will read key texts of the Enlightenment, the 18th century intellectual movement that challenged the traditional sources of social authority in the name of reason, individual liberties and progress.
- Secularization: The emergence of secular nation-states and social orders that sought their legitimacy from the popular will, rather than divine will.

How these intellectual-social currents, which gathered force first in Europe, Britain and North America gradually became globalized will be our second main focus of interest. Here we will look at:

- Women's Rights and Modernity: The often contradictory relationship between the rhetoric of freedom and equality and the continued exclusion of women from the public sphere through the Enlightenment will be examined.

- Colonial modernity: How colonialism both enabled and distorted the growth of science and secularism in colonial societies, with India as an example.
- Multiple Modernities: Different cultural routes to modernity in the globalizing world will be examined.

Selected Readings

- Anderson, Marshall, *All that is Solid melts into Air: Experience of Modernity* Penguin, USA, 1988
- Gay, Peter, *The Enlightenment: An Interpretation, vol I and II* Basic Books, 1973.
- Hall, Stuart (ed.), *Formations of Modernity* Polity Press, 1992
- Jacob. Margaret, *The Cultural Meaning of the Scientific Revolution* Knopf, 1988.
- Nanda, Meera, *Breaking the Spell of Dharma: A Case of Indian Enlightenment* Three Essays Collective, 2002.
- Pathak, Abhijit, *Indian Modernity: Contradictions, Paradoxes and Possibilities* Gyan, 2008.
- Singer, Milton, *When a Great Tradition Modernizes: An Anthropological Approach to Indian Civilization* Midway Reprints, 1980.

HSS622: Cities: Urban theory and laboratory

[Cr:4, Lc:2, Tt:0, Lb:2]

Course Outline

HISTORY: What is a city, evolution of settlements to cities, early and classical cities, medieval cities, colonial cities, industrialization and the city, trade and the city, Islamic city, city in Hindu thought and planning, port cities, the modernist city, Globalization and the city.

FORM: Understanding urban form, map reading and interpretation, city in literature, art, film; Lynch's 'Image of the city'; Public space and public life, 'organic' city versus planned city, Google earth and the city, case studies (may include Mohenjodaro, Banaras, Rome, London, New Delhi, New York, Jaipur, Istanbul, Venice, Paris, Chicago, Mexico city, Chandigarh among others.)

FUNCTION: Understanding urban transportation, waste collection and disposal, electricity and water distribution and services in the city, urban ecology, city-hinterland relationships, urban farming, city and water, urban parks.

THEORY: urban systems, central place theory, world systems theory, capitalism and the city, flexible accumulation through urbanization, theory of gentrification, sustainability issues in the city, urban sprawl, climate change and the city, segregation, politics of development in cities, migration and urban slums, politics of participation and protest, Social difference (gender, caste, class, nationality) in the city.

Recommended Reading

- Richard T. LeGates, Frederic Stout, *City Reader*, (Routledge Urban Reader Series). Taylor & Francis (2011).
- Italo Calvino, *Invisible Cities*, Harcourt Brace Jovanovich (1978).
- Tim Hall, Heather Barret, *Urban Geography* Routledge (2012).
- Ash Amin, Nigel Thrift, *Cities: Reimagining the Urban Polity*, (2002).
- Spiro Kostof, *The City Shaped: Urban Patterns and Meanings Through History*, Bulfinch (1993).

HSS623: Bodily encounters: Mobility, migrancy and movement

[Cr:4, Lc:2, Tt:0, Lb:2]

Course Outline

- Migration and mobility are the defining characteristics of contemporary society. According to UN data (2010) about 1/6th of the worlds population is on the move. This course seeks to understand human mobitliy from a social, economic and political perspective.
- A brief spatial history of Human mobitliy from prehisoty to contemporary times.
- Theories of migration, Push and Pull factors, volunatry versus involuntary migration, internal migation and immigration.
- Understanding migration in the context of relationship between people, the state and identity.
- Immigration, remitances, brain drain, diaspora.
- Race and migration.
- Labour, working class and migration.
- Gender and migration, Feminization of migration. Encampment and international refugees.
- Disaster induced displacement, urbanization induced displacement, experiencing displacement.
- Travel writings, diasporic fiction, memoirs, films and narratives.

Recommended Reading

- Ian Goldin, Geoffrey Cameron & Meera Balarajan,*Exceptional People: How Migration Shaped Our World and Will Define Our Future*, Princeton University Press. (2011)
- Peggy Levitt, *The Transnational Villagers*, University of California Press. (2001).

- Portes, Alejandro & Josh DeWind (eds), *Rethinking Migration: New Theoretical and Empirical Perspectives*, Berghahn Books. (2007).
- Cathy A. Small, *Voyages: From Tongan Villages to American Suburbs*, Cornell University Press. (1997).
- Miriam Davidson, *Lives on the Line: Dispatches from the US-Mexico Border*, University of Arizona Press. (2000)
- Salazar-Parrenas, R, *Servants of Globalization. Women, Migration and Domestic Work*, Stanford University Press. (2001).
- Ong, Aihwa, *Flexible Citizenship: The Cultural Logics of Transnationality*, Durham: Duke University Press. (1999).
- Baldassar, L & Merla, L. (eds),*Transnational Families, Migration and the circulation of Care*, London. Routledge. (2013).
- Lavie, S. & Swedenburg, T., *Displacement, Diaspora, and Geographies of Identity*, London: Duke University Press.(1996).

HSS624: Understanding cultures: Past and present using fieldwork, laboratory and archives

[Cr:4, Lc:1, Tt:0, Lb:3]

Course Outline This course introduces the students to multiple methods of understanding human cultures across the ages. It is an interdisciplinary introduction to methods used in Anthropology, Archeology and History. The course is largely field based and incorporates theory through engaging students in situated practices. A significant portion of the course will be taught in the field.

- **Ethnographic Methods:** Understanding Culture: historical and critical approaches to studying culture Ethnography: planning a qualitative study, subjective engagements in the field, representation of a reality. Techniques: Participant observation , structured and open-ended interviews Visual Anthropology Interrogating the field in fieldwork Ethics in research: Insider/outsider debate, politics of representation, self and the other, observer and the observed Analyzing and writing up ethnographic research: Content analysis, Discourse analysis, meaning making, representation.
- **Archeological Methods:** History of research methods in global and Indian archeology Reading, writing and presenting in archeology: reading and gauging published materials; writing grant proposals; publishing general and scientific articles in archeology; presenting research results Archeology field methods: planning stage, documentation required, equipment required (e.g. Global Positioning System), survey and excavation methods; documenting geological and archaeological sections, surface collections of artifacts. Archeology lab methods: curation, cataloging, database construction, specimen labeling and photography, experimental archeology portion, quantifying data and basic statistics of large data sets; maintaining field equipment and labs.
- **Archival Methods:** Understanding Archive: Documentation, History and Structure History and Memory: Interrogating Archive.

Recommended Reading

- Burke H. & Smith C., *The Archaeologists Field Handbook*, Allen 7 Unwin (2007).
- Joglekar, P. P., *Research Methods for Archeology Students*, Ravindra Gurjar & Gayatri Sahitya (2014).
- Denzin and Lincoln (Eds.), *Handbook of Qualitative Methods*, (Second Edition), Sage (2000).
- Geertz, C., *The Interpretation of Cultures*, Basic Books (1973).

HSS625: The archaeology of ancient technologies

[Cr:4, Lc:2, Tt:0, Lb:2]

Course Outline

- *Technological innovations and tool use in the animal world*: Tool use by monkeys, apes, birds, mammals and their evolutionary and cultural significances.
- *History of ancient human technology (Prehistoric to Protohistoric stages)*: developmental histories of key technologies by various cultural groups and societies since the last 3 million years; longevity of certain tool types and tool-kits.
- *Theoretical concepts*: Paleolithic and Chalcolithic lifeways; key technological innovations and their subsequent geographic dispersals; cultural and socio-economic impacts; techno-cultural change and stasis; human ecology and technological adaptations.
- *Experiential and experimental archaeology*: Replicating stone tools, spears, atlatls, bows & arrows, rock art, pottery, iron slag; testing artifact efficiency and material impact (e.g. stone on meat/bone/wood and vice versa; firing of pottery and utilization for boiling/cooking; making rock paintings using natural minerals/materials)
- *Scientific methods*: Sourcing raw materials, provenance verses provenience; Systematic project execution; activity documentation and data quantification; microscopic analyses; residue analyses; hypotheses testing; cognitive abilities

Recommended Reading

- Chapters from edited volumes and articles from such sources as *Journal of Archaeological Method & Theory and Journal of Archaeological Science.*
- Coles, J. 2010. *Experimental Archaeology.*
- Flores, J. R., Paardekooper, R. (Eds.) 2014. *Experiments Past: Histories of Experimental Archaeology.*
- Foulds, F. W. F. 2013. (Ed.) *Experimental Archaeology and Theory: Recent Approaches to Archaeological Hypotheses.*
- Whittaker, J. C. 1994. *Flintknapping: Making and understanding stone tools.*

HSS626: Economic history of modern India

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- This course will examine the stages in the economy of Modern India from first stage of colonialism to the British industrial domination of the nineteenth and financial imperialism of early twentieth century and trends in economic history writing. The course will also deal with the development of Indian industries and capitalist class during the early twentieth century in its struggle against British monopoly of Indian economy. A brief recourse to the economic developments in the post-independence period will be provided.

Recommended Reading

- Amiya Kumar Bagchi, *Colonialism and Indian Economy*, Oxford University Press, 2010.
- B. R. Tomlinson, *The Economy of Modern India, 1860-1970*, Cambridge University Press, 1993.
- Tirthankar Roy, *The Economic History of India, 1857-1947*, Oxford University Press, 2000.
- Aditya Mukherjee, *Imperialism, Nationalism and the making of Indian Capitalist Class, 1920-1947*, Sage Publications, 2002.
- Book chapters and Journal articles (List of Journals - *Indian Economic and Social History Review, Economic and Political Weekly, Journal of Economic History, Past and Present, Journal of Asian Studies, Modern Asian Studies*).

HSS627: The idea of India: Intellectual imaginary of nation

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline This course will engage with the ideas on India articulated by the leading figures of modern India M.K. Gandhi, Jawaharlal Nehru, B.R. Ambedkar, V.D. Savarkar, M.S. Golwalkar, S.A. Dange, M.N. Roy among other thinkers and in the process deal with the theme of history, culture, religion, caste and class in the imaginary of nation. Focusing on the key texts (stated below) of these thinkers and interpretative secondary readings on them, the course will attempt to understand the durability of their thought and the legacy it has created in contemporary India as indeed the heterogeneous and contested imaginary of nation.

- M. K. Gandhi, Hind Swaraj.
- Jawaharlal Nehru, The Discovery of India.
- B. R. Ambedkar, Castes in India, Annihilation of Caste and Philosophy of Hinduism.
- V. D. Savarkar, Hindutva: Who is a Hindu?

- M. S. Golwalkar, Bunch of Thoughts, We, or Our Nationhood Defined.
- S. A.Dange, India from Primitive Communism to Slavery.
- M. N. Roy, India in Transition and other writings.

Recommended Reading

- Anthony J. Parel, Gandhi: *Hind Swaraj and Other Writings*, Cambridge University Press, 1997.
- C. A. Bayly, *Recovering Liberties: Indian Thought in the Age of Liberalism and Empire*, Cambridge University Press, 2012.
- Christophe Jaffrelot, *The Hindu Nationalist Movement and Indian Politics 1925 to the 1990s*, Penguin Books, 1999.
- Christopher Jaffrelot, *Dr. Ambedkar and Untouchability: Analyzing and Fighting Caste*, Columbia University Press, 2005.
- Kris Manjapra, M. N. Roy: *Marxism and Colonial Cosmopolitanism*, Routledge India, 2010.
- Martha C. Nussbaum, *The Clash Within: Democracy, Religious Violence, and India's Future*, Harvard University Press, 2009.
- Ramachandra Guha, *Makers of Modern India*, Harvard University Press, 2011.
- Sabyasachi Bhattacharya, *Talking Back: The Idea of Civilization in the Indian Nationalist Discourse*, Oxford University Press, 2012.
- Sunil Khilnani, *The Idea of India*, Penguin Books, 2004.

HSS628: Epistemology of science

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Introduction: Epistemological roots of scientific knowledge.
- Theories of scientific knowledge: Rationalism and empiricism, foundational, coherentism, correspondence.
- Naturalised epistemology and evolutionary epistemology.
- Scientific objectivity:
  - Theory-Ladenness and Incommensurability,
  - Standpoint Theory, Contextual Empiricism and Trust in Science,
  - Objectivity as Freedom from Personal Biases: Measurement and Quantification, inductive and statistical inference.
- Is Science progressive? Aspect of scientific progress, theories of scientific progress-realism and instrumentalism, empirical success and problem solving, explanatory power, unification and simplicity, truth and information.

Recommended Reading

- Aronson, J.L., Harr, R. and Way, E.C.,*Realism Rescued: How Scientific Progress is Possible*, London: Duckworth, 1994.
- Callebaut, W. and Pinxten, R. (eds.),*Evolutionary Epistemology*, Dordrecht: D. Reidel, 1987.
- Chisholm, Roderick,*Theory of Knowledge, 2nd edition. Englewood Cliffs*, NJ: Prentice-Hal, 1977.
- Dilworth, C.,*Scientific Progress: A Study Concerning the Nature of the Relation Between Successive Scientific Theories*, Dordrecht: Reidel, 1981.
- Kuhn, T.S.,*The Structure of Scientific Revolutions*, Chicago: University of Chicago Press, 1962. 2nd enlarged ed, 1970.
- Lacey, H.,*Is Science Value-Free?*, London: Routledge, 1999.
- Niiniluoto, I., *Scientific Progress*,Synthese, 1980, 45: 427464.
  - 1984,*Is Science Progressive?*,Dordrecht: D. Reide
- Reichenbach, H., *On Probability and Induction,Philosophy of Science*, 1938. 5: 214
- Salmon, Wesley, *The Foundations of Scientific Inference*, University of Pittsburg Press,(1967).
  - 1984, *Scientific Explanation and the Causal Structure of the World.*
  - 1990, *Four Decades of Scientific Explanation*,(1990).
  - 1998, *Causality and Explanation*,(1998)

HSS629: Metaphysics of science

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Nature of metaphysics and science, metaphysical foundations of science.
- Realism and Anti-realism debates in philosophy of science, varieties of realism and anti-realism.
- Laws and the nature of causation, causal processes, models of laws of nature and its critiques.
- Concepts of scientific essentialism, natural kinds and dispositions, natural kinds in the physical and the biological sciences.
- Essential ideas of naturalized metaphysics.

Recommended Reading

- A. Chakravartty, *A metaphysics for scientific realism: knowing the unobservable*, Cambridge University Press (2007).
- C. Dilworth, *The metaphysics of science*, Springer (2007).
- B. Ellis, *Scientific essentialism*, Cambridge University Press (2007).
- J. Ladyman and D. Ross,*Everything must go: Metaphysics Naturalized*, Oxford University Press (2007).
- J. LaPorte, *Natural kinds and conceptual change*, Cambridge University Press (2004).
- E. J. Lowe, *Four category ontology- A metaphysical foundation for natural science*, Oxford University Press (2006).
- S. Psillos, *Scientific realism: how science tracks truth*, Routledge (2005).

HSS630: Social theory and religion

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline Religion continues to play a vital role in the lives of contemporary Indians. The growing importance of religion in the public sphere is also self-evident. And yet, a social scientific study of religion is conspicuous by its absence in educational institutions. This is unfortunate as it deprives students of creative ways of thinking about religions, and placing them in history and society. This course is intended to familiarize students with the rich resources social theory offers on how to think about religion. Students will be introduced to nine major theories of religion: Animism and Magic (E.B. Tylor and J.G. Frazer), Religion and personality (Sigmund Freud and Sudhir Kakar), Society as Sacred (Emily Durkheim), Religion as alienation (Karl Marx), The Reality of the Sacred (Mircea Eliade), Societys construct of the heart (E.E. Evans-Pritchard), Religion an Cultural System (Clifford Geertz), Religion as Source of Social Action (Max Weber) and Evolutionary theories of religion.

Recommended Reading

- James Beckford, *Social Theory and Religion*, Cambridge University Press, 2003.
- Daniel Pals, *Seven Theories of Religion*, Oxford University Press, 1996.
- Brian S. Turner, *Religion and Modern Society*, Cambridge University Press, 2011.

HSS631: Epistemology and logic

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Topics on Epistemology: Introductory discussions on epistemology as a branch of philosophy- The major themes that concern epistemology like sources of knowledge, nature of belief and justification and skepticism. Sources of justification. Traditional analysis of the concept of knowledge. Gettier counterexamples to the traditional analysis of knowledge. Theories of justification including foundationalism, coherentism, reliabilism and virtue epistemology. Internalism and Externalism. Skepticism. An Introduction to Indian Epistemology.
- Logic: What is the subject matter of logic? Basic terms in logic. Truth, validity, argument and propositions. Fallacies in logic. Purposes and types of definitions. Categorical syllogism. Compound statements, connectives and their truth. Statement forms material equivalence and logical equivalence. Formal proofs of validity, invalidity and inconsistency. Quantifier logic. Nature of Evidence and nature of arguments by analogy. An introduction to philosophical logic. Schools of thought in Indian logic.

Recommended Reading

- Robert Audi, *Epistemology: A Contemporary Introduction to Theory of Knowledge* Routledge (2010).
- Noah Lemos, *An Introduction to Theory of Knowledge* Cambridge University Press (2007).
- Paul Moser, *Oxford Handbook of Epistemology* Oxford (2005).
- Copi and Cohen, *Introduction to Logic* Prentice Hall (2009).
- Cohan and Nagel, *An Introduction to Logic and Scientific Method* Hackett Publishing (1934).
- A. C. Grayling, *Introduction to Philosophical Logic* Blackwell (2001).
- Jwala Prasad, *History of Indian Logic* Munshiram Monharlal Publishers (1987).

HSS632: Philosophy of rationality

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline This is a theme based course on reason and rationality. It is a reading course.

- Idea of reason and rationality. Structure and substance of rationality, theoretical and practical reason. Evidence and analysis. Historicist theories of rationality.Scientific rationality.
- Science and religion and conflict. Debates on faith and reason. Dawkins, Gould, Gutting and Marx on religion(with focus on role of reason).
- Science and psuedoscience- the nature of its demarcation.
- Rationality in Indian thought.
- Reason in the context of justice, morality and identity. Idea of public reason.

Recommended Reading

- R. Audi, *Architecture of Reason*, Oxford University Press, 2002
- R. Dawkins, *The God Delusion*, Bantam Press, 2008
- P. Kurtz, *Science and Religion*, Prometheus Books, 2003
- J. Ganeri, *Philosophy in Classical India*, Routledge, 2001

Suggested Reading

- J. Elster, *Reason and Rationality*, Princeton University Press, 2009
- Selected entries from `http://plato.stanford.edu`

HSS633: Ethics

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Introduction to Moral Theory: Normative ethics and Meta-ethics. Connection between the two.
- Meta-ethical theories: Moral Relativism, Naturalism, Non-naturalism, Moores challenge to naturalism, Emotivism and challenge to naturalism, Prescriptivism, Norm expressivism, Error theory and Moral Realism.
- Normative Ethics: Consequentialism, Kantian ethics, Virtue Ethics and Contractualism.
- Science and Ethics.
- Additional Topics.
- Modern Theories of Justice.

Recommended Reading

- Miller, Alexander 2013. *Contemporary Metaethics: An Introduction*, 2nd Edition, Polity Press
- Frankena, William 1999. *Ethics*, 2nd Edition, Prentice Hall India
- Bennett, Christopher 2010. *What is this Thing Called Ethics?* Routledge
- Hudson, W. D. 1983. *Modern Moral Philosophy*, 2nd Edition, Macmillan
- Kurtz, Paul (ed.) 2007. *Science and Ethics*, Prometheus Books
- Brighouse, Harry 2004. *Justice*, Polity Press
- Sandel, Michael 2010. *Justice: Whats the right thing to do?* Penguin

HSS634: Themes in infrastructure studies

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Introduction: What is Infrastructure (studies)?
- Subject/Object.
- Railways.
- Bijli, Sadak, Pani (Electricity, Road, Water).
- Virtual Things: Finance, Telecommunication, Internet, UID.
- Energy Politics.
- Climate Change and the New Frontiers of Justice.
- The Infrastructure Working Class.
- Conclusion: What is Public/Common Good?

Recommended Reading

- Anand N., *PRESSURE: The Politechnics of water supply in Mumbai*, Cultural Anthropology,2011. 26(4):54264
- Anand N., *Municipal disconnect: on abject water and its urban infrastructures*. Ethnography, 2012. 13(4):487509
- Barry A., *Political Machines: Governing a Technological Society*. London: Continuum, 2001.
- Bear L., *Lines of the Nation: Indian Railway Workers, Bureaucracy, and the Intimate Historical Self*, New York: Columbia Univ. Press, 2007.
- Bennett J., *Vibrant Matter: A Political Ecology of Things*, Durham, NC: Duke Univ. Press, 2010.
- Deleuze G., *Postscript on the societies of control*. October 59:37, 1992.
- Graham S., Marvin S., *Telecommunications and the City: Electronic Spaces*, Urban Places. London: Routledge, 1996.
- Graham S., Marvin S., *Splintering Urbanism: Networked Infrastructures, Technological Mobilities and the Urban Condition*, London: Routledge, 2001.
- Guldi Jo., 2012, Roads to Power: Britain Invents the Infrastructure State,Boston, Harvard University Press, 2013.
- Harvey P., *The topological quality of infrastructural relation: an ethnographic approach*. Theory Culture Society, 2012. 29(45):7692.
- Harvey P., Knox H., *The enchantments of infrastructure. Mobilities*, 2012. 7(4):52136
- Hughes T. P., *Networks of Power: Electrification in Western Society*, 18801930. Baltimore, MD: Johns Hopkins Univ. Press, 1993.
- Larkin Brain, *The Politics and Poetics of Infrastructure, Annual Review of Anthropology*, 42. 327-43, 2013.

- Latour Bruno,*Pandoras Hope: Essays on the Reality of Science Studies*, Boston, Harvard University Press, 1999.
- Mrzek R., *Engineers of Happy Land: Technology and Nationalism in a Colony*, 2002, Princeton University Press, 2002.
- Mitchell T., *Carbon Democracy: Political Power in the Age of Oil.* New York: Verso, 2011.
- *Public Culture. Special issue on Infrastructures of the Urban*, No 70 Duke 978 0 8223 6788 8.
- Smith Carl, *City Water, City Life: Water and the Infrastructure of Ideas in Urbanizing Philadelphia*, Boston and Chicago, University of Chicago Press, 2013.

HSS635: Political philosophy

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Introduction to Political Theory: The meaning of political; what is a political theory? Nature of ideology, Nature of the human condition.
- Fundamental concepts of political thought: Power, Authority, Legitimacy, Liberty, Equality, Justice, Democracy, Citizenship, Civil Society.
- Fundamental political ideologies, their history and important thinkers: Liberalism, Conservatism, Socialism, Nationalism and Multiculturalism.
- Types of Political Arguments: Secularism, Freedom of Speech and Affirmative Action.

Recommended Reading

- I. Adams, *Political Ideology Today*, Manchester University Press, Manchester 2001.
- R. Bhargava and A. Acharya, *Political Theory*, Pearson, New Delhi 2016.
- H. Brighouse, *Justice*, Polity Press 2004.
- A. Heywood, *Political Theory An Introduction*, Palgrave Macmillan 2015.
- A. Heywood, *Politics*, 4th Edition, Palgrave Macmillan 2014.
- W. Kymlicka, *Contemporary Political Philosophy*, 2nd Edition, OUP 2014.
- B. R. Nelson, *Western Political Thoughts: From Socrates to the Age of Ideology*, Pearson, New Delhi 1996.
- M. Sandel, *Justice: Whats the right thing to do?* Penguin 2010.
- A. Swift, *Political Philosophy*, 3rd Edition, Polity Press, United Kingdom 2013.

HSS636: Climate change and sustainable development

[Cr:4, Lc:3, Tt:0, Lb:1]

Course Outline The course initiates a study of climate change impact, adaption and mitigation strategies in the framework of sustainable development.

- Introduction to climate and climate change. Natural and anthropogenic climate change.
- Learning from the past: Climate Change in Deep Time: Snowball Earth, Icehouses and Greenhouses
- Assessment of future climate change impacts on freshwater resources and their management practises, agriculture, food security, forests and fibre products, coastal systems and low lying areas, mountainous areas and fragile ecosystems, industries, settlements and society, human health.
- Implication of future climate change for rural and urban societies.
- Learning from the past: The loss of the "Saraswati" river and its impact on the urban phase of the Indus Valley civilisation.
- Case studies on present day climate change, perception of climate change and adaption to changing cropping patterns and water availability among rural communities in the Himalaya mountains. The effect of climate change on vulnerable communities.
- Climate change and gender.
- Assessment of future impacts and adaption strategies for the Indian subcontinent. Strategies of coping with inaccurate predictions. Assessing current gaps in the scientific understanding of local climate change and its effect on Monsoon rainfall and agricultural output.
- Inter-relationships between climate change adaptation and mitigation. Perspectives on climate change and sustainability and the link between sustainable development and climate change mitigation.
- Economic growth beyond "peak oil". Perspectives on the role of active climate change mitigation in the energy and transport sector in accomplishing sustainable and inclusive growth and its importance for national security and political independence throughout the 21st century. Perspectives on the the link between sustainable growth in agriculture, food security and National Security. Waste management and human health. Mitigation from a cross sectoral perspective.

Recommended Reading

- Andrew Dessler, *Introduction to Modern Climate Change*, CUP, 2012
- W. F. Rudimann, *Earth's Climate-Past and Future*, W. H. Freeman & co., 2001
- *Climate Change 2007 - Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the IPCC.*

- *Climate Change 2007 - Mitigation of Climate Change Contribution of Working Group III to the Fourth Assessment Report of the IPCC.*
- Pragya D. Varma (Ed), *Reflections of Climate Change Leaders from the Himalayas, Report Case Studies Detailed. Thematic Group: Livelihoods and People's Perceptions*, LEAD India, 2010
- Nellemann, C., Verma, R., and Hislop, L. (eds). *Women at the frontline of climate change: Gender risks and hopes A Rapid Response Assessment*, 2011. United Nations Environment Programme, GRID-Arendal.

Suggested Reading

- Bates, B. C., Z. W. Kundzewicz, S. Wu and J. P. Palutikof, (eds), *IPCC Technical Paper VI - June 2008 - Climate change and water*
- O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlmer, C. von Stechow (eds), IPCC, 2011: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change*, Cambridge University Press.
- *IPCC, 2011: Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)*, Prepared by Working Group II of the Intergovernmental Panel on Climate Change

HSS637: Reading records

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline This course acquaints us with the nature and the culture of the colonial archive in South Asia. It proposes to study samples from different genres of English Language record. It reads records along and against the archival grain to study the politics of truth.

- Key Categories: Archive, Document, File, Record, Context, Text, Footnote.
- Sources of History and Histories of Sources.
- Alternative Records: News Paper, Diary, Photographs, Street Signs, Proverbs.
- Reading Revenue Records: SiteBengal, 1792-1956.
- Prose of Counter-Insurgency: SiteBengal, 1792-1857.
- Primitive Accumulation of Capital and Indentured Labour in South Asia, 1890s-1930s.
- Reading Colonial Urbanism: SiteCalcutta and Bombay, 1857-1947.
- Reading the Partition Records: SiteWest Bengal, 1950s.
- Postcolonial Passages.

Recommended Reading

- A. L. Stoler, *Duress: Imperial Durabilities in Our Times*, Duke University Press (2016).
- A. L. Stoler, *Along the Archival Grain: Epistemic Anxieties and Colonial Common Sense*, Princeton University Press (2010).
- B. Raman, *Document Raj: Writing and Scribes in Early Colonial South India*, University of Chicago Press (2012).
- M. S. Hull, *Government of Paper: The Materiality of Bureaucracy in Urban Pakistan*, UC Press (2012).

HSS638: Ethnographic research and writing

[Cr:4, Lc:2, Tt:2, Lb:0]

Course Outline

- Introduction to anthropology, ethnography and history of ethnographic methods; What is culture and how to study it? What is the field? Investigating the idea of native informant. Nature of questions in ethnographic research; Research design;
- Methods of ethnography: fieldwork, participant-observation, interviewing, biography, life histories; audio and visual methods;
- Analysis of ethnographic data: writing field notes, transcription, coding, grounded theory, analysis of visual material; immersive and multi-sited ethnography; interrogating power in the field; The spatial turn in anthropology and ethnography;
- Writing culture: describing, framing and theorizing from the field; investigating experience and emotions in the field;
- Reading ethnographies: feminist ethnography; urban ethnography; disaster ethnography; ethnography of globalization, institutional ethnography, ethnography of the virtual world;
- Experimental ethnographies: sensory ethnography, participative ethnography, auto-ethnography; ethnographic filmmaking; interface of ethnography, history and fiction; ethics, positionality and reflexivity; writing ethnography.

Suggested Reading

- M. N. Srinivas, *The Remembered Village*, Second Edition, Oxford University Press. March 2013.
- M. Gordon, *Ghetto at the Center of the World: Chungking Mansions, Hong Kong*, University of Chicago Press. 2011.
- L. Nader, *Ethnography as Theory*, HAU: Journal of Ethnographic Theory 1(1): 211-219, 2011.

- C. McGranahan, *What is Ethnography? Teaching Ethnographic Sensibilities Without Fieldwork*, Teaching Anthropology 4: 23-36, 2014.
- M. Foucault, *The Archaeology of Knowledge and the Discourse on Language* New York: Vintage. Pp. 3-17, 21-39, 1994[1966].

HSS639: Advanced theory and method in Paleoanthropology

[Cr:4, Lc:2, Tt:0, Lb:2]

Course Outline This course is uniquely tailored for doctoral students who need guided exposure to fill specific theoretical and methodological knowledge gaps in paleoanthropology and archaeology. Select sub-disciplines and topics to be covered can be broadly classified under (but are not limited to) prehistory, protohistory, experimental archaeology, ethnoarchaeology, bioarchaeology, archaeo-astronomy, rock art studies, geology, taphonomy, vertebrate paleontology and paleoecology. The primary goal of this course is to teach focused topics in relation to the students growing research interests. The structure of this course will encourage critical and original thinking of controversial topics and contemporary debated issues, and students will be expected to strategically select and confront existing hypotheses and theories using theoretical, laboratory and/or field-based methods. At the end of the course, the student should present an informed and critical theoretical synthesis of the selected topic as well as turn in a small practical project including preliminary research results and their paleoanthropological implications. This will further help refine and develop their general topical interest into a viable doctoral research topic, and also provide valuable experience in paleoanthropological theory and method.

- Students will compile their own provisional reading list; additional advanced readings will be assigned and span methodological, empirical and theoretical types.
- Readings will also be supplemented by select websites, documentaries and basic fieldwork at local libraries, academic institutions, archives, heritage sites, museums and to other relevant locations of scientific, educational and cultural significance.
- Active participation expected in intensive critical discussions, oral presentations (including intellectual debates and conference presentations), pinpointed writing exercises and/or specific task-based laboratory exercises (if required) at IISER Mohali or other suitable institutions.
- Laboratory methods to be learned can include modeling, petrography (eg. XRF), geochronology (eg. OSL, paleomag, C14), osteology, geochemistry (e.g. stable isotopes), statistics of large databases, genetic studies, remote sensing and GIS, laser scanning, computer applications, brain imaging, palynology, microscopy (eg. optical, SEM) and so forth. Materials to be analyzed can include sediments, plants, vegetables, meat, stone, wood, bone, teeth, antler, shell, eggshell, terracotta, tin, copper, bronze, iron, pigment, paint, cloth, leather and so forth.

Recommended Reading

- Malainey, Mary E., *A Consumers Guide to Archaeological Science*, Springer Press, 2011.
- Select advanced papers from *Nature, Science, PLoS ONE, J. of Archaeological Science, J. of Human Evolution, J. of Archaeological Method and Theory and Current Anthropology.*

HSS640: Charlie Chaplin's aesthetic universe

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- An exploration of Chaplin's aesthetic universe that makes a critical mind rethink the intricacies of human experience.
- Issues such as poverty, unemployment, optimism and pessimism, the rag-to-riches story, capitalism and its discontents, political history, the contemporaneity of Chaplin
- A unique medium: Commingling Black humour with non-verbal performance
- Chaplin's Oeuvre: Representative films:- The Kid (1921), The Gold Rush (1925), City Lights (1931), Modern Times (1936), The Great Dictator (1940), Limelight (1952), A King in New York (1957)
- Select Chaplinesque Criticism: Wes D Gehring's Chaplin's War trilogy, Kristen Thompson's Chaplin's Romantic Comedy, Tom Gunning's Chaplin and the American Culture, David Robinson's Chaplin's Life and Art, Neil Hurley's The Social Philosophy of Chaplin, Slavoj Zizek's psychoanalytic treatment of Chaplin's movies, to name a few.

Recommended Reading

- Charles Chaplin, *My Autobiography*, Penguin Classics, London, 1964.
- Constance B. K., *Chaplin's Impure Comedy: The Art of Survival*, Film Quarterly, 1992.
- David Robinson, *Chaplin: His Life and Art.* London, Paladin, 1986.
- Huff Theodore, *Charlie Chaplin*, Abelard-Schuman, New York, 1951.
- Neil Hurley, *The Social Philosophy of Charlie Chaplin.* An Irish Quarterly Review, 1960.
- Northrop Frye, *The Great Charlie*, Canadian Forum, 1941.
- Richard Carr., *Charlie Chaplin: A Political Biography from Victorian Britain to Modern America*, Routledge, London, 2017
- Slavoj Zizek, *Enjoy Your Symptom: Jacques Lacan in Hollywood and Out*, Routledge, New York, 1992.
- Wes D. Gehring, *Chaplin's War Trilogy: An Evolving Lens in Three Dark Comedies, 1918-1947.* McFarland & Co, Jefferson, 2014.

HSS641: Research methods in the humanities and social sciences

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- This course is tailored for HSS doctoral students who need exposure to the diverse research methods in various fields in the humanities and social sciences. The primary goal of this course is to teach focused topics through pre-assigned readings that will span methodological, empirical and theoretical types, of which a balance will be sought during the course. The targeted readings will be coupled with intensive critical discussions with the relevant faculty, oral presentations (including intellectual debates), writing exercises, watching documentaries, task-based laboratory exercises and/or local field assignments (including collection of empirical and/or archival data. This course familiarizes the students with research approaches and skills. It aims to impart lectures on the following: formulating research arguments, documenting various sources, expressing the thoughts in language, writing research papers, to name a few. This course also sensitizes the researchers to the pitfalls in research, in particular, intentional and unintentional plagiarism. In addition, the researchers will also be exposed to the techniques of reading and making sense of journal articles from their respective fields. At the end of the course, the student should present an informed and critical synthesis from all the readings done; this will further help refine their general topical interest into a suitable doctoral research topic. To obtain more general knowledge of the methods required for independent doctoral research, the student(s) may also interact with relevant experts in the field of their interest, in addition to the instructor(s).

Recommended Reading

- D. Nolan, *Method in Analytic Metaphysics, in The Oxford Handbook of Philosophical Methodology*, (Eds. H. Cappelen, T. S. Gendler and J. Hawthorne), Oxford Handbooks Online (2016).
- H. White, *The Fiction of Narrative: Essays on History, Literature, and Theory*, 19572007, John Hopkins University Press (2010).
- J. Gibaldi, *Introduction to Scholarship in Modern Languages and Literatures*, The Modern Language Association of America, 2nd Edition (1992).
- MLA Handbook, *The Modern Language Association of America*, 8th Edition (2016).
- M. McHugh, *Feminist Qualitative Research: Toward Transformation of Science and Society*, in The Oxford Handbook of Qualitative Research (Ed., Patricia Leavy), Oxford Handbooks Online (2014).
- Select chapters from authored/edited books and articles from relevant journals *(e.g. Current Anthropology, American Anthropologist, American Ethnologist, Ethnography; J. of Archaeological Science, J. of Human Evolution, J. of Archaeological Method and Theory, J. of World Prehistory, Antiquity, History and Theory, Past & Present, Modern Asian Studies;*

Philosophy and Phenomenological Research, Philosophical Studies, Indian Journal of Philosophy, Studies in History and Philosophy of Science, Osiris, ISIS; Critical Inquiry, Modern Fiction Studies, American Literature, The Explicator, Journal of Modern Literature, SubStance, Diacritics).

4.5 Mathematical Sciences

MTH405: Homological algebra

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Categories and functors.
- Exact sequences and complexes.
- Hom and tensor product, Projective and injective modules, Resolutions of modules.
- Derived functors of additive functors, Ext and Tor, Homological dimension.
- (Co)Homology of groups.
- Exact couples and spectral sequences, Applications in commutative algebra and theory of groups.

Recommended Reading

- P. J. Hilton and U. Stammbach, *A Course in Homological Algebra*, Springer (1997).
- Joseph J. Rotman, *An Introduction to Homological Algebra*, (2nd edition), Springer (2008).
- H. Cartan and S. Eilenberg, *Homological Algebra*, Princeton University Press (1999).
- Sergei I. Gelfand and Yuri I. Manin, *Methods of Homological Algebra*, Springer (2010).
- S. MacLane, *Homology*, Springer (Classics in Mathematics) (1995).
- D. G. Northcott, *A First Course in Homological Algebra*, Cambridge University Press (2009).
- L. R. Vermani, *An Elementary Approach to Homological Algebra*, Chapman & Hall/CRC (2003).
- M. Scott Osborne, *Basic Homological Algebra*, Springer (Graduate Texts in Mathematics 196) (2000).

MTH406: Fourier analysis

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Fourier series of a periodic function, Cesàro and Abel summability.
- Poisson Kernel and Dirichlet problem in the unit disc.
- Pointwise and L^2-convergence of Fourier series.
- Some application of Fourier series.
- Fourier transformation on $\mathbb{R}$, convolution, Plancherel theorem, inversion formula.
- Weierstrass approximation theorem, Poisson summation formula, Hiesenberg uncertainty principle.
- Fourier transformation on $\mathbb{R}^d$.

Additional Topics

- Fourier analysis on finite Abelian group.

Recommended Reading

- E. M. Stein and R. Shakarchi, *Fourier Analysis*, Princeton University Press (2003).
- Walter Rudin, *Real and Complex Analysis*, McGraw-Hill International Edition (1987).
- G. B. Folland, *Fourier Analysis and Its Applications*, American Mathematical Society (1992).
- Anton Deitmar and Siegfried Echterhoff, *Principles of Harmonic Analysis*, Springer (2009).

MTH407: Algorithms and complexity

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Review of Turing machines and algorithms as implemented using them.
- Sorting and searching algorithms (including data structures like balanced search trees, heaps etc).
- Tree and graph traversal: depth-first and breadth first search with applications (e.g. finding biconnected components of a graph in linear time).
- Algorithm paradigms like divide-and-conquer, the greedy method (minimum spanning tree algorithms, some matroid theory), dynamic programming algorithms, backtracking and branch-and-bound.
- Complexity of algorithms. NP-Complete and NP-Hard.

Recommended Reading

- Alfred V. Aho, J.E. Hopcroft and Jeffrey D. Ullman: *The Design and Analysis of Computer Algorithms*, Addison-Wesley (1974).
- Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest, Clifford Stein, *Introduction to Algorithms,*, The MIT Press (2001).
- J. Kleinberg and E. Tardos, *Algorithm Design*, Addison Wesley (2005).

MTH408: Riemannian geometry

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Riemannian manifolds, Model spaces of Riemannian geometry, Connections, Christoffel symbols, Covariant derivatives, Geodesics, Existence and uniqueness of geodesics.
- Parallel translations, Riemannian connections, Exponential maps, Normal coordinates, Geodesics of the model spaces.
- Geodesics and minimizing curves, First variation formula, Gauss lemma, Hopf-Rinow theorem.
- Riemannian curvature tensor, Symmetries of curvature tensor, Riemannian submanifolds, Second fundamental form.
- Gauss-Bonnet theorem (local and global form), Jacobi fields, Second variation formula, Curvature and topology.

Recommended Reading

- John M. Lee, *Riemannian Manifolds; An introduction to curvature*, GTM-176, Springer (1997).
- J. A. Thorpe, *Elementary topics in Differential Geometry*, UTM, Springer (1979).
- Marcel Berger, *A Panoramic view of Differential Geometry*, Springer (2002).
- Issac Chavel, *Riemannian Geometry; A modern introduction*, Cambridge University Press, Cambridge (1993).
- M. P. do Carmo, *Riemannian Geometry*, Birkhauser, Boatan (1992).
- S. Gallot, D. Hulin, J. Lafontiane, *Riemannian Geometry*, Springer-Verlag (1987).
- Peter Petersen, *Riemannian Geometry*, Springer-Verlag (1998).

MTH409: Computational methods

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Numerical Computation: Number representaion, machine precision, round-off errors, truncating errors, random numebr generation, avail- abel numerical software.
- Linear Algebra: Solving systems of linear equations, finding inverses of matrices, Gauss-Jordan elimination, Gaussian elimination, LU decomposition, ill-conditioned systems, iterative methods (Jacob's method, Gauss-Seidel, Relaxation methods) and convergence; eigen values and eigen vectors, characteristic polynomial, power methods, Jacobi's method, QR method.
- Curve Fitting: Interpolation techniqes (Newton, Lagrange), difference formulas, cubic splines, method of least squares, two-dimensional interpolation.
- Root Finding: Bisection, False position, Newton-Raphson methods, contraction mapping methods, roots of polynomials.
- Numerical Differentiation and Integration: numerical differentiation, Newton-Cotes integration formulas, Romberg integration, Quadratures, improper integrals, multiple integrals.
- Differential Equations: Euler's method, Runge-Kutta methods, multi- step methods, Bulirsch-Stoer extrapolation methods, boundary value problems.
- PDEs: Elliptic equations, one-dimensional and two-dimensional parabolic and hyperbolic equations.
- Real-Life Examples: Google search engine, 1D and 2D simulations, weather forecasting.

Recommended Reading

- Robert J. Schilling and Sandra L. Harris, *Applied Numerical Methods for Engineers*, Thomson-Brooks/Cole (1999).

MTH410: Algebraic topology

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Homotopy, retract, deformation retract, contractible spaces and homotopy type, fundamental group and its properties, The fundamental group of circle, van Kampen theorem (statement without proof), applications of van Kampen theorem.
- Simplicial complexes, polyhedra and triangulations, barycentric subdivision and simplicial approximation theorem.
- Orientation of simplicial complexes, simplicial chain complex and homology, properties of integral homology groups, induced homomorphisms. degree of a map from n-sphere to itself and its applications

- Invariance of simplicial homology groups. Lefschetz fixed point theorem, Borsuk-Ulam theorem.
- Definition and examples of covering spaces. path lifting and homotopy lifting property.
- Covering homomorphisms, deck transformations, classification of Coverings, existence of universal covering (statement without proof).
- Graphs, coverings of graphs and their fundamental groups.

Recommended Reading

- Satya Deo, *Algebraic Topology: A Primer*, Texts and Readings in Mathematics Vol. 27, Hindustan Book Agency (2003).
- William Massey, *Algebraic Topology: An Introduction*, Springer (Graduate Texts in Mathematice Vol. 127), (1977).
- Allen Hatcher, *Algebraic Topology*, Cambridge University Press (2002).
- M. Greenberg and J. Harper, *Algebraic Topology: A First Course*, Addision-Wesley (1981).
- H. Seifert and W. Threlfall, *A Textbook of Topology*, Academic Press (1980).

MTH411: Commutative and homological algebra

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- *Recapitulation: Ideals, factorization rings, prime and maximal ideals, modules.*
- Nilradical and Jacobson radical, extensions and contractions of ideals.
- Localization of rings and modules.
- Integral dependence, integrally closed domains, going up and going down theorem, valuation rings.
- Noetherian and Artinian rings, chain conditions on modules.
- Exact sequences of modules, tensor product, projective and injective modules.
- Basics of categories and functors.
- Exact sequences and complexes in categories, additive functors, derived functors EXT and TOR functors.
- Discrete valuation rings and Dedekind domains.

Recommended Reading

- M. F. Atiyah and I. G. Macdonald, *Introduction to Commutative Algebra*, Addison Wesley (1969).
- Nathan Jacobson, *Basic Algebra* Vol. II, Dover Publications (2009).
- Joseph J. Rotman, *An Introduction to Homological Algebra*, (2nd edition), Springer (2008).
- L. R. Vermani, *An Elementary Approach to Homological Algebra*, Chapman & Hall/CRC (2003).

MTH412: Structure of algebras

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Tensor product of modules and algebras.
- Simple modules, Schur's lemma, semisimple modules, isotypical components.
- Artinian rings, semisimple rings, Jacobson radical, nil ideals and nilpotent ideals, Wedderburn Artin structure theory.
- Complex group algebras and representation theory of finite groups.
- Primitive and semiprimitive rings, Jacobson density theorem.
- Structure of algebras, Burnside's theorem, Finite dimensional central simple algebras, Brauer group.

Recommended Reading

- Nathan Jacobson, *Basic Algebra* Vol. II, Dover Publications (2009).
- T. Y. Lam, *A first course in noncommutative rings*, Springer (2001).
- TIFR Notes on semisimple rings.

MTH413: Advanced probability

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Radon Nikodym Theorem. Conditional Expectation. Regular conditional probability. Relevant measure theoretic development.
- Discrete parameter martingales with various applications.
- Path properties of continuous parameter martingales.
- Introduction to Brownian Motion.

Recommended Reading

- David Williams, *Probability with Martingales*, Cambridge University Press (1991).
- Patrick Billingsley, *Probability and Measure*, John Wiley & Sons, Inc., New York (1995).
- Leo Breiman, *Probability*, Society for Industrial and Applied Mathematics (1968).

MTH414: Advanced complex analysis

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Examples of conformal mappings. Schwarz reflection principle
- Univalent functions. Spaces of Analytic functions. Riemann mapping theorem.
- Infinite products and Weierstrass factorisation theorem.
- Gamma function, Riemann Zeta function, prime number theorem.
- Elliptic functions.

Recommended Reading

- Lars Ahlfors, *Complex Analysis*, McGraw Hill (1979).
- John B. Conway, *Functions of one Complex Variable*, Springer (GTM), (1979).
- W. Tutschke and H. L. Vasudeva *An Introduction to Complex Analysis: Classical and Modern Approaches*, Chapman & Hall/CRC Press (2005).

MTH415: Enumerative problems in geometry

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Examples of counting problems in geometry: Grassmanians and intersections. Chasles problems on conics. Fixed points of transformations. Bezout's theorem and 9-point circles.
- How to "count properly": Transversal intersections. Fundamental theorem of algebra and multiplicity.
- Grassmanians and Projective space: Cell decompositions. Schubert cells. Schubert calculus.
- Moving and blowing-up: Resultants and plane curve intersections. Singular intersections by moving. Singular intersections by blow-up.

- The Hilbert Polynomial: Interpretation of coeffs of the Hilbert polynomial
- Intersection theory on Algebraic surfaces/4-manifolds. Divisors and their intersections. Neron-Severi group Hodge Index theorem
- Introductory K-theory Lambda rings Chern classes for lambda rings Formal Grothendieck-Riemann-Roch theorem

Recommended Reading

- W. Fulton and R. Lazarsfeld, *Interesection Theory*, Memoirs of AMS.
- J. W. Milnor, *Topology from a differentiable viewpoint* Princeton Univ. Press (1965).
- J. W. Milnor and J. D. Stasheff, *Characteristic Classes* Princeton Univ. Press (1974).
- W. Fulton, *Intersection theory* 2nd ed. Springer (1998).
- M. F. Atiyah and I. G. McDonald, *Commutative Algebra* Oxford University Press (1978).
- A. Beauville, *Complex Algebraic Surfaces I* London Math. Society (1996).
- V. Srinivas, *Algebraic K-Theory* Birkhauser (2008).

MTH416: Arithmetic of elliptic curves

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline The course aims to introduce elliptic curves and their moduli with an emphasis on curves over finite and number fields. Statements of theorems will be explained in detail and some relevant proofs will be given. Some examples of classical problems that can be studied using elliptic curves will be taken up and the use of the SAGE system to make calculations on elliptic curves will be introduced.

- Analytic theory: Doubly periodic functions and the Weierstrass form.
- Modular theory: Lattices in complex numbers and their classification.
- Algebraic theory: Tate-Weierstrass eqation and group law.
- Conversions between different forms of elliptic curves: Recognising ellptic curves hidden in various problems.
- Elliptic curves over finite-fields: Endomorphisms and Frobenius.
- Elliptic Curves over number-fileds: Mordell-Weil theorem.
- Calculations: Calculating points on elliptic curves, calculating rank of an ellptic curve, calculating modular forms.

The following advanced topics could also be addressed:

- L-functions of elliptic curves: The terms of the L-function. The statement of the Birch and Swinnerton-Dyer conjecture and its similarity with the Dirichlet unit theorem.
- Modularity of Elliptic curves: Shimura-Taniyama-Weil conjecture and the statement of the Theorem of Wiles-Taylor.

Recommended Reading

- R. V. Gurjar et al, *Elliptic Curves* Narosa/NBHM (2006).
- J. H. Silverman, *The Arithmetic of Elliptic Curves* Springer GTM 106 (1986).

MTH418: Fuchsian groups

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Several models of the hyperbolic space: the upper-half space model and the Poincaré disc model.
- Hyperbolic distance, area and geodesics.
- The Möbius group: action of $\mathrm{P}SL(2,\mathbb{R})$ on the hyperbolic space.
- Classifying different types of isometries.
- Hyperbolic triangles, hyperbolic trigonometry, hyperbolic polygons.
- Fuchsian groups: discrete subgroups of $\mathrm{P}SL(2,\mathbb{R})$.
- Fundamental domains and Dirichlet regions.
- Limit sets. Elementary and non-elementary Fuchsian groups.
- Poincaré's theorem and groups generated by side-pairing transformations.

Recommended Reading

- S. Katok, *Fuchsian Groups*, Chicago Lectures in Mathematics, University of Chicago Press.
- J. Anderson, *Hyperbolic Geometry*, Springer Undergraduate Mathematics Series, Springer-Verlag, 1999.
- Alan F. Beardon, *The Geometry Of Discrete Groups*, Graduate Texts in Mathematics 91, Springer-Verlag, 1983.
- John G. Ratcliffe, *Foundation Of Hyperbolic manifolds*, Graduate Texts in Mathematics 149, Springer-Verlag, 1994

MTH419: Number theory

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Congruences, theorems of Chevalley and Warning, absolutely irreducible polynomials modulo primes.
- p-adic numbers, convergence in p-adic metric, Ostrowski's theorem.
- Valuations, local fields, structure of multiplicative group of local fields.
- Quadratic forms over p-adic numbers, Hilbert symbol, Hasse-Minkowski theorem.
- Characters of finite Abelian groups, Dirichlet series, Zeta function and L-functions, Dirichlet density theorem, Dirichlet's Theorem on primes in an arithmetic progression.

Recommended Reading

- Z. I. Borevich and I. R. Shafarevich, *Number Theory*, Academic Press (1966).
- Jean-Pierre Serre, *A course in Arithmetic*, Springer-Verklag Graduate Texts in Mathematics, Vol. 7 (1973).
- Kenkichi Iwasawa, *Local Class Field Theory*, Oxford University Press (1986).

MTH420: Linear operators in Hilbert spaces

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Recapitulation: Bounded linear operator and their spectrum. Compact operator and their spectral theory, Example of compact operators, Fredholm alternative.
- Commutative Banach algebras: spectrum, resolvent, maximal ideals and Gelfand Theorem.
- Gelfand theory for commutative C^* algebras.
- Resolutions of identity operator and integration with respect to projection valued measure.
- Decomposition of spectrum: absolutely continuous, singular and point spectra.
- Functional calculus for bounded self adjoint operator.
- Spectral resolution of normal and unitary operators.
- Square root of positive operators and polar decomposition of bounded operators.

Additional Topics:

- Introduction to theory of unbounded Operators.

Recommended Reading

- Walter Rudin, *Functional analysis* Second edition. International Series in Pure and Applied Mathematics. McGraw-Hill, Inc. (1991).
- Peter D. Lax *Functional Analysis*, Wiley Interscience (2002).
- K. R. Davidson, *C^*-Algebras by Example* Text and Readings in mathematics 11, Hindustan Book Agency (1996).
- M. Reed and B. Simon, *Methods of Modern mathematical physics I, Functional Analysis*, Academic press (1975).
- W. Arveson, *An invitation to C^*-algebras*, Graduate Texts in Mathematics, No. 39. Springer-Verlag (1976).

MTH421: Combinatorial group theory

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Free Groups: groups defined by generators and relations, the graph of a group.
- Factor groups and subgroups: word groups, reduced free groups, presentations, subgroups of a free group.
- Nielsen transformations: Reduction process, automorphisms of free groups.
- Free products and amalgamation: Universal property of a product. Categorical definitions. HNN extensions.
- Commutator calculus. Lower central series. Lie elements. Baker-Hausdorff formula.

Additional Topics

- Discrete subgroups of Lie groups.
- Mapping Class groups.
- Groups and Trees.

Recommended Reading

- W. Magnus, A. Karrass, D. Solitar *Combinatorial Group Theory*, Dover Books on Mathematics, 2004.
- R. C. Lyndon, P. E. Schupp, *Combinatorial Group Theory*, Classics in Mathematics, Springer, 1977.
- D. J. S. Robinson, *A course in the Theory of Groups*, Graduate Texts in Mathematics 80, Springer-Verlag, 1995.

Suggested Reading

- M. S. Raghunathan, *Discrete Subgroups of a Lie Group*, Springer Verlag.
- J. Birman, *Mapping Class groups*, Princeton University Press.
- J. P. Serre, *Trees*, Wiley Press.

MTH422: Representations of finite groups

Course Outlie

- Introduction to multilinear algebra, tensor algebra, symmetric algebra and exterior algebra.
- Representations and basic examples, direct sum and tensor product of representations.
- Irreducible representations, complete reducibility and Maschke's theorem, Schur's lemma.
- Character theory of representations, orthogonality relations, decomposition of the regular representation.
- Character tables of Abelian, dihedral and small groups.
- Dimension theorem, Burnside's pq-theorem.
- Restriction of a representation, induced representations, Frobenius reciprocity, Mackey's irreducibility criterion.
- Representation theory of symmetric groups.

Recommended Texts

- Benjamin Steinberg, *Representation Theory of Finite Groups*, Springer (Universitext), 2012.
- Gordon James and Martin Liebeck, *Representations and Characters of Groups*, Cambridge University Press, 2001.

Suggested reading

- William Fulton and Joe Harris, *Representation Theory: A First Course*, Springer (Graduate Texts in Mathematics 129), 1991.
- Jean-Pierre Serre, *Linear Representations of Finite Groups*, Springer (Graduate Texts in Mathematics 42), 1977.

MTH423: Structure of finite groups

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Sylow theory. Fitting subgroup F(G).
- Subnormal subgroups. Characteristic subgroups. Wielandt zipper lemma. Baers theorem on subgroups of F(G).
- Commutators; solvable and nilpotent groups. Schur multiplier.
- Semi-direct products; central products and wreath products.
- Automorphism group. Horosevskiis theorem on the orders of elements in Aut(G).
- Hall-subgroups. Schur-Zassenhaus Theorem.
- Coprime action. Fitting theorem.
- Transfer. Burnsides normal p-complement theorem. Focal subgroup.
- Frobenius actions.
- The Thompson subgroup.
- Burnsides paqb-theorem.
- Permutation groups. Simple groups.

Recommended Reading

- M. Aschbacher, *Finite Group Theory. Cambridge Studies in Advanced Mathematics*, Cambridge University Press, 2000.
- B. Huppert, *Endliche Gruppen I. Grudlehren der mathematischen Wissenschaften*, Volume 134. Springer 1967.
- Martin Isaacs,*Finite Group Theory. Graduate Studies in Mathematics*, Volume 92. American Mathematical Society. 2008.
- Derek J. S. Robinson, *A Course in the Theory of Groups*, GTM Vol. 80. Springer, 1996.
- Harvey E. Rose, *A Course on Finite Groups*, Universitext. Springer, 2009.
- Joseph J. Rotman, *An Introduction to the Theory of Groups*, Springer, 1995.
- Bertram A. F. Wehrfritz,*A Second Course on Group Theory*, World Scientific, 1999.

MTH424: Introduction to Lie algebras

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Lie algebras: definition and examples, ideals and homomorphisms, quotient algebras, low dimensional Lie algebras.
- Universal enveloping algebras, Poincare-Birkhoff-Witt theorem.
- Solvable and nilpotent Lie algebras, Engels theorem, Lies theorem.
- Representations of Lie algebras, Schurs lemma, representations of sl(2,C).
- Killing form, Cartans criteria for solvability and semisimplicity, derivations of semisimple Lie algebras.
- Cartan subalgebras, root space decomposition, Cartan subalgebras as inner product spaces.
- Root systems, Weyl group of a root system, Dynkin diagrams.
- Classical Lie algebras sl(n,C),so(n,C),sp(n,C).
- Classification of root systems, irreducible root systems and complex simple Lie algebras.

Recommended Reading

- Karin Erdmann & Mark J. Wildon,*Introduction to Lie Algebras*, Springer Undergraduate Texts in Mathematics, Springer, 2006.
- James E. Humphreys, *Introduction to Lie Algebras and Representation Theory*, Springer-Verlag, 1980.

MTH425: Geometric group theory

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Free groups, group presentations, Cayley graphs.
- Amalgamated free products and HNN extensions.
- Structure of a group acting on a tree.
- Ends of a group.
- Group actions and quasi-isometries.
- Hyperbolic spaces. Hyperbolic groups.
- Growth of groups. Polynomial, sub-exponential, exponential growth of groups. Gromovs theorem on groups of polynomial growth.
- Grigorchuk group.
- Subgroup growth of free groups.

Recommended Reading

- Bowditch, B. H.: *A course on geometric group theory*, MSJ Memoirs, Mathematical Society of Japan, Volume 16, 2006.
- Bridson, M. R.; Haefliger, A.: *Metric spaces of non-positive curvature*, Grundlehren der mathematischen Wissenschaften, Volume 319, Springer, 1999.
- Ghys, E.; de la Harpe, P.; Editors: *Sur les Groupes Hyperboliques dapr'es Mikhael Gromov*, Progress in mathematics, Birkhäuser, 1990.
- Pierre de la Harpe: *Topics in Geometric Group Theory*, Chicago Lectures in Mathematics, The University of Chicago Press, 2000.
- Alexander Lubotzky, Dan Segal. *Subgroup Growth.* Birkhuser, 2003.
- Mann, A.: *How groups grow*, London Mathematical Society Lecture Note Series 395, Cambridge University Press, 2012.

MTH426: Algebraic curves

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Noetherian rings and Noetherian modules, Hilbert basis theorem, affine space and algebraic sets, ideal of a set of points, algebraic subsets of a plane, Hilbert's Nullstellensatz, integral and algebraic extensions.
- Coordinate rings, affine coordinate transformations, discrete valuation rings, ideals with finitely many zeros, multiple points, tangent lines and local rings.
- Projective space and projective algebraic sets, affine and projective varieties, product spaces, linear system of curves and Bézout's theorem, Max Noether's theorem.
- The Zariski topology, morphism of varieties, algebraic function fields and dimension of varieties, rational maps.
- Rational maps of curves, blowing up of a point in $\mathbb{A}^2$ and $\mathbb{P}^2$, quadratic transformations and non singular model curves.
- Divisors, Riemann's theorem and the genus of a non singular model curve, derivations and differentials, canonical divisors and the Riemann-Roch theorem.

Recommended Reading

- William Fulton , *Algebraic Curves*, http://www.math.lsa.umich.edu/ wfulton/.
- Igor R. Shafarevich, *Basic Algebraic Geometry I*, Springer, Third Edition.

Suggested Reading

- C. Musili, *Algebraic Geometry for Beginners*, Hindustan Book Agency.

MTH427: Introduction to global analysis

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Presheaf, Sheaf, tale space, Differentiable Manifolds sheaf theoritic approach.
- First order Differential operators, locally free sheaves and Vector Bundles, theorem of Frobenius.
- Differential operators of higher order.
- Integration on Manifold and adjoints of Differential operators.
- Local analysis of Elliptic operators : Schwartz space and Densities, Fourier transforms, Distributions, Sobolevs theorem, Interior regularity of Elliptic solutions, Rellichs theorem.
- Elliptic operators on Differentiable Manifolds, Regularity theorem, finiteness theorem, Elliptic Complexes and Laplacian.

Additional Topics

- Pseudo-Differential operators on Manifolds.
- Fredholm operators and the Index of a Fredholm operator.

Recommended Reading

- S. Ramanan, *Global Calculus*, American Mathematical Society, Providence, RI (2005).
- Raghavan Narasimhan, *Analysis on Real and Complex Manifolds*, North-Holland Publishing Co., Amsterdam (1968).

Advanced Reading

- R. O. Wells, *Differential analysis on complex manifolds*, Second edition, GTM 65, Springer-Verlag (1980).
- P. B. Gilkey, *Invariance theory, the heat equation, and the Atiyah-Singer index theorem*, Second edition, CRC Press (1995).

MTH428: Commutative algebra and combinatorics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Review of Primary decompositions of modules, Associated primes, pri- mary decompositions in graded Modules.
- Dimension theory, Hilbert function of a graded module, Hilbert-Samuel polynomial of a local ring, system of parameters and multiplicity.
- Regular sequences, Depth of a module, Cohen-Macaulay module, Macaulay theorem, Graded depth.
- Stanley-Reisner rings (or face rings) of simplicial complexes, Hilbert series, h-vectors and f-vectors. Macaulays theorem on Hilbert functions. Shellability and Cohen-Macaulayness.
- Partially ordered sets, Mbius functions, Mbius inversion, Eulerian posets, Shellable posets, Poset rings.

Additional Topics

- Local Cohomology of Stanley-Reisner rings and Reisner crietrion for Cohen-Macaulayness.
- Upper bound theorem.
- Free resolution of monomial ideals.

Recommended Reading

- H. Matsumura, *Commutative ring theory*, Cambridge University Press, 1986.
- W. Bruns And J. Herzog, *Cohen-Macaulay Rings (Revised edition)*, Cambridge University Press, 1998.
- S. R. Ghorpade, A R Shastri, M K Srinivasan and J K Verma(Editors), *Combinatorial Topology and Algebra*, Lecture notes Series 18, Ramanujan Mathematical Society 2013.
- E. Miller and B. Sturmfels, *Combinatorial commutative algebra*, GTM-227, Springer, 2004.
- J. Herzog and T. Hibi, *Monomial Ideals*, GTM-260, Springer, 2011.
- Balwant Singh, *Basic Commutative Algebra*, World Scientific, 2013.
- R. H. Villarreal, *Monomial Algebra*, Marcel Dekker, 2001.

MTH429: Introduction to Lie groups

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Topological groups, Matrix Lie groups, examples of Matrix Lie group, the Lie algebra of a Matrix Lie group.
- The Baker-Campbell-Hausdorff formula, Correspondence of Matrix Lie group and Lie algebra homomorphisms, covering groups, subgroups and subalgebras.
- Basic Representation theory, representations of SU(2), SO(3), sl(2, $\mathbb{C}$), su(2), the Heisenberg group etc., Schur lemma, complete reducibilty.
- Manifolds and Lie groups, Matrix Lie groups as Lie groups, examples of nonmatrix Lie group, Haar measure on Lie groups.

Additional Topics

- Representation of compact Lie groups, the Peter-Weyl theorem and its applications.

Recommended Reading

- D. Bump, *Lie groups*, GTM 225, Springer-Verlag, New York, 2004.
- C. Chevalley, *Theory of Lie Groups*, Princeton Mathematical Series, vol. 8. Princeton University Press, Princeton, 1946.
- V. S. Varadarajan, *Lie groups, Lie algebras, and their representations*, GTM 102, Springer-Verlag, New York, 1984.
- F. Warner, *Foundations of differentiable manifolds and Lie groups*, GTM 94, Springer-Verlag, 1983.

MTH430: Random graphs

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction: Background from probability theory, convergence of random variables, concentration inequalities, Markov chains, martingales.
- Fundamental Random Graph Models: Random Binomial Graphs (also known as Erdos-Renyi graphs), Uniform Random Graph, Geometric Random graphs.
- Branching Processes: Survival and Extinction, Total Progeny, Subcritical and Supercritical Branching process, Binomial and Poisson Branching Processes.
- Phase Transition in Random Graphs: Phase transition of Erdos-Renyi graphs of degree smaller than 1, Phase transition for degree larger than 1, giant connected components.
- Small-World Networks and Preferential Attachment Models: Degree sequences, degree sequences of real-world networks.

Additional Topics

- Stochastic Processes on Random Graphs.

Recommended Reading

- B. Bollobas, *Random Graphs*, 2nd Edition, Cambridge University Press, 2001.
- M. Penrose: *Random Geometric Graphs*, Oxford University Press, 2003.
- A. Frieze and M. Karonski, *Introduction to Random Graphs*, Cambridge University Press, 2015.
- S. Janson, T. Luczak and A. Rucinski, *Random Graphs*, Wiley 2000.

MTH431: Applications of Fourier analysis

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Poisson Summation Formula; Uncertainty Principles: Heisenberg, Benedicks, Amrein-Berthier, Donoho-Stark, Tao.
- Hardy-Littlewood Maximal function: weak(1,1) and L^p inequalities. The method of Maximal functions for a.e. convergence. Marcinkeiwicz Interpolation.
- Norm convergence (Fourier series and Integrals). The Hilbert Transform, Calderon-Zygmund Decomposition.
- Interpolation of Operators. Hausdorff-Young Theorem. Khinchines inequality. Best possible indices.
- Dirichlets Theorem. Roths Theorem.

Recommended Reading

- E. M. Stein and R. Shakarchi, *Fourier Analysis*, Princeton University Press (2003).
- J. Douandikoetxea, *Fourier Analysis*, American Mathematical Society (2001).
- E. M. Stein and G. Weiss, *Introduction to Fourier Analysis on Euclidean spaces*, Princeton University Press (1971).
- In addition, Some notes and papers.

MTH432: Category theory

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Categories, Functors, Natural Transformations, Representable functors, Duality, Sections and Retractions, Yoneda Lemma, Abelian Categories.
- Adjoint Functors, Universal Problems, Monads, Reflexive subcategories, Limits and colimits, Diagram categories.
- Constructions with Limits, Generators and cogenerators, Adjoint functor theorem, Full and Faithful functors.
- Kan extensions, coends, density, all concepts are Kan extensions.

Recommended Reading

- Saunders Maclane, *Categories for the Working Mathematician*, Springer (1978)
- Bodo Pareigis, *Categories and Functors*, Academic Press (1970)
- Jean Giraud, *Cohomologie non-ablienne*, Springer (1971)

MTH433: Geometric algebra

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- The general and special linear groups.
- Bilinear forms and associated notions.
- Alternating forms and symplectic groups.
- Quadratic forms and orthogonal groups. Witts cancellation and extension theorems. Cartan-Dieudonne theorem. Associated simple groups.
- Structure of Clifford algebras and spin groups.
- Hermitian forms and unitary groups.

Additional Topics

- Compact real forms of the classical groups, associated Lie algebras and Weyl groups.
- Composition algebras and principle of triality.

Recommended Reading

- Larry C. Grove, *Classical groups and geometric algebra*, Graduate Studies in Mathematics, Vol. 39, American Mathematical Society, Providence, RI (2000).
- Nathan Jacobson, *Basic algebra (volumes I and II)*, Dover (2009).
- Serge Lang, Algebra, *Graduate Texts in Mathematics (211)*, Springer-Verlag, New York Inc. (2002).
- Emil Artin, *Geometric algebra*, Wiley India Pvt. Ltd. (1988).
- Hermann Weyl, *Classical groups*, Princeton University Press, Princeton (1946).

MTH434: Quadratic forms over fields

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Quadratic forms, diagonalization, Witts cancellation theorem.
- Witt rings and their presentations, classification of small Witt rings.
- Norm forms of quaternion algebras, Discriminant and Clifford invariants of quadratic forms.
- Quadratic forms under algebraic extensions.
- Quadratic forms under transcendental extensions, Cassels-Pfister Theorem, Milnors exact sequence.
- Pfister forms and function fields.
- Numerical invariants : level, Pythagoras number, u-invariant.

Recommended Reading

- T. Y. Lam, *Introduction to Quadratic Forms over Fields*, American Math-ematical Society, 2004.
- Richard Elman, Nikita Karpenko, Alexander Merkurjev, *The Algebraic and Geometric Theory of Quadratic Forms*, American Mathematical Society (Colloquium Publications), 2011.
- Winfried Scharlau, *Quadratic and Hermitian Forms*, Grundlehren der mathematischen Wissenschaften 270, Springer-Verlag, 1985.

MTH435: Random processes

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Markov Chains: Classification of states, Chapman-Kolmogorov Equation, Strong Markov Property, Stationary distribution, Convergence to stationarity.
- Transient/Recurrent behaviour of random walks, Reflection principle.
- Martingales: Stopping time, Doobs inequality, Convergence theorems.
- Markov Process: Infinitesimal generator and Markov Semigroup, Birth and Death process.
- Poisson Process: Mapping theorem, Existence theorem, Queues.

Additional Topics

- Markov Chain Mixing, Random Walks on Graphs.

Recommended Reading

- Sheldon M. Ross, *Stochastic Processes*, Wiley, 1995, ISBN-13: 9780471120629.
- R. Durrett, *Probability: Theory and Examples*, 4th edition, Cambridge University Press, ISBN: 9780521765398.
- W. Feller, *An Introduction to probability theory*, vol. 1, 1968 (3rd edition, ISBN-13: 9780471257080) and vol. 2 (2nd edition, ISBN-13: 978-0471257097), Wiley.
- J. F. C. Kingman, *Poisson Processes*, Oxford Science Publications, Clarendon Press, 1993, ISBN-13: 9780198536932.

MTH436: An introduction to Knots and Braids

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Recapitulation of basic manifold theory, fundamental groups and covering spaces.
- Knots and links, equivalence of knots, isotopy of knots, knot diagrams, Reidemeister moves.
- Basic operations of knots, mirror image, connected sum, Whitehead double, torus links.
- Basic link invariants, unknotting number, linking number, knot groups and their Wirtinger presentations, 3-colorings of knots, Seifert surfaces and knot genus, Jones and Alexander polynomials of knots.
- Braids, braid groups, knots as closures of braids, Alexander's theorem, Markov's Theorem, representations of braid groups, automorphisms of braid groups, generalisations of braid groups.

Additional Topics

- Quandles, construction of knot quandle, quandle cohomology, construction of knot invariants using quandles.

Recommended Reading

- Joan S. Birman, *Braids, Links, and Mapping Class Groups,*. (AM-82), Annals of Mathematics Studies, 1974.
- R. H. Crowell and R. H. Fox, *Introduction to Knot Theory*, Springer Verlag, 1963.
- M. Elhamdadi and S. Nelson, *Quandles: An Introduction to the Algebra of Knots*, American Mathematical Society, 2015.
- C. Kassel and V. Turaev, *Braid Groups*, Springer Verlag, 2008.
- A. Kawauchi, *A Survey of Knot Theory*, Birkhuser Basel, 1996.

MTH601: Topics in algebra

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Groups acting on sets, Quotients, Direct products, Semidirect products, Exact Sequences, Automorphism groups of various objects, Linear groups, Nilpotent and Solvable groups, Structure of finitely generated abelian groups, Sylow Theorems, Free Groups, Generators and relations, Amalgamation.
- Linear Transformations, Eigenvalues and eigenvectors, Triangulation, Diagonalizable transformations, Spectral Theorems.
- Modules, Direct Products and Direct Sums, Modules over PIDs, Various Canonical Forms, Simple and semisimple modules, Semisimple rings, Wedderburn-Artin structure Theory.
- Categories, Groupoids, Small categories, Full subcategories, Functors, Left and right adjoints of functors, Universal objects, Natural transformations of functors, Equivalence of categories.
- Algebraic numbers, Field extensions, Constructible numbers, Ruler and Compass Constructions, Splitting Fields, Algebraic Closure and Normality, The Fundamental Theorem of Algebra, Separability, Galois extensions, Galois group of a Galois extension, The Galois Pairing, Finite Fields, Cyclic Extensions, Cyclotomic Extentions, Solvability by radicals, The general equation of degree n, Transcendental extensions and transcendence basis.

Recommended Reading

- Nathan Jacobson, *Basic Algebra - Vol II*, W.H. Freeman (1989); Hindustan Book Agency (Indian Edition).
- Serge Lang, *Algebra*, Springer (2002).
- Tsit-Yuen Lam, *A first course in Noncommutative Rings*, Springer (2001).

MTH602: Topics in topology

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- The Fundamental Group: Homotopy and path homotopy, contractible spaces, deformation retracts, Fundamental groups, Covering spaces, Lifting lemmas and their applications, Existence of Universal covering spaces, Galois covering, Seifert-van Kampen theorem and its application.
- Higher Homotopy Groups: Cobrations, Cober homotopy equivalence, Fibration, Fiber homotopy equivalence. Co-fiber sequences, Fiber sequences, Higher homotopy groups, long exact sequences associated to brations, CW complexes, Homotopy excision and suspension theorems.

- Homology and Cohomology: Simplicial and singular homology: Simplicial complexes, barycentric subdivision and its uses, Singular homology, Homotopy invariance, Excision theorems, Mayer-Vietoris sequences, Homology with arbitrary coecients, Singular cohomology, cup products, cohomology ring, Poincaré duality.

Recommended Reading

- J. Peter May, *A concise course in Algebraic Topology*, Chicago Lectures in Mathematics, Univ. Chicago Press (1999).
- Allen Hatcher, *Algebraic Topology*, Cambridge University Press (2002); online available at the author's webpage: `http BBC//www.math.cornell.edu/ hatcher/AT/ATpage.html`

MTH603: Mathematics seminar course

[Cr:2, Lc:2, Tt:0, Lb:0]

Course Outline The aim of this course is to make PhD students understand and present technical talks of their interest. Faculty and Mathematics PhD students will meet once a week. Suitable topics will be decided with the mutual consent of the participants. Occasionally visitors of the institute will be asked to give a talk in this course.

MTH604: Homological and commutative algebra

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

Homological Algebra

- Categories and functors, Derived functors, Hom and $\otimes$ functors, Flat, projective and injective modules, Resolutions of modules, Ext and Tor functors.
- Cohomology of groups.

Commutative algebra

- Recollection of rings, ideals, Spec and MaxSpec of rings, Zariski topology.
- Modules, Finitely generated modules, Nakayama lemma, Localisation of rings and modules.
- Chain conditions, Noetherian rings, Hilbert basis theorem, Artinian rings, Noetherian and Artinian modules.
- Associated primes and Primary decomposition, Integral extensions, Going up and going down theorems, Noether normalisation theorem, Hilbert Nullstellensatz and their geometric interpretations.

- Valuation rings and Dedekind domains, Ideal class group.
- Direct and inverse limits, Completions, Graded rings and modules, Artin-Rees lemma.
- Dimension theory, Hilbert and Samuel functions, Dimension theorem, Krull's principal ideal theorem.
- Regular sequences, Depth, Cohen-Macaulay rings, Gorenstein rings, Regular rings.

Recommended Reading

- Hideyuki Matsumura, *Commutative Ring Theory*, Cambridge Series in Advanced Mathematics 8, Cambridge University Press (1989).
- Kenneth S. Brown, *Cohomology of Groups*, GTM 87, Springer-Verlag (1982).
- M. F. Atiyah and I. G. Macdonald, *Introduction to Commutative Algebra*, Perseus Books Group (1994).
- David Eisenbud, *Commutative Algebra with a view toward Algebraic Geometry*, GTM 150, Springer-Verlag (1995).
- R. Y. Sharp, *Steps in Commutative Algebra*, Cambridge University Press (2000).

MTH605: Topics in analysis

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Lebesgue integral and construction of Lebesgue measure on $\mathbb{R}^n$, Non measurable sets, Fatou's Lemma and Convergence Theorems, L^p spaces and their completeness, Reisz representation Theorem for $C_0(X)$; X locally compact.
- Complex Measure, Radon-Nikodym Theorem, Differentiation of an integral, Absolutely continuous of functions, Hahn decomposition Theorem, Product measure and Fubini Theorem.
- Fourier series and Fourier transform, L^2 theory.
- Theory of Distributions.

Recommended Reading

- Walter Rudin, *Real and Complex Analysis*, McGraw-Hill International Editions, Mathematics Series, McGraw-Hill Education (1987).
- Walter Rudin, *Functional Analysis*, Tata McGraw-Hill (1990). (for the Theory of Distributions)
- Halsey L. Royden, *Real Analysis*, Prentice Hall, Third Edition (1988).

MTH606: Mathematics seminar course

[Cr:2, Lc:2, Tt:0, Lb:0]

Course Outline

- The aim of this course is to make PhD students understand and present technical talks of their interest. Faculty and Mathematics PhD students will meet once a week. Suitable topics will be decided with the mutual consent of the participants. Occasionally visitors of the institute will be asked to give a talk in this course.

MTH607: Euclidean harmonic analysis

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Review of basics; Fourier Series, Fourier Transforms in $\mathbb{R}^n$; Plancherel and Fourier Inversion Theorems. Convolutions.
- The Schwartz Space and Tempered Distributions.
- Poisson Summation Formula and applications. Uncertainty Principles: Heisenberg, Benedicks-Amrein-Berthier, and Beurling. Paley-Wiener Theorems.
- Translation Invariant Operators on L^p spaces. Interpolation Theorems (Reisz-Thorin and Marcinkeiwicz).
- Maximal functions. Hilbert Transform and convergence of Fourier Series and Integrals. Calderon-Zygmund Singular Integrals.

Additional topics (a subset of the following):

- Littlewood-Paley inequalities; Hormander-Mihlin and Marcinkeiwicz Multipliers.
- H^1-BMO
- Time- frequency phase plane analysis. Wavelets.

Recommended Reading

- E. Stein and R. Shakarchi: *Fourier Analysis*, Princeton University Press (2003).
- E. Stein and R. Shakarchi: *Complex Analysis*, Princeton University Press (2005).
- Javier Duoandikoetxea: *Fourier Analysis*, AMS (2001).

MTH608: Algebraic number theory-I

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Characteristic and minimal polynomial of an element relative to a finite extension, Equivalent definitions of norm and trace, Algebraic numbers, algebraic integers and their properties.
- Integral bases, discriminant, Stickelberger's theorem, Brille's theorem, description of integral basis of quadratic, cyclotomic and special cubic fields.
- Ideals in the ring of algebraic integers and their norm, factorization of ideals into prime ideals, generalised Fermat's theorem and Euler's theorem.
- Dirichlet's theorem on units, regulator of an algebraic number fields, explicit computation of fundamental units in real quadratic fields.
- Dedekind's theorem for decomposion of rational primes in algebraic number fields and its application, splitting of rational primes in quadratic and cyclotomic fields.

Recommended Reading

- Saban Alaca and Kenneth Williams, *Introductory Algebraic Number Theory*, Cambridge University Press (2003).
- M. Ram Murty and J. Esmonde *Problems in Algebraic Numbers Theory*, Springer-Verlag (2004).
- Wladyslaw Narkiewicz, *Elementary and Analytic Theory of Algebraic Numbers*, Springer-Verlag (2004).
- Erich Hecke, *Lectures on the Theory of Algebraic Numbers*, Springer-Verlag (1981).
- Paula Ribenboim, *Algebraic Numbers*, John Wiley & Sons (1972).
- Harry Pollard and Harold Diamond, *The Theory of Algebraic Numbers*, Dover Publications (2010).

MTH609: Algebraic number theory-II

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Index of ramification, residual degree, norm of ideals for relative extensions of algebraic number fields and their properties. Fundamental equality.
- Different, Discriminant and Dedekind's theorem on ramified prime ideals in extensions of algebraic number fields.
- Finiteness of class number and determination of class numbers in special cases.
- Dirichlet's Density theorem and simple applications.
- Dirichlet's class number formula and its explicit determination for cyclotomic and quadratic fields in terms of L-series.

Recommended Reading

- M. Ram Murty and J. Esmonde, *Problems in Algebraic Number Theory* Springer-Verlag (2004).
- Saban Alaca and Kenneth Williams, *Introductory Algebraic Number Theory* Cambridge University Press (2003).
- Wladyslaw Narkiewikz, *Elementary and Analytic Theory of Algebraic Numbers* Springer-Verlag (2004).
- Erich Hecke, *Lectures on the Theory of Algebraic Numbers* Springer-Verlag, (1981).
- Paulo Ribenboim, *Algebraic Numbers* John Wiley and Sons (1972).

4.6 Physical Sciences

PHY421: Laser physics and advanced optics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction to Lasers: Principles of laser action, threshold criteria, building blocks of a laser, Basic properties of laser light, coherence, directionality, photon flux, Lasers and Masers, Survey of laser applications.
- Atom-Field interaction: Einstein's A and B coefficients, Coherent and incoherent emissions, three-level and four level schemes, Rate equation model for laser, Optical pumping.
- Gaussian beam and Optical resonators: Propagation of Gaussian beam, ABCD Matrix, linear and ring resonators, Confocal cavity, stability analysis of cavity, cavity modes, quality factor.
- Types of Lasers: Gas lasers: CO_2 and Ar-ion, Liquid dye laser, Solid state lasers (Ruby laser, Nd:YAG), semiconductor lasers, edge emitting and vertical cavity surface emitting lasers, Pulsed laser operation, Q-switching, saturable absorption, mode locking, Ultrafast lasers.
- Nonlinear Optics: Polarization properties of lasers, Jones Matrix formalism, Nonlinear effects, second harmonic generation, Kerr effect, Pockel effect, self focusing and defocusing, Optical isolators.
- Topics in Advanced Optics: Semiclassical theory of laser, Correlation function and coherence concepts, Photon statistics in cavities, one atom laser, Laser cooling and trapping of atoms, Introduction to optical lattices and atom optics.

Recommended Reading

- A. E. Siegman, *Lasers*, University Science Books (1986).
- K. K. Sharma, *Optics, Principles and applications*, Academic Press USA (2006).
- J. T. Verdeyen, *Laser Electronics*, 03rd edition, Prentice Hall, (1995).
- K. Thyagarajan and A.K. Ghatak, *Lasers: Theory and Applications*, Springer (1981).
- M. Sargent III, M.O. Scully and W.E. Lamb, Jr., *Laser Physics*, Westview Press (1978).
- L. Mandel and E. Wolf, *Optical Coherence and Quantum Optics*, Cambridge University Press (1995).
- B. B. Laud, *Lasers and Nonlinear Optics*, John Wiley & Sons Inc. (1985).
- C. Cohen-Tannoudji, J. Dupont-Roc, and G. Grynberg, *Atom-Photon-Interactions: Basic Processes and Applications*, Wiley-Interscience NY (1998).

PHY422: Computational methods in physics I

[Cr:4, Lc:3, Tt:0, Lb:3]

Course Outline

- Number representation in computers, round off error, relative error estimation, error propagation.
- Solution of Linear Systems $AX = B$: Matrix arithmetic, Numerical Diagonalization of matrices. Singular value decomposition. Eigenvalue problem. Gaussian Elimination, LU Factorization, Jacobi and Gauss-Seidel method, Error estimation and Residual Correction method.
- Interpolation: Polynomial interpolation, Newton, Lagrange and Hermite interpolation, spline interpolation.
- Numerical Differentiation: Differentiation of interpolating polynomials, Backward, forward and centered difference methods, method of undetermined coefficients.
- Numerical Integration: Trapezoidal and Composite Trapezoidal, Simpson's Rule, Gaussian quadrature, Monte Carlo Integration.
- Solution of Nonlinear Equations $f(x) = 0$: Iteration, Bracketing methods for locating a root, Newton-Raphson and Secant methods.
- Optimization: Minimization, minimization in several dimensions, Monte Carlo Markov Chains based methods. Metropolis method, convergence of Markov Chains.

Recommended Reading

- H. M. Antia, *Numerical Methods For Scientists And Engineers*, 02nd edition, Birkhauser Basel (2002).
- *Numerical Recipes in C: The Art of Scientific Computing*, W. H. Press, S. A. Teukolsky, W. T. Vellerling and B. P. Flannery, Cambridge University Press (1992).

PHY423: Mathematical methods for physicists II

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Fourier series: General properties, applications of Fourier series, properties of Fourier series, Gibbs phenomenon, discrete Fourier transform, relation with fast Fourier transforms.
- Integral transforms: Fourier integral, Fourier transforms, inversion theorem, Fourier transform of derivatives, convolution theorem, Laplace transform and its relation to Fourier transform. Laplace transform solution to differential equations. convolution theorem, Inverse Laplace transform.
- Introduction to integral equations: Integral transforms, generating functions, Neumann series, separable Kernels, Hilbert-Schmidt theory.
- Calculus of Variations: One dependent and an independent variable, Euler's equations, several dependent variables, several independent variables, Lagrangian multipliers, variation with constraints.

Recommended Reading

- H. J. Weber and G. B. Arfken, *Essential Mathematical Methods for Physicists*, Academic Press (2004).
- D. A. McQuarrie, *Mathematical Methods for Scientists and Engineers*, Viva Books (2009).
- Mary L. Boas, *Mathematical Methods in the Physical Sciences*, Wiley (2005).

PHY424: Relativistic quantum mechanics and quantum field theory

[Cr:4, Lc:4, Tt:0, Lb:0]

Knowledge of the content of **PHY302**, **PHY303**, **PHY306** *and* **PHY310** *is essential to follow this course.*

Goal: To trace the path from single particle Non-relativistic Quantum Mechanics (QM) to the necessity of many body interpretations of its relativistic generalizations. Introduction of Quantum field theory as a comprehensive language to describe many body relativistic quantum systems which resolves the paradoxes of single body Relativistic QM.

Course Outline

- Relativistic Quantum Mechanics: Klein-Gordon equation, Dirac equation and its plane wave solutions, significance of negative energy solutions, spin angular momentum of the Dirac particle. Non-relativistic limit of Dirac equation, Electron in electromagnetic fields, spin magnetic moment, spin-orbit interaction. Problems of relativistic one-particle theories and the need for QFT.
- Classical field Theory: Symmetries and Noether's theorem. Stress-energy tensor and propagator theory for Schrodinger, Klein-Gordon and Dirac theories.
- Relativistic Quantum Field Theory: Canonical quantization of real and complex scalar fields. Quantization of Spin half-field. Dirac, Weyl and Majorana fields. Wick's theorem for spin 0, 1/2. Heisenberg and Interaction pictures and Perturbation theory for correlation functions. Feynman rules for correlators. Spin-statistics theorem (non-interacting), Causality.

Recommended Reading

- J. J. Sakurai, *Advanced Quantum Mechanics*, (Pearson), 1967.
- A. Lahiri and P. Pal, *A First Book of Quantum Field Theory*, (Narosa), 2007.
- M. Peskin and D. Schroeder, *An introduction to Quantum Field Theory*, (Westview Press), 1995.
- H. Mandl and G. Shaw, *Quantum Field Theory*, (Wiley-Blackwell), 2010.
- M. Srednicki, *Quantum Field Theory*, (Cambridge University Press), 2007.
- L. H. Ryder, *Quantum Field Theory*, (Cambridge University Press), 1996.

PHY425: Computational methods in physics II

[Cr:4, Lc:3, Tt:0, Lb:3]

Knowledge of the content of **PHY422** *is essential to follow this course.*

Course Outline

- Solution of Ordinary Differential Equations, Euler's method, Runge-Kutta methods, Initial and Boundary Value Problems.
- Fast Fourier Transforms, relation with Fourier series and Fourier transforms.
- Partial differential equations: Diffusion equation, Wave equation, Poisson equation. Finite element and relaxation methods.
- Parallel computing: Decomposition of problems, functional, data and domain decomposition. Shared memory and distributed memory parallelization. Optimization with co-processors and GP-GPUs.
- Topics in Numerical Simulations (At least two topics to be covered):
    1. Many particle simulations with short range interactions.
    2. Many particle simulations with long range interactions.

3. Computational Fluid Dynamics.
4. Simulations of spin systems.
5. Simulations of quantum mechanical scattering.
6. Parameter estimation for $n > 3$ unknown parameters from experimental/observational data.

Recommended Reading

- H. M. Antia, *Numerical Methods For Scientists And Engineers*, 02nd edition, Birkhauser Basel (2002).
- *Numerical Recipes in C: The Art of Scientific Computing*, W. H. Press, S. A. Teukolsky, W. T. Vellerling and B. P. Flannery, Cambridge University Press (1992).
- *Programming Massively Parallel Processors: A Hands-on Approach*, by David B. Kirk, Wen-mei W. Hwu, Publisher: Morgan Kaufmann; 3rd edition (2016)
- *Computational Physics, J. M. Thijssen, Cambridge University Press (1999)*

PHY601: Review of classical mechanics

[Cr:4, Lc:2, Tt:2, Lb:0]

Course Outline

- Lagrangian and Hamiltonian formulation of classical mechanics, two body central force problem, rigid body motion, special theory of relativity, phase space formulation of classical mechanics. Nonlinearity and chaos. (The methodology of the course will be based on learning by problem solving)

Recommended Reading

- H. Goldstein, *Classical mechanics*, 03rd edition, Addison-Wesley, Cambridge MA (2001).
- L. D. Landau and E.M. Lifshitz, *Mechanics*, 03rd edition, Butterworth Heinemann (1976).

PHY602: Review of electrodynamics

[Cr:4, Lc:2, Tt:2, Lb:0]

Course Outline

- Gauss law, Electrostatics, boundary value problems, Greens function, magnetostatics, Electrodynamics, Faraday's law, Amperes law, Maxwell's equations, covariant form of Maxwell equations, electromagnetic waves and their propagation, retarded potentials, radiation. (The course will be based on learning by problem solving)

Recommended Reading

- J. D. Jackson, *Classical Electrodynamics*, 3rd edition, New York: Wiley.
- D. J. Griffiths, *Introduction to Electrodynamics*, 03rd edition, Prentice-Hall NJ (1999).
- L. D. Landau and E.M. Lifshitz, *The Classical theory of fields*, 4th edition, Pergamon (1994).

PHY603: Review of statistical mechanics

[Cr:4, Lc:2, Tt:2, Lb:0]

Course Outline

- Review of thermodynamics. Equation of state, equilibrium and stability, Van der Waal gas, phase transitions, Laws of thermodynamics. Carnot engine, heat pump. Disorder and Entropy. Phase space. Probability density and functions of a random variable, Liouville Theorem.
- Microcanonical ensemble, Boltzmann probability. Canonical ensemble, partition function, Monoatomic ideal gas, virial theorem, energy fluctuations, collection of harmonic oscillators, statistics of paramagnetism, polyatomic gas. Grand canonical ensemble, density and energy fluctuations. Density matrix formalism. Examples.
- Quantum statistics. Indistinguishable particles, symmetric vs anti-symmetric wave function. Ideal Bose gas and ideal Fermi gas in quantum ensembles and thermodynamic properties, Blackbody radiation. Bose-Einstein condensation. Specific heat of solids. Pauli paramagnetism. Introduction to Phase transitions.

Recommended Reading

- R. K. Pathria, *Statistical Mechanics*, 02nd edition, Butterworth-Heinemann (1996).
- K. Huang, *Statistical Mechanics*, 02nd edition, Wiley (1987).
- L. D. Landau and E. M. Lifshitz, *Course in Theoretical Physics Vol. 5*, 03rd edition, Butterworth-Heinemann (1984).

PHY604: Review of quantum mechanics

[Cr:4, Lc:2, Tt:2, Lb:0]

Course Outline

- Classical vs. Quantum Mechanics, Simple 2-state QM system. Hilbert Spaces, Operators. Observables - Compatible Observables, Tensor Product Spaces, Uncertainty Relations. Position, Momentum and Translation. Eigenvalue Problems.

- Time Evolution (Quantum Dynamics). Schroedinger, Heisenberg and Interaction Pictures; Energy-time Uncertainty, Interpretation of Wavefunction. Ehrenfest, Quantization, Path Integrals. Quantum Particles in Potential and EM Fields - Gauge Invariance, Aharanov-Bohm.
- Angular Momentum: $SO(3)$ vs. $SU(2)$. Lie Algebra and Representations of $SU(2)$. Spherical Harmonics. Addition of Angular Momenta. Tensor Operators and Wigner-Eckardt Perturbation Theory: Rayleigh-Schroedinger (Nondegenerate Time-independent) Perturbation Theory. Examples in Hydrogen Atom.
- Symmetry groups in QM. Parity. Time reversal. Identical particles - permutations. Pauli exclusion. Central field approximation. Hartree equations. Scattering: Born approximation. Spherical waves. partial wave scattering. Low-energy scattering, bound states, resonances. Coulomb scattering.
- Relativistic quantum mechanics: Dirac equation. Klein-Gordon equation. Relativistic particles and group theory. Solutions to Dirac: free particle, relativistic Hydrogen atom.

Recommended Reading

- L. Schiff, *Quantum mechanics*, 03rd edition, McGrawHill (1968).
- J. J. Sakurai, *Modern quantum mechanics*, Addison-Wesley (1993).
- C. Cohen-Tannoudji, *Quantum mechanics Vols 1 and 2*, Wiley-Interscience (2006).

PHY622: Mathematical methods for physicsts III

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline Topics are divided into three groups. First set of topics and one of the other two is to be taught in a given instance.

- Linear Algebra: Vector spaces, Inner product, Linear maps, Vector algebra, Operator algebra, Conjugation of operators, Hermitian operators, Unitary operators, Projection operators, Functions of operators, Matrices, Similarity transformations, Determinant, Trace, Direct sums, Subspaces, Invariant subspaces, Eigenvalues and eigenvectors, Spectral decomposition, Polar decomposition.
- Group Theory: Groups, Subgroups, Classes and Invariant subgroups, Cosets, Factor groups, Homomorphism and isomorphism of groups, Group representations, Reducible and Irreducible representations, Unitary representations, Schur's Lemmas, Lie groups and Lie algebras, Rotation groups $SO(2)$ and $SO(3)$, Special unitary group $SU(2)$, Irreducible representations of $SO(2)$, $SO(3)$ and $SU(2)$ and their applications, Homogeneous Lorentz group, Poincare group, Young diagrams.
- Differential equations: linear and nonlinear differential equations, nonlinear differential equations relevant in physics. Klein-Gordon; Sine-Gordon equation; KdV equations; soliton solutions. Stochastic differential equations, Langevin equation, Fokker Planck equations.

Recommended Reading

- Sadri Hassani, Mathematical Physics, Springer (2013).
- H. J. Weber and G. B. Arfken, *Essential Mathematical Methods for Physicists*, Academic Press (2004).
- Wu-Ki Tung, Group Theory in Physics, World Scientific (2008).
- M. Hamermesh, Group Theory and Its Application to Physical Problems, Dover Publications (1989).
- Howard Georgi, Lie Algebras in Particle Physics, Levant Books (2009).
- J. V. Jose, and E. J. Saletan, *Classical Dynamics: A Contemporary Approach*, Cambridge University Press (2002).
- C. Gardiner, *Handbook of Stochastic Methods for Physics, Chemistry and the Natural Sciences*, Springer (2004).

PHY631: Quantum computation and quantum information

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introducing quantum mechanics. Quantum kinematics, quantum dynamics, quantum measurements. (The course is self contained and does not assume a background in quantum mechanics). Single qubit, multiqubits, gates. Density operators, pure and mixed states, quantum operations, environmental effect, decoherence. Quantum no-cloning, quantum teleportation.
- Cryptography, classical cryptography, introduction to quantum cryptography. BB84, B92 protocols. Introduction to security proofs for these protocols.
- Introduction to quantum algorithms. Deutsch-Jozsa algorithm, Grover's quantum search algorithm, Simon's algorithm. Shor's quantum factorization algorithm.
- Errors and correction for errors. Simple examples of error correcting codes in classical computation. Linear codes. Quantum error correction and simple examples. Shor code. CSS codes.
- Quantum correlations, Bell's inequalities, EPR paradox. Theory of quantum entanglement. Entanglement of pure bipartite states. Entanglement of mixed states. Peres partial transpose criterion. NPT and PPT states, bound entanglement, entanglement witnesses.
- Physical realization of qubit system. Different implementations of quantum computers. NMR and ensemble quantum computing, Ion trap implementations. Optical implementations.

Recommended Reading

- M. A. Nielsen and I .L. Chuang, *Quantum Computation and Quantum Information*, Cambridge University Press (2000).
- J. Preskill's Lecture Notes on Quantum Information `http://www.theory.caltech.edu/people/preskill/ph229/`

PHY632: Advanced experiments in physics

[Cr:4, Lc:0, Tt:0, Lb:12]

Course Outline This course is intended for Advanced MS (Physics Major) students with an interest in gaining experience in an experimental physics research group. The course can be offered every semester, with a set of instructors drawn from the available experimental research groups. The mode of instruction will comprise a combination of lectures, tutorials and minor research projects to be carried out in the research lab of the concerned instructor currently the available modules are as follows out of which depending upon the instructs at least two will be included in the course.

- NMR Spectroscopy Lab: Applying the Fourier transform to the NMR signal. Digital data processing, Nyquist theorem, Discrete Fourier transform, FFT algorithm, window functions and apodization. Physical basis of the NMR signal, phase correction, phase cycling. Redfield-Bloch relaxation theory and Master equation approach to identifying relaxation processes in systems of two and three coupled spins. The basic 2D FTNMR experiment and application to finding the structure of a biomolecule. Pulsed field gradients and understanding diffusion processes in polymer chains. Selective pulse rotations, composite pulses and implementation of an NMR Quantum Computing algorithm.
- Femtosecond Laser Lab: Experiments with cw laser, cavity stability, beam parameters, divergence, diameter, intracavity frequency doubling. Experiments with femtosecond laser: measurement of femtosecond laser parameters, pulse duration, autocorrelation, spectral width, repetition rate, beam diameter, divergence, application of fs pulses to measure speed of light in vacuum, air and in glass. Pump-probe spectroscopy, interferometric stability, ultrafast phenomenon measured by fs pump probe setup.
- Low Temperature Physics Lab: This lab will focus on low noise electronics. Projects will involve integrating different electronic equipments in one Labview programme. As an example varying gate voltage from a DAQ card output and measuring the conductance using a lock-in amplifier (a mock device like a commercial JFET or MOSFET will be used). Students will also do some hands on Radio-frequency electronics like designing co-planar waveguides on a PCB . They will be expected to understand concepts like noise figures and noise temperatures, develop cryogenic amplifiers to be tested at liquid nitrogen temperatures.
- Solid State Physics Lab: Students will make new compounds by mixing up starting materials/chemicals. These could be superconducting, magnetic, or could show other interesting properties. Students will also do characterization and imaging of these and other materials using a Scanning

Electron Microscope (SEM). Specifically students will look at gold nano-particles and the wonder material graphene using the SEM.

Recommended Reading

- M. Sayer and A. Mansingh, *Measurement, Instrumentation and Experiment Design in Physics and Engineering*, Prentice-Hall of India Pvt.Ltd (2004).
- D. M. Pozar, *Microwave Engineering*, 03rd edition, Wiley (2004)
- E. Fukushima and S .B. Roeder, *Experimental Pulse NMR: A nuts and bolts approach*, Westview Press (1993)
- R. C. Richardson & E. N. Smith, *Experimental Techniques In Condensed Matter*, Westview Press (1998).

PHY633: Mesoscopic physics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Review of quantum mechanical notation. Basic problems in QM like transmission via a potential well, density of states Fermi golden rule, Landau quantization of electrons in magnetic field and Aharonov-Bohm effects.
- Review of semiconductor concepts . Overview of fabrication techniques of mesoscopic devices
- 2-D electrons confined to semiconductor hetero-structures. Quantized Hall phenomena and associated Shubnikov-deHass Oscillations. Phenomenological theory along Laughlin's gauge invariance arguments , Widom-Sreda thermodynamic formulations, followed by Thouless's winding number approach. Scaling theory of localization in 1-D and 2-D. 2-D systems showing metallic phases due to e-e interactions. Wigner crystals in extremely dilute 2-D electron systems in high magnetic fields. Other 2-D electron systems like graphene, electrons on helium surfaces and organic transistors.
- Landauer transmission formalism. Application of formalism to explain quantized conductance of devices like quantum point contacts. Weak localization nd Aharonov-Bohm effect in gold rings and other systems. Violation of Kirchhoff's circuit laws for quantum conductors.
- Overview of superconductors. London equations . Classic flux quantization experiments of Doll & Nabauer , Deaver & Fairbank. Josephson effect and SQUIDS. Landau Zener tunneling and Macroscopic quantum effects in SQUID based devices.
- Nano-mechanical systems. Applications to mass sensing filters etc. Dissipation phenomena in nano-mechanical resonators and possibility of achieving macroscopic quantum states in mechanical systems.
- Spintronics. Johnson-Silsbee experiments , Datta Das Transistors , Giant magneto-resistance and applications .

Recommended Reading

- Y. Murayama, *Mesoscopic Systems*, Wiley VCH (2001).
- S. Datta, *Electronic Transport in Mesoscopic Systems*, Cambridge University Press (1997).
- A. Cleland, *Foundations of Nanomechanics*, Springer (2001).
- M. Ziese and M. J. Thornton, *Spin Electronics (Lecture Notes in Physics)*, Springer (2001).

PHY634: NMR in physics and biology

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline The course is intended for advanced MS and PhD students with an interest in applications of nuclear magnetic resonance (NMR) to problems in structural biology, medicine and physics. The course will also include tutorials and hands-on experience with actual data obtained from the NMR facility.

- Physical basis of the NMR signal. Bloch equations and the macroscopic view. Zeeman splitting, Larmor precession, Resonance phenomenon, Spin echo. The NMR spectrometer. Basic hardware components including the magnet, rf transmitter, probe and receiver. Fourier transform NMR. Digitizing the signal using the DFT. The FFT algorithm. The rf pulse and its excitation profile. Data processing techniques for resolution enhancement and S/N improvement
- The chemical shift. The diamagnetic effect and the paramagnetic term. Chemical shift anisotropy. Hydrogen bonding. Scalar coupling. Investigation of exchange processes. The Nuclear Overhauser effect (NOE). The density matrix and the product operator formalism. Rf pulses and evolution. Coherence transfer. Origins of relaxation in systems of coupled spins. Application to gaining information about dynamics in biomolecules over biologically relevant timescales. The TROSY experiment.
- The basic 2DNMR experiment. Extension to three dimensions. Assignment strategies, triple resonance experiments and structure determination protocols for proteins.
- Overview of new and exciting developments in NMR: Nucleic acids and macromolecular assemblies. Drug design and discovery. Fast acquisition. Metabolic studies by NMR. Residual dipolar couplings. Protein folding by NMR.
- Pulsed field gradients and studies of diffusion by NMR. Applications to the physics of polymers, non-Newtonian fluids and macromolecular crowding.
- Basics of Magnetic Resonance Imaging (MRI). Use of magnetic field gradients to create a correspondence between intensity, frequency or phase, and spatial coordinates. fMRI (Functional MRI) and imaging processes in the brain Basics of flow and MR angiography.

Recommended Reading

- M. H. Levitt, *Spin Dynamics-Basics of Nuclear Magnetic Resonance*, 02nd edition, Wiley (2008).
- J. Cavanagh, W. J. Fairbrother, A. G. Palmer III and N. J. Skelton, *Protein NMR spectroscopy, principles and practice*, 2nd edition, Academic Press (2006).
- B. Blumich, *Essential NMR: For scientists and engineers*, Springer (2005).
- J. Keeler, Understanding NMR spectroscopy, 2nd edition, Wiley (2010).
- K. V. R Chary and G. Govil, *NMR in Biological Systems: From molecules to human*, Springer (2008).
- M. L. Lipton and E. Kanal, *Totally accessible MRI*, Springer (2008).
- D. W. McRobbie, E. A. Moore, M. J. Graves and M. R. Prince, *MRI from Picture to Proton*, 2nd edition, Cambridge University Press (2007).

PHY635: Gravitation and cosmology

[Cr:4, Lc:3, Tt:1, Lb:0]

Knowledge of the content of **PHY301**, **PHY303** *and* **PHY310** *is essential to follow this course.*

Course Outline

- Review of special relativity and Newtonian gravity.
- Equivalence principle, local inertial frames.
- The metric tensor. Measurements of lengths and synchronization of clocks.
- Coordinate transformations, manifolds and tensors.
- Christöffel symbols, geodesic equation, geodesic deviation equation and the curvature tensor.
- Stress-energy tensor, Bianchi identities, Einstein's equation.
- Maxwell's equations in curved space time, stress-energy tensor for the electromagnetic field.
- Synchronous coordinates.
- Gravitational field of a point mass, Schwarzschild metric and black holes. Orbits around a point mass, precession of perihelion, lensing equation. The horizon and the singularity in the Schwarzschild metric.
- Gravitational field of a star, interior and exterior solutions, gravitational field of a rotating body, Kerr metric.
- Post Newtonian (PN) and Post Minkowski (PM) description of theories of gravity. Experimental tests of the general theory of relativity.
- Linearized field equations, gauge freedom. scalar, tensor and vector modes. Gravitational waves.

- Symmetries and Killing vectors.
- The cosmological principle, Robertson-Walker metric, Friedmann equations. Solutions of the Friedmann equations.
- Cosmological redshift, distances in cosmology. Observational constraints from distance measurement.
- Cosmic-Microwave Background Radiation (CMBR) in the standard cosmological model, flatness and horizon problems, inflationary scenarios.
- Brief overview of the thermal history of the universe and formation of large scale structure.

Recommended Reading

- L. D. Landau and E. M. Lifshitz, *Classical Theory of Fields*, Butterworth-Heinemann (1980).
- C. W. Misner, K. S. Thorne and J. A. Wheeler, *Gravitation*, W. H. Freeman (1973).
- S. Weinberg, *Gravitation and Cosmology*, John Wiley & Sons (1972).
- T. Padmanabhan, *Gravitation: Foundations and Frontiers*, Cambridge University Press (2010).
- S. Weinberg, *Cosmology*, Oxford University Press (2008).
- J. B. Hartle, *Gravity: An introduction to Einstein's General Relativity*, Benjamin Cummings (2003).
- B. F. Schutz, *A first course in general relativity*, Cambridge University Press (2009).
- P. J. E. Peebles, *Principles of Physical Cosmology*, Princeton University Press (1993).
- T. Padmanabhan, *Theoretical Astrophysics: Volume 3, Galaxies and Cosmology*, Cambridge University Press (2002).
- S. Dodelson, *Modern Cosmology*, Academic Press (2003).

PHY636: Advanced condensed matter physics

[Cr:4, Lc:3, Tt:1, Lb:0]

Knowledge of the content of **PHY302**, **PHY304** *and* **PHY402** *is essential to follow this course.*

Course Outline

- Introduction and Motivation: Energy, length and time scales in solid state; complexity and emergent behavior; brief review of key concepts in quantum mechanics and statistical mechanics.
- Second quantization: Quantum fields as creation and annihilation operators; Fermi and Bose statistics; commutation and anticommutation relations.

- Tight-binding models and their applications: one-band and multi-band models; electronic structure and crystal lattices; metals and insulators; magnetic materials.
- Transition metal compounds: spin, charge and orbital degrees of freedom and their interplay; manganites; cuperates; pnictides.
- Phase Transitions: Examples of phase transitions; Ginzburg-Landau approach; Renormalization group methods.
- Special Topics (some of them will be as term papers): Strong coupling expansion; Monte-Carlo methods; Exact-diagonalization methods; BCS theory of superconductivity; double-exchange and Kondo-lattice models; Bose-Einstein condensation; Graphene and the quantum Hall effect.

Recommended Reading

- M. Tinkham, *Introduction to Superconductivity*, Dover Publications (2004).
- C. J. Pethick and H. Smith, *Bose-Einstein Condensation in Dilute Gases*, Cambridge University Press (2008).
- G. D. Mahan, *Many Particle Physics*, Springer (2010).
- N. Goldenfeld, *Lectures on Phase Transitions and the Renormalization Group*, Westview Press (1992).
- A. L. Fetter and J. D. Walecka, *Quantum Theory of Many Particle Systems*, Dover Publications (2003).
- P. Fazekas, *Lecture Notes on Electron Correlation and Magnetism*, World Scientific (1999).
- N. W. Ashcroft and N. D. Mermin, *Solid State Physics*, Brooks Cole (1976).

PHY637: Astrophysics

[Cr:4, Lc:3, Tt:1, Lb:0]

Knowledge of the content of **PHY301**, **PHY303**, **PHY304** *and* **PHY403** *is essential to follow this course.*

Course Outline

- Brief history of observational astronomy; retrograde motion. Celestial coordinate systems, time keeping and precession.
- Kepler's and Newton's law. Virial Theorem and its applications. Quantisation of light. Quantifying fluxes, magnitudes, fluxes, luminosity, colour indices.
- Types of telescopes and fundamental principles: Refraction, reflection, resolution. Types of aberrations. Types of mounts and detectors. Nyquist theorem.
- Observing parameters for photometry. Classification of stellar spectra: Boltzmann and Saha equations.

- Classification and measurement of physical quantities for stars. Types of star clusters and their properties. Binary systems: classification, properties, observations.
- Stars on the main sequence. Nuclear reactions and generation of energy. Relation between mass, radius and luminosity of main sequence stars. Life time on main sequence, variation with mass of stars. Evolution of stars beyond the main sequence.
- Interior of stars: the Lane-Emden approximation, pressure, opacity and energy transport. Derivation of physical properties of stars with theoretical models. Profiles of spectral lines. Types and source of opacities. Extinction curves.
- Stellar remnants: white dwarfs, Chandrasekhar limit, Neutron stars, Black holes.
- Acquisition of data to final images: steps in photometry and spectroscopy.
- Statistical properties of galaxies: morphological classification, fundamental parameters, surface brightness, rotation curves and evidence for the existence of dark matter. Structure and dynamics of elliptical galaxies. Groups and Clusters of galaxies. Large-scale structure of the Universe: cosmic filaments, environment of galaxies, distance measurement using Tully-Fisher method.
- Inter-Galactic Medium (IGM), Quasar absorption systems, Damped Lyman alpha systems.
- Inter-stellar medium (ISM), Jeans length. phases of ISM, estimation using pressure equilibrium. photo-ionisation equilibrium.
- Active galactic nuclei. Classification of AGN. Unified theory of AGN. Radio galaxies. Weighing supermassive black holes using Virial theorem.
- Expansion of the universe, Hubble's law. Newtonian cosmology.

Recommended Reading

- Bradley W. Carroll and Dale A. Ostlie, *Introduction to Modern Astrophysics*, 2nd Edition, Addison Wesley (2006)
- Frederick R. Chromey, *To measure the Sky: An introduction to Observational Astronomy*, Ist Edition, Cambridge University Press (2010)
- D. Scott Birney, Guillermo Gonzalez and David Oesper, *Observational Astronomy*, 2nd Edition, Cambridge University Press (2006)

PHY638: Physics of fluids

[Cr:4, Lc:3, Tt:1, Lb:0]

Knowledge of the content of **PHY301**, **PHY303** *and* **PHY310** *is essential to follow this course.*

Course Outline

- Ideal fluids: Conservation of mass and the equation of continuity, Euler's equation, hydrostatics, energy and momentum flux, potential flow, incompressible fluids. Waves in an incompressible fluid.
- Viscous fluids: Equation of motion, energy dissipation in an incompressible fluid. Reynolds numbers. Laminar wake.
- Turbulence: Stability of flows, instability of tangential discontinuities, transition to turbulence. Description of turbulent flows using correlation functions. Turbulent flow and the phenomenon of separation with examples.
- Thermal conduction in fluids, heat transfer in a boundary layer, heating of a body in a moving fluid, convection.
- Diffusion: The equations of fluid dynamics for a mixture of fluids, diffusion of suspended particles in a fluid.
- Surface phenomena like capillary waves.
- Sound: Sound waves, the energy and momentum of sound waves, reflection and refraction, propagation of sound in a moving medium, absorption of sound.
- Shocks: Propagation of disturbances in a moving gas, surfaces of discontinuity, junction conditions, thickness of shock waves.
- One dimensional gas flow: flow of gas in a pipe, flow of gas through a nozzle, one-dimensional travelling waves, characteristics and Riemann invariants.
- Physics of strong explosions, Sedov-Taylor solution.

Recommended Reading

- L. D. Landau and E. M. Lifshitz, *Fluid Mechanics: Volume 6 (Course of Theoretical Physics)*, Butterworth-Heinemann (1987).
- G. K. Batchelor, *An Introduction to Fluid Dynamics*, Cambridge University Press (2000).

PHY639: Topics in biophysics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Review of essential physical principles and laws, forces, energy, laws of thermodynamics; Life and its physical basis.
- The cell and its components: membranes, cytoskeleton, organelles. The central role of macromolecules: proteins, nucleic acid, carbohydrates. Brownian motion and viscosity and their influence on particle motion in the cell.
- Cell movement, movements of proteins, cytoskeleton, molecular motors, actin, myosin, active and passive transport, adhesion, cell signalling, Brownian motion, viscosity, physics at low Reynolds number.

- The Cell Membrane: lipid bilayers, Liposomes.
- Structure and function of proteins, structural organization within proteins: primary, secondary, tertiary, and quartenary levels of organization, stability of proteins, protein folding problem, free energy and denaturation, motions within proteins, how enzymes work, measurement of binding and thermodynamic analysis.
- Nucleic acids and genetic information, DNA double helix, How structure stores information, DNA replication process, From DNA to RNA to protein, DNA packing, DNA denaturation, unzipping, RNA transcription.
- Neurons, action potential, Hodgkin-Huxley analysis, ion channels and pumps, biophysics of the synapse, Neural networks.
- Fluorescent imaging techniques, electron microscopy, x-ray crystallography, NMR spectroscopy, atomic force microscopy, optical tweezers.

Recommended Reading

- R. Phillips, J. Kondev and J. Theriot, *Physical biology of the cell*, Taylor & Francis (2008).
- M. Daune, *Molecular biophysics structures in motion*, Oxford University Press (1999).

PHY640: Non-equilibrium statistical mechanics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Qualitative comparison of equilibrium and nonequilibrium systems. Review of thermodynamic ensembles, phase space density, Liouville equation.
- Langevin equation, fluctuation-dissipation theorem, velocity autocorrelation.
- Master equations, Chapman-Kolmogorov equation, Kramers-Moyal expansion, Discrete Markov processes, solution of Master equation, stationary distribution, detailed balance, Einstein-Smoluchowski equation.
- Fokker-Planck equation, Ornstein-Uhlenbeck (OU) distribution, the diffusion equation. Diffusion in three dimensions, Diffusion in a finite region, reflecting and absorbing boundaries. Brownian motion, Wiener processes, relationship between OU and Wiener processes, Survival probability, mean first-passage time.
- Diffusion in a potential, Langevin equation in an external potential, Kramer's equation, Brownian oscillator, Smoluchowski equation, Kramer's escape rate. Diffusion in a magnetic field.
- Green-Kubo formulas, Dynamic mobility, power spectral density, Wiener-Khinchin theorem, white and colored noise.

Recommended Reading

- V. Balakrishnan, *Elements of Nonequilibrium Statistical Mechanics*, Ane Books, New Delhi (2008).
- R. Zwanzig, *Nonequilibrium Statistical Mechanics*, Oxford University Press (2004).
- N. G. van Kampen, *Stochastic Processes in Physics and Chemistry*, North Holland Amsterdam (1985).
- H. Risken, *The Fokker-Planck Equation: Methods of Solution and Applications*, Springer-Verlag Berlin (1996).

PHY641: Advanced classical mechanics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Aim: An advanced course in classical mechanics that lays down the foundation for further study of modern physics, from quantum mechanics to statistical mechanics to nonlinear dynamics. Stress will be on the more modern formalisms, concepts, and techniques of classical mechanics that find applications in a variety of fields.
- Topics:
  - Lagrangian Formulation of Mechanics; Constraints and Configuration Manifolds; Symmetries and Conservation laws
  - Hamiltonian Formulation of Mechanics; Hamilton's Equations of Motion (Symplectic Approach)
  - Canonical Transformations; Action-Angle Variables; Poisson brackets and Invariants; Integrable Systems
  - Canonical Perturbation Theory
  - Adiabatic Invariants; Rapidly Varying Perturbations
  - KAM theorem; Non-integrability and Chaos in Hamiltonian Systems
  - Introduction to Continuum Dynamics and Classical Fields (Sine-Gordon Equation; Klein-Gordon equation; Solitons)
  - Semiclassical Quantization (Einstein-Brillouin-Keller Quantization; Gutwiller Trace Formula)

Recommended Reading

- J. V. Jose and E. J. Saletan, *Classical Dynamics - A Contemporary Approach*, Cambridge University Press (1998).
- M. Tabor, *Chaos And Integrability In Nonlinear Dynamics: An Introduction*, Wiley-Interscience (1989).

PHY642: Non-equilibrium thermodynamics

[Cr:4, Lc:3, Tt:1, Lb:0]

Knowledge of the content of **PHY202** *and* **PHY304** *is essential to follow this course.*

Course Outline

- Review of equilibrium thermodynamics: Laws of thermodynamics, Gibbs equation, Legendre transforms of thermodynamic potentials. Stability of equilibrium states.
- Classical Irreversible thermodynamics (CIT): Generalized forces and fluxes, Local equilibrium hypothesis, Onsagar reciprocity relations, stationary states, minimum entropy production, applications, limitations of CIT.
- Coupled transport phenomena: Thermoelectric effect, Seebeck effect, diffusion through a membrane.
- Finite-time thermodynamics: Finite time Carnot cycle, Generalized potentials, thermodynamic length, criteria for optimal performance. Quantum models of heat engines.
- Extended irreversible thermodynamics: Heat conduction, Fourier vs. Cattaneo's law, extended entropy, non-local terms, applications.

Recommended Reading

- G. Lebon, D. Jou and J. Casas-Vazquez, *Understanding Non-equilibrium Thermodynamics*, Springer (2008).
- H. B. Callen, *Thermodynamics and an Introduction to Thermostatistics*, 2nd edition, John Wiley and Sons (1985).
- I. Prigogine, *Introduction to Thermodynamics of Irreversible Processes*, 3rd edition, Interscience Publishers (1967).
- S. R. De Groot and P. Mazur, *Non-equilibrium Thermodynamics*, Dover Publications, New York (2011).

PHY643: Electrodynamics of continuous media

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Review of Maxwell's equations in free space. Definition of auxiliary fields in Matter and Maxwell's equations in materials.
- Electrostatics of conductors, Brief overview of thermodynamic relations and Electrostatics of Dielectrics.
- Steady currents in matter, Drude model, Galvanomagnetic phenomena, Thermoelectric and Thermomagnetic Phenomena Static magnetic fields, gyromagnetic phenomena

- Superconductivity (London's Phenomenological formulation) Quasi static effects , skin effect overview of circuit theory
- Electromagnetic waves in material media. Kramers Kronig relations for AC susceptibilities Wave guides.

Recommended Reading

- L. D. Landau & E. M. Lifshitz *Electrodynamics of Continuous media*, 2nd edition Elsevier (1981).
- R. Becker, *Electromagnetic fields & Interactions*, Dover Publications (1982).
- M. W. Zemansky, *Heat & Thermodynamics*, 7th edition, McGraw Hill (1997).
- N. W. Ashcroft & N. D. Mermin, *Solid State Physics*, Holden Day (1976).

PHY644: Foundations of quantum mechanics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction Quantum theory (QT) is empirically a very successful theory; there is however an apparent lack of understanding of the theory. This is mostly due to the fact that, unlike the space-time structure, the cut between the ontology and epistemology in QT is difficult to resolve. The two fundamental concepts–the *nonlocal* correlations (entanglement) between space-like separated systems and the *indistinguishability* (non-orthogonality) of quantum states–is widely believed to separate QT from classical theories. In this course we take a foundational approach to QT from the outside: *i.e.*, since classical theories are completely devoid of entanglement, it is compared with various foil theories that are also nonlocal and indistinguishable in the sense of QT, such that their special nature in the theory can be quantified. The two concepts will be explained in this course through the variety of topics it has motivated in the field of quantum information and computation, or vice versa.
- Mathematical Review: The review of the Hilbert-space formulation of quantum mechanics, quantum states, quantum dynamics, and measurements qubits, block-sphere representation, Pauli algebra, pure versus mixed states, tensor-product, entanglement, purification, VECing an operator, quantum operations, LOCC, unitary versus non-unitary dynamics, decoherence, positive versus completely positive maps, Kraus decomposition
- Correlations: EPR paradox, the realism and no-signaling principle, the hidden variable theories, the violation of Bell-type inequalities by entangled states (CHSH, Mermin, and Svetlichny inequalities), Nonlocal PR box, simulating quantum correlations, shared randomness, entanglement and computational complexity
- Indistinguishability: discrimination and estimation of unknown quantum states, von Neumann versus POVM measurements, quantum tomography, nature of probabilities in QT, contextuality, Gleason's theorem,

Kochen-Specker theorem, compression of information, Von Neumann entropy, accessible information and Holevo's theorem, bit commitment, efficient simulation of Hamiltonian dynamics

Recommended Reading

- A. Peres, *Quantum Theory: Concepts and Methods*, Kluwer Dordrecht (1995).
- J. S. Bell, *Speakable and Unspeakable in Quantum Mechanics*, Cambridge University Press (2004).
- M. A. Nielsen and I. L. Chuang, *Quantum Computation and Quantum Information*, Cambridge University Press (2000).
- J. Preskill's Lecture Notes on Quantum Information `http://www.theory.caltech.edu/people/preskill/ph229/`
- B. Schumacher and M. D. Westmoreland, *Quantum Processes, Systems and Information*, Cambridge University Press (2010).

PHY645: Topics in quantum physics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Classical limit of Quantum mechanics: Semi-classical quantization, WKB. Coherent states as "best approximants" to classical behaviour. Squeezed states.

  This topic will explore solutions of the Schroedinger equation using approximate methods, mainly based on the saddle point method. Relationships to Bohr-Sommerfeld methods and to the path integral will lead to approximate wavefunctions, energy levels, and to classical mechanics.

- Perturbation theory: time dependent and independent, Standard material including degenerate cases. Borel resummation, Diagrammatics, Fermi golden rule Non perturbative effects. Instantons.

- Quantum systems in classical fields: Aharonov-Bohm, Landau levels etc. Studying quantum systems coupled to classical electric and magnetic fields. Phases in quantum mechanics. Hall effect, Hofstadter problem. Problems with Semi-classical theory of radiation (Bohr-Rosenfeld analysis).

- Scattering theory: 1-d, 2-d and 3-d. Poles of the scattering matrix. Analyticity properties. Reference: e.g., Sakurai

- Symmetry in Quantum mechanics: Ordinary and supersymmetry. Conserved quantum numbers. Degeneracy and splitting. Wigner-Eckart theorem Representations of symmetry groups. Galilean invariance in quantum mechanics

- Matrix Quantum Mechanics (and quantum gravity): This topic will explore the quantum mechanics of systems with large numbers of degrees of freedom. Large N limit, Nuclear energy levels, Thomas-Fermi model, and a relation to quantum gravity are possible sidelights.

- Quantum Light: Quantum description of optical fields. classical and non-classical light. Photon statistics, sub-Poisson light, squeezed light.

Recommended Reading

- J. J. Sakurai, *Modern Quantum Mechanics*, Addison Wesley (1993).
- S. Coleman, *Aspects of symmetry: Selected Erice lectures*, Cambridge University Press (1988).
- L. Mandel and E. Wolf, *Optical Coherence and Quantum Optics*, Cambridge University Press (1995).

PHY646: Quantum field theory and the Standard Model

[Cr:4, Lc:4, Tt:0, Lb:0]

Knowledge of the content of **PHY424** *is essential to follow this course.*

Goal: To complete the introduction of all basic tools required for computation and interpretation of observables in High Energy Physics.

Course Outline

1. Functional methods and Observables: Generating functionals, Vacuum bubbles, and Connected Green's functions, Combinatorics from functional differentiation, Exact propagator and its spectral decomposition, Functional differentiation for fermionic fields, S matrix and LSZ formula, Feynman rules for scattering amplitudes, Scattering cross-section and Decay rate calculations.
2. QED and U(1) gauge invariance: Photon propagator and gauge fixing, Feynman rules for QED, QED processes.
3. Lie groups and Lie algebras: Unitary and orthogonal groups and their representations, Tensor methods, Non-abelian covariant derivative and field strength, gauge invariant action, Feynman rules for non-abelian theories.
4. Spontaneous symmetry breaking: Goldstone theorem and Higgs mechanism, Unitary and R-xi gauges and massive vector propagators,
5. Standard Model: Spontaneously broken chiral gauge theory, CKM mixing and charged Lepton masses, B, L symmetries of SM masses, Feynman rules for SM, Effective current current Fermi theory, Meson and Baryon currents, Pion decay constant, Propagator for unstable particles, FEYNCALC, FEYNRULES and MADGRAPH for automated tree calculation, Weinberg d=5 operator and neutrino masses, Neutrino oscillations.
6. Loop diagrams in scalar QFT: Wick rotation, Feynman parameters and dimensional regularization, Passarino-Veltman functions and use of tables thereof, Power counting, BPHZ renormalization of phi^3 + phi^4 theory, Running mass and pole mass, anomalous dimensions, Running couplings, Renormalization Group and necessity use of running couplings.

Recommended Reading

- M. E. Peskin and D. Schroeder, *Introduction to Quantum Field Thoery*, (Westview Press), 1995.
- M. Srednicki, *Quantum Field Theory*, (Cambridge university Press), 2007.
- R. J. Rivers, *Path Integral Methods in Quantum Field Thoery*, (Cambridge university Press), 1988.
- A. Lahiri and P. B. Pal, *A First Book of Quantum Field Thoery*, (Narosa), 2007.
- T. P. Cheng and L. F. Li, *Gauge Theory of Elementary Particle Physics*, (Oxford University Press), 1988.
- L. H. Ryder, *Quantum Field Theory*, (Cambridge University Press), 1996.
- T. Goto, *Formulae for Supersymmetry*, MSSM and More, http://research.kek.jp/people/tgoto/

PHY647: Basic atomic collisions and spectroscopy

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Summary: The course will cover basic theory of atomic structure, spectroscopy and collisions and related experimental techniques. I would like to stress more on the experimental techniques, if the students are able to spend some time in laboratories doing such work. Possibilities of visits are to the Accelerator at Panjab University, Chandigarh and Inter-University Accelerator Centre, Delhi. I haven't explored these yet, but would like to. The feasibility of such an arrangement will depend on the number of students.
- Rutherford Scattering, Concept of cross-section Quantum Mechanical Scattering Theory Information expected from studying of Ion-Atom Collisions
- Experimental Techniques for measuring scattering cross-sections Generation of charged particle beams and neutral beams Techniques for detecting charged and neutral particles and photons
- Theory of atomic spectra, fine structure. Information expected from studying atomic spectra.
- Experimental techniques for spectroscopy Lineshape, absoprtion, emission Optical spectrographs Methods of excitation.

Recommended Reading

- B. H. Bransden and C. J. Joachain, *Physics of Atoms and Molecules*, Longman Publishing Group (1982).
- H. E. White, *Atomic Spectra*, McGraw Hill (1934).

- M. R. C. McDowell, *Introduction to the theory of ion-atom collisions*, North-Holland Publishing (1970).
- J. A. R. Samson, *Techniques of Vacuum Ultraviolet Spectroscopy*, V U V Associates (1990).
- J. M. Hollas, *Modern Spectroscopy*, Wiley (2004).
- W. Demtroder, *Laser Spectroscopy*, Springer (2008).

PHY648: Laser fundamentals and applications

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Basics of radiation-matter interaction: Einstein theory of absorption and emission in thermal equilibrium, spontaneous and stimulated emission, Einstein coefficients.
- Laser Fundamentals: Lasing principle, optical pumping, population inversion, light amplification, self sustained coherent oscillations.
- Laser rate equations: Two, three and four level systems, Laser cavities & modes, Plane & spherical resonators, Mode selection.
- Lasers: He-Ne, Cd-Se, Argon ion, CO2, Nd:YAG, Nd: Glass, Semi-conductor lasers, Dye lasers, Ti:sapphire lasers. fiber lasers, free electron lasers.
- Q-switching, Mode locking, Hole-burning, Pulse compression and ultrashort pulse lasers.
- Additional topics which are useful in this course: Non-linear processes: Propagation of light waves in a non-linear optical media, anisotropic nonlinear medium, Second harmonic generation, Phase matching, Four wave mixing, Stimulated Raman scattering, Optical Kerr effect, Pockel effect. Other nonlinear processes.

Advanced Topics Role of lasers in quantum optics experiments, Laser spectroscopy, Lasing without inversion, extremely narrow line width lasers. Laser cooling and trapping of atoms, Bose Einstein condensation.

Recommended Reading

- Thyagarajan and Ghatak, *Lasers–Fundamentals and Applications* 2nd Edn. Springer
- Orazio Svelto *Principles of Laser* 5th Edn. Springer.
- B. B. Laud, *Lasers & Non-linear Optics*, Wiley Eastern, (1985)

PHY649: Advanced experiments in physics: Lasers and optics

[Cr:4, Lc:0, Tt:0, Lb:12]

Course Outline This elective course aims to provide hands on training and exposure to the forefront of laser Physics and optical technology. The emphasis would be to assemble few thought provoking experiments from scratch on an optical-table. Indulging into some open-ended experimentation and original thinking would be encouraged.
One would learn nuts and bolts of various available lasers, including the Femtosecond laser system. Coherent manipulation of light by various (bio)-photonic crystal and opto-mechanics of fluid interfaces by radiation pressure shall be covered among other relevant topics.

Suggested modules

- Basics of laser operation and working
- Training session with femtosecond lasers
- Deformation of fluid interfaces by radiation pressure of a laser beam
- Understanding and characterization of Photonic crystals
- Interferometric techniques for thin-film characterizations
- Laser safety and radiation hazard
- Optical spectroscopy of various light sources

Suggested reading

- A. E. Sigman, *Lasers*, University Science Books, 1986.
- A. Ghatak, *Optics* McGraw-Hill, 2008.

PHY650: Ultra low temperature physics

[Cr:4, Lc:2, Tt:0, Lb:10]

Course outline The course will have lecture components that introduce both experimental and theoretical ideas in low temperature physics. The remaining hours will involve hands on experience in designing and experiments in the ultra low temperature laboratory.

Review of laws of thermodynamics

- liquefaction of helium and properties of liquid helium including phenomena like super-fluidity , second sound, phenomenological two fluid theories. Landau theory of quasi-particles, vortices and quantization of circulation
- Properties of Helium 3 and Helium3 helium 4 mixtures
- Solid state systems below 4.2K (mainly acoustic , thermal and electronic properties)
- Overview of topics like super-conductivity spin glasses
- Tehcniques below 4.2K , Adiabatic demagnetization , principles of helium3 helium 4 refrigeration, nuclear demagnetization techniques to reach temperatures below 1mK

- Electronics and instrumentation below 4.2K examples like discovery of cosmic microwave background (CMB) using cryogenic amplifiers
- Low temperature thermometry including modern techniques like coulomb blockade primary thermometry
- Modern cryofree techniques to reach below 10 K .

Recommended reading

- C. Enss & S. Hunklinger, *Low temperature Physics*, Springer (2005)
- G. K. White & P. Meeson *Experimental Techniques in low temperature physics* Oxford (2002)
- D. S. Betts *An Introduction to Millikelvin Technology* Cambridge (1989)

PHY652: Phase transition and critical phenomena

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Review of thermodynamics and equilibrium Statistical Mechanics. Partition function for interacting system, virial expansion. Zeros of the partition function.
- Ising model, mean eld theory, Brag Williams approximation. Equivalence of Ising model to other models, Spontaneous magnetization, Solution of Ising model using transfer matrix, high and low temperature expansions and Monte Carlo simulations.
- Order parameter, correlation function, critical exponents, scaling hypothesis, importance of dimensionality. Landau free energy, Landau-Ginzburg mean eld theory, Functional integration, Gaussian model.
- Renormalization group transformations, xed points, real and momentum space renormalization.
- Non-linear model, XY model, Two dimensional solids and melting (Kosterlitz-Thouless transition).

Recommended Reading

- Kerson Huang, *Statistical Mechanics*, Second Ed. John Wiley Sons, Singapore 2000.
- R. K. Pathria,*Statistical Mechanics*, Second Ed. Butterworth-Heineman Oxford 1996.
- N. Goldenfeld, *Lectures on Phase Transitions and the Renormalization Group*, Levant Books, Kolkata 2005.
- J. J. Binney, N. J. Dowrick, A. J. Fisher & M. E. J. Newman, *The theory of Critical Phenomena*, Oxford 2002.
- J. M. Yeomans, *Statistical Mechanics of Phase Transitions*, Oxford 1997.

PHY653: Physics of polymers

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline Introduction to polymers, coarse-graining in polymers. Brownian motion and stochas-tic processes, Ornstein-Uhlenbeck process, FluctuationDissipation theorem, Correlation and response functions,Fokker-Planck and Smoluchowski equation and its application. Interacting Brownian particleshydrodynamic interactions and its origin. Review of equi-librium statistical mechanicscanonical and microcanonical ensembles.

- Statics of single chain polymers end to end distance, distribution of end to end distance in models of polymer (freely jointed chain, freely rotating chain, Worm-like chain model and Gaussian chain).
- Dynamics of single chain Rouse model, Zimm model, density modes and dynamical scaling. Viscoelasticity origin of viscoelasticity, constitutive relations, microscopic stress tensor.
- Statics and Dynamics of many chain systems: Thermodynamics of mixing Entropy and free energy of mixing, Flory-Huggins theory, classi cation of good and poor solvents, Gaussian approximation to concentration uctuation, scaling theory statics.
- Dynamics of the density modes wave-vector dependent relaxation times. scaling theory dynamics.
- Rod like polymers: rotational and translational di usion. Dynamic light scattering of rod like polymers. Onsager theory of phase transition isotropic and nematic order.
- Experimental tools in polymer physics intermediate scattering functions, static and dynamic structure factors.

Recommended Reading

- M. Rubinstein & Ralph H. Colby., *Polymer Physics (Chemistry)*, Oxford University Press, USA, 1 edition, 6 2003.
- Pierre-Gilles de Gennes, *Introduction to Polymer Dynamics (Lezioni Lincee)*, Cambridge University Press, 9 1990.
- M. Doi & S. F. Edwards. *The Theory of Polymer Dynamics (Monographs on Physics)*, Oxford University Press, USA, 12 1986.
- Pierre-Gilles Gennes, *Scaling Concepts in Polymer Physics.*, Cornell University Press, 1 edition, 11 1979.
- Crispin Gardiner, *Stochastic Methods: A Handbook for the Natural and Social Sciences (Springer Series in Synergetics)*, Springer, softcover reprint of hardcover 4th ed. 2009 edi-tion, 10 2010.
- N. G. Van Kampen, *Stochastic Processes in Physics and Chemistry, Third Edition (North-Holland Personal Library)*, North Holland, 3 edition, 5 2007.

PHY654: Cosmology and galaxy formation

[Cr:4, Lc:3, Tt:1, Lb:0]

Knowledge of the content of **PHY635** *is essential to follow this course.*

Course Outline

- Galaxies, types of galaxies, morphological distribution, large scale distribution of galaxies, clustering of galaxies, large scale homogeneity and isotropy, A cosmic inventory.
- Hubbles law, expansion of the universe, comoving coordinates.
- Cosmological principle, Friedman-Robertson-Walker-Lemaitre model, Cosmological models. Distance redshift relation. Luminosity distance and angular diameter distance. Measurement of Hubbles constant, age of the universe, distance measurements and estimation of cosmological parameters. Accelerated expansion.
- Newtonian limit, non-relativistic perturbation theory, growth of perturbations in the linear limit. Nonlinear growth of perturbations. N-Body simulations.
- Dark matter halos, universal density profiles.
- Theory of mass functions, excursion sets, merger rates for halos.
- Formation of galaxies, feedback from star formation and evolution of galaxies. Super massive black holes and active galactic nuclei. Comparison of models with observations.
- Clusters of galaxies, intra-cluster medium, Sunyaev-Zeldovich effect.
- History of the universe: the dark ages, formation of first galaxies, reionization, evolution of the inter galactic medium. Revisiting the cosmic inventory.

Recommended Reading

- *Large Scale Structure of the Universe*, P. J. E. Peebles, Princeton Series in Physics, Princeton University Press, 1980.
- *Principles of Physical Cosmology*, P. J. E. Peebles, Princeton Series in Physics, Princeton Uni- versity Press, 1993.
- *Structure Formation in the Universe*, T. Padmanabhan, Cambridge University Press, 1993.
- *Theoretical Astrophysics, Vol.III: Galaxies and Cosmology*, T. Padmanabhan, Cambridge University Press, 2002.
- *Galaxy Formation*, Malcolm S. Longair, Astronomy and Astrophysics Library, Springer, 2000.
- *Cosmology*, S. Weinberg, Oxford University Press, 2008.
- *Gravitation and Cosmology*, S. Weinberg, Wiley.

- *Galaxy Formation and Evolution*, Houjun Mo, Frank van den Bosch and Simon White, Cambridge University Press, 2010.
- *Cosmological Physics*, J. A. Peacock, Cambridge Astrophysics, Cambridge University Press, 1998.

PHY655: Special topics in particle physics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Overview of Particle Physics, including major historical and latest developments.
- Introduction to Relativistic Quantum Mechanics and Quantum Field Theory.
- Relativistic Kinematics and Phase Space: Introduction to relativistic kinematics, particle reactions, Lorentz invariant phase space, two-body and three- body phase space etc.
- Invariance principles and Conservation Laws: Invariance in classical mechanics and in quantum mechanics, parity, charge conjugation, time reversal invariance, CPT theorem, O(3), SU(2), SU(3), quark model etc.
- Abelian and Non-Abelian gauge transformations: Construction of lAbelian and Non-Abelian gauge invariant lagrangians. Spontaneous symmetry breaking. Spontaneous symmetry breaking of a gauge theory.
- Standard Model of Particle Physics: formulation of V-A theory of weak interactions. Electroweak unification.SU(3)X SU(2)X U(1) gauge theory etc.
- Beyond the standard model: Flavor mixings, mass matrices. CKM and PMNS matrices. CP violation etc. Grand Unified theories.

Recommended Reading

- *An introduction to High Energy Physics*, D. H. Perkins, Cambridge Press 4th ed.2000.
- *Introduction to Quarks and Partrons*, F. E. Close, Academic Press, London, 1979.
- *Gauge Theories of Weak, Strong and Electromagnetic Interactions*, C. Quigg, Addison-Wesley, 1994.
- *First book of Quantum Field Theory*, A. Lahiri and P. Pal, Narosa, New Delhi. 2nd ed. 2007.

PHY656: Quantum principles and quantum optics

[Cr:3, Lc:3, Tt:0, Lb:0]

Course Outline

- Introduction to fundamental principles of quantum mechanics, quantum superposition, quantum en-tanglement, EPR paradox. Quantization of electromagnetic field, concept of photon, vacuum field, zero point energy, Casimir effect, coherent states of light, squeezed states, phase space representation of quantum states of light, classical analogy of a coherent state.
- Beam splitter quantum mechanics, first and second order interference, Mandel-Ou effect, Hanbury-Brown-Twiss (HBT) effect, HBT effect for classical and quantum light, photIntroduction to fundamental principles of quantum mechanics, quantum superposition, quantum en-tanglement, EPR paradox. Quantization of electromagnetic field, concept of photon, vacuum field, zero point energy, Casimir effect, coherent states of light, squeezed states, phase space representation of quantum states of light, classical analogy of a coherent state. Beam splitter quantum mechanics, first and second order interference, Mandel-Ou effect, Hanbury-Brown-Twiss (HBT) effect, HBT effect for classical and quantum light, photon bunching and anti-bunching, higher order coherence. Single photon interference experiments, type-I and type -II down conversion, generation of entangledphotons, polarization entangled photons, experiments based on entangled photons, quantum erasure, wheeler s delayed choice thought experiment, delayed choice quantum erasure. Atom-light interaction, semi-classical model, population oscillations, quantum model of atom-photoninteraction, collapse and revival of population, dressed state picture of atom-light interaction, atom-photon entanglement. Introduction to laser cooling, optical molasses, magneto optical trap, sisyphus cooling, trapping ofneutral atoms, evaporative cooling, Bose Einstein condensation. on bunching and anti-bunching, higher order coherence.
- Single photon interference experiments, type-I and type -II down conversion, generation of entangledphotons, polarization entangled photons, experiments based on entangled photons, quantum erasure,
- wheeler s delayed choice thought experiment, delayed choice quantum erasure.
- Atom-light interaction, semi-classical model, population oscillations, quantum model of atom-photoninteraction, collapse and revival of population, dressed state picture of atom-light interaction, atom-photon entanglement.
- Introduction to laser cooling, optical molasses, magneto optical trap, sisyphus cooling, trapping ofneutral atoms, evaporative cooling, Bose Einstein condensation.

Recommended Reading

- J. J. Sakurai, *Modern Quantum Mechanics*, Pearson Education, Inc.
- C. Gerry, P. Knight,*Introductory Quantum Optics*, Cambridge University Press.
- M. O. Scully & M. S. Zubairy, *Quantum Optics*, Cambridge University Press.
- D. Bouwmeester, A. Ekert & A. Zeilinger (Eds), *The Physics of Quantum Information*

PHY657: Radio-frequency and microwave circuits

[Cr:4, Lc:3, Tt:0, Lb:3]

Course Outline

- This course will emphasize importance of radio-frequency and microwave circuits in modern physical experiments ranging from applications like fast circuits in quantum computing or measuring the cosmic microwave background.
- Review of Maxwells equations and basic electrodynamics, lumped versus distributed circuit elements Basics of transmission lines Wave guides, analysis of microwave networks using S-matrix parameters, smith chart, impedance matching tuning , passive components like attenuators, directional couplers , magic-Tee, phase shifters bias tee, microwave resonators and planar circuits like micro-strips, coplanar waveguides. Active components like low noise amplifiers and basics of microwave ICs. Mixers , low noise amplifiers , basics of microwave synthesizers .
- Additional topics : Analogy between theory of transmission lines and simple tunneling in quantum mechanics, applications to physical systems. Microwave instruments like radars. Basics of test equipment like network analyzer, RF lock-in amplifier . Detailed study of applications of Microwave or RF circuits in selected modern physics experiments e.g. cyclotron resonance of carriers in semiconductors, Nuclear magnetic resonance, radio astronomy, rotational spectra of molecules using microwave spectroscopy etc.
- Laboratory work involves designing, construction and testing of few components.

Recommended Reading

- R. E. Collin, *Foundations of Microwave Engineering*, 2nd Edition Wiley (2001).
- D. M. Pozar, *Microwave Engineering*, 4th Edition , Wiley (2011).
- F. E. Terman, *Electronic & Radio Engineering*, McGraw Hill (1955).
- J. A. Stratton, *Electromagnetic Theory*, Mc Graw Hill (1941).
- Feynman et.al, *Feynman Lectures Volume II*, Addison Wesley (1964).
- L. Brilloin, *Wave propagation in periodic structures*, McGraw Hill (1946).
- R. Teppati et.al, *Modern RF and Microwave Measurement Techniques*, (The Cambridge RF and Microwave Engineering Series), Cambridge University Press (2013).

PHY658: Advanced QFT methods and special topics in high energy physics

[Cr:4, Lc:4, Tt:0, Lb:0]

Knowledge of the content of **PHY424** *and* **PHY646** *is essential to follow this course.*

Goal: To cover advanced field theoretic methods and a selection of special topics in subareas of Theoretical High Energy Physics.

Course Outline

- Renormalization of gauge theories. Power counting for spinors and vectors. Renormalization of Yukawa theory and QED. Current conservation and Ward identities.
- Anomalies. ABJ anomalies and gauge theory consistency. Accidental and approximate symmetries of the Standard Model. Chiral symmetry breaking and properties of pions and kaons.
- Path Integrals and Functional Methods. Schwinger-Dyson equations. 1PI and Wilson effective actions. Effective potential. Faddeev-Popov quantization of Yang-Mills theories. Ghosts. BRST symmetry. Renormalization of Yang-Mills Higgs. Asymptotic freedom and confinement. Anomalies and functional measure. Wess-Zumino-Witten theory.

Recommended Reading

- M. Peskin and D. Schroeder, *Introduction to Quantum Field Theory*, (Westview Press), 1995.
- M. Srednicki, *Quantum Field Theory*, (Cambridge University Press), 2007.
- R. J. Rivers, *Path Integral Methods in Quantum Field Theory*, (Cambridge University Press), 1987.
- S. Weinberg, *Quantum Theory of Fields*, Volume 1,2,3 (Cambridge University Press), 1996.
- T. P. Cheng and L. F. Li, *Gauge Theory of Elementary Particle Physics*, (Oxford University Press), 1988.
- L. H. Ryder, *Quantum Field Theory*, (Cambridge University Press), 1996.
- T. Goto, *Formulae for Supersymmetry*, MSSM and more, http://research.kek.jp/people/tgoto/.

Special Topics 1: GUTs and Supersymmetry

- Beyond the Standard Model, See-saw mechanism, Models for neutrino masses, Left-Right Symmetric Model, Pati-Salam Model. SU(5), SO(10) Grand Unification, Fermion masses in GUTs.
- Supersymmetry: Four and two component notation, Supersymmetry algebras, Supermultiplets and superfields. Gauge-invariant actions for chiral superfields. Supersymmetric gauge theories. Broken supersymmetry and Witten index. Spontaneous supersymmetry breaking at tree level. Supergravity basics, Gravity-mediated supersymmetry breaking. Supersymmetric LR models and GUTs.

Recommended Reading

- J. Wess and J. Bagger: *Superymmetry and Supergravity* (Princeton University Press), 1992.
- R. N. Mohapatra, *Unification and Supersymmetry*, (Springer), 2003.
- S. P. Martin, *A Supersymmetry Primer Perspectives on Supersymmetry*, pp 1-98, (World Scientific), 1998, https://arxiv.org/abs/hep-ph/9709356

Special Topics 2: Lattice field theory and Non-perturbative aspects of field theory

- Lattice Field Theory: Scalar fields on the lattice, Markov Chain Monte Carlo, Metropolis algorithm, Statistical and systematic errors, Abelian and non-abelian gauge theories, Gauge-invariant observables, Scaling and continuum limit, Nielsen-Ninomiya theorem, Fermions on the lattice, Lattice Quantum Chromodynamics, Algorithms for fermions, Finite density and the sign problem, Lattice supersymmetry, Large-N gauge theories.
- Extended Field Configurations: Topology in field theory, Topological solitons and instantons, 't Hooft-Polyakov monopole, Instantons in Yang-Mills theories, U(1) problem, B, L violation by EW instantons, Theta angle and strong CP problem, Fluctuations around extended field configurations, Vacuum decay.

Recommended Reading

- C. Gattringer and C. B. Lang, *Quantum Chromodynamics on the Lattice: An Introductory Presentation*, (Springer), 2010.
- T. Degrand and C. DeTar, *Lattice Methods for Quantum Chromodynamics*, (World Scientific), 2006.
- H. J. Rothe, *Lattice Gauge Theories: An Introduction*, (World Scientific), 2005.

Special Topics 3: Perturbative QCD and Collider Physics

- Deep inelastic scattering of Leptons and Hadrons. Parton model and Parton distribution functions. Bjorken scaling. Sum rules. Scaling violation. Factorization and Hard processes. Elementary processes in QCD. Renormalization schemes, Renormalization of composite operators, Operator Product Expansion. Infrared divergences, KLN theorem and IR safe observables, Resummation, Parton shower and Monte-Carlo event generators, Elements of next-to-leading order QCD corrections.

Recommended Reading

- F. Halzen and A. D. Martin, *Quarks & Leptons: An Introductory Course in Modern Particle Physics*, (Wiley India), 2008.
- M. E. Peskin and D. V. Schroeder, *An Introduction to Quantum Field Theory*, (Westview Press), 1995.
- R. K. Ellis, B. R. Webber, W. J. Stirling, *QCD and Collider Physics*, (Cambridge University Press), 2003.

- R. D. Field, *Applications of Perturbative QCD*, (Basic Books), 1989.
- T. Muta, *Foundations of Quantum Chromodynamics: An Introduction to Perturbative Methods in Gauge Theories*, (World Scientific), 2009.

PHY660: Nonlinear optics

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Introduction to anisotropic media, double refraction, wave propagation in anisotropic medium, applications of index ellipsoid, energy and momentum of light field in anisotropic media, wave plates, physics of polarization controlling devices, electro-optic modulators.
- Concepts of nonlinear phenomena, nonlinear electric polarizability, second order nonlinear processes; second harmonic generation, conceptual description of phase matching, parametric up and down conversion, parametric oscillators and amplifiers, entangled photon generation.
- Third order nonlinear processes; third harmonic generation, optical Kerr effect, self focusing, self phase modulation, super-continuum generation, cross phase modulation, four wave mixing, optical phase conjugation and its applications.
- Nonlinear optical effects in optical waveguides and optical fibers, applications of nonlinear optics in quantum optics experiments, nonlinear effects in Bose-Einstein condensation, higher order nonlinear effects.

Recommended Reading

- *The Principles of Nonlinear Optics*, Y. R. Shen, John Wiley and Sons Inc (2003).
- *Nonlinear Optics*, Robert Boyd, Elsevier Inc (2008).
- *Nonlinear Fiber Optics*, G. P. Agrawal, Elsevier Inc (2013).

PHY661: Selected topics in classical and quantum mechanics

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Group theory and symmetry in physics.
- Symplectic groups and their uses in physics, uncertainty relations.
- Geometric Phases in physics.
- Classical theory of constrained systems.
- Quantum Theory of Angular Momentum.
- Theory of Wigner distributions.
- The Wigner theory of UIRs of the Poincare group.
- Dissipative quantum mechanics.

Recommended Reading

- *Lectures on Advanced Mathematical Methods for Physicists*, Sunil Mukhi and N. Mukunda, World Scientific (2010).
- *Symplectic Techniques in Physics*, V. Guillemin and S. Sternberg, Cambridge University Press (1990).
- *Angular Momentum in Quantum Mechanics*, A. R. Edmonds, Princeton University Press (1996).
- *Decoherence and the Quantum-to-Classical Transition*, M. A. Schlosshauer, Springer (2008).
- *Geometric Phases in Physics*, Advanced Series in Mathematical Physics Volume 5, Edited by F. Wilczek and A. Shapere, World Scientific (1989).
- *Constrained Dynamics: With Applications to Yang-Mills Theory, General Relativity, Classical Spin, Dual String Model: Lecture Notes in Physics*, Kurt Sundermeyer, Springer-Verlag (1982).
- *Distribution Functions in Physics: Fundamentals*, M. Hillery, R. F. OConnell, M. O. Scully and E. P. Wigner, Physics Reports, 106, pp121167 (1984).

PHY662: Statistical physics of fields

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Collective Behavior, from particles to fields : Introduction, Phonons & elasticity, Phase transitions, Critical Behavior.
- Statistical Fields : Introduction, The Landau-Ginzburg Hamiltonian, Saddle point approximation and mean field theory, Continuous symmetry breaking and Goldstone modes, Discrete symmetry breaking and domain walls.
- Fluctuations : Scattering and fluctuations, Correlation functions and susceptibilities, Lower critical dimension, Comparison to experiments, Gaussian integrals, Fluctuation corrections to the saddle point, The Ginzburg criterion.
- The scaling hypothesis : The homogeneity assumption, Divergence of correlation length, Critical correlation functions and self similarity, The renormalization group (conceptual), The renormalization group (formal), The Guassian model (direct solution), The Gaussian model (renormalization group).
- Perturbative renormalization group : Expectation values in the Gaussian model, Expectation values in perturbation theory, Diagrammatic representation of perturbation theory, Susceptibility, Perturbative RG (first order), Perturbative RG (second order), The epsilon expansion, Irrelevance of other interactions, Comments on the epsilon expansion.

- Lattice systems : Models and methods, Transfer matrices, Position space RG in one dimension, The Niemeijervan-Leeuwen cumulant approximation, The Migdal-Kadanoff bond moving approximation, Monte Carlo simulations.
- Series expansions : Low temperature expansions, High temperature expansions, Exact solution of the one dimensional Ising model, Self duality in the two-dimensional Ising model, Dual of the three dimensional Ising model, Summing over phantom loops, Exact free energy of the square lattice Ising model, Critical behavior of the two-dimensional Ising model.
- Beyond spin waves : The nonlinear sigma model, Topological defects in the XY model, Renormalization group for the Coulomb gas, Two-dimensional solids, Two-dimensional melting.
- Dissipative dynamics : Brownian motion of a particle, Equilibrium dynamics of a field, Dynamics of a conserved field, Generic scale invariance in equilibrium systems, Non-equilibrium dynamics of open systems, Dynamics of a growing surface.

Recommended Reading

- Mehran Kardar, *Statistical Physics of Fields.*
- P. M. Chaikin & T. C. Lubensky, *Principles of condensed matter physics.*

PHY663: Relativistic cosmology and the early universe

[Cr:4, Lc:3, Tt:1, Lb:0]

Knowledge of the content of **PHY635** *is essential to follow this course.*

Course Outline

- Expansion of the Universe, Friedman-Robertson-Walker-Lemaitre model, Geodesics and Distance, geodesic deviation, Standard candles and Standard Rulers.
- Standard cosmological model: radiation dominated era, matter domination, dark energy and accelerated expansion. Horizon problem, flatness problem. Inflationary paradigm.
- Thermal history of the universe, primordial nucleosynthesis, decoupling of neutrinos, weakly interact- ing massive particles, electron-positron annihilation, matter radiation decoupling, last scattering surface, cosmic microwave background radiation.
- Scalar fields in an expanding universe. Generation of perturbations in inflation, Tensor and Scalar per- turbations, Reheating.
- Perturbations in an expanding universe. relativistic perturbation theory, growth of perturbations in dif- ferent scenarios. Fluctuations in the cosmic microwave background radiation. Transfer Functions, Baryon Acoustic oscillations,
- Sachs-Wolfe and Integrated Sachs Wolfe effect, Silk damping, The observed fluctuations in the cosmic microwave background radiation and its relation with Cosmological Parameters, Observational constraints.
- Late time perturbations, geometric effects, redshift space distortions.

Recommended Reading

- T. Padmanabhan, *Theoretical Astrophysics, Vol.III: Galaxies and Cosmology*, Cambridge University Press, 2002.
- S. Weinberg, *Cosmology*, Oxford University Press, 2008.
- Ruth Durrer, *The cosmic microwave background*, Cambridge University Press, 2008.
- Scott Dodelson, *Modern Cosmology*,Elsevier, 2005.

PHY664: Quantum thermodynamics

[Cr:4, Lc:3, Tt:1, Lb:0]

Knowledge of the content of **PHY202**, **PHY302** *and* **PHY304** *is essential to follow this course.*

Course Outline

- Review of Thermodynamics: laws of thermodynamics, thermodynamic potentials, work extraction processes, entropy and information, Maxwell's demon, Landauer principle.
- Review of quantum mechanics: density matrix formalism, composite quantum systems, reduced density matrix, entanglement, purity, quantum entropy, relative entropy, quantum measurements.
- Quantum thermodynamic machines: heat cycles, quantum thermodynamic processes, quantum adiabatic theorem, thermal efficiency, effect of interacting working medium, quantum friction, quantum Maxwell's demon.
- Time evolution. Liouville-von Neumann equation, Heisenberg and interaction picture, Markovian quantum master equation, Lindblad operators, weak coupling limit, relaxation to equilibrium, decay of two-level system, coherence enhanced efficiency of quantum heat engine.

Recommended Reading

- J. Gemmer, M. Michel, G. Mahler, *Quantum Thermodynamics: Emergence of Thermodynamic Behavior Within Composite Quantum Systems*, Lecture Notes in Physics, Springer (2009).
- G. Mahler, *Quantum Thermodynamic Processes: Energy and Information Flow at the Nanoscale*, Pan Stanford (2014).
- H. P. Breuer and F. Petruccine, *Theory of Open Quantum Systems*, Clarendon Press, Oxford (2002).

PHY665: Quantum phases of matter and phase transitions

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction and Motivation: Brief review of key concepts in quantum mechanics and statistical mechanics.
- Phase Transitions: Concept of phase and phase diagrams, examples of phase transitions, statistical mechanics and phase transitions, Landau theory of phase transitions, order parameter, relation to statistical mechanics, Superconducting phase transition.
- Theory of superconductors: Electrodynamics of superconductors, Ginzburg-Landau theory, BCS theory, Abrikosovs theory of type II superconductors, Andersons theory of disordered superconductors, Unconventional supercondcutors, heavy Fermions, Order parameter symmetry, Josephson effect and SQUID, Superconducting qubits.
- Topological phases of matter and topological phase transitions: Quantum Hall effect and the emergence of topological invariants, Topological band theory, Model Hamiltonians, Topological properties and protections, Characterizing topological materials, Topological states of quantum matter, Topological insulators, Topological crystalline insulators, Topological superconductors, Weyl and 3D Dirac semimetals, Topological phase transitions.

Recommended Reading

- N. W. Ashcroft and N. D. Mermin, *Solid State Physics*, Brooks Cole (1976).
- L. D. Landau; E. M. Lifshitz, *Statistical Physics*, Butterworth-Heinemann, 1996.
- M. Tinkham, *Introduction to superconductivity*, Dover Publications, 2004.
- J. Hajdu, *Introduction to the Theory of the Integer Quantum Hall Effect*, (1994).
- A. Bansil, Hsin Lin, and Tanmoy Das, *Topological Band Theory*, Rev. Mod. Phys. 88, 021004 (2016).
- M. Z. Hasan and C. L. Kane, *Topological Insulators*, Rev. Mod. Phys. 82, 3045 (2010).

PHY666: Open quantum systems

[Cr:4, Lc:3, Tt:1, Lb:0]

Knowledge of the content of **PHY302** *and* **PHY403** *is essential to follow this course.*

Course Outline

- Quantum probability: Pure states and statistical mixture of quantum states, density matrix formalism, composite quantum systems, quantum entropy and quantum measurements.
- Dynamical equation for open quantum systems: Quantum dynam- ical semigroups, Markovian quantum master equation, microscopic deriva- tion of quantum master equation, weak-coupling limit.

- Decoherence: The decay rates of an open system in quantum Brownian motion and damped harmonic oscilator.
- Optical quantum master equation: Matter in quantized radiation fields, decay of two-level system in thermal and squeezed thermal bath, Resonance fluorescence, damped harmonic oscillator and Caldeira-Leggett model.
- Non-Markovian quantum processes: Nakajima-Zwanzig projection operator technique, time-convolutionless projection operator method, ex- act solution of the spontaneous decay of a two-level system, Jaynes-Cummings model of resonance.
- Stochastic approach for open quantum systems: Stochastic Schrdinger equation, homodyne photodetection, hetrodyne photodetection, and quantum trajectory approach.

Additional Topics

- Markov Chain Mixing, Random Walks on Graphs.

Recommended Reading

- H. P. Breuer and F. Petruccione, *The theory of open quantum systems*, 1st edition, Oxford University Press (2003).
- U. Weiss, *Quantum Dissipative Systems*, 3rd edition, World Scientific (2008).
- H. Carmichael,*An Open System Approach to Quantum Optics*, Springer-Verlag (1991).
- H. Carmichael, *Statistical Methods in Quantum Optics 1: Master equa- tions and Fokker-Planck Equations*, Springer (2008).
- H. Carmichael, *Statistical Methods in Quantum Optics 2: Non-Classical Fields*, Springer (2008).
- R. P. Feynman and F. L. Vernon Jr., *The Theory of a General Quantum System Interacting with a Linear Dissipative System*, Annals of Physics 281, 547607 (1963).

PHY667: Quantum magnetism

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction: Basic magnetic properties, units in magnetism, magnetic moments and angular momentum, Bohr magneton, precession, quantum mechanics of the spin.
- Isolated Magnetic moments: Magnetization and magnetic susceptibility, paramagnetism and dia-magnetism, Brillouin function, Van-Vleck Paramagnetism, Hunds rules for the ground state of ions, adiabatic de-magnetization.

- Magnetic moments in solids: Crystalline electric fields, splitting of orbital degeneracy, orbital angular momentum quenching, Jahn-Teller distortion.
- Interactions between Magnetic moments: Dipolar interactions, exchange interactions, origin of exchange, super-exchange and double exchange interactions, RKKY interaction.
- Magnetic ordering: Ferro-, Ferri-, and anti-ferromagnetic ordering, Weiss molecular field models of magnetic ordering, spin glasses, excitations of the ordered states, magnons, spin-waves.
- Measuring Magnetism:
    1. Bulk techniques - Magnetometers, vibrating sample magnetometer (VSM), SQUID based magnetometers.
    2. Microscopic techniques - neutron scattering, Nuclear Magnetic Resonance (NMR), Electron Spin Resonance (ESR), and muon spin rotation (muSR).
- Special Topics: Hubbard model, Mott insulators, Magnetism in low-dimensional and geometrically frustrated systems, BEC of Magnons, quantum spin liquids.

Recommended Reading

- J. Crangle and E. Arnold, *Solid State Magnetism*,(1991).
- S. Blundell, *Magnetism in Condensed Matter*, (Oxford University Press 2005).
- P. Mohn, *Magnetism in the Solid State*, (Springer, 2005).
- Ashcroft and Mermin, *Solid State Physics*.

PHY668: Soft condensed matter

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Forces, energies and timescales in condensed matter . What is soft matter ? Basic phenomenology of soft condensed matter systems: Colloids, polymers, membranes, liquid crystals. Viscous, elastic and viscoelastic behaviour.
- Order Parameter, Phases and Phase transitions. Symmetry, order parameter and models. Mean-field theory and phase diagrams. Landau theory. Liquid-gas transition, solid-liquid transition, Ramakrishnan and Yussouff density functional theory.
- Colloidal Systems. Single colloidal particle in a liquid Stokes law and Brownian motion, Forces between colloidal particles. Depletion interactions. Stability and phase behavior of colloids.
- Polymers. Model systems, chain statistics, polymers in solutions and in melts, flexibility and semi-flexibility, distribution functions, self-avoidance, rubber elasticity, viscoelasticity, reptation.

- Surfaces, Interfaces and Membranes. Interfacial tension. Fluctuation of Interfaces. Wetting. Fluid vs. solid membranes, energy and elasticity, surface tension.
- Liquid Crystals. Liquid crystal phases. Nematic-Isotropic transition. Distortions and topological defects. Frederiks transition. Polymer liquid crystals.
- Soft Biological Materials. Composition of cell. Cellular cytoskeleton. Statistical view of dynamics inside a cell : Active vs. Passive transport. Introduction to soft active matter.

Recommended Reading

- R. A. L. Jones, *Soft condensed matter*, Oxford University Press 2002.
- I. W. Hamley, *Introduction to soft matter*, Wiley, New York 2007.
- M. Doi, *Soft matter physics*, Oxford University Press 2013.
- P. M. Chaikin & T. C. Lubensky, *Principles of condensed matter physics*, Cambridge University Press 1995.
- T. A. Witten, *Structured fluids – polymers, colloids, surfactants*, Oxford University Press 2004.
- P. Nelson, *Biological physics*, Freeman, New York 2004.
- L. S. Hirst, *Fundamentals of soft matter science*, CRC Press, London 2013.
- J. V. Selinger, *Introduction to the theory of soft matter*, Springer, New York 2016.
- M. Kleman & O. D. Lavrentovich,*Soft matter physics*, Springer, New York 2003.
- S. Safran, *Statistical Thermodynamics Of Surfaces, Interfaces, And Membranes*, (Frontiers in Physics), Westview Press, 2003.
- S. Ramaswamy, *Active Matter, J. Stat. Mech. Theory and Experiment*, Spl. Issue on statphys 26, 2017.
- M. C. Marchetti, J. F. Joanny, S. Ramaswamy, T. B. Liverpool, J. Prost, Madan Rao, and R. Aditi Simha, *Hydrodynamics of soft active matter*, Rev. Mod. Phys. 85, 1143 (2013).

4.7 Inter-disciplinary Elective Courses

IDC305: Selected analytical techniques

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline This course consisting of four major analytical topics as described below is developed for students with interest in interdisciplinary subjects.

- Magnetic Resonance Spectroscopy: Introduction to NMR: Spin and spin angular momentum, CW NMR, pulse NMR, sampling, bandwidth, detection and acquisition of NMR signals, time and frequency domain spectra, FT-NMR, resolution and sensitivity in NMR. Spin interactions in NMR, chemical shift, scalar or J-coupling, dipolar interaction and quadrupole interaction, quantum mechanical description of spin-interactions, spin interactions in the solution and solid-state.

  Introduction to EPR: Zeeman Effect, Spin Relaxation and Bloch Equations, Anisotropy of the hyperfine interactions. Instrumentation: CW and pulsed EPR instrument and experimental techniques. Detection of radicals and paramagnetic metal centers; EPR in Catalysis, Porus Materials, Biology and Medicine.

- Molecular Magnetism: Definitions and Experimental Methods. Instruments for measuring magnetization and susceptibility measurements. Diamagnetism, Paramagnetism, Ferromagnetism and Anti-ferromagnetism. Magnetic Anisotropy. Hard and Soft Magnetic materials. 1-D, 2-D and 3-D Magnetic materials. Chiral molecule-based magnets. Magnets for communication and information technology.

- Mass Spectrometry: Types of mass analysers (magnetic, quadrupole, time of flight, etc.), types of detectors (electron multipliers, Faraday cup, microchannel plates, and array transducers), types of ion sources (electron impact ionization, fast atom/ion bombardment (FAB), secondary ion mass (SIM), thermal ionization, laser ionization, matrix-assisted laser desorption and science (for example, ultra-trace analysis, isotope ratio measurements, and surface characterization).

- Thermal Analysis and Microscopy Techniques: For characterization of materials, Biomaterials, and Pharmaceutical Products. Principles and applications of various thermal analysis techniques, such as Thermogravimetric analysis (TGA), Differential Scanning Calorimetry (DSC), Differential Thermal Analysis (DTA), Dynamic Mechanical Analysis (DMA), Thermomechanical Analysis (TMA). Principles and applications of spectroscopic techniques for surface analysis, such as Atomic Force Microscopy (AFM), Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM).

Recommended Reading

- M. H. Levitt, *Spin dynamics: Basics of Nuclear Magnetic Resonance*, 2nd edition, John Wiley & Sons, England (2008).

- R. S. Macomber, *A Complete introduction to modern NMR techniques*, 1st edition, John Wiley & Sons, England (1998).

- J. A. Weil and J. A. Bolton, *Electron Paramagnetic Resonance: Elementary theory and Practical Applications*, 2nd edition, Wiley Interscience (2007).

- E. de Hoffmann and V. Stroobant, *Mass Spectrometry: Principles and Applications*, 3rd edition, Wiley Interscience (2007).

- M. Getzlaff, *Fundamentals of Magnetism*, 1st edition, Springer (2007).
- M. E. Brown, *Introduction to Thermal Analysis: Techniques and Applications*, Springer, 2nd edition (2001).
- L. Que (ed.), *Physical Methods in Bioinorganic Chemistry: Spectroscopy and Magnetism*, University Science Books (2000).

IDC306: Biocomputing

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline Following content will be taught in biological context.

- Introduction to Computation: history of computation, need of computation in modern biology.
- The types of biological data and databases: sequence, structure, expression, interaction, enzyme activity, genomic and population data-sets.
- Common data formats used in biology: separator delimited text files and their relevance, fasta sequence format, alignment files, tree representation, HTML/XML files, bed/gff files etc.
- Working with text editors and spreadsheets.
- Data compression: Huffman encoding, Burrows wheeler transformation, Gif, Jpeg, Png, Zip, Tar etc.
- Command-line programming: working with Linux/Cygwin shell, regular expressions, installing software in Linux, vi editor, shell scripting, working with MS DOS
- Introduction to relational databases: MySQL
- Basic computer programming: elements of programming, PERL or Python.
- Advanced computer programming : writing functions/packages, writing images, working with databases through programs, connecting to servers/WWW, developing user interfaces with HTML/CGI and Tk
- Statistical computing using R: basic R functions, statistical tests of significance, working with advanced packages
- Graphics: working with Gimp, Photoshop, Illustrator and MS powerpoint for basic imaging.

Suggested reading

- James Tisdall, *Beginning Perl for Bioinformatics*
- Haddock & Dunn, *Practical computing for biologists*
- Peter Dalgaard, *Introductory Statistics with R*

IDC307: Introduction to computational biology

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline This course intends to give an introduction to information storage and processing by biological macromolecules (DNA and protein sequences) and biochemical pathways in cellular processes. This is an interdisciplinary area in modern biology evolving through the past two decades with inputs from mathematics, statistics, physical sciences, computer science and several other engineering sciences, to understand how biological systems work.

- History of the rise of Bioinformatics and Computational Biology.
- Basic information theory.
- Cell as an information-processing system.
- DNA and Proteins as informational molecules.
- Computation in network of genes, protein structure, protein-protein interactions.
- Biochemical pathways and cellular processes: Models of regulation.
- Basics of metabolic control analysis.
- Network analysis of biochemical pathways.
- Introduction to some biological repositories of information.

Recommended Reading

- J. Ramsden, *Bioinformatics: An Introduction (Computational Biology)*. Springer (2015).
- A. Lesk, *Introduction to Bioinformatics*. Oxford University Press (2015).
- J. M. Bower, Hamid Bolouri, *Computational Modeling of Genetic and Biochemical Networks*, Ane Books (2004).
- J. Collado-Vides and R. Hofestdt, *Gene Regulation and Metabolism*, MIT Press (2004).

IDC401: Theoretical biology

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction: What is Theoretical Biology? Role of other disciplines in the study of biological systems.
- Theoretical Ecology and Epidemiology: Short survey of discrete equations and differential equations. Models of population growth for single and interacting species. Modelling the spread of infection in a population.
- Theories of Pattern Formation in Developmental Biology: Diffusion and cell-cell communication. Models of spatial pattern formation.
- Theoretical analysis of biochemical pathways and gene regulation Short introduction to control theory. Types of feedback regulation in biochemical pathways. Gene circuits. Network representation of biochemical pathways.

Recommended Reading

- L. Edelstein-Keshet, *Mathemtical Models in Biology*, SIAM Classics in Applied Mathematics 46 (2005).
- J. D. Murray, *Mathematical Biology I and II*, Springer (2007).
- L. Segel, *Mathematical Models in Molecular and Cellular Biology*, Cambridge University Press (1984).
- U. Alon, *An Introduction to Systems Biology*, Chapman and Hall/CRC (2006).

IDC402: Nonlinear dynamics, chaos and complex systems

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline This aims to be a course in nonlinear dynamics and chaos with an interdisciplinary approach. The emphasis of the course will be on general concepts, illustrated by applications to problems in physics, chemistry and biology (ranging from mechanical vibrations to biological rhythms). In each illustration, the scientific background of the problem will be explained at an elementary level. The emphasis will be on the analysis of the dynamical equations that model the phenomena. The topic details are given below:

- First-order differential equations and their bifurcations.
- Limit cycles and their bifurcations.
- Phase plane analysis of flows on lines and circles.
- Lorenz equations and introduction to dynamical characteristics of chaos.
- Iterated maps (eg. Logistic map, Tent map).
- Routes to chaos (in particular, period doubling).
- Concepts in renormalization, fractals, multifractals and strange attractors.
- Spatiotemporal Chaos in extended nonlinear systems (eg. Coupled Map Lattices).
- Illustrations from mechanical vibrations, lasers, biological rhythms, superconducting circuits, insect outbreaks, chemical oscillators, genetic control systems and chaotic waterwheels.

Recommended Reading

- S. H. Strogatz, *Nonlinear Dynamics and Chaos: With Applications To Physics, Biology, Chemistry, And Engineering (Studies in nonlinearity)*, 01st edition, Westview Press (2001).
- Edward Ott, *Chaos in Dynamical Systems*, 02nd edition, Cambridge University Press, (2002).
- M.Tabor, *Chaos and Integrability in Nonlinear Dynamics: An Introduction*, 01st edition, Wiley-Interscience (1989).

IDC403: Protein engineering

[Cr:4, Lc:3, Tt:0, Lb:0]

Course Outline

- Background Concepts: Protein structure and function; Protein folding and misfolding; Protein stability (enzymatic, thermodynamic and kinetic).
- Objectives, Concepts and Approaches: Creation of new or altered structural proteins, catalysts, transporters, receptors and transcription factors; Redesign of structure, function, stability and aggregation; Creation of designer proteins; Combinatorial approaches to protein engineering; Rational approaches to protein engineering.
- Tools: Molecular visualization; Molecular modelling; Recombinant DNA technology- based strategies; Constructs, vectors, strains, affinity fusion tags; Chemical modification strategies; Use of labels; Heterologous protein expression; Protein purification approaches; Protein handling; Protein biochemical and physico-chemical characterization; Design and development concepts relating to functional assays
- Combinatorial Protein Engineering: Chemical mutagenesis; Error-prone PCR; Synthetic peptide combinatorial libraries; Principles and applications of phage display and bacterial display; Selection and screening approaches for folding and function
- Rational Protein Engineering: Backbone Reversal; Domain or sub-structure fusion; Global conservative mutagenesis; Excision of super-secondary structures; Substructure shuffling with symmetric structures; Surface reengineering to obviate aggregation; Disulphide bond introduction to prevent domain dissociation; Topology scrambling through loop redesign; Active surface transplants between homologous beta sheet proteins; Whole surface transplants; Enzyme active site transplants; Loop transplants on beta/alpha barrels; Site- directed mutagenesis to alter protein kinetic stability or thermodynamic stability; Protein hydrophobic core reengineering; Reengineering of protein surface electrostatics.

Recommended reading

- Sheldon J. Park & Jennifer R. Cochran (Eds) *Protein Engineering and Design*, CRC Press (2009).
- Mallorie N. Sheehan *Protein Engineering: Design, Selection, and Applications*, Nova Science Publishers, Inc. (2011).
- Jeffrey L. Cleland & Charles S. Craik (Eds), *Protein Engineering: Principles and* Practice, Wiley (1996).

IDC404: Computational genomics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction to genes, genomes and genetics Genome sequencing Methods Computational algorithms and analysis
- Genome organization Linear organization, gene clusters, bricks, ridges Three dimensional genome organization, 3C, 4C, 5C, HiC, ChIA-PET
- Genome Evolution Evolution of genome complexity Evolution of non-random genome organization Error mitigation in genome.
- Functional genomics Microarrays, RNAseq, GRO-Seq, RNA-PET; ChIP-chip, ChIP-seq, DamID etc Replication timing, Repli-seq
- Genome and diseases Essential genes and disease genes Genome wide association studies
- Genomic data browsing UCSC genome browser Ensemble genome browser GEO database
- Statistical analysis for genome scale datasets Data normalization FDR calculations Data-mining techniques: clustering, SOM, PCA etc Differential gene expression analysis Function/pathway/motif/gene-set enrichment analysis Peak detection for TF-binding data
- Network perspective of genome regulation DNA-DNA, DNA-protein, protein-protein interaction networks Higher order network of networks

Recommended Reading

- Arthur M. Lesk, *Introduction to Genomics*
- Jonathan Pevsner, *Bioinformatics and functional genomics*
- Sorin Draghici, *Statistics and Data Analysis for Microarrays Using R and Bioconductor*

IDC405: Atmospheric dynamics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Atmospheric structure and composition scale height potential temperature Lapse rates geopotential hydrostatic balance buoyancy frequency Equations of motion coriolis force geostrophic balance thermal wind equation vorticity and potential vorticity
- Acoustic waves Internal gravity waves Atmospheric tides Rossby waves Forced planetary waves Equatorially trapped waves
- The Walker circulation El nino and the southern oscillation Intraseasonal oscillation Quasi-biennial oscillation Semi annual oscillation
- Dynamical instability Convective instability Baroclinic instability Barotropic instability

Recommended Reading

- D. G. Andrews, J. R. Holton & C. B. Leovy, *Middle Atmospheric Dynamics*, Academic Press (1987)
- J. R. Holton, *An introduction to Dynamic Meteorology*, Elsevier Academic Press (2004)
- T. Beer, *Atmospheric Waves*, Adam Hilger Limited (1974)
- J. R. Holton, J. A. Curry & J. A. Pyle, *Encyclopedia of Atmospheric Sciences (Vol 1 6)*, Academic Press (2002)

IDC407: Network science

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction and history of networks: Pervasiveness of networks in nature and everyday life, Surprising powers of networks, Bucket chain, MafiaBoy, Eulers theorems, Strong and weak ties: Granovetter, Six degree of separation: Stanely Milgram.
- Network data: Social networks, World Wide Web and Internet, Wikipedia and Facebook networks, highway and flight networks, power grids, biological networks, ecological networks, economics networks, dark networks, disease networks, happiness networks etc.
- Structure of networks: Network attributes, vertex, edge, weak links, date/party links , components, Planar/nonplanar, cyclic/noncyclic, directed/undirected, weighted graphs, trees, Random model of networks: Erdos-Renyii, Small world property of networks, Scale-free networks and their importance in robustness of systems, Hierarchical networks and clustering coefficient, Network motif, modules, overlapping modules and their relevance, Network centralities: degree, betweenness, closeness, Eigen vector centrality, and community centrality, Centrality-lethality paradigm and the conflicts in biological context, Different topologies of networks: Assortativity, dis-assortativity, Rich-club phenomenon, Networks of networks, Coupled and interdependent networks.
- Dynamics of networks: Preferential attachment model, Network percolation, Information flow in the networks, Perturbation and error propagation in networks, Epidemic models, Synchronization of networks, Controllability of networks.
- Statistical analyses of networks: Mapping networks, Network data structures: adjacency matrix, hash of hash/arrays etc, Sampling networks for control analyses, Quantifying network, node and edge attributes, Graph traversal, Graph partitioning, Identification and scoring of network modules, Quantifying group evolution, Modeling network dynamics, Modeling gene regulatory networks, Reconstructing networks from multi-dimensional datasets (like microarray), Network visualization and analysis software: Cytoscape, Pajek, Osprey etc.
- Research paper discussion: Key papers across disciplines will be discussed.

Recommended Reading

- Barabsi, Albert-Lszl.Linked: *The New Science of Networks.*Perseus Books Group. ISBN9780738206677.
- M. E. J. Newman (2010).*Networks: An Introduction.* Oxford: Oxford University Press. ISBN0-19-920665-1.
- Csermely, P. (2006, re-print: 2007, 2nd paperback edition: 2009) *Weak links: Stabilizers of Complex Systems from Proteins to Social Networks*, Springer Verlag, pp. 392, see the downloadable chapters here: www.weaklink.sote.hu/weakbook.html. The Google version of the book: http://books.google.com/books?id=bu34G3A2E9YC

IDC408: Environmental hygiene, sanitation and waste management

[Cr:4, Lc:2, Tt:1, Lb:1]

Course Outline

- Perspectives on Environmental Hygiene, Sanitation and Waste Management
- Participatory Learning in Environmental Hygiene, Sanitation and Waste Management
- Sociology of Environmental Hygiene, Sanitation and Waste Management
- Infrastructure for Sanitation- part 1
- Infrastructure for Sanitation- part 2
- Review of governance initiatives towards implementation of sanitation and waste management
- Wastewater
- Technology for Recovery of Resources and Treatment
- Solid Waste Management
- Management of Collectives
- Change Management

Recommended Reading

- Drinan E. and Spellman F., *Water and Wastewater Treatment: A Guide for the Non-engineering Professional*, CRC Press (ISBN 9781439854006)
- Tchobanoglous G., *Integrated Solid Waste Management Engineering Principles And Management Issues*, (ISBN-13:978-9339205249)
- Metcalf & Eddy, *Wastewater Engineering: Treatment and Resource Recovery*, 5th Edition, McGraw-Hill Education, 2013 (ISBN-13: 978-0073401188)

- Bruce E. Rittmann and Perry L. McCarty, *Environmental Biotechnology: Principles and Applications*, 2nd edition, McGraw-Hill Education, 2019 (ISBN-13: 978-1260440591)
- Girard J., *Principle of Environmental Chemistry*, Jones and Barth (ISBN-13:978-1449693527)
- Denzin N. K. and Lincoln Y. S. S., *The Sage Handbook of Qualitative Research*, Sage 2011, (ISBN-13:978-1-4129-7417-2)
- Ramaswamy R. Iyer, *Towards Water Wisdom, Limits, Justice, Harmony*, Sage Publishing.

Additional Reading

- *Kaveri Gill: Of Poverty and Plastic: Scavenging and Scrap Trading Entrepreneurs in India's Urban Informal Economy*, OUP, 2010
- *Collin McFarlane Sanitation in Mumbai's Informal Settlements: State, 'Slum' and Infrastructure,Environment and Planning A*, 2008
- Nikhil Anand, *Hydraulic City*, Duke University Press, 2017.
- Jones J. A. A, *Water sustainability a global Perspective*, 1st edition, Routledge, 2010 (ISBN-13:978-1444104882)
- Bower L., *The microbes fight back: Antibiotic resistance*, 2015, RSC Publishing (ISBN-13:978-1782621676)

IDC620: Computational biology

[Cr:4, Lc:3, Tt:0, Lb:1]

Course Outline In-silico modeling and computational analysis of intracellular processes and genome and protein sequences to study their structure and function.

- Cell as an information-processing system.
- DNA and Proteins as informational molecules.
- Biochemical pathways and cellular processes: Models of regulation; Basics of metabolic control analysis, and flux balance analysis.
- Network analysis of genes, protein structure, protein-protein interactions, and biochemical pathways.
- Basic data mining/machine learning applications in biology.

Recommended Reading

- James M. Bower, Hamid Bolouri, *Computational Modeling of Genetic and Biochemical Networks* Ane Books (2004).
- Christopher Fall, Eric Marland, John Wagner, John Tyson, *Computational Cell Biology* Springer (2002).
- Julio Collado-Vides and Ralf Hofestädt, *Gene Regulation and Metabolism* MIT Press (2004).

IDC621: Modelling complex systems

[Cr:4, Lc:2, Tt:0, Lb:3]

Course Outline Different classes of models of spatiotemporal phenomena will be investigated in this course. Emphasis will be on hands-on implementation of these models in computer programs.

- Cellular Automata Models: basic framework and specific examples such as models of spreading of infectious disease and sandpile models of self-organized criticality.
- Oscillator Chains: basic framework and specific examples (e.g. the Kuramoto model of phase oscillators); synchronization phenomena in such coupled systems.
- Coupled Map lattices: pattern formation in this class of model systems; characterization of correlations in space and time.
- Complex Networks: small-world networks; scale-free networks; hierarchical networks; modular networks.

Recommended Reading

- K. Kunihiko, *Overview of Coupled Map Lattices*, Chaos, vol. 3 (1992) 279.
- M. E. J. Newman, *The Structure and Function of Complex Networks*, SIAM Review 45, 167-256 (2003).
- J. A. Acebroen, L. L. Bonilla, C. J. Perez Vicente, F. Ritort, and R. Spigler, *The Kuramoto model: A simple paradigm for synchronization phenomena*, Rev. Mod. Phys. vol. 77 (2005) 137.
- Bak, P., Tang, C. and Wiesenfeld, K., *Self-organized criticality: an explanation of 1/f noise*. Physical Review Letters, vol. 59 (1987) 381.

IDC622: Physical basis of medical diagnostics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction to medical physics. Interaction of soft-matter/ tissue with X-ray, CT, Ultrasound, light, EM waves.
- Partial differential equation and modelling those interactions.
- Solving PDE with FEM and circular radon transform. Basic concept of diagnosis with matrix theory and tomography. Beers Lambert ray theory, Ray projections, Radon transform and its mathematical framework.
- Projections, Fourier transform, Fourier slice theorem and diagnosis of soft matter.
- Computerized Tomography like X-ray, x-ray CT, MRI, Optical methods, Ultrasound imaging, Photoacoustic and PET Imaging.
- Diffraction theory in living system. ART, Algorithms for retrieving the interior properties of tissue/materials from boundary measurements.

Recommended Reading

- J. T. Bushberg, *The Essential Physics of Medical Imaging.*
- B. H. Brown, *Medical Physics and Biomedical Engineering*, et al, IoP Publishing.
- B. K. Johnson, *Optics and Optical Instruments*, Dover Books, 1960 III Ed.
- John Webster, *Medical Instrumentation Application and Design*, Ed. John Wiley & Sons 2009.
- Herman, G. T., *Image Reconstruction from Projections. Implementation and Applications*, Topics in Applied Physics. Berlin-Heidelberg-New York, Springer.

IDC623: Field and lab-based methods in geology, ecology, and archaeology

[Cr:4, Lc:2, Tt:0, Lb:2]

Course Outline

- This course is meant for advanced students who need to learn traditional and new methods of fieldwork and laboratory research required in their research. The course aims to acquaint students to the evolutionary history of life on earth and the ecological and geological forces that influenced it as well as past anthropogenic impacts on the earths ecosystem during human dispersals and environmental adaptations. Covered topics will span anthropology, archaeology, ethnoarchaeology, geology, ecology, paleontology, taphonomy and animal behaviour. A significant portion of the course will be taught through field lectures and extensive fieldwork at select pre-specified locations. Topics include:
  - surveys and excavations,
  - data collection (e.g. artifacts, fossils),
  - site documentation,
  - geological descriptions and mapping techniques.
- Anthropological methods may involve interactions with indigenous communities and ethnoarchaeological documentation. Ecological studies will cover the evolution of life on earth, its climate history and the associated changes in the faunal and floral communities and tracing macroevolutionary changes as seen in fossil records. Fieldwork will include:
  - field-sampling techniques,
  - identification and quantification of faunal diversity and,
  - field-based observations of animal behaviour.
- Geological studies will include hands-on mechanics of fieldwork, geological mapping and synthesis of data (e.g. identification of geomorphological features, analysis of lithological & sedimentological features). Recent concepts and theories in geology (e.g., biomarkers and stable isotope geochemistry) for the understanding of the earths climate history and

associated vegetational changes will be taught. Lab work will involve working with artifacts, fossils, animal bones, casts, modern fauna/flora, geological samples and so forth. Lab activities will include specimen preparation and cleaning, curation and cataloguing, qualitative and quantitative analyses, experimental archaeology and microscopy. Additional instructional topics to be addressed include database management, community outreach and awareness, and ethics in field and lab research. Both the field and classroom lectures will be multidisciplinary in nature and be given by suitable IISER Mohali faculty (e.g. HSS, EES, DBS) as well as through invited guest lectures from external faculty and experts.

Recommended Reading

- H. Burke & C. Smith, *The Archaeologists Field Handbook*, (2004).
- W. D. Allmon, and D. J. Bottjer, *Evolutionary paleoecology: the ecological context of macroevolutionary changes*, Columbia University Press. (2001).
- A. L. (Ed.) Coe, *Geological field techniques*, John Wiley & Sons. (2010).
- Select chapters from various edited volumes and select journal articles

IDC631: Geochemistry

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Chemical composition of organic matter: Structure of natural products; Geochemical implications of compositional variation;
- Production, preservation and degradation of organic matter: Depositional environments associated with accumulation of organic matter;
- Long term fate of organic matter: Diagenesis; Humic material; Catagenesis and metagenesis; Distribution of fossil organic carbon;
- Chemical stratigraphic concepts: Biologically mediated transformations; Diagenesis at a molecular level; Source of environmental indicators; Thermal maturity and molecular transformations; Maturity of organic carbon; Isotopic paleontology;
- Origin of petroleum: Deep earth gas hypothesis; Abiogenic hydrocarbon gases; Thermogenic hypothesis;
- Properties of elements and mineral reactions Periodic table; States of matter; Geochemical classification; Nucleus and radioactivity; Early diagenesis; Hydrothermal reactions; Metamorphism;
- Fractionation of stable isotopes: Principles of stable isotope fractionation; Phanerozoic climates; Rise of atmospheric oxygen; Geochemical environment and the origin of life;
- The solid Earth: Geochemical variability of magma; Magmatism of different tectonic sites; Growth of Continental crust;

Recommended Reading

- G. Faure, *Geochemistry: Principles and Applications of Geochemistry*, 2nd edition, Prentice Hall (1998).
- G. Faure and T. M. Mensing, *Isotopes: Principles and Applications*, Wiley (2004).
- S. D. Killops and V. J. Killops, *An Introduction to Organic Geochemistry*, Wiley-Blackwell (2005).
- W. H. Schlesinger, *Biogeochemistry: Treatise on Geochemistry Volume 8*, Elsevier Science (2005).

IDC632: Introduction to atmospheric chemistry and physics

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Composition of Earth's Atmosphere, Temperature Structure and Atmospheric Regions, Pressure, Density, and Mixing Ratios, Evolution of the Atmosphere, Carbon, Nitrogen and Oxygen Cycles.
- Atmospheric Dynamics, Stability, Turbulence and Vertical Transport, General Circulation, Water (vapour, clouds and rain).
- Radiation, Black body, Ultraviolet, Infrared, Photochemical Processes, Greenhouse Effect, Scattering by Aerosols and Clouds.
- Stratospheric Chemistry, Ozone Observations, Chapman Model, Catalytic Loss Cycles, Antarctic Ozone Hole, Montreal Protocol.
- Chemical Kinetics, Methane Oxidation Cycle, Multi-Phase Processes
- Tropospheric Chemistry: Sources, Sinks, and Species, Hydroxyl Radical, Volatile Organic Compounds and Aerosol, Tropospheric Ozone and Air Quality, Photochemical Smog, Acid Rain, Air pollution to Climate Change
- Analytical Techniques & Special Topics, Optical Methods, Mass Spectrometric Methods

Recommended Reading

- D. J. Jacob, *Introduction to Atmospheric Chemistry*, Princeton University Press (1999).
- J. H. Seinfeld and S. N. Pandis, *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*, Wiley-Interscience (1998).
- B. J. Finlayson-Pitts and J. N. Pitts Jr., *Chemistry of the Upper and Lower Atmosphere*, Academic Press (2000).
- S. S. D. Qin et. al. (eds.), *IPCC 2007 Fourth Assessment Report, Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press (2007).

IDC633: Introduction to environmental sciences

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Thinking about Environmental Science, Evolution of Earth's Systems, Big Bang to the Present, Evolution of Atmosphere and Life
- Biogeochemical Cycles: Global Carbon Cycle, Global Hydrological Cycle, Earth's Elemental Reservoirs
- Global Systems and Energy Flow, Ecosystem Productivity, Human Population, Energy , Fossil Fuels, Renewable Sources of Energy, Nuclear Energy
- Biomes, Landscapes, Ecosystems, Tropical Rain Forests, Forests and Fires, Wastelands, Fisheries
- Earth's Climate: Radiation balance, Albedo: Particles and Clouds, Greenhouse Effect, International Agreements on Greenhouse Gases
- Atmosphere : Atmospheric Composition and Structure, Atmosphere and Ocean Circulation, Global Change of Atmospheric Composition, Anthropogenic impacts on the atmosphere: Tropospheric Ozone, Stratospheric Ozone Depletion, Photochemical Smog
- Air pollution : Pollutants and their Effects, Carbon Monoxide, Sulphur Dioxide, Particles (PM 2.5 and PM 10), Nitrogen Oxides and VOCs, Emission Control, Reformulated Gasoline
- Biosphere: Nitrogen Cycle and Food Production, Fertilizer and Green Revolution, Nutrition: Energy and Calories, Protein, Minerals and Vitamins, Antioxidants
- Water Pollution and Water Treatment: Point and Nonpoint Sources of Pollution, Regulation of Water Quality, Water and Sewage Treatment, Health hazards
- Toxic Chemicals, Acute and Chronic Toxicity, Toxic Metals, Persistent Organic Pollutants in the Environment, Cancer Incidence and Testing
- Pesticides in the Environment, Herbicides, Genetically Modified Organisms (GMOs), GM Plants, BT Brinjal Controversy
- Sustainability and the Future, Selected Case Studies of Environmental Disasters, Glimpses of Field Work in Environmental Science,

Recommended Reading

- D. B. Botkin and E. A. Keller, *Earth As a Living Planet*, 08th edition, John Wiley & Sons (2010).
- T. Spiro and W. Stigliani, *Chemistry of the Environment*, Pearson Prentice Hall Publishers (2002).
- D. J. Jacob, *Introduction to Atmospheric Chemistry*, Princeton University Press (1999).

- S. S. D. Qin et. al. (eds.), *IPCC 2007 Fourth Assessment Report, Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press (2007).

IDC635: Aerosol measurements: Principles and applications

[Cr:4, Lc:3, Tt:0, Lb:1]

Course Outline

Introduction: What is aerosol, Major particle types in the troposphere, Size distribution, formation, transport and removal of atmospheric aerosol particles, Climate effect of aerosol particles, Effect of aerosol particles on the hydrological cycle, Health effects of tropospheric aerosol.

Principles of aerosol measurements: Historical aspects, Bridging Science and Applications in Aerosol Measurements, Aerosol Fundamentals, Gas and Particle Motion, Physical and Chemical Changes in the Participate Phase, Size distribution Characteristics of Aerosols.

Measurement Techniques: Sampling for off-line Analysis of Aerosols: Filter Collection, Inertial, Gravitational, Centrifugal, Electrostatic and Thermal Collection Techniques, Off-line techniques: Chemical Analysis Methods of Atmospheric Aerosol Components, Analysis of individual Particles and surface properties, On-line techniques: Real time single particle analysis, dynamic mass and surface area measurements, Size distributions measurements and size separation techniques, optical properties, quantifying the effect of on the hydrological cycle cloud condensation nuclei and ice nuclei, real time measurements of biological particles.

Applications: Nonspherical particle measurements: Shape factors different diameter definitions fractals and fibres, Aerosol measurements in the workplace, Ambient aerosol sampling, Indoor Aerosols, Aerosol measurements from an Aircraft, Radioactive Aerosol, Personal exposure assessment, Aerosol measurements in the defence sector

Recommended Reading

- Pramod Kulkarni, Paul Baron, E. Willeke, *Aerosol Measurements: Principles, Techniques, Applications and Significance*
- Friedlander, *Smoke Dust and Haze fundamentals of Aerosol Dynamics*
- William Hinds, *Aerosol technology*
- Seinfeld & Pandis, *Atmospheric Chemistry and Physics*

4.8 Nano-Science Elective Courses

INS651: Biomolecular interactions: Spectroscopic and calorimetric methods

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction to biomolecules/biopolymers- proteins, lipids, carbohydrates, nucleic acids; properties of biopolymers.
- Introduction to fluorescence- Concepts, fundamental physical mechanisms involved in the generation of fluorescence light, interactions between biomolecules and electromagnetic radiation and environmental effects can generate changes in the measured fluorescence parameters, and how these changes can be exploited for monitoring of biomolecules and their interactions.
- Biomolecular Fluorescence Spectroscopy-Foster resonance energy transfer (FRET); Fluorescence lifetime imaging microscopy (FLIM);Fluorescence correlation spectroscopy (FCS); Ultra-sensitive fluorescence spectroscopy; Fluorescence polarization; Stopped Flow fluorescence; Microscopic techniques (fluorescence microscopy, confocal microscopy, total internal fluorescence microscopy).
- Biomolecular Circular Dichroism Spectroscopy- Concepts; Fundamentals of polarization; Differential absorption of light by molecules; Application to bio-molecular structure determination; Application in chemical stability, folding/unfolding kinetics/reactions of proteins, protein-protein interactions, protein-DNA interactions, protein-ligand interactions and DNA-ligand interactions; Stopped flow CD.
- Biomolecular IR Spectroscopy- Concepts; Vibration modes; IR active/inactive modes; IR regions and stretching frequencies; Important stretching frequencies in biology; IR sample preparation; ATR-IR studies; Bio-ATR measurements; 2D IR spectroscopy applied to biomolecules; IR spectroscopy applied to biomedical sciences.
- Biomolecular NMR Spectroscopy- Concepts and fundamentals; Chemical shifts; J-coupling; Assignment of NMR peaks; NMR applied to proteins; Isotope labelling and sample preparation; 2D NMR; Types of 2D NMR and their applications: NOESY, HSQC, COSY, TROSY; Dynamics and Ligand Binding.
- Thermodynamics and Kinetics of Protein folding/unfolding and protein ligand interactionsProtein folding problem; free energy landscape; native and denatured state; the molten globule state; entropy, enthalpy contributions; Gibbs-Helmholtz equation, vant Hoff and Arrhenius equations; disulphide bridges, secondary structure formation; multi-domain and multi-subunit proteins; Protein folding inside the cell; chaperones and cellular complexes; protein misfolding, aggregation and diseases.
- Biomolecular Calorimetry: Isothermal Calorimetry, Differential Scanning Calorimetry; Data analysis and applications.
- SPR methods for biomolecular interactions- Concepts and fundamentals; modes; Data analysis and applications.
- Other methods for determining biomolecular interactions- Two-hybrid screening, phage display; co-immunoprecipitation; cross-linking methods; affinity electrophoresis; proximity ligation assay; dynamic light scattering; theoretical methods (docking).

Recommended Reading

- J. R. Lakowicz, *Principles of fluorescence spectroscopy.*
- B. Valeur, *Molecular fluorescence: Principles and applications.*
- J. Cavanagh et al., *Protein NMR Spectroscopy - Principles and Practice.*
- Charles R. Cantor & Paul R. Schimmel, *Biophysical Chemistry (Parts I-III).*
- I. Tinoco et al., *Physical Chemistry: Principles and Applications in Biological Sciences.*

INS652: Characterization of nanomaterials

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Basic concepts
- Synthesis of materials
- Diffraction and scattering techniques (XRD, SAXS, DLS, SANS)
- Electron microscopy
- Scanning Probe Microscopy
- Spectroscopy : UV-Vis, IR, Fluorescence, ultrafast spectroscopy, NMR, Raman, SERS
- Confocal technique: Confocal Raman, Confocal FL, FCS
- Surface Characterization: BET, XPS
- Electrochemistry: CV, Electrochemical analysis
- Magnetic: Superparagnetism
- Basic concepts of biochemistry
- DSC, ITC, TGA/DTA, CD
- Separation techniques: HPLC, GC, GCMS
- Mass spectroscopy
- Applications of nanotechnology

INS653: Chemistry of nanomaterials: Synthesis, properties and applications

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction to Nanoscience and Nanotechnology: Definition of nanodimensional materials - Historical milestones - Unique properties due to nano size, Classification of Nanomaterials, Nanofabrication methods- Bottom up and top down approaches.
- Synthetic methodologies- Sol-gel, Microemulsion, Chemical Vapour Deposition, Physical Vapour Deposition, Molecular beam epitaxy, Template based synthesis, Spray Pyrolysis, Vapor (solution)-liquid-solid growth, (VLS or SLS, Lithography, Molecular Self-Assembly.
- Synthesis, properties and applications of various nanostructures-Carbon nanostructures, Metal and metal oxide based nanostructures, Core-shell nanostructures, Soft Nanocomposites, Biomolecular Nanostructures, Directed assembly of Biological and Chemical nanostructures.

Recommended Reading

- Guozhong Cao, *Nanostructures and Nanomaterials: Synthesis, Properties and Applications.*
- C. N. R. Rao, Achim Mller, A. K. Cheetham,*The Chemistry of Nanomaterials: Synthesis, Properties and Applications.*
- T. Pradeep, *Nano: The Essentials Understanding Nanoscience and Nanotechnology.*
- Dieter Vollath,*Nanomaterials: An Introduction to Synthesis, Properties and Applications.*

INS654: Electron microscopy

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Introduction to Microscopy- Importance of using electrons, concept of resolution, Abbes equation, Comparison between light and electron microscope, Interaction of electrons with matter (brief description of secondary electrons, back scattered electrons, Characteristic X-rays, Auger electrons, cathodoluminiscence, transmitted electrons).
- Configuration of Electron Microscopes- Electron Gun, Electron Lenses, Detectors, Vacuum Pumps
- Diffraction- Concept, SAD, CBED, Electron Back Scattered Diffraction (EBSD).
- Fundamentals of Scanning Electron Microscope- Instrumentation, modes of operation, working, Environment Scanning Electron Microscope (ESEM), Low kV SEM, Energy Dispersive X-ray Analysis (EDX), Sample Preparation.
- Fundamentals of Transmission Electron Microscope- Instrumentation, working,Imaging: Basic Principle, Bright field and dark field; High resolution TEM; Scanning Transmission Electron Microscopy (STEM); Electron Energy Loss Spectroscopy (EELS); Sample Preparation.

Recommended Reading

- D. B. Williams & C. B. Carter, *Transmission Electron Microscopy: A Text book for Material Science.*
- W. Zhou & Z. Linwang (editors), *Scanning Microscopy for Nanotechnology: Techniques and Applications.*

INS655: Photoluminescence spectroscopy with emphasis on applications in materials science including nanomaterials

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Basic Principles of Photoluminescence spectroscopy
- Photoluminescence properties of Semiconductor and Metal nanoparticles, Concept of Upconversion emission of nanomaterials
- Measurement of luminescence properties of nanomaterials using different techniques of PL Spectroscopy: Static PL Spectroscopy and Time-Correlated Single-Photon Counting (TCSPC) techniques
- Theory and Applications of Nanoparticles based Energy Transfer
- Metal-Enhanced Fluorescence Spectroscopy
- Probing Photoluminescence dynamics in colloidal nanomaterials with advanced PL spectroscopy
- An introduction to Super-Resolution Spectroscopy and its application in optical imaging

Recommended Reading

- J. R. Lakowicz, *Principles of Fluorescence Spectroscopy.*
- I. Pelant, J. Valenta, *Luminescence Spectroscopy of Semiconductors.*
- Challa S. S. R. Kumar, *UV-VIS and Photoluminescence Spectroscopy for Nanomaterials Characterization.*
- M. Sauer, J. Hofkens, J. Enderlein, *Handbook of Fluorescence Spectroscopy and Imaging: From Ensemble to Single Molecules.*

INS656: Principle and applications of synthetic and biological self-assembling materials

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Self-assembly in bulk and interfaces, basic concepts and examples, rules of selfassembly, synthetic self-assembled materials: microscopic and macroscopic interactions.
- Self-assembly in Nature, biomimetic systems and soft materials: micelles, vesicles, liposomes and bilayers, gels: hydrogels, organogels and ionogels, liquid crystalline materials, dendrimers, DNA self-assembly, self-assembled monolayers.
- Mechanically-interlocked molecular architectures, rotaxanes and cyclotides, catenanes, molecular knots, dynamic covalent chemistry, self-replicating systems, dynamic assembly of block-copolymers, supramolecular nanotubes.
- Applications of self-assembled systems in drug delivery systems, antimicrobial agents, artificial photosynthetic machines, enzyme mimics, tissue engineering.

Recommended Reading

- Jonathan W. Steed, Jerry L. Atwood, *Supramolecular Chemistry.*
- Alex Li, *Molecular Self-Assembly - Advances and Applications.*
- Joost N. H. Reek (Editor) & Sijbren Otto (Editor), *Dynamic Combinatorial Chemistry.*
- Ian W. Hamley, *Introduction to Soft Matter: Synthetic and Biological Self-Assembling Materials*

INS657: Carbon nanomaterials and its applications

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction to Carbon nanomaterials and its physical properties: C-C bonding, Types of carbon fullerenes, Crystal structure of selected carbon nanomaterials: CNT, Graphene, nano crystalline diamond, Electronic Band structure of CNT and Graphene, Electrical transport properties of graphene & CNTs, Thermal transport and electron-phonon interaction, Effect of structural disorder, Elastic Properties, Optical response.
- Synthesis and Characterizations: Brief introduction to various techniques of CNTs and Graphene- Arc Discharge, Thermal CVD, Microwave plasma CVD, Laser Ablation; Growth mechanism; Special synthesis techniques- Vertical aligned growth of CNT, Selective area growth of CNT, single walled CNT growth, Large area graphene synthesis, nano-patterning on graphene , Characterization of Carbon Nanomaterials: Raman spectroscopy, SEM, HRTEM, AFM, STM.
- Applications of CNTs and Graphene: Field emission, Electronic Devices, Optoelectronic devices, Chemical and Biological sensors.

Recommended Reading

- Hugh O. Pierson, *Handbook of Carbon, Graphite, Diamond, and Fullerenes.*
- Francois Leonard, *The properties of Carbon Nanotube Devices.*
- M. S. Dresselhaus, G. Dresselhaus, *Phaedon Avouris, Carbon Nanotubes: Synthesis, Structure, Properties, and Applications.*
- Mikhail I. Katsnelson, Mikhail Iosifovich Katsnelson, *Graphene: Carbon in Two Dimensions.*
- M. S. Dresselhaus, G. Dresselhaus, P. C. Eklund, *Science of Fullerenes and Carbon Nanotubes: Their Properties and Applications.*
- Hassan Raza, *Graphene Nanoelectronics: Metrology, Synthesis, Properties and Applications.*

INS658: Nanobiotechnology and nanomedicine: Basics and applications

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Introduction to Chemical Biology: Basic properties and biosynthesis of proteins and nucleic acids, chemistry, and metabolism of major carbohydrate, lipid, and amino acid classes, energy production pathways including photosynthesis.
- Introduction to Cellular and Molecular biology: Cell structure and function; structural organization and function of intracellular organelles; cell division and cell cycle; cell signalling; cellular communication; current research on cell structure, function, and dynamics. Topics include complex cell phenomena such as cell division, apoptosis, compartmentalization, transport and trafficking, motility and adhesion, differentiation, and multicellularity.
- Biological transport and Homeostasis, Enzymes, Applied Biotechnology, Biofermentations, Mammalian Cell Culture Methods, Tissue Engineering and regenerative medicine.
- Biosensors and their applications, Nanotechnology in health care, Nanotechnology in molecular therapy, Nanotoxicology.

Recommended Reading

- Lehninger Principles of Biochemistry Voet, D. & Voet, J. G, *Biochemistry.*
- Berg, J. M., Tymoczko, J. L. & Stryer, L.. Freeman, *Biochemistry.*
- William J. Thieman & Michael A. Palladino,*Introduction to Biotechnology.*
- A. R. Allman, *Fermentation Microbiology and Biotechnology.*

- Ulrich Meyer (Editor), Thomas Meyer (Editor), Jrg Handschel (Editor), Hans Peter Wiesmann (Editor),*Fundamentals of Tissue Engineering and Regenerative Medicine. Dilsat Ozkan-Ariksoysal, Biosensors and their Applications in Healthcare. doi:* 10.4155/9781909453647, eISBN (PDF): 978-1-909453-64-7

- Stephen R. Grobmyer (Editor), Brij M. Moudgil (Editor), *Cancer Nanotechnology: Methods and Protocols.*

- V. Zucolotto (Foreword), Nelson Durn (Editor), Silvia S. Guterres (Editor), Oswaldo Luiz Alves (Editor), *Nanotoxicology - Materials, Methodologies and Assessments.*

INS659: Thermal properties at nanoscale

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline

- Heat transfer mechanism: Laws of macroscopic heat transfer and their limits, Electrons and Phonons, thermal properties of solid and fluids and thermal radiation.

- Simulation methods: Solutions of the Boltzmann and Maxwell equations, Technique of Molecular dynamics simulations, First-principles based approaches.

- Experimental techniques: Introductions to different forms of near-field microscopy and discuss their application in thermal science, Photothermal microscope and reflectometry, Hybrid technique and multipurpose microscopes.

Recommended Reading

- J. Ziman, *Electrons and Phonons: The Theory of Transport Phenomena in Solids.*

- Richard M. Martin, *Electronic Structure: Basic Theory and Practical Methods.*

- S. Volz(Ed.), *Microscale and Nanoscale Heat Transfer.*

- Supriyo Datta, *Quantum Transport: Atom to Transistor.*

INS660: Plasmonics and its applications

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline Plasmonics has been an exponentially growing field for the past century and is a key concept and research tool in biology, chemistry and physics. It is used in imaging, sensing, and nano / biotechnology. This course will describe plasmonics for a general audience and focus on technology aspect for the same. Basic Requirement: Masters in biology, chemistry, physics or technology with a basic understanding of maxwells equations and mathematical operators.

- Introduction: Metal Optics: An introduction, What is a plasmon?, Types of Plasmons, Plasmon-Polaritons.
- Surface Plasmons on Smooth Surfaces: Drude Model, Ideal Case of metal-dielectric interface, Dispersion relation for EM waves in electron gas, Dispersion relation for surface plasmon polaritons, Different modes and their physical meaning.
- Surface plasmon on surfaces of small roughness: Scattering, Volume roughness, inelastic light scattering.
- Theory behind excitation of surface plasmons: Surface-plasmon-polariton waveguides, Long Range and Short Range Plasmons. Tunability of EM with SP.
- Fabrication of plasmon supporting systems: CVD, PVD, Electrodeposition, Thermal Deposition, Self-assembly, E-Beam Lithography, Interference Lithography.
- Experimental set-ups for exciting surface plasmons:Otto, KC, Grating, Wave-guiding, antenna.
- Working and Applications of Plasmonics: Biological sensing devices: SPR, Imaging, Chemical Moieties and their plasmonic response: QDs Optical and optoelectronic devices: SERS, TERS.

Recommended Reading

- H. Raether, *Surface Plasmons on smooth and Rough surfaces and on gratings*, Springer 1986.
- Md Rahman (Ed.), Krzysztof Lukaszkowicz (2011). *Review of Nanocomposite Thin Films and Coatings Deposited by PVD and CVD Technology*, Nanomaterials, ISBN: 978-953-307-913-4.
- C. S. Wu, *High-energy Electron Beam Lithography for Nanoscale Fabrication, Lithography*, Michael Wang (Ed.), ISBN: 978-953-307-064-3, Yoshiyuki Makiuchi and ChiiDong Chen (2010).
- S. A. Maier, *Plasmonics: Fundamentals and Applications*, Springer 2007.
- Shahbazyan and Stockman, *Plasmonics: Theory and Applications*, Springer 2013.
- Er-Ping Li and Hong-Son Chu, *Plasmonic Nanoelectronics and Sensing*, EuMA High Frequency Technologies Series 2014.

INS661: Nano/Micro Opto-electronic-mechanical systems

[Cr:4, Lc:3, Tt:1, Lb:0]

Course Outline MOEMS and NOEMS has been an exponentially growing field for the past century and has its key applications in all existing devices like cell phones, pedometers, CCDs etc. It is extensively used in sensing applications in technological applications. This course will describe synthesis and characterization of NOEMS and MOEMS for a general audience and focus on technology aspect for the same. Furthermore, it gives a hands on experience in designing and making a microfluidic channels using a laser engraver. Basic Requirement: Masters in chemistry, physics or technology with a basic understanding of materials, stress, strain and electrical circuits.

- **Introduction to basics**:

  Part 1: Optics: Reflection, Refraction and Diffraction,
  Part 2: Mechanics: Elasticity, structures and
  Part 3: Electronics: Capacitors, AC Circuits, Sensors and Actuators.

- **Fabrication**:

  Part 1: Substrates and Doping, Resists,
  Part 2: Thin Films Deposition methods: CVD, PVD, self-assembly Etc.
  Part 3: Lithography: E-beam, Soft Lithography Contact Lithography, Thermal Lithography, Interference lithography, etc.
  Part 4: Etching: Wet and Dry,
  Part 5: Wafer Bonding and Integration.

- **Materials and Processes**:

  Part 1: Difference in material properties and their effects on N/M-OEMS,
  Part 2: Determination of material properties,
  Part 3: Biomaterial Processing.

- **Design Trade offs**:

  Part 1: Analog Designs,
  Part 2: Mechanical Packing,
  Part 3: Optical Arrangement.

- **Microfluidics**:

  Equipments: Hands on training on Laser engraver, Simulating a microfluidic channel, Designing a device.

- **Case Studies: Working and Applications**:

  i) Commercial Accelerometers, Pedometers: Capacitive,
  ii) Bio N/M-OEMS,
  iii) Optical-MEMS.

Recommended Reading

- P. V. Zant, *Microchip Fabrication*, McGraw-Hill Education; 5 edition 2004 ISBN: 978-0071432412
- Ning Xi and King Lai, *Nano Optoelectronic Sensors and Devices: Nanophotonics from Design to Manufacturing*, Elsevier Inc. 2011, eBook ISBN: 9781437734720.
- J. T. Borenstein et al., *Microfluidic Cell Culture Systems*, 2012, eBook ISBN: 9781437734607,

- C. S. Kumar, *Microfluidic Devices in nanotechnology*, Wiley 2010 ISBN: 978-0-470-59069-0
- Sam Zhang, *Nanostructured thin films and coatings: Mechanical Properties*, CRC Press 2010 ISBN 9781420094022
- H. Baltes et al, *Enanabling technology for MEMS and Nanodevices*, Wiley-VCH, 2008

INS662: Energy conversion and storage

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- **Module-1: Photovoltaic Cell** Introduction, Semiconductor Junctions, Solar Cell Parameters and Equivalent Circuit, Losses and Efficiency Limits, PV Technology, Silicon Solar Cells, Thin-film solar cells, Third Generation Concepts
- **Module-2: Electrocatalysis** Introduction; Hydrogen from different routes and viability, electrocatalysis & catalysis; effect of potential on rate of reaction; rates of complex processes; potential energy diagrams and electrocatalysis (some correlation); quantum mechanical aspects; Radiationless transfer theories; some examples of electrocatalytic reactions; hydrogen electrode reactions; oxygen electrode reactions; organic oxidations; General remarks on practical electrocatalysts, Electrochemical CO 2 reduction.
- **Module-3: Photocatalytic Water Splitting** Introduction, Basic Principles of Photocatalytic water splitting, Experimental method for water splitting, General view of elements constructing heterogeneous photocatalyst materials, UV-Active Photocatalysts for Water Splitting, Approaches to Modifying the Electronic Band Structure for Visible- Light Harvesting, Approaches for Efficient Photogenerated Charge Separation, Hydrogen, Oxygen Generation Systems Containing Sacrificial Reagents, Overall Water-Splitting Systems, Photo electrochemical water splitting, Photocatalytic CO 2 reduction.
- **Module-4: Waste Energy Harvesting** Introduction, Special topic on renewable energy, Energy sources, Mechanical energy harvesting: Piezoelectric effect, Nanopiezotronics, Triboelectric effect, Thermal energy harvesting: Thermoelectric effect, Pyroelectric effect, Nanogenerator, Self-powered Systems, Device fabrication.
- **Module-5: Fuel Cell** Design Types of fuel cells, their operational principles and basic electrochemistry for understanding key processes in the fuel cell. Performance Explore laws governing fuel cell operation, Kinetics electrode kinetics, Tafel equation, charge transfer reaction, electrocatalysis - design, activation kinetics, Fuel cell charge and mass transport. PEMFC, Methanol, Alkaline and Phosphoric Acid Fuel Cells, Molten Carbonate Fuel Cell, Solid oxide Fuel cells (SOFCs).

- **Module-6: Energy Storage** Batteries: Battery Applications and Parameters, History of Batteries, Principles of Batteries, Lead Acid Batteries, Lithium Ion Batteries, Lithium recycling, Beyond Lithium Ion Batteries. Supercapacitor: Introduction, Historical overview: Capacitor, Ultracapacitor and supercapacitor, Electrical energy storage mechanism electrochemical capacitors, Similarities and differences between supercapacitor, battery and hybrid electrical storage devices, Component of supercapacitor, Energetics and elements of the kinetics of electrode process, Energy vs power, AC Impedance behavior of ECs, Practical aspects of preparation and Evaluation of device performances, Technology development.

Recommended Reading

- O'Hayre, R. P., S. Cha, W. Colella, F. B. Prinz, *Fuel Cell Fundamentals*, Wiley, NY (2006).
- A. J. Bard & L. Faulkner,*Electrochemical Methods: Fundamentals and Applications*, Wiley, 2000.
- L. B. Kong, T. Li, H. H. Hng, F. Boey, T. Zhang, S. Li, *Waste Energy Harvesting: Mechanical and Thermal Energies*, Springer, Berlin 2014.
- Klaus Jger, Olindo Isabella, Arno H. M. Smets, Ren A. C. M. M. van Swaaij, Miro Zeman, *Solar Energy; Fundamentals, Technology, and Systems*, Copyright 2014, Delft University of Technology.
- Braian E. Conway, *Comprehensive Treatise of Electrochemistry*, Volume 7, Springer, 1984.
- Braian E. Conway, *Kinetics and Mechanism of electrode processes*, Plenum Press, 1983.
- J. Schneider, D. Bahnemann, J. Ye, G. Li Puma, D. D. Dionysiou, *Photocatalysis: Fundamentals and Perspectives*, RSC, 2016.
- F. Barbir, *PEM Fuel Cells*, 2nd Ed., Elsevier, 2012.

INS663: Nanotechnology in drug delivery

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- **Fundamentals of Nanotechnology in Drug Delivery** Nanotechnology in Drug Delivery: Past, Present and Future; Conventional delivery of pharmaceuticals and its limitations; Significance of nano-size in Pharmacy, biotechnology and medicine; Physicochemical Principles of nano-sized Drug Delivery Systems; Biopharmaceutical, Physiological, and Clinical Considerations for Nanotechnology in Drug Delivery
- **Pharmacokinetics and Bio distribution** Introduction: Definitions, concepts of Absorption, Distribution, Metabolism and excretion, concentration time profile, Bioavailability, bio pharmaceutics and pharmacokinetics in drug research. Biotransformation of drugs: Drug

metabolizing enzymes, chemical pathways of Drug transformation, Phase-I and Phase-II reactions, Factors affecting drug transformation Prodrugs: Application of produg design, enhancement of bioavailability and duration of action, limitations. Bioavailability and Bioequivalence: measurement of bioavailability, Plasma level-time studies, intro-in vivo correlations

- **Nano carriers for Drug Delivery: Design, fabrication Properties and applications** Closed bilayered system: Introduction, structural aspects, preparation, characterization, evaluation and applications of liposomes, niosomes, erythrosomes etc. Polymeric Nanoparticles: Introduction, preparation, characterization, evaluation and pharmaceutical applications. Nano-emulsions and polymeric micelles drug vehicles: Introduction, composition of the multiple emulsion and stability, Miscellaneous- Organic inorganic hybrid nanoparticles, Solid Lipid Nanoparticles, Self-emulsifying drug delivery systems (SEDDS). Mode of application of Nano carriers- Oral, Parenteral, Pulmonary, Nasal, Transdermal, Ocular, dental etc.

- **Controlled and Targeted drug delivery** Programmed Drug Delivery Systems- principles of sustained, controlled, pulsatile and triggered release of drug from nanoparticles. Concept of targeting- Targeting Approaches, Transport Across Biological Barriers, mechanisms of drug targeting, Ideal carrier system and approach Disease-Related Approaches by Nanotherapeutics- nanoparticles for Cancer, Skin Diseases, Bacterial, Diseases, Parasites Diseases and Inflammatory Disease.

- **Nano toxicology and regulatory issues- Potential Risks and Remedies** Human health and safety- Interaction of nanomaterials with biological systems, Toxicology of nanoparticles- in-vitro and in-vivo, Complications with Nanotoxicity studies, environmental impact of nano-materials, Regulatory Toxicology. **Bio-imaging tools Overview of tools and tasks in various biological and biomedical imaging modalities, such as fluorescence microscopy and electron microscopy (SEM, TEM).**

Recommended Reading

- Recommended readings:

- Michael E. Aulton (Editor), *Aulton's Pharmaceutics*, Churchill Livingstone Publisher , 2013

- Alexander T. Florence; David Attwood, *Physicochemical Principles of Pharmacy* Pharmaceutical Press, 2011

- Milo Gibaldi and Donald Perrier,*Pharmacokinetics*, Second Edition, Informa publisher 2006

- Ram B. Gupta, Uday B. Kompella, *Nanoparticle technology for Drug delivery*,Taylor & Francis publisher, 2006

- M. A. Mateescu P. Ispas-Szabo E. Assaad, *Controlled Drug Delivery*, Woodhead Publishing , 2014

- Padma Devarajan, Sanyog Jain, *Targeted Drug Delivery : Concepts and Design*, Springer publisher, 2015

- Philippe Houdy, Marcel Lahmani, Francelyne Marano, *Nanoethics and Nanotoxicology*, Springer-Verlag Publisher 2011
- P. Michael Conn, *Essential Bioimaging Methods*,Academic Press, 2009

INS664: Physics of low dimensional materials

[Cr:4, Lc:4, Tt:0, Lb:0]

Course Outline

- Introduction to mesoscopic transport: Basic length and the corresponding energy and time scales in metals. Drud model; Diffusion equation and Einstein relation; classical size effects. Basic physics of electrical conduction, Concept of Ballistic and Diffusive Transport, atomistic views of electron transport to understand what makes electron flow, electron transport in a one-level model, quantum of conductance, coulomb blockade, quantum interpretation of capacitance, level broadening, open-systems, coherent transport, Non-equilibrium density matrix, Transmission Spectra, Landauer-Bttike formalism, Greens functions method, Incoherent electron transport due to electron-phonon couplings Electronic Device Junctions: Band bending due to Metal-Semiconductor, Semiconductor-Semiconductor Junctions; Ohmic and Schottky Junctions
- Magneto-transport at low dimension: Introduction to Classical and quantum Hall effect, Integral Quantum Hall effect, Fractional Quantum Hall effect, Non Abelian quantum Hall states
- Magnetic order, Concept of Single domain and Super-paramgnetism: Hydrogen atom problem, Hydrogen Molecule, heitler-london model, Idea of exchange interaction, Different kind of magnetic interaction. Minimization of total energy: formation of domain.. Single domain particle. Relaxation of Single domain particle. fokker planck equation. High barrier limit of a single domain particle, Single domain particle under magnetic field at finite temperature. Idea of instrumental time scale, blocking temperature. Dependence of blocking temperature on external parameters, Mossbauer Experiments.
- Magnetic Anisotropy, Magnetostriction, Magnetic Domains at lower dimension: Phenomenology of Magnetic anisotropy and Magnetostriction, Mechanism of different magnetic anisotropy: annealing effect, induced anisotropy, Magnetostatic energy of magnetic domain structures, types of magnetic domains and domain walls, effect of reduced dimensions on structure of domains and walls, micromagnetics,
- Thermal transport at nano-scale: Laws of macroscopic heat transfer and their limits, Electrons and Phonons, thermal properties of solid and fluids and thermal radiation. Basic of different simulation methods and experimental technique Solutions of the Boltzmann and Maxwell equations. Technique of Molecular dynamics simulations. First-principles based approaches Introductions to different forms of near-field microscopy and discuss their application in thermal science Experimental technique for nanoscale measurement.

Recommended Reading

- *Theory of Quantum Transport at Nanoscale An Introduction*, Ryndyk, Dmitry A., Springer.
- *Quantum Transport: Atom to Transistor*, Supriyo Datta.
- *A Paradigm Called Magnetism*, Sushanta Datta Gupta, World scientific.
- *Introduction to solid state Physics*, C. Kittel, Wiley.
- *Physics of ferromagnetism*, S. Chikazumi, Springer.
- *Electrons and Phonons: The Theory of Transport Phenomena in Solids*, J. Ziman.
- *Microscale and Nanoscale Heat Transfer*, S. Volz (Ed.)

4.9 Seminar and Project Courses

Further details about these courses can be found in the booklet on "Rules, Procedures and Guidelines for Academics at IISER Mohali".

Seminar Courses

There are three types of seminar courses at IISER Mohali during each regular semester. Master's seminar courses are for attending (IDC351/IDC352) and delivering (IDC451/IDC452) seminars respectively. The PhD seminar courses (IDC601/IDC602) require students to attend *and* deliver seminars.
All students at the appropriate level are required to participate in these seminars. Evaluation will be based on participation and on the quality of the talk or poster (in the case of delivery courses).

Project Courses

Final-year students in the BS-MS programme are required to undertake two-semester projects (PRJ501/PRJ502) under the supervision of a designated guide.
Students in the Integrated PhD programme must undertake a semester long project (PRJ401 or PRJ402). The PRJ401 course envisages a single mini-project with a presentation at the end. The extended version of this is PRJ402 which has 4 additional credits.