



Guidebook of Curriculum

**BS MS Dual Degree Program
IISER Pune**

August 2015



**भारतीय विज्ञान शिक्षा एवं अनुसंधान संस्थान
Indian Institute of Science Education & Research (IISER) Pune**

← **Vision and Mission** →

- Establish scientific institutions of the highest caliber where teaching and education are totally integrated with state-of-the-art research
- Make learning of basic sciences exciting through excellent integrative teaching driven by curiosity and creativity
- Entry into research at an early age through a flexible borderless curriculum and research projects

Guidebook of Curriculum

**BS MS Dual Degree Program
IISER Pune**

August 2015



**भारतीय विज्ञान शिक्षा एवं अनुसंधान संस्थान
Indian Institute of Science Education & Research (IISER) Pune**

Contents

	Page No.
BS MS Program Curriculum: Introduction	1-2
Biology	
Introduction	3-4
List of Courses	5
Details of Courses	6-27
Chemistry	
Introduction	28-30
List of Courses	31
Details of Courses	32-56
Mathematics	
Introduction	57-59
List of Courses	60
Details of Courses	61-81
Physics	
Introduction	82-83
List of Courses	84-86
Details of Courses	87-107
Earth and Climate Science	
Introduction	108
Details of Courses	109-110
Interdisciplinary Courses	111-112
Humanities and Social Sciences	113-114

Objectives

The IISER model of education is concept-based and inquiry-driven, as opposed to the more traditional content-based models. There is a strong emphasis on the interdisciplinary nature of today's science, and recognition of the importance of research experience in undergraduate education.

Courses offered in the undergraduate program at IISER Pune form part of a comprehensive program that will enable the students to understand the basic laws of nature and develop necessary skills to apply them to any desired area or discipline. The program is planned as student-centric collaborative learning. Students get trained for a career in basic sciences or any related applied science or technology.

General Pattern

Courses offered during the first two years (Semesters I to IV) are meant as basic and introductory courses in Biology, Chemistry, Mathematics, Physics and Earth and Climate Science. These are common and mandatory for all students. These courses are meant to give a flavor of the various approaches and analyses and to prepare the students for advanced courses in later years of study. In addition, there will be Interdisciplinary Courses for computational skills and mathematical methods. Students are also given training to develop skills in Communication, Creative & Technical Writing and History of Science through courses in Humanities and Social Sciences.

In the third and fourth years (Semesters V-VIII), students have the freedom to choose advanced courses based on their interest and inclination. Courses offered in the first two years would help them make an informed judgment to determine their real interest and aptitude for a given subject. Students also have the freedom to choose advanced courses from more than one discipline to achieve interdisciplinary expertise.

One of the novel features that the curriculum at IISER Pune offers is semester-long projects called Lab Training/ Theory projects, which are given the same weightage as a regular course of 3 credits. By availing this, a student can work in an experimental lab or take up a theory project every semester. This is meant to help the student get trained in research methodology, which will form a good basis for the year-long project work in the fifth year. Only one such course per semester is permitted.

The fifth year will be devoted to a thesis by research, which completes the requirements of the program.

Credits and Coursework

Every student has to register for approximately 21 credits in a semester. During Semesters I-IV, the student has to register for all the courses offered. During Semesters V-VIII, she/he can register for up to 25 credits per semester, the

minimum being 18. Each credit earned requires 2.5 hours of study per week. This includes contact hours and self study as shown in the table below.

Credits	Semesters	Nature of course	Contact hours per week	Self study* hrs/week
3	Semester I-IV	Introductory	2 lectures & 1 tutorial	4.5
3	Semester I-IV	Lab courses	1 Session of 3 hours	4.5
2	Semester I-IV	IDC/HSS/ECS	2	3.0
4	Semester V-VIII	Advanced and basic courses	3	7.0
3	Semester V-VIII	Introductory/ Interdisciplinary/ Specialized	2	5.5
4/3	Semesters V-VIII	Lab courses	4/3	6/4.5
3	Semester V-VIII	Lab training/ Theory project	3	4.5

*The contact hours are to be supplemented by self study that includes assignments, seminars, projects, library work and group work.

Details of Courses

The list of courses offered from each discipline with brief contents and lists of reference books is given below. Other relevant details like objectives, prerequisites, topic in detail, pattern of assessment, additional books for study and reference etc. will be prepared by the course instructor and communicated to the students well in advance before start of each semester.

BIOLOGY

The overarching philosophy of the curriculum in Biology stems from one of the primary mandates of the IISERs—to expose undergraduate students to interdisciplinary research in the basic sciences and to provide them with the necessary skills, knowledge and training to pursue successful careers in science.

The first four semesters serve as an introduction to Biology. Keeping in mind the diversity amongst the incoming students in their school education, we introduce all students to the unity and diversity of biology and the hierarchy of organization of biological systems. We emphasize the distinctness of biological systems while demonstrating the continuum from the physical/chemical world to Biology.

The courses in these semesters introduce variation, evolution, diversity and the irreducible complexity of life and biological systems. The unity of life is presented through a thorough description of biology at sub-organismal (reductionist as well as systems view) and organismal levels. At the sub-organismal reductionist level, students are introduced to the building blocks of life (biochemistry and molecular biology), information perpetuation and transfer (genetics), cells as the basic functional unit of life (cell biology) and higher levels of organization (tissue systems and physiology). In terms of the systems view at the sub-organismal level, the students learn about design principles of biological systems (systems biology) and the development of the organism. In organismal biology, students focus on interactions of the organisms with the environment, dynamics of populations/communities and evolution at various temporal and structural scales.

Courses in the third and fourth years cover in greater detail the content introduced in the first two years. Courses such as cell and molecular biology, biophysics and biochemistry, physiology, genetics, biostatistics and evolution and ecology comprise core courses that allow students to obtain a deeper understanding of biology. Advanced courses in areas such as immunology, neurobiology, disease biology, developmental biology, ecology, and epigenetics provide students an opportunity to gain a specialized and comprehensive understanding of those fields.

Building on the foundations in physical, mathematical, chemical and information sciences, the Biology curriculum integrates concepts, examples and techniques from other disciplines. Experts from other disciplines regularly contribute to courses in Biology, and the curriculum emphasizes quantitative and computational applications in biology through courses in mathematical biology, biostatistics, bioinformatics, biophysics, chemical biology and computational biology.

There is a strong emphasis on using current primary literature in the classroom. This ensures a continually updated content, and at the same time, trains students to read, understand, and critically evaluate the primary scientific literature.

Participatory teaching techniques such as group learning, assignments and student presentations are actively used.

To encourage research-based learning techniques, our lab courses of the first three semesters are designed with small open-ended experimental modules. Third and fourth year students are encouraged to participate in lab/theory projects in Biology research groups in addition to the classroom-based courses. These provide an opportunity to independently design and carry out laboratory and/or theoretical projects and participate in reading projects, often leading to meta-analysis of published literature in a given field. The goal is to expose students to contemporary research practices and tools including literature reviews, advanced techniques, data collection and analysis, and to scientific writing and presentation.

In the final (fifth) year, students undertake an independent, stand-alone research project. The project can be carried out in any laboratory within or outside Pune. The goal is to develop the technical, analytical and cognitive skills necessary to pursue a career in scientific research. This is the culmination of the training from the previous years and is an opportunity to directly participate in the process of knowledge production in Biology.

List of Courses in Biology

Semester I

- | | | |
|------------|--|-------------|
| 1. BIO 101 | Introductory Biology I: Basic Principles | [3 credits] |
| 2. BIO 121 | Biology Lab I: Basic Biology | [3 credits] |

Semester II

- | | | |
|------------|--|-------------|
| 3. BIO 102 | Introductory Biology II: Cellular and Molecular Biology | [3 credits] |
| 4. BIO 122 | Biology Lab II: Biochemistry, Genetics & Molecular Biology | [3 credits] |

Semester III

- | | | |
|------------|---|-------------|
| 5. BIO 201 | Introductory Biology III: Evolution and Ecology | [3 credits] |
| 6. BIO 221 | Biology Lab III: Ecology and Evolution | [3 credits] |

Semester IV

- | | | |
|------------|---|-------------|
| 7. BIO 202 | Introductory Biology IV: Biology of Systems | [3 credits] |
|------------|---|-------------|

Semester V and VII

- | | | |
|-------------|------------------------------|---------------|
| 8. BIO 301 | Lab Training/Theory Project | [3 credits] |
| 9. BIO 310 | Biostatistics | [4 credits] |
| 10. BIO 311 | Advanced Cell Biology | [4 credits] |
| 11. BIO 312 | Animal Physiology I | [4 credits] |
| 12. BIO 313 | Advanced Molecular Biology | [4 credits] |
| 13. BIO 314 | Bioinformatics | [4 credits] |
| 14. BIO 320 | Genetics | [4 credits] |
| 15. BIO 322 | Biophysics I | [4 credits] |
| 16. BIO 334 | Neurobiology I | [3 credits] |
| 17. BIO 335 | Animal Behaviour | [3 credits] * |
| 18. BIO 401 | Lab Training /Theory Project | [3 credits] |
| 19. BIO 410 | Advanced Biochemistry I | [4 credits] |
| 20. BIO 411 | Ecology I (Basic Ecology) | [4 credits] |
| 21. BIO 420 | Developmental Biology | [4 credits] * |
| 22. BIO 431 | Epigenetics | [3 credits] |
| 23. BIO 452 | Plant Biology II | [3 credits] * |
| 24. BIO 454 | Structural Biology | [3 credits] |

Semester VI and VIII

- | | | |
|-------------|-------------------------------|---------------|
| 25. BIO 302 | Lab Training /Theory Project | [3 credits] |
| 26. BIO 321 | Plant Biology I | [4 credits] |
| 27. BIO 323 | Immunology I | [4 credits] * |
| 28. BIO 351 | Biology and Disease | [3 credits] * |
| 29. BIO 352 | Animal Physiology II | [3 credits] |
| 30. BIO 353 | Immunology II | [3 credits] * |
| 31. BIO 354 | Neurobiology II | [3 credits] * |
| 32. BIO 402 | Lab Training /Theory Project | [3 credits] |
| 33. BIO 412 | Microbiology | [4 credits] * |
| 34. BIO 413 | Mathematical Biology | [4 credits] * |
| 35. BIO 417 | Advanced Biochemistry II | [4 credits] * |
| 36. BIO 422 | Evolution | [4 credits] |
| 37. BIO 423 | Ecology II (Advanced Ecology) | [4 credits] * |
| 38. BIO 435 | Biophysics II | [3 credits] * |
| 39. BIO 441 | Genome Biology | [3 credits] * |
| 40. BIO 442 | Computational Biology | [3 credits] * |
| 41. BIO 491 | Literature Review | [3 credits] |

* Courses offered once in two years

Details of Courses in Biology

BIO 101	Introductory Biology I: Basic Principles	3 credits
----------------	---	------------------

Introduction: Students attending this course need not have taken biology at the HSC level. The course is intended as an introduction to the main conceptual framework of biology as a science, outlining the diversity, organization and fundamental principles of living systems.

Content:

Module 1: Introduction: What is biology: Salient features of life; Importance of biology on the frontiers of science and technology; Brief history of biology; How plants, animals and microorganisms shaped human history.

Module 2: The logical structure of biology: concepts of complexity, emergent properties, adaptation, optimality, diversity, chance and necessity, structure-function relationship, theme and variations, individual variability and plasticity; Nature of experimentation in biology and statistical inference.

Module 3: Broad overview of life on earth, origin and progression of life on earth, Evolution, concept of adaptive versus neutral evolution; classification/taxonomy and phylogeny; Molecular relationships between life forms.

Module 4: Biological information: Nature of biological information; Mechanisms of transmission of information: genetic, epigenetic, cultural and other mechanisms of inheritance; Central dogma of molecular biology.

Module 5: Mechanism of perpetuation of life at molecular, cellular, organismal and population levels.

Recommended Reading:

1. Principles of Biology: Interactive textbook from Nature Education
2. Biology: N. Campbell and J. Reece (2005) 7th edition, Pearson, Benjamin, Cummings

BIO 102	Introductory Biology II: Cellular and Molecular Biology	3 credits
----------------	--	------------------

Introduction: This course aims to introduce you to several important facts and fundamental concepts in biology. It is aimed to give you an insight on how organisms work at the single and multicellular levels (cellular aspects) by initially providing a molecular framework to understand the basic inter-molecular interactions (biochemical aspects) that drive underlying cellular processes. This course, more than anything, hopes to spark your imagination and thinking about how biological systems function and are regulated.

Content: This course will cover a wide range of topics starting with the very basic molecules necessary for life (water) and go on to discover the structure, function and interrelationships between all important biomolecules (like proteins, carbohydrates, nucleic acids and lipids) that collectively carry out the essential

functions of life. We will then move higher on the complexity scale to understand the principles underlying cellular organization and talk about the development of cell theory, cell types: prokaryotes vs. eukaryotes, single cell to multi-cellular organism. We will study cell structures, beginning with the cell envelope of bacteria, plant and animal cells, cell membranes and their properties and structure of the cell membrane. We will also discuss the cellular cytoskeletal components, actin, microtubules and microfilaments and motor proteins. Moving on, we will study the endomembrane system (endoplasmic reticulum, Golgi complex, endosomes, lysosomes), cell nucleus and chromatin structure. We will also look at how cells use many of the above components and processes to talk to each other and the environment. Finally, we will briefly discuss the central dogma of life, looking at DNA replication, mitosis and meiosis, RNA, transcription and translation.

Recommended Reading:

1. Biochemistry: D. Voet, and J.G. Voet (2010), 4th edition, Wiley
2. Harper's Illustrated Biochemistry: R. Murray, V. Rodwell, D. Bender, K.M. Botham, P.A. Weil and P.J. Kennelly (2009) 28th edition, McGraw Hill-Medical
3. Biology: N. Campbell and J. Reece (2005) 7th edition, Pearson, Benjamin, Cummings
4. Biology: P.H. Raven, G.B. Johnson, J.B. Losos and S.R. Singer (2005) 7th edition, McGraw Hill
5. Molecular Biology of the Cell: B. Alberts, A. Johnson, J. Lewis, M. Raff, K. Roberts and P. Walter (2007) 5th edition, Garland Science

BIO 121

Biology Lab I: Basic Biology

3 credits

Content: This practical course will cover basic concepts in biology, cell biology and cell culturing techniques with an emphasis on 3D's in biology – draw, describe and differentiate. Experiments include: Basics of microscopy; Field trip; Microscopy of samples; Micrometry of different cells; Staining of bacteria, fungi, Plant cells, Blood cells and Bone marrow; Osmosis; Mitosis; Crude cultures – Bacteria and Protozoa; Pure culture techniques; Sterilization and media preparation; Streaking of bacteria; Enumeration of bacteria.

BIO 122

Biology Lab II: Biochemistry, Genetics and Molecular Biology

3 credits

Content: This practical course will cover biochemical, genetic and molecular basis of life. Experiments include: Glucose estimation; Lipid estimation; Amino acid Paper chromatography; Protein estimation; Enzyme assay and Kinetics; Human genetic traits and blood grouping; DNA isolation; DNA estimation; Transformation; Plasmid isolation; Agarose gel electrophoresis; Restriction digestion and Ligation; PCR demonstration; ATC PTC demonstration; Animal handling, inoculation, dissection.

BIO 201 Introductory Biology III: Evolution and Ecology 3 credits

Introduction: This is an introductory course that would help the students in terms of A) understanding of: 1) the basic concepts in ecology and evolution, 2) how organisms interact with each other, and the environment, to form various patterns of distribution and behaviour, and 3) the modes of inquiry in the investigation of ecological and evolutionary questions; and B) ability to: 1) visualize how these concepts connect to real-life situations, and 2) investigate questions in classical genetics, ecology and evolution using the modes of inquiry in (A 3), as well as in biology/science/academic inquiry in general.

Content: Introduction: An overview of biological processes; Why study ecology and evolution?

Population ecology: Survivorship curves, Life-tables, Simple population dynamics models and their behavior, Spatial ecology.

Life history evolution: Basic concepts; Community ecology/ Species interaction: Competition; Predation; Ecosystem dynamics: Food webs; biodiversity; conservation biology; Classical Genetics: Mendel's laws, linkage; Population genetics: H-W equilibrium; mutation; selection; genetic drift; inbreeding

Macroevolution and diversity of life: Macroevolutionary concepts: reproductive isolation, speciation

Recommended Reading:

No single text book can be prescribed. The following books shall cover much of the proposed syllabus:

1. Ecology - From Individuals to Ecosystems: M. Begon, C.R. Townsend, and J.L. Harper (2005) Blackwell Publishing
2. Ecology Concepts and Applications: M.C. Molles (2009) McGraw Hill
3. Evolutionary Analysis: S. Freeman, and J. Herron (2004) 4th edition, W. Prentice Hall

BIO 202 Introductory Biology IV: Biology of Systems 3 credits

Introduction: Biological systems are elaborate machines with parts that interact in surprising ways. This course can be envisaged as the antithesis of reductionism. Rather than take the biological machine apart, we will try to put it together and demonstrate that the properties that emerge are often more than a sum of its parts. Using thematic examples from subcellular to organismal scales, we will try to derive organizational principles that mediate interactions between components. The course will introduce quantitative methods necessary to develop a systems perspective.

The goal of the course is to build from the previous introductory courses, introduce the concept of complex systems and demonstrate that by probing the design principles of complex biological systems one can begin to address the following:

What are the engineering constraints operating in biological systems?

How do biological systems achieve robustness?
How does complexity emerge from simple interactions?
How are biological systems optimized for efficiency?

Content: Introduction to complex systems; Emergent properties and evolution of biological complexity; Signal transduction; Gene regulation and gene regulatory networks; Network motifs; Fertilization and organismal development; Pattern formation; Reaction-diffusion; Evolution of body plans; Regeneration and stem cells; Physiology and models of the immune system; Physiology and models of the nervous system; Oscillation in biology.

Recommended Reading:

1. Molecular Biology of the Cell: B. Alberts, A. Johnson, J. Lewis, M. Raff, K. Roberts and P. Walter (2002) 4th edition, Garland Science
2. Principles of Development: L. Wolpert, J. Smith, T. Jessell, P. Lawrence, E. Robertson and E. Meyerowitz (2006) 3rd edition, Oxford University Press
3. An Introduction to Systems Biology: Design Principles of Biological Circuits: U. Alon (2006) 1st edition, Chapman & Hall/CRC
4. Mathematical Biology: J.D. Murray (2007) Vol. I. 3rd edition, Springer

BIO 221 Biology Lab III: Ecology and Evolution 3 credits

Content: This practical course will cover basic concepts in ecology and evolution. Practicals include: Evolution of Ethnocentrism; Isolation of organisms; Global Population Dynamics Database; Plant Biodiversity field work; Growth curve (Factorial design 3 pH × 2 temperatures); Effect of nutritional selection on bacterial growth; Chemical ecology and its impact on diatom diversity; Behavioral Ecology.

BIO 301/302 Lab Training / Theory Project 3 credits

The larger objective of this course is to encourage students to participate in ongoing research at IISER. This may be in the form of a reading/literature review/theoretical and computational project/lab based research project.

The student has to identify, talk to and mutually agree on a research project with a faculty member before registering for this course. The scope, duration, structure, expectations, and evaluation criteria for the course are decided by the project supervisor.

BIO 310 Biostatistics 4 credits

Introduction: The course introduces biologists to probability and statistics with a strong emphasis on using computer simulation of random number distributions to understand the importance of statistical analysis.

Content: Statistical measures, Probability: Basic concepts, distribution functions,

change of variables; Fitting data: fitting functions, goodness of fit, correlation, regression, smoothing, interpolation, extrapolation; Statistical tests: Parametric and non-parametric tests, null hypothesis, statistical significance, confidence intervals, Type I and II errors, ANOVA, multiple testing; Time series analysis: Correlation, periodicity.

Recommended Reading:

1. Biometry: The Principles and Practice of Statistics for Biological Research: R.R. Sokal and H.A. Rohlf (1995) 3rd edition, W.H. Freeman
2. Biostatistical Analysis: J.H. Zar (1998) 4th edition, Prentice Hall

BIO 311	Advanced Cell Biology	4 credits
----------------	------------------------------	------------------

Introduction: This course will provide a detailed insight into advanced concepts of cellular structure and function. It also aims to give you a sense of the complex regulatory mechanisms that control cell function.

Content: This course covers a wide range of advanced cell biology topics discussing in some detail membrane structure, transport, intracellular compartments, protein sorting and vesicular traffic. It will also discuss the cell cycle and cell division. Finally we will be looking at mechanisms of cell communications, cell junctions and adhesion to the extracellular matrix, looking at the role and regulation of the cytoskeleton and motor proteins and also see how many of these process work together to drive cell migration. This course will also provide an introduction to the types and role of mechanical forces in cells. www.iiserpune.ac.in/~nagaraj/Bio311_Adv_Cell_Bio.html

Recommended Reading:

1. Molecular Biology of the Cell: B. Alberts, A. Johnson, J. Lewis, M. Raff, K. Roberts and P. Walter (2007) 5th edition, Garland Science
2. Molecular Biology of the Gene: James Watson et al., (2007) 6th edition, Benjamin Cummings
3. Molecular Cell Biology: H. Lodish, A. Berk, C.A. Kaiser et al (2007) 6th edition, W.H. Freeman Reviews recommended on the course website

BIO 312	Animal Physiology I	4 credits
----------------	----------------------------	------------------

Introduction: The course aims at imparting in-depth knowledge of the human physiology. The rationale is to provide an insight into the various organ systems, their functions, interactions, regulation and pathology. The course will also include a lab-work and demonstrations of the live systems using fish models and histological preparations. The course material will be useful to any undergraduate who is keen to understand the physiological process and will help to broaden the understanding of biological processes.

Content: Skeletal and smooth muscle systems, human cardio-vascular system and blood, excretion and regulation of the body fluids, gaseous exchange, transport and

tissue respiration, physiology of digestion and gastrointestinal hormones, endocrines and reproduction.

Recommended Reading:

1. Textbook of Medical Physiology: A.C. Guyton, J.C. Hall (2008) Elsevier-Saunders
2. Williams Textbook of Endocrinology: H.M. Kronenberg et al. (2008) Saunders
3. Eckert Animal Physiology: D.J. Randall et al. (2002) W.H. Freeman
4. Comparative Animal Physiology: P.C. Withers et al. (2001) Brooks Cole
5. Animal Physiology: R.W. Hill, G.A. Wyse and M. Anderson (2008) Sinauer Associates

BIO 313

Advanced Molecular Biology

4 credits

Introduction: This course will provide fundamental concepts from this enormous and ever-growing field of Molecular Biology to undergraduate students. This course will help students to have a sound knowledge of molecular biology, which will also enable them to carry out research using molecular biology techniques.

Content: This course covers a detailed analysis of the molecular mechanisms that control the maintenance, expression, and evolution of prokaryotic and eukaryotic genomes. The topics covered in lectures and readings of relevant literature include maintenance and expression of the genome including DNA replication, mutability and repair of DNA, genetic recombination, gene regulation, transcription, RNA splicing and translation. In particular, the logic of experimental design and data analysis is emphasized in particular molecular cloning methods and tools for studying gene and gene activity.

Recommended Reading:

1. Molecular Biology of the Gene: J.D. Watson, T.A. Baker, S.P. Bell, A.A.F. Gann, M. Levine and R.M. Losick (2007) 7th edition, Benjamin Cummings
2. Molecular Biology: Weaver (2011) 5th edition, McGraw-Hill Science
3. Principles of Gene Manipulation: S.B. Primrose, R. Twyman and R.W. Old (2002) 6th edition, Wiley-Blackwell
4. Molecular Biology and Genomics: C. Mulhardt (2006) 1st edition, Academic Press

BIO 320

Genetics

4 credits

Introduction: The goal of this course is to build upon Basic Genetics, which the students learnt in their high school and the first few semesters at IISER Pune. This course is designed to revise basic concepts and then move on to advanced concepts. A strong emphasis will be laid on modern tools and techniques as also the utility of

model organisms, which are the workhorses of the science of genetics. The course is taught with a historical timeline, introducing concepts in genetics as they occurred over time.

Content: A Refresher Course for Mendelian Genetics, Non-Mendelian Genetics: Linkage, Incomplete Dominance, Maternal Inheritance, Extra-nuclear inheritance, Sex-linked inheritance, Sex determination, Dosage Compensation, Epigenetics, Genomic imprinting. The Chromosomal basis of inheritance. Genomes, genomics and the Dynamic Genome. The Genetics of Bacteria and Bacteriophages. Bacterial transposons. Vertical and Horizontal gene transfer. Transformation, Transfection & Transduction. Genetic Complementation. Genetic Mapping. Genetic screens as a basis for functional genomics. Deficiencies, EMS & X-ray based mutagenesis screens. Creating alleles. Enhancer traps, EP-Lines, RNA-inheritance, FLP-FRT & Cre-Lox Systems. Nusslein-Volhard & Weischaus Zygotic and Maternal Screens. Gene isolation Manipulation and the techniques that revolutionized modern genetics Working with Nucleic Acids and Proteins. Polymerase Chain Reaction. DNA Sequencing, Southern, Western & Northern Blots. In-situ Hybridization, FISH, SNP's, RFLP's, EST's, STS & Oligonucleotide Arrays. Gene Cloning vs. Animal Cloning, Nuclear transplantation, stem cells & iPS cells. The utility of the following Model Organisms will be discussed: Escherichia coli, Arabidopsis thaliana, Caenorhabditiselegans, Drosophila melanogaster & Mus Musculus. In addition to the lectures the course will include student presentations on famous geneticists and a book review or an essay.

Recommended Reading:

1. Introduction to Genetic Analysis: A.J. Griffiths et al. (2008) 9th edition, W.H. Freeman
2. Reviews and Essays provided by the Coordinator
3. The Selfish Gene: R. Dawkins (1976) Oxford University Press

BIO 321

Plant Biology I

4 credits

Introduction: The objective of this course is to acquaint students with the fundamentals of plant biology, evolution of land plants, plant architecture, growth & development (signal perception & transduction), phytohormones and their functions. For every topic, information from the molecular level to physiological level will be discussed. This course will also help the students to acquire basic knowledge about plant's life. The students will have an in depth understanding to follow the contemporary research in basic and applied plant sciences.

Content: Introduction to land plants, evolutionary history of plants; plant cell and plasmodesmata, tissue organization; photosynthesis- light and dark reactions, molecular mechanisms, ecological considerations; respiration; lipid metabolism; water transport and mineral nutrition; translocation in the phloem, macromolecular (RNA/Protein) transport, transporter genes; plant hormones

(biogenesis and mode of actions); plant growth and development, embryogenesis, pattern formation, stem cells & Shoot Apical Meristem (SAM) architecture; the control of flowering, ABC models, molecular mechanisms; photoreceptors and light control of plant development.

Recommended Reading:

1. Plant Physiology: L. Taiz and E. Zeiger (2010) 5th edition, Sinauer Associates Inc
2. Biochemistry and Molecular Biology of Plants: B. Buchanan et. al. (2002) American Society of Plant Physiologists (ASPP)
3. Physiology and Behavior of Plants: P. Scott (2008) 1st edition, Wiley Publishers
4. Plant Biochemistry: H.W. Heldt and B. Piechulla (2010) 4th edition, Wiley Publishers

BIO 322

Biophysics

4 credits

Introduction: Students will be introduced to the new and interdisciplinary field of physical biology of the cell. This topic is at the intersection of physics and biology, with connections to mathematics, physical chemistry and cell physiology.

Content: Order of magnitude physics applied to biology, molecular biophysics, cellular biophysics, physics in development, and biophysical techniques with special emphasis on light in biology. Laboratories will be conducted for measuring molecular thermodynamics of biological macromolecules, quantifying cellular dynamics and measuring diffusion.

Recommended Reading:

1. Biological Physics: Energy, Information, Life: P. Nelson (2003) W.H. Freeman
2. Physical Biology of the Cell: R. Philips, J. Kondev and J. Theriot (2008) Garland Sciences
3. Biological Physics of the Developing Embryo: G. Forgacs (2005) Cambridge University Press

BIO 323

Immunology I

4 credits

Introduction: Immunology (BIO 323) is a 4 credit-hour lecture course that will acquaint you with the molecules, cells and organs of the immune system. You will learn about the structural features of the components of the immune system as well as their functions, but the primary emphasis of this course will be on the mechanisms involved in immune system development and responsiveness. This course is essentially a series of lectures highlighting basic concepts in immunology.

Content: Development of the immune system, innate immunity, immunoglobulin

structure and genetics, antigen-antibody reactions, the major histocompatibility complex and antigen presentation, T cell receptors (genetics, structure, selection), T cell activation and effector functions, adhesion molecules, immune responses to infections organisms and tumors, autoimmune diseases, allergies, immune deficiencies and AIDS. The major experiments that allowed the elucidation of various mechanistic features of the immune system will be featured to help you understand how immunologists think and work towards unraveling such complex interplay of molecules and cells.

Recommended Reading:

1. Janeway's Immunobiology: K.M. Murphy, P. Travers and M. Walport (2007) 7th edition, Garland Science
2. Kuby Immunology: T.J. Kindt, B.A. Osborne and R.A. Goldsby (2006) 6th edition, W.H. Freeman

BIO 334

Neurobiology I

3 credits

Introduction: The course introduces neuroscience as a specialized discipline. The overarching goal of the course is to provide a detailed description of the logic of the nervous system from the perspectives of evolution, organization, development, physiology and its emergent properties. The course is aimed at students interested in understanding the fundamental basis of the neural function and those interested in pursuing neuroscience in the future.

Content: Evolution and organization of the nervous system; electrical properties of neurons; ionic basis of membrane potentials and the action potential; synaptic transmission and neurotransmitters; development of the nervous system; experience-dependent synaptic refining & plasticity; introduction to Hebb's postulate and learning and memory.

Recommended Reading:

1. Principles of Neural Science: E. Kandel et al. (2000) 4th edition, McGraw-Hill Medical
2. Neuroscience: M. Bearet al. (2006) 3rd edition, Lippincott Williams & Wilkins
3. Development of the Nervous System: D. Saneset al. (2005) 3rd edition, Academic Press
4. Foundations of Cellular Neurophysiology: D. Johnston and S. Wu (1994) 1st edition, MIT Press

BIO 335

Animal Behaviour

3 credits

Introduction: This course provides an introduction to theories and methodologies in the study of animal behaviour. During the course, students gain first-hand experience in both reading and critiquing scientific studies, and in designing and carrying out methodical studies in behaviour. Many of the classes revolve around

discussions of scientific papers, calling for active student participation. This course is especially relevant to students interested in ecology and evolution, and generally to any student of biology.

Content: Research methodologies. Proximate and ultimate causes of behaviour. Evolution of behaviour, adaptationism, genetic and cultural inheritance. Individual and social learning, cognition. Behavioural ecology of foraging, group living, sociality, movement, mating, parental care, aggression, interspecific interactions: theories and empirical tests. Evolution of cooperation and communication.

Recommended Reading:

1. Principles of Animal Behaviour: L.A. Dugatkin (2004) W.W. Norton & Co
2. An Introduction to Behavioural Ecology: J.R. Krebs and N.B. Davies (1993) Blackwell Publishing
3. Animal Behaviour: J. Alcock (2009) Sinauer Associates

BIO 351

Biology and Disease

3 credits

Introduction: Objectives of this course are to 1) integrate the biology (cell, molecular and physiology) taught so far, 2) develop insights into biology revealed by the disease condition, and 3) teach technology development and translation prompted by the disease condition. Cancer, neurodegenerative disorders, infectious diseases, disorder of the cardiovascular system and genetic diseases will be studied.

Content: What is Cancer and profile of a cancer cell; causes of cancer and how it spreads; molecular biology of cancer; What is neurodegeneration and biology of the disease; molecular basis of neurodegenerative disorders; Major types of heart diseases and their causes; review some of the methods for detecting and investigating heart disease; How genetic traits are inherited; effects of single gene mutations; types of chromosomal mutations; ways in which single gene mutations are treated; Types and symptoms of some common infectious diseases; outline preventive measures; general effects of antibiotics on infectious organisms, discuss some general aspects of the management and treatment of specific infectious diseases.

Recommended Reading:

1. Biology of Disease: N. Ahmed, M. Dawson, C. Smith and E. Wood (2006) 1st edition, Taylor & Francis
2. One Renegade Cell: The Quest For The Origin Of Cancer (Science Masters): R.A. Weinberg (1999) 1st edition, Basic Books
3. The Biology of Cancer: R. Weinberg (2006) 1st edition, Garland Science
4. The Biology Of Disease: Murray, Jonathan and Kirk (2001) 2nd edition, Wiley-Blackwell

Prerequisite: Advanced Cell Biology (BIO 311) and Advanced Molecular Biology (BIO 313)

BIO 352

Animal Physiology II

3 credits

Introduction: While the students have been given extensive training in human physiology during BIO 312, BIO 352 offers insights into the physiology of non-mammalian vertebrates and invertebrates. Special physiological adaptations displayed by animals, radiated in diverse habitats will be studied and their relevance to evolution will be analyzed. Insect physiology will be dealt in considerable detail. The course will provide in-depth knowledge regarding a range of biological processes operating at levels from cell to organism and prepare him/her to pursue research in any area of animal and human physiology.

Content: Physiology of circulation, respiration, excretion, ionic balance in sub-mammalian vertebrates, physiology of reproduction, thermoregulation in ectothermic and endothermic animals; Nervous and sensory systems across various invertebrate groups; Circulation, ionic balance and excretion, respiration, digestion, moulting, sensory, nervous and neuroendocrine systems and reproduction in insects.

Recommended Reading:

1. Eckert Animal Physiology: D.J. Randall et al. (2002) W.H. Freeman
2. Comparative Animal Physiology: P.C. Withers et al. (2001) Brooks Cole
3. Animal Physiology: R.W. Hill, G.A. Wyse and M. Anderson (2008) Sinauer Associates

Prerequisite: Animal Physiology I (BIO 312)

BIO 353

Immunology II

3 credits

Introduction: This course will cover advanced topics in immunology.

Content: Toll-like receptors; Regulation of NK cell activity; Host-pathogen interactions; Subversion of the host immune responses by intracellular parasites; Ontogeny and function of dendritic cells; Autoantibodies in health and disease; Molecular interactions between the T cell receptor and MHC molecules; Immune synapse; Polyspecificity of T cell receptor recognition; Molecular mimicry and epitope spreading; T cell memory; Peripheral tolerance and regulatory lymphocytes; Animal models of immune dysregulation; Interactions between the immune and the nervous systems.

Recommended Reading:

1. Kuby Immunology: T.J. Kindt, B.A. Osborne and R.A. Goldsby (2006) 6th edition W.H. Freeman
2. In addition, reading assignments for this course will be from recently published papers from the primary literature

Prerequisite: Immunology I (BIO 323)

BIO 354**Neurobiology II****3 credits**

Introduction: This course builds from BIO 334 (Neurobiology I), and focuses on higher functions of the nervous system. Systems level functions like, sensory and motor systems, processing of pain and emotion, arousal and circadian rhythms will be discussed from qualitative and quantitative perspectives. Traditional and new imaging modalities will be introduced. Emerging areas of astrocytic and glial feedback, mirror neurons and current understanding of cognition will also be discussed. This course is essential for students desirous of pursuing research in any branch of neurosciences.

Content: Autonomous nervous system; Sensory systems and sensory processing; Motor control and pattern generators; Brain imaging: electro-encephalography, positron emission tomography, functional magnetic resonance imaging; Sleep and circadian rhythms; Processing of emotion; Learning and memory; Neurobiology of perception and cognition; astrocyte and glial feedback; Current topics: mirror neurons, neurodegeneration.

Recommended Reading:

1. Principles of Neural Science: E. Kandel et al. (2000) 4th edition, McGraw-Hill Medical
2. Neuroscience: M. Bear et al. (2006) 3rd edition, Lippincott Williams & Wilkins
3. Foundations of Cellular Neurophysiology: D. Johnston and S. Wu (1994) 1st edition, MIT Press
4. The Other Brain: D. Fields (2009) 1st edition, Simon and Schuster
5. Mathematical Physiology I: J. Keener and J. Sneyd (2008) 2nd edition, Springer
6. Neuroscience: D. Purves et al. (2011) 5th edition, Sinauer Associates

Prerequisite: Neurobiology I (BIO 334)

BIO 401/402**Lab Training / Theory Project****3 credits**

The larger objective of this course is to encourage students to participate in ongoing research at IISER Pune. This may be in the form of a reading/literature review/theoretical and computational project or a lab based research project.

The student has to identify, talk to and mutually agree on a research project with a faculty member before registering for this course. The scope, duration, structure, expectations, and evaluation criteria for the course are decided by the project supervisor.

BIO 410**Advanced Biochemistry I****4 credits**

Introduction: This course aims to provide students with a comprehensive grounding in the fundamentals of Biochemistry. We start with the very basic

molecule necessary for life (water) and go on to discover the structure, function and interrelationships between important biomolecules that collectively carry out the essential functions of life (like nucleic acids, proteins and carbohydrates). It also introduces the concepts underlying routine and advanced methodologies that are used in analyzing biochemical data. This course is a prerequisite for BIO 417 (Advanced Biochemistry II).

Content: Water and life; Biomolecules: Structural and functional aspects of proteins, nucleic acids and carbohydrates; Nucleic acids: Structure and function, RNA world, ribozymes, DNA as the genetic information carrier; Protein folding, dynamics and interaction: Thermodynamic principles, binding and protein folding reactions analyzed from the framework of enthalpy, entropy, free-energy and heat capacity. Enzyme biochemistry: Enzymes as biological catalysts, kinetics of unireactant systems, inhibition systems, enzyme activation, multisite and allosteric enzymes; Carbohydrates: Structure and function; Biochemical techniques: Protein and nucleic acid isolation, electrophoresis, chromatography, mass spectrometry, isothermal titration calorimetry and isotope exchange.

Recommended Reading:

1. Biochemistry: D. Voet and J.G. Voet (2010/2004), 4th/3rd edition, Wiley
2. Biochemistry: The chemical reactions of living cells: D.E. Metzler (2003) Volumes I & II, 2nd edition, Academic Press

BIO 411

Ecology I (Basic Ecology)

4 credits

Introduction: This course will cover the basic theoretical framework of ecology. The basic organizing structure of the course is centered around the hierarchical levels of biological organizations in Ecology: starting at the level of individuals, to populations, species interactions, communities and finally ecosystems.

Content: Topics covered will include: Introduction - history, philosophy and practice of ecology; Ecology of individual organisms - physiological ecology; population ecology - population growth and regulation, evolution of life-history, species interactions, trophic interactions; Community ecology - community structure and properties, succession and disturbance; Ecosystem ecology – biodiversity, productivity and energy flow, biogeochemistry.

Recommended Reading:

1. Ecology: from individuals to ecosystems: M. Begon, C.R. Townsend, and J.L. Harper (2006) 4th edition, Blackwell Publishing
2. Ecology: R.E. Ricklefs and G.L. Miller (2000) 4th edition, W.H. Freeman
3. The Ecology of Plants: J. Gurevitch, S.M. Schener, and G.A. Fox (2006) 2nd edition, Sinauer and Associates

BIO 412**Microbiology****4 credits**

Introduction: This course covers the unique aspects of microbial life. Students are assumed to have studied basic courses in biochemistry, physiology, molecular biology and population biology. A number of phenomena are unique to the microbial world which may not be covered under general biology courses. This course emphasizes on aspects of both basic and applied biology of prokaryotic and eukaryotic microorganisms.

Content: Microbial diversity: Cultural and culture independent methods, taxonomy, functional anatomy of prokaryotic and eukaryotic microbial cells. Microbial physiology: Unique pathways for fermentation, biodegradation and biosynthesis. Microbial growth kinetics. Development and differentiation in microorganisms: spores, cysts, biphasic growth, Dictyostelium development, myxobacterial development, Biofilms and signaling among microbial cells. Microbial genetics. Regulation of gene expression in prokaryotes; bacteriophage life cycle and phage genetics. Bacterial cell cycle and cell division in bacteria, host-parasite interactions, a brief overview of virology.

Recommended Reading:

1. Microbiology: An Introduction: G.J. Tortora, B.R. Funke and C.L. Case (2004) 8th edition, Pearson Education
2. Bacterial and Bacteriophage Genetics: E.A. Birge (2006) Springer
3. Flint S.J., Enquist L.W., Racaniello V.R., Skalka A.M. (2008)
4. Principles of Virology (Volume I), 3rd Edition.

BIO 413**Mathematical Biology****4 credits**

Introduction: This course is an introduction to modeling biological processes and systems. Classical examples, such as from neuroscience and other topics in physiology, will be used to examine various methods and techniques that are frequently useful. This course will be interesting to applied math students looking to understand how mathematics is useful in biology, and modeling in general. It is now well recognized that quantitative methods are profoundly important to solving biological problems of the present century; biology students will learn to appreciate how quantitative methods improve understanding of experimental data, and in some cases are indispensable.

Content: Classical examples will be drawn from the literature that best illustrate the seamless integration of mathematics and biology, such as modeling in neuroscience (the classification of spiking activity based on different bifurcation scenarios), enzyme kinetics (slow-fast analysis and the Michaelis-Menten equations), cell cycle modeling, and others.

Recommended Reading:

1. Dynamic Models in Biology: S.P. Ellener and J. Guckenheimer (2006) Princeton University Press

2. Mathematical Physiology: J. Keener and J. Sneyd (2008) Springer
3. Theoretical Neuroscience: P. Dayan and L. Abbott (2005) MIT Press
4. Mathematical Models in Biology: L. Edelstein-Keshet (2005) Random House

BIO 417**Advanced Biochemistry II****4 credits**

Introduction: This course constitutes specialized topics related to membrane biochemistry and metabolism. The first deals with understanding physical principles underlying formation, organization and dynamics of membranes and also includes case studies from contemporary literature discussing working with artificial membrane systems and reconstitution of membrane proteins into such systems. The second constitutes a survey of metabolic pathways from a molecular point-of-view.

Content: Membrane Biochemistry: Lipid structure and dynamics, membrane protein insertion and folding, lipid and protein organization in membranes, Molecular recognition principles on membranes, Lipid and protein sorting, membrane fusion and fission, homeoviscous adaption, Membrane-mimetic systems, membrane protein purification and reconstitution; Metabolism: Amino acid, lipid, carbohydrate, nucleotide and glycogen metabolism, metabolic pathways such as glycolysis, citric acid cycle, electron transport and oxidative phosphorylation.

Recommended Reading:

1. Molecular Biology of the Cell: B. Alberts, A. Johnson, J. Lewis, M. Raff, K. Roberts and P. Walter (2002) Garland Science
2. Life - As a Matter of Fat: O. Mouritsen (2004) Springer
3. The Structure of Biological Membranes: P. Yeagle (2004) CRC Press
4. Biochemistry: The chemical reactions of living cells: D. Metzler (2001) Academic Press
5. Primary research articles and reviews will be utilized to provide contemporary insights into the field

Prerequisite: Advanced Biochemistry I (BIO 410)

BIO 420**Developmental Biology****4 credits**

Introduction: The goal of this course is to introduce students to the patterns and mechanisms of Animal and Plant development. Model organisms such as *Drosophila*, *Xenopus*, *C.elegans* and *Arabidopsis* will be used to explain commonalities and differences in molecular mechanisms. The instructors will move on to advanced topics, using current research papers, once the history and basic concepts of development have been explained.

Content: History of developmental Biology, evolutionary developmental biology,

an overview of early development, from Egg to Embryo. Commonly used Experimental methods in developmental biology; Introduction to positional information, axes, coordinates and morphogen gradients; Generation and Interpretation of gradient information and Pattern formation; Modes of cell-cell interactions during tissue organization: Self-organization, lateral inhibition, induction, and recruitment; Growth, differentiation and cancer; Evolution of body plan; Stem cell biology and tissue repair; Regeneration; Nervous system development; Embryogenesis in plants. Genes controlling embryogenesis; The control of flowering and molecular signaling. Specification of the floral organ identity; New twists on old model and Quartet theory for floral organ specification.

In addition to the lectures, the course will include paper reading, group discussions, some demonstrations, debates and assignments.

Recommended Reading:

1. Developmental Biology: S.F. Gilbert (2006) 8th edition, Sinauer Associates
2. Principles of Development: L. Wolpert, R. Beddington, T. Jessell, P. Lawrence, E. Meyerowitz and J. Smith (2008) Oxford University Press
3. Plant Physiology: L. Taiz and E. Zeiger (2006) 4th edition, Sinauer Associates

Prerequisite: Courses in Genetics, Cell Biology and Molecular Biology, at IISER Pune or in your B.Sc/ M.Sc course.

BIO 422

Evolution

4 credits

Introduction: This course provides an introduction to the diverse field of evolutionary biology. In the first part of the course, the mechanisms of evolution within populations are explored using mathematical models for changes in gene frequencies and trait values. These principles are used to build theories to explain different facets of the diversity of life in the latter part of the course, hence introducing the student to various sub-fields of evolutionary biology. This course will be useful to any student interested in studying complex systems, mathematical modeling or biology.

Content: Brief history of evolutionary thought. Population genetics: Hardy-Weinberg equilibrium, models for selection, mutation, drift, migration, inbreeding, linkage. Molecular evolution and neutral theory. Quantitative genetics, adaptive landscapes, Fisher's fundamental theorem, Price's equation, Wright's shifting balance theory; History of life on earth; Species concepts, speciation, phylogenetic trees. Adaptations, life history evolution, experimental evolution, multi-level selection, sexual selection, sociobiology. Evolutionary developmental biology, extended evolutionary synthesis. Evolutionary psychology, evolutionary medicine, evolution and society; Critical thinking in evolutionary biology.

Recommended Reading:

1. Evolutionary Analysis: S. Freeman and J.C. Herron (2007) Prentice Hall
2. Evolution: D.J. Futuyma (1997) Sinauer Associates
3. Evolution: N.H. Barton, D.E.G. Briggs, J.A. Eisen, D.B. Goldstein and N.H. Patel (2007) Cold Spring Harbor Laboratory Press
4. Principles of Population Genetics: D.L. Hartl and A.G. Clark (1997) Sinauer Associates
5. Evolution—The Extended Synthesis: M. Pigliucci and G.B. Muller (2010) MIT Press

BIO 423

Ecology II (Advanced Ecology)

4 credits

Introduction: This course will cover current topics in Ecology. Instead of attempting a comprehensive review of general Ecology, this course will focus on in-depth coverage of a few select topics. Some of the topics introduced in BIO 411 (Ecology I) will be covered in greater detail here and other topics like Molecular Ecology and Global Warming and Climate Change will be introduced. The primary method of organization for this course will be readings and class discussions from the primary literature in Ecology. Knowledge of elementary mathematics and statistical procedures is desirable but not essential.

Content: History, Philosophy and the Practice of Ecology; Physiological Ecology; Ecological Genetics; Functional Ecology; Phenotypic Plasticity; Biodiversity and Climate Change; Macroecology; Applied Ecology – Conservation Biology; Recreational Ecology

Recommended Reading:

1. Ecology: From Individuals to Ecosystems: M. Begon, C.R. Townsend and J.L. Harper (2006) 4th edition, Blackwell Publishing
2. Ecology: R.E. Ricklefs and G.L. Miller (2000) 4th edition, W.H. Freeman
3. The Ecology of Plants: J. Gurevitch, S.M. Schener and G.A. Fox (2006) 2nd Edition, Sinauer and Associates
4. Assigned readings from scientific journals

Prerequisite: Ecology I (Basic Ecology): BIO 411

BIO 431

Epigenetics

3 credits

Introduction: The objectives if this course are to introduce students to basics concepts in gene regulation, chromatin biology, genome-environment interaction, epigenetics and its applications in genomics and disease biology. The course would be useful for the students who are interested in learning about the organization of genes and their organization at molecular level and also using a systems approach. The discussions will encompass biochemistry, bioinformatics, genomics, proteomics, computational biology and systems biology.

Content: This course will begin with the fundamentals of regulation of gene expression and chromatin organization (6 lectures) and then emerging concepts of how DNA sequence can dictate chromatin organization at the domain level will be discussed (6 lectures), with specific emphasis on regulatory elements such as boundary elements and insulators (6 lectures). The implications of these in development, differentiation and disease will be discussed using specific examples (12 lectures).

Recommended Reading:

1. Histone variants – ancient wrap artists of the epigenome: Talbert, P.B. and Henikoff, S. *Nat. Rev. Mol. Cell Biol.*, 2010 doi:10.1038/nrm2861
2. Divide and (epigenetic) rule: Chromatin domains as functional and structural units of genomes. Mishra, R.K. and Galande, S. *Journal of Indian Academy of Sciences*, Platinum Jubilee issue, 2009, pp 211-224
3. Bernstein et al. (2007). The mammalian epigenome. *Cell*, 128:669-681
4. Fuks, F. (2005). DNA methylation and histone modifications: teaming up to silence genes. *Curr Opin Genet Dev.*, 15(5):490-495
5. Lunyak, V.V. (2008). Boundaries. Boundaries...Boundaries???. *Curr Opin Cell Biol.*, 20(3):281-287

Prerequisite: Genetics (BIO 320)

BIO 435

Biophysics II

3 credits

Introduction: This course, Biophysics II, will deal with molecules, cells and tissues. The novelty of this course will be an introduction to the non-equilibrium aspects of biophysics applied to molecules. The course will begin with a detailed treatment of the role of water and its biophysics and end with the physics of developmental pattern formation. Assessment will be based on research paper reading, assignments, laboratories and a term paper. The term paper topic will be chosen by the student within two-weeks of the start of the course, a mid-semester update and an end-semester submission.

Content: Mathematics of water and crowding, dynamics of macromolecules particular molecular motors and the cytoskeleton, non-equilibrium approaches, mechano-biology of cells with a focus on muscles, nerves and stem cells, tissue dynamics and development (embryology), literature review, term paper, labs on macromolecular crowding and pattern formation.

Recommended Reading:

1. Mechanics of the Cell: D. Boal (2001) Cambridge University Press
2. Physical Biology of the Cell: Philips, Kondev, Theriot & Orme (2009) Garland Science, Taylor and Francis Group LLC.3
3. Biological Physics of the Developing Embryo: G. Forgacs and S. Newman (2005) Cambridge University Press
4. Biological Physics: P. Nelson (2007) W.H. Freeman

5. Biophysics: An Introduction: R. Glaser (2010, 2012) Springer
6. Life in Living Fluids: S. Vogel (1996) Princeton University Press
7. Lehrbuch Der Biophysik: E. Sackmann and R. Merkel (2010) Wiley-VCH Verlag GmbH & Co KGaA

Prerequisite: Biophysics (BIO 322)

BIO 441

Genome Biology

3 credits

Introduction: The goals of this course are to introduce students to the recent and ongoing excitement in the science of Genome Biology and Genomics. This course would be useful to any student with an interest to understand the basic workings of our genomes and how recent findings are being translated using interdisciplinary methods at a rapid rate to address fundamental biology of cells. This is now paving the way for the diagnosis and treatment of complex human diseases.

Content: Nucleic acid chemistry, DNA, RNA, proteins, DNA-hydrogen bonding, base pairing, replication, sequencing, annealing, hybridization, RNA, transcription, Amino acids, proteins, protein synthesis. Biology of Genomes; Synthetic genomes; Biology of the nucleus – nuclear architecture (cell biology and cytogenetics meets genomics); Mechanobiology and the nucleus; Advanced Chromosome biology – karyotyping & Spectral Karyotyping (SKY), FISH methods, chromosome painting studies and molecular cytogenetics, Copy number variations (CNV), array-comparative genomic hybridization (a-CGH), Chromosome conformation capture, 3C, 4C and Hi-C; microarrays, Next generation DNA sequencing; RNA Sequencing; Chip-Seq, Functional Genomics, Bioinformatics & computational biology; Transcriptomics; Cancer Genomics, Epigenomics, Chemical Genomics; Metabolomics; Proteomics; Genomics & stem cells; Systems biology

Recommended Reading:

1. Molecular Biology of the Cell: B. Alberts, A. Johnson, J. Lewis, M. Raff, K. Roberts and P. Walter (2007) 5th edition (Sections: 1-3, Chapters: 1-8)
2. Gibson et al, *Science*, 2010:329, 52–56
3. http://cshperspectives.cshlp.org/cgi/collection/the_nucleus
4. Shivashankar, G.V. (2010). Nuclear mechanics and genome regulation, *Methods Cell Biol.*, 98:xiii
5. Vorsanova, S.G. et al (2010). Human interphase chromosomes: a review of available molecular cytogenetic technologies, *Mol Cytogenet.*, Jan 11; 3:1
6. Padilla-Nash, H.M. et al (2006). Spectral karyotyping analysis of human and mouse chromosomes. *Nat Protoc.*, 1(6):3129-3142
7. Metzker, M.L. (2010) *Nature Reviews Genetics* 11:31-46

BIO 442**Computational Biology****3 credits**

Introduction: The goal of this course is to gain a broad understanding of the computational methods that are applied to various problems in biology. One could study the computational methods in isolation, or learn them by applying them to a set of eclectic problems from various sub-fields in Biology. The approach that we choose is grounded in a discipline that has arguably gained the most from the application of mathematical and computational tools, namely Neuroscience. In this hands-on course, we will apply various computational methods to model different aspects of neurobiology across spatial and temporal scales. These methods will find wide application across different biological systems.

Content: Simulating the dynamics of single neurons and networks using ordinary differential equations; Modeling channel kinetics in single neuron models; Intracellular dynamics using reaction diffusion equations; Monte Carlo simulations of cellular signaling pathways; Parameter optimization

Recommended Reading:

1. David Sterratt, Bruce Graham, Andrew Gilles. Principles of Computational Modeling in Neuroscience, Cambridge University Press; 1st edition (August 15, 2011)
2. Erik de Schutter, Computational Modeling Methods for Neuroscientists, The MIT Press; 1st edition
3. Leah Edelstein-Keshet, Mathematical Models in Biology (Classics in Applied Mathematics). SIAM: Society for Industrial and Applied Mathematics; 1st edition (February 2005)

BIO 452**Plant Biology II****3 credits**

Introduction: This course would enable students to learn applied aspects of plant science. Students would gain knowledge of a variety of techniques as well as their direct applications in crop improvement program. Hands on practical sessions in this course would give them the exposure to a number of tools which are essential in plant biotech industries. The training will equip the students with necessary intellectual background and the skills to undertake research in cutting edge areas of plant biology.

Content: Plant cell, tissue and organ culture (micropropagation, somatic embryogenesis, organogenesis, protoplasts and somatic hybridization); plant genetic transformation and transgenic and transplastomic plants; plant metabolites and engineering of plant metabolic pathways; production of phytochemicals by cell, tissue and hairy root cultures; molecular farming; phytoremediation; crop improvement tools: molecular markers and marker mediated applications in plant breeding techniques, quantitative genetics, breeding strategies, biotechnology in crop improvement (biotic and abiotic stress, nutritional quality, defense responses); seed technology, molecular tests for seed analysis; visits to plant biotech companies.

Recommended Reading:

1. Introduction to Plant Tissue Culture: M.K. Rajdan (2003) 2nd edition, Science Publishers
2. Plant Biotechnology-the genetic manipulation of plants: A. Slater (2008) 2nd edition, Oxford University Press
3. Genetically Modified Crops (2011) 2nd edition, Imperial College Press, Worlds Scientific Publishers

Prerequisite: Plant Biology I (BIO 321)

BIO 454

Structural Biology

3 credits

Introduction: The emphasis of the course is on conceptual understanding of structure of biomolecules and some of the techniques used to determine and analyze them. The course also aims to enable students to understand, critically evaluate and use bimolecular structural information available in literature and public databases.

Content: Introduction to structures of biomolecules: proteins and nucleic acids; Recombinant technology and purification techniques to isolate biomolecules; Determination of atomic structure using X-ray crystallography; Studying macromolecular assembly using electron microscopy; Biophysical and spectroscopic techniques to understand structures; Graphics tools to visualize and analyze atomic structure of biomolecules; Understanding biological phenomenon with structures.

Recommended Reading:

1. Introduction to Protein Structure: C. Branden and J. Tooze (1999) 2nd edition, Garland Science
2. Biomolecular Crystallography: Principles, Practice, and Application to Structural Biology: B. Rupp (2009) 1st edition, Garland Science
3. Understanding DNA: C. Calladine, H. Drew, B. Luisi and A. Travers (2004) Elsevier Academic Press
4. Textbook of Structural Biology: A. Liljas, L. Liljas, J. Piskur, G. Lindblom, P. Nissen and M. Kjeldgaard (2009) 1st edition, World Scientific Publishing

Prerequisite: Advanced Biochemistry I (BIO 410)

BIO 491

Literature Review

3 credits

Introduction: This main objective of this course is to familiarize students with the primary scientific literature. This will include use of search tools; reading, analyzing, and critically evaluating the primary literature; and, effectively summarizing and communicating (oral and written) this information.

Content: The scientific literature – primary, secondary, and tertiary literature;

Database searches – tools and strategies; Reading and evaluating the scientific literature - Academic writing – plagiarism and referencing, Format and Style; Writing a literature review. Different members of the Biology faculty will contribute to this course. Faculty member will choose topics from their own area of research expertise, and highlight through readings and discussions the nuances of reading and evaluating the literature in diverse topics like biochemistry, neurobiology, theoretical biology, etc.

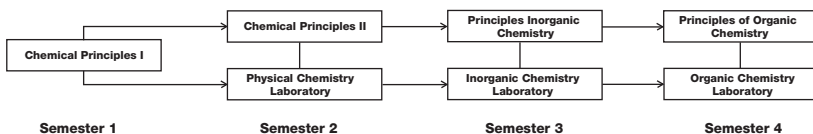
Recommended Reading:

Reading assignments for this course will be from a variety of scientific journals.

CHEMISTRY

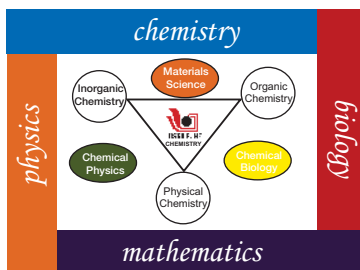
Core Courses in Chemistry during the First Two Years of the BS MS Program

The courses in the first two semesters will lay the foundation for advanced concepts in chemistry. Here the students will look at matter and its properties at the level of atoms and molecules. They will make connections with phenomena in everyday life and understand them in microscopic terms. Some topics covered include atomic and molecular structure, periodic trends, using light to see molecules, thermodynamics, and kinetics. These two courses along with a lab in the second semester will serve as a base for the ensuing two semesters of inorganic and organic chemistry, both accompanied by laboratory courses. The laboratory courses have been designed to complement classroom interactions. Together, these seven courses in the first four semesters should sufficiently prepare a student for advanced courses in chemistry and serve as the minimum for anyone who wishes to major in other disciplines of science such as physics or biology.



The Ideology behind the Chemistry Courses

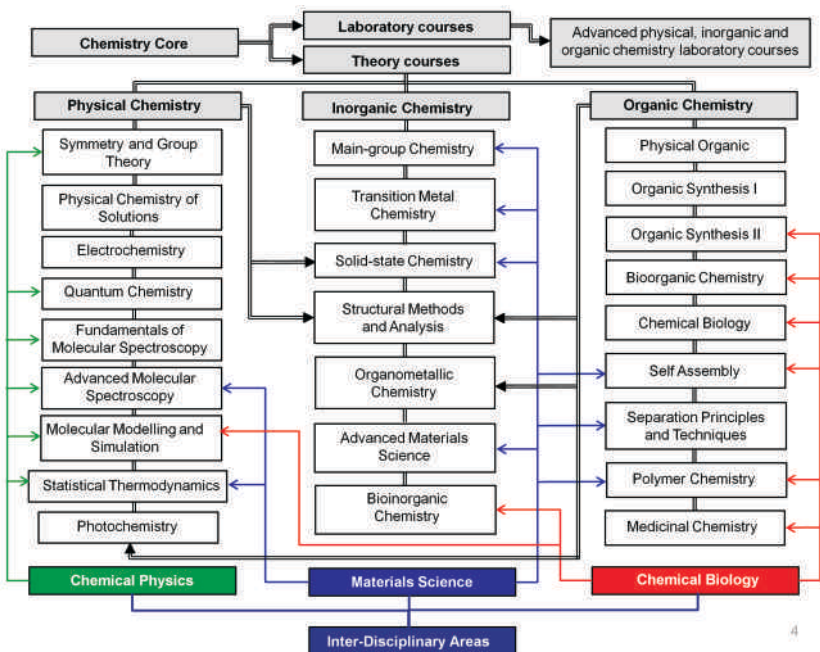
The chemistry program has been broadly divided into three groups: physical chemistry, inorganic chemistry and organic chemistry. Each semester has at least one “core” course (4-credit) from these groups that a student may opt for. They are also arranged in sequence so that all topics in a particular group are covered by the end of the eighth semester. In addition to these core courses, students also have an option of choosing a potpourri of 3-credit courses. These 3-credit courses are not only important for students who wish to major in chemistry but also useful for students who wish to choose chemistry as a minor discipline of interest.



Suggestions to Students wanting to “Major in Chemistry”

Students who wish to study chemistry as the major subject of interest may opt for a majority of the core courses offered each semester and as many electives as possible in chemistry. Several sequences are available for students to choose from such as organic, inorganic and physical chemistry. If the student is interested in inter-disciplinary areas, one could choose from three available options, materials science, chemical physics and chemical biology. Of course, other combinations of courses yielding the right mix for chemistry and other disciplines might also be possible. In addition, students are allowed to register for two lab/theory projects during their third and fourth years as an elective course.

A flowchart describing all the available courses under each branch of chemistry and their relationship(s) to the inter-disciplinary areas of research is given below.



Inter-disciplinary courses in Chemistry

Inter-disciplinary courses are divided roughly into three streams:

1. **Chemical Physics:** These cover courses in the interface of physics and chemistry and include Symmetry and Group Theory, Advanced Molecular Spectroscopy, Statistical Thermodynamics, and Quantum Chemistry and Solid State Chemistry. When combined with suitable physics courses, a student might have a good exposure to both chemistry and physics.

2. **Chemical Biology:** Several courses in the interface of chemistry and biology are offered by the chemistry division. Starting from the sixth semester, a sequence of courses of Bioorganic Chemistry, Chemical Biology and Medicinal Chemistry can complement relevant course in biology division to cover advanced topics in the interface of these two streams.

3. **Materials Science:** Courses offered under this broad section would cover areas that are common to chemistry, physics and to some extent biology. Starting from fifth semester a series of courses such as Self-assembly in Chemistry, Solid-state chemistry, Polymer chemistry and Advanced materials chemistry will give good insights to relevant courses both in physics and biology. Further, the courses offered under this section would be useful to all the students who want to specialize in any branch of organic, inorganic or physical chemistry.

Credit System

4 credits: Typically, there will be three lectures a week. Often instructors devote 2 lectures for theory and 1 lecture for tutorial. In addition, assignments, self-study and group exercises would be part of the course.

3 credits: Typically, there will be two lectures a week. In the senior years, these courses require solid background in the prerequisites mentioned for the course. In the first two years, there will be one tutorial also in addition to lectures. All laboratory courses are of 3 credits with 3 lab hours per week.

List of Courses in Chemistry

Semester I

1. CHM 101 Chemical Principles I [3 credits]

Semester II

2. CHM 102 Chemical Principles II [3 credits]
3. CHM 121 Chemistry Laboratory I - Physical Chemistry [3 credits]

Semester III

4. CHM 201 Principles of Inorganic Chemistry [3 credits]
5. CHM 221 Chemistry Laboratory II - Inorganic Chemistry [3 credits]

Semester IV

6. CHM 202 Principles of Organic Chemistry [3 credits]
7. CHM 222 Chemistry Laboratory III - Organic Chemistry [3 credits]

Semester V

8. CHM 311 Physical Organic Chemistry [4 credits]
9. CHM 312 Main Group Chemistry [4 credits]
10. CHM 320 Symmetry and Group Theory [4 credits]
11. CHM 301 Lab Training/Theory Project - I [3 credits]
12. CHM 331 Self-assembly in Chemistry [3 credits]
13. CHM 332 Separation Principles and Techniques [3 credits]
14. CHM 340 Advanced Organic Chemistry Laboratory [3 credits]

Semester VI

15. CHM 310 Quantum Chemistry [4 credits]
16. CHM 321 Organic Synthesis – I [4 credits]
17. CHM 322 Transition Metal Chemistry [4 credits]
18. CHM 323 Fundamentals of Molecular Spectroscopy [4 credits]
19. CHM 302 Lab Training/Theory Project – II [3 credits]
20. CHM 334 Physical Chemistry of Solutions [3 credits]
21. CHM 351 Bioorganic Chemistry [3 credits]
22. CHM 360 Advanced Inorganic Chemistry Laboratory [3 credits]

Semester VII

23. CHM 410 Advanced Molecular Spectroscopy [4 credits]
24. CHM 411 Organic Synthesis – II [4 credits]
25. CHM 413 Bioinorganic Chemistry [4 credits]
26. CHM 401 Lab Training/Theory Project – III [3 credits]
27. CHM 430 Advanced Physical Chemistry Laboratory [3 credits]
28. CHM 431 Chemical Biology [3 credits]
29. CHM 432 Solid State Chemistry [3 credits]
30. CHM 436 Molecular Modelling and Simulation [3 credits]
30. CHM 445 Electrochemistry [3 credits]

Semester VIII

32. CHM 420 Structural Methods and Analysis [4 credits]
33. CHM 421 Polymer Chemistry [4 credits]
34. CHM 422 Statistical Thermodynamics [4 credits]
35. CHM 423 Medicinal Chemistry [4 credits]
36. CHM 402 Lab Training/Theory Project – IV [3 credits]
37. CHM 433 Photochemistry [3 credits]
38. CHM 441 Advanced Materials Science [3 credits]
39. CHM 442 Organometallic Chemistry: Principles and Applications [3 credits]

Details of Courses in Chemistry

CHM 101	Chemical Principles I	3 credits
---------	-----------------------	-----------

Introduction: The objective of this two-part course is to look at chemistry at the level of atoms and molecules, and to make connections between the rules governing such microscopic particles to what we observe in the macroscopic world. The first part of this course, Chemical Principles I, focuses on structure and properties of atoms and molecules.

Contents: Building blocks of chemistry, Need for quantum mechanics, Wave-particle duality of light, Wave-particle duality of matter, Wave function and Schrödinger equation, Energy quantization; particle in a box model, Hydrogen atom, Multielectron atoms, Periodic trends, Relativistic effects, Chemical bonding, Seeing molecules and their motion, Energy states and transitions between them, What drives a chemical transformation, Nuclear chemistry.

Recommended Reading:

1. Physical Chemistry: Peter Atkins and Julio de Paula
2. Chemical Principles: S.S. Zumdahl (2009) 6th edition, Houghton-Mifflin Company

CHM 102	Chemical Principles II	3 credits
---------	------------------------	-----------

Introduction: This course builds on the concepts in Chemical Principles I and focuses on the changes that molecules undergo (thermodynamics) and how fast these changes happen (kinetics). In addition, a part of this course also deals with bonding, hybridization, conformations and stereochemistry of organic molecules with emphasis on practical applications.

Contents: Thermodynamics in everyday life, System and surroundings, Macroscopic and microscopic understanding of temperature, internal energy, heat and work, Conversion of internal energy into work and heat, Reversible, quasistatic and irreversible work, Entropy as the driving force for change, Microscopic definition of entropy $S = k_B \ln W$, Gibbs free energy, Chemical equilibrium, Rates of chemical reactions and their experimental determination, Temperature dependence of reaction rate, Mechanism of chemical reactions, Catalysis, Reaction rate theories.

Carbon Compounds and Chemical Bonding: Conformations of acyclic and cyclic systems; strain energy cyclic systems; High energy materials from cyclic strained systems; Renewable energy models from small strained cyclic systems. Stereochemistry: Importance of stereochemistry, Chirality in biomolecules, Assigning chirality, Stereochemical descriptors, Interaction of chiral molecules with light, Optical activity; Organic Chemistry in day-to-day life, for example, cosmetics, artificial sweeteners, food additives etc.

Recommended Reading:

1. Physical Chemistry: Peter Atkins and Julio de Paula
2. Chemical Principles: S.S. Zumdahl (2009) 6th edition, Houghton-Mifflin Company
3. Organic Chemistry by Jonathen Clayden, N. Greeves, S. Warren, P. Wothers Oxford University Press
4. Organic Chemistry by Solomon, John Wiley & Sons Inc; 2nd or 3rd edition

CHM 121 Chemistry Laboratory I – Physical Chemistry 3 credits

Introduction: This course is designed to acquaint students with the practice of experimental physical chemistry. The goal of the labs is to provide modest introductions to the core area of scientific activity which would help students to apply the principles of thermodynamics, kinetics and spectroscopy presented in the physical chemistry lecture course in some illustrative experiments. Students are encouraged to understand the interconnection between the experimental foundation and the underlying theoretical principles and appreciate the limitations inherent in both theoretical treatments and experimental measurements. Students will gain familiarity with a variety of measurement techniques which will help them to understand the methods, to develop laboratory skills and to develop the ability to work independently. Orientation towards good attitudes and habits and toward learning the safe way of doing science will be provided.

Contents: Acid Base Titration using pH meter, Acid Base Titration using conductivity method, Potentiometric titrations, Heat of Neutralization, Kinetic Study of Ester hydrolysis, Activation Parameter calculations, Colligative properties of Solutions, Optical Activity by Polarimetry, UV-VIS Spectrophotometry

Recommended Reading:

1. Experiments in Physical Chemistry: C.W. Garland, J.W. Nibler and D.P. Shoemaker (2008) 8th edition, McGraw-Hill Science/Engineering/Math
2. Physical Chemistry: P. Atkins and J. de Paula (2006) 8th edition, W.H. Freeman

CHM 201 Principles of Inorganic Chemistry 3 credits

Introduction: This course will introduce the students the most rudimentary principles behind the chemistry of inorganic compounds. In this course an overview introduction to the common elements of the periodic table from alkali metals to noble gases through transition-metal and main group elements will be given and their property such as periodicity, structure and bonding, acidity and basicity, redox reactivity etc. will be discussed. At the end of the course, the students should be able to derive the structure of various covalent compounds, apply the concept of acid-base chemistry to various reactions and as a whole

understand the importance of the elements of the periodic table for living matter.

Contents: Atomic Structure, electronic configuration, periodicity, sizes of atoms and ions, ionization energy, electron affinity, relativistic effects, chemical bonding, Lewis theory, valance bond and molecular orbital theories, solid state structures and properties, concepts of acids and bases, Brønsted and Lewis theory, hard and soft acids and bases, oxidation and reduction, electrode potentials, Nernst equation, representation of electrochemical data, importance of water splitting, batteries and fuel cells, coordination complexes, theories of bonding in transition metal compounds, some introduction to main group compounds.

Recommended Reading:

1. Inorganic Chemistry: Shriver and Atkins (2006) International Student Edition, 4th edition, Oxford University Press
2. Concepts and Models of Inorganic Chemistry: B. Douglass, D. McDaniel and J. Alexander (2006) 3rd edition (student edition), Wiley-India
3. Inorganic Chemistry: J.E. Huheey, E.A. Keiter and R.L. Keiter (2007) 4th edition, Pearson Education
4. Concise Inorganic Chemistry: J.D. Lee (1999) 5th edition, Blackwell Science

CHM 202

Principles of Organic Chemistry

3 credits

Introduction: This course includes structural chemistry of organic compounds with an emphasis on electronic structure, reactivity, conformation and stereochemistry. These concepts will prepare students for a mechanistic-based approach to learning organic reactivity. Emphasis will be given towards developing problem-solving skills unique to organic chemistry.

Contents: Reactive Intermediates; Carbocations and Carbanions chemistry, Free radicals and Carbenes, Acidity, basicity, and pKa, Acidity, The definition of pKa, Basicity, Factors that influence the acidity and basicity, HSAB Principle, Stereochemistry, Reactions: Nucleophilic addition reaction: Nucleophilic addition reaction to carbonyl group: Molecular orbitals explain the reactivity of the carbonyl Group, angle of nucleophilic attack on aldehydes and ketones, Electrophilic addition reactions: Alkenes react with bromine, water; bromohydrin formation etc. Conjugate addition: Conjugation changes the reactivity of carbonyl group, Alkenes conjugated with carbonyl groups, Substitution Reactions: Nucleophilic substitution at saturated carbon: Nucleophilic substitution, Structure and stability of carbocations, The SN1 and SN2 mechanisms for nucleophilic substitution. Neighbouring group participation (NGP), Aromatic electrophilic and nucleophilic substitutions, Elimination Reactions: Types of elimination reactions and factors that affecting the elimination reactions. Organic Chemistry in Real Life Applications: Interaction through Chemical Communications, Farms to Pharma: Importance of stereochemistry in Medicinal Chemistry, Antioxidants; anti cancer

agents, Life Saving Drugs, Fertilizers and fragrance; Molecular devices, Impact on industrial economy.

Recommended Reading:

1. Organic Chemistry: J. Clayden, N. Greeves, S. Warren and P. Wothers (2000) 1st edition, Oxford University Press
2. Organic Chemistry: T.W.G. Solomons, 2nd or 3rd edition, John Wiley & Sons
3. March's Advanced Organic Chemistry: M. Smith and J. March, 5th or 6th edition, Wiley-Interscience

CHM 221 Chemistry Laboratory II– Inorganic Chemistry 3 credits

Introduction: This laboratory course aims at demonstrating experimentally the concepts that are introduced in the introductory inorganic chemistry course that will run parallel to this lab course. Experiments based on some of the key topics that are introduced in the theory courses such as acids and bases, redox chemistry, chemistry of coordination and main group compounds will be carried out enhancing a further understanding to these topics. Through these experiments the students not only will have a complete knowledge of these topics but also will learn the use of various techniques such as analytical and spectroscopic methods to study them.

Contents: Acid-base titrations relevant to the neutralizing power of antacids, conventional and photochemical synthesis of coordination compounds, complexometric and spectroscopic estimation of metal ion concentrations in coordination compounds, redox titration relevant to the iodine content in common salts, synthesis of disinfectants containing main group compounds such as Alum, soaps and micelles.

Recommended Reading:

A Collection of Interesting General Chemistry Experiments: A.J. Elias (2007) Revised edition Universities Press (India) Pvt. Ltd.

CHM 222 Chemistry Laboratory III – Organic Chemistry 3 credits

Introduction: This laboratory course will provide opportunity for the students to learn the nuances in organic synthesis. Students will be trained to setup reactions, monitor reactions by functional group analysis and by thin layer chromatography. In this course, students will learn basic separation and purification techniques (e.g., filtration, recrystallization and column chromatography) that are commonly used in organic synthesis. Students will be also trained in isolating natural products from natural sources. Furthermore, students will characterize the synthesized or isolated compounds by determining the melting point or by IR, UV and NMR spectroscopy. Together this organic chemistry lab course will set a platform for

students who wish to pursue research in experimental chemistry.

Contents: Functional group analysis, classical name reactions and oxidation, reduction, cycloaddition, aromatic electrophilic substitution reactions, isolation of natural products and synthesis of fluorescent compounds, purification techniques such as recrystallization and column chromatography.

CHM310

Quantum Chemistry

4 credits

Introduction: The objective of this course is to understand the rules governing the behavior of molecules and atoms – the theory of quantum mechanics – and thereby get a feeling for how to explain and predict chemical properties. The course starts by discussing the fundamental principles of quantum mechanics with an emphasis on the physical implications of this elegant, yet non-intuitive theory. It then applies quantum mechanics to simple model systems and eventually to atoms and molecules. It explores one of the most pervasive concepts in chemistry: the chemical bond. The ideas discussed in this course will be useful to those who wish to pursue further study in the areas of theoretical and computational chemistry, spectroscopy, molecular biology and materials science.

Contents: Introduction to quantum mechanics and quantum chemistry, postulates of quantum mechanics, particle in a box, harmonic oscillator, rigid rotor, hydrogen atom, variational principle, perturbation theory, introduction to many electron systems, electron spin, antisymmetry, Slater determinants, 2-e systems, valence bond theory, molecular orbital theory, introduction to Hartree-Fock theory.

Recommended Reading:

1. Quantum Chemistry: D.A. McQuarrie (2007) 2nd edition, University Science Books
2. Quantum Chemistry: I.N. Levine (2008) 6th edition, Prentice Hall
3. Modern Quantum Chemistry: Introduction to Advanced Electronic Structure Theory: A. Szabo and N. Ostlund (1996) New edition, Dover Publications

CHM311

Physical Organic Chemistry

4 credits

Introduction: The main objective of this course is to expose students to the fundamental concepts of structure and function in organic reactions. The use of kinetics and thermodynamics to elucidate mechanisms of reactions will be dealt with. At the end of this course, students will be in a position to predict reactivity patterns and propose reasonable mechanisms.

Contents: Basic concepts of acidity, basicity, and pKa; Equilibria, kinetics and mechanisms; Rearrangements; Radical Reactions; Mechanisms in Biological Chemistry; Advanced Molecular Orbital Theory; Stereochemistry and conformational analysis; Thermal pericyclic reactions; Sigmatropic and electrocyclic reactions; Synthesis and Reactions of carbenes.

Recommended Reading:

1. Organic Chemistry: J. Clayden, N. Greeves, S. Warren and P. Wothers (2000) 1st edition, Oxford University Press
2. Modern Physical Organic Chemistry: E. Anslyn and D.A. Dougherty (2006) 1st edition, University Science Books
3. Advanced Organic Chemistry: Part A: Structure and Mechanism: R.J. Sundberg and F.A. Carey (2000) 4th edition, Kluwer/Plenum Press
4. Physical Organic Chemistry: N. Isaacs (1995) 2nd edition, Addison-Wesley-Longman

Prerequisite: None, but this course is a prerequisite for Organic Synthesis I and II.

CHM312**Main Group Chemistry****4 credits**

Introduction: The objective of this course is to focus on the chemistry of main group elements such as hydrogen, alkali metals and P-block elements from group 13 – 18 of the periodic table. The central theme of this course is to give a detailed account on the fundamental concepts relevant to structure and bonding, acids and bases, redox behavior, reactions and applications of the main group elements and their compounds. In addition to providing a necessary foundation for inorganic chemistry, this course will also emphasize the role of main group compounds in multi disciplinary areas of chemistry such as supramolecular, organometallic, materials science and catalysis.

Contents: Theories of bonding, acids and bases, thermodynamic acidity parameters; hydrogen and classical hydrogen bond, water, hydrates, hydrogen ions, metal hydrides, activation of hydrogen complexes; alkali metals in liquid ammonia; boron, boranes, carboranes, borazines and borates; allotropy of carbon; silane and polysilanes, silicone Polymers, silicates; compounds of nitrogen, activation of nitrogen, nitrogen fixation, hydrogen, halogen, oxygen and nitrogen compounds of phosphorous; oxygen and singlet oxygen, ozone, complexes of molecular oxygen; N-S compounds; sulphides, oxides and oxoacids of sulphur, chalcogenides and polychalcogenides; halogens, polyhalides, interhalogen compounds, charge-transfer complexes of Halogens; Compounds of Xenon and other noble gases; Zintl compounds and homometallic clusters; elemental and compound semiconductors; energy, polarity, and reactivity of M-C bond; organometallic chemistry of the main group elements.

Recommended Reading:

1. Advanced Inorganic Chemistry: F.A. Cotton, G. Wilkinson, C.A. Murillo and M. Bochmann (1999) 6th edition, Wiley-Interscience
2. Chemistry of the Elements: A. Earnshaw and N. Greenwood (1997) 2nd edition, Butterworth-Heinemann
3. Inorganic Chemistry: D. Shriver and P. Atkins (2006) International Student Edition, 4th edition, Oxford University Press

4. Inorganic Chemistry: J.E. Huheey, E.A. Keiter, and R.L. Keiter; Modified by O.K. Medhi (2007) 4th edition, Pearson Education Inc.

CHM 320	Symmetry and Group Theory	4 credits
----------------	----------------------------------	------------------

Introduction: The objective of this course is to recognize symmetry in molecules and understand its role in chemistry. The course will explore the role of symmetry in (A) determining molecular properties like optical activity and dipole moment (B) classifying and assigning nomenclature to molecules, molecular states and molecular motions, (C) bringing about simplifications in the application of quantum mechanics to molecules and (D) determining spectroscopic selection rules based on molecular symmetry. Group theory applied to the study of molecular symmetry has far reaching consequences in chemistry and the course will provide an in-depth appreciation of this.

Contents: Symmetry elements and operations, *Schönflies notation* of point group, prediction of dipole moment and optical activity from the viewpoint of symmetry, definition of group, subgroup and class, matrix representation of a point group, reducible and irreducible representations, great orthogonality theorem and its corollaries, construction of character tables and meaning of all the terms in a character table, Mulliken symbols for irreducible representations, direct product of irreducible representations, application of symmetry to quantum mechanics, application of symmetry to spectroscopy – electronic, IR and Raman selection rules, projection operator and its application to symmetry adapted linear combinations, construction of molecular orbital correlation diagram of simple and complex molecules, Hückel π molecular orbital of a conjugated system.

Recommended Reading:

1. Chemical Applications of Group Theory: F.A. Cotton (1963) 1st edition, Wiley Interscience
2. Molecular Symmetry and Group Theory: R.L. Carter (1997) John Wiley & Sons
3. Symmetry and Spectroscopy: D.C. Harris and M.D. Bertolucci (1989) Dover Publications
4. Group Theory and Quantum Mechanics: M. Tinkham (2003) Dover Publications

Prerequisite: None. Strongly recommended for students planning to take Quantum Chemistry and Molecular Spectroscopy

CHM 321	Organic Synthesis – I	4 credits
----------------	------------------------------	------------------

Introduction: This course primarily deals with various strategies involved in logical organic synthesis by incorporating basic organic transformations, reactions, and reactivity. Various functional group transformations, reagents, and reaction mechanisms, will be discussed to provide students a clear understanding

and importance of organic synthesis. This course should serve as a stepping stone for students looking to progress to more advanced synthetic concepts and methodologies.

Contents: The concept of protecting functional groups, oxidations and reductions in functional group transformations, enantioselective reduction and oxidation, diastereofacial selectivity in acyclic systems, The chemistry of carbon-carbon sigma and pi bonds and related reactions: Reactions of Carbon-Carbon Double and triple bonds, formation of carbon-carbon single, double and triple bonds and rings, chemistry of enolates, Organometallic Reagents in organic syntheses.

Recommended Reading:

1. Advanced Organic Chemistry: Part B: F.A. Carey and R.J. Sundberg (2007) 5th edition, Springer
2. March's Advanced Organic Chemistry: M. Smith and J. March (2001) 5th edition, Wiley-Interscience
3. Organic Chemistry: J. Clayden, N. Greeves, S. Warren and P. Wothers (2000) 1st edition, Oxford University Press
4. Modern Organic Synthesis An Introduction: G.S. Zweifel and M.H. Nantz (2006) 1st edition, W.H. Freeman

Prerequisite: Physical Organic Chemistry (CHM 311)

CHM 322

Transition Metal Chemistry

4 credits

Introduction: The objective of this course is to provide a detailed account to the chemistry of transition metals and emphasize their relationship to other multi-disciplinary topics such as bioinorganic chemistry and organometallic chemistry. The central theme of this course is to focus on the fundamental concepts needed to understand the transition metal chemistry relevant to their structure, bonding, properties such as spectral characteristics, reactivity, stereochemistry etc. This course will be useful to all those students who have opted for chemistry as a major subject. At the end of this course, students will also learn about the role of transition metals in several other fields like materials science, biology and catalysis.

Contents: Crystal and ligand field theories, crystal field stabilization energies, Irving-Williams series, 10Dq and pairing energies, molecular orbital diagrams for coordination complexes, magnetic susceptibilities and Jahn-Teller effects. Spectroscopic terms, LS-coupling scheme, ligand field transitions, charge transfer bands, selection rules, Orgel diagrams, Tanabe-Sugano diagrams and circular dichroism. Thermodynamic and kinetic factors, labile and inert complexes, ligand substitutions in octahedral and square planar complexes, stereochemical effects. Oxidation/reduction potentials, Nernst equation and redox stability in water, complementary and non-complementary redox reactions, Inner and outer sphere electron transfer and Marcus theory, electron transfer in metalloproteins. Basic terminologies, kinetic factors affecting quantum yield, photochemistry of Co, Rh, Cr and Ru.

Recommended Reading:

1. Inorganic Chemistry: D. Shriver and P. Atkins (2006) 4th edition, Oxford University Press, International Student Edition
2. Inorganic Chemistry: J.E. Huheey, E.A. Keiter and R.L. Keiter (2007) 4th edition, Pearson Education
3. Reaction Mechanisms of Inorganic & Organometallic Systems: R.B. Jordan (2007) 3rd edition, Oxford University Press

CHM 323 Fundamentals of Molecular Spectroscopy 4 credits

Introduction: The objective of this course is to teach the fundamentals of major branches of spectroscopy and its applications. Spectroscopy is an important research tool in all areas of science (Chemistry, Physics and Biology) to determine the structure, property and interaction of molecules. In principle, the interaction of light with matter provides a great deal of physical, chemical and biological information about a system of interest, and ultimately defines many of the observational techniques used. In this course, this radiation-matter interaction and the quantitative information it can provide about molecular systems will be examined.

Contents: Introduction to radiation-matter interaction, Rotational Spectroscopy, Infrared Spectroscopy, Raman Spectroscopy, Electronic Spectroscopy, Nuclear Magnetic Resonance (NMR) Spectroscopy, Electron Spin Resonance (ESR) Spectroscopy.

Recommended Reading:

1. Fundamentals of Molecular Spectroscopy: C. N. Banwell and E. M. McCash (1994) 4th edition, Tata McGraw Hill
2. Physical Chemistry - A Molecular Approach: D. A. McQuarrie and J. D. Simon (1998) 1st edition, Viva Books
3. Molecular Spectroscopy: J. L. McHale (1999) 1st Edition, Pearson
4. Spectra of Atoms and Molecules: P. F. Bernath (2005) 2nd edition, Oxford University Press
5. Physical Chemistry: P. W. Atkins and J. D. Paula (2010) 9th edition, Oxford University Press
6. Spectroscopy, G. M. Lampman, D. L. Pavia, G. S. Kriz, J. R. Vyvyan (2010) 4th Edition, Cengage Learning

CHM 331 Self-assembly in Chemistry 3 credits

Introduction: This chemistry course is aimed to provide fundamental aspects of self-assembly in chemistry and its application for supramolecular architectures. This course is beneficial for students who are interested in molecular materials, nanomaterials, biology-chemistry interface and self-assembly in chemical and biological systems. The course also consists of student's seminars on selected topics, problem solving, and idea generation and laboratory experiments on making and testing of self-assembled objects.

Contents: Introduction to self-assembly and supramolecular chemistry, types of non-covalent interactions, importance of pre-organization, determination of association, problem solving, metal ion-macro-ligand supramolecular structures and metallo-supramolecular polymers. Single & self-complementary system, two, three and four and multiple arm hydrogen bonding systems, switching of recognition functions, hydrogen bonded supramolecular polymers, etc. Guest-host approaches in cyclodextrins, Calixarenes, Molecular rings & Nots, Rotaxanes and Dendrimers with examples. Anionic, cationic and neutral Micelles, critical micelle concentration (CMC) determination, bolaamphiphilies and application of micelles in drug delivery, etc. Origin of liquid crystals, mesogens self-organization, Types: nematic, smectic and cholestric liquid crystals and characterization of LC-materials. Self-assembly in DNA, protein and peptides.

Recommended Reading:

1. Selected Topics covered in Comprehensive Supramolecular Chemistry, Volume 8
2. Core concepts in Supramolecular chemistry and Nano-chemistry: Authors; J.W. Steed
3. Supramolecular Chemistry: Fundamentals and Applications: Advanced Text book: Authors: Katsuhiko Ariga
4. Introduction to Soft mater: Synthetic and Biological Self-Assembling Materials: Authors: Ian W. Hamley
5. Review and research articles, communications and notes published in international journals (will be provided)

CHM 332	Separation Principles and Techniques	3 credits
----------------	---	------------------

Introduction: Separation plays a crucial role in Chemistry and Biology, where sample purity is of utmost importance e.g. Pharmaceuticals, Biopharmaceuticals and Fragrances etc. In this course, we will learn theory and practice of separation. We will have hands on training on HPLC, GC, GC MS, Centrifugation, Electrophoresis and few other Chromatographic techniques.

Contents: Thermodynamics, diffusion rates, mass transfer etc. Solvent extraction, distillations, liquid-liquid extraction and other methods of separation. Types of Chromatography: GC, HPLC, hyphenated techniques. Electrophoresis, centrifugation DNA/Protein separations / purifications. Green Separation process separation using zeolite and polymer membranes. Chiral separations, molecular recognition, molecule imprinting and polymer separations.

Recommended Reading:

1. An Introduction to Separation Science: B.L. Karger, L.R. Snyder and C. Horvath (1973) 2nd edition, John Wiley & Sons
2. Handbook of Separation Process Technology: R.W. Rousseau (1987) 1st edition, John Wiley & Sons

3. Separation Process Principles: J.D. Seader and E.J. Henley (2005) 2nd Edition, John Wiley & Sons

CHM334**Physical Chemistry of Solutions****3 credits**

Introduction: This course is designed to teach elementary physical chemistry of solutions to have an insight on the thermodynamic treatment of the chemical problems. Special emphasis will be given to the study of stability in macroscopic systems undergoing phase change and rigorous calculations of equilibrium properties of solutions will be undertaken. Numerical problems related to equilibrium properties, colligative properties, transport properties, conductivity, mobility, viscosity etc. will be taken care to have hands on experiences. Apart from the familiarity with the routine thermodynamic calculations of chemical systems, students would be exposed to contemporary areas such as ionic liquids, polymer and gel electrolytes, chemical sensors, biosensors, Fuel cells with emerging application potential.

Contents: Thermodynamic Description of mixtures, Partial Molar Quantities, Ideal Solutions, Nonideal solutions, Gibbs-Duhem Relation, Equilibrium constant for solutes, vapour-pressure lowering, Application to biology and polymer science, Electrolytes in Solution, Ionic Liquids, Ionic Mobilities, Dielectric Effect, Ionic Strength, Dissociation of Weak Electrolytes, Debye-Huckel Theory, Activities in more Concentrated Solutions, Polymer and Gel electrolyte, Thermodynamic description of Electrochemical Cells, Nernst equation, Activity Coefficients from EMF's, Equilibrium Constant from EMF's, Chemical Sensors, Fuel Cells, Impact on Biochemistry, Phase Equilibria, Pressure-Temperature Phase Diagrams, Phase Rule, Immiscible Liquids, Eutectic Formation, Solid-Compound Formation, Three-Component, Solid-Liquid Systems, Liquid-vapor, Pressure-Composition Diagrams, Boiling-Point Diagrams, Distillation, Adsorption of Gases, Supercritical fluids, Impact on Materials Science.

Recommended Reading:

1. Physical Chemistry: P.W. Atkins and J.de Paula (2010) 8th edition, Oxford University Press
2. Physical Chemistry: G.M. Barrow (2007) 5th edition, Tata McGraw Hills Publishing
3. Physical Chemistry: I.N. Levine (2010) 5th edition, Tata McGraw Hills Publishing
4. Modern Electrochemistry: Bockris and Reddy (1998) 2nd edition, Springer

Prerequisites: Essentials of Physical Chemistry covered during 1st and 2nd semester

CHM 340 Advanced Organic Chemistry Laboratory 3 credits

Introduction: This laboratory course will provide reasonable opportunity for the students to learn the nuances in organic synthesis. Classical name reactions, rearrangements and multi-step reactions will be performed in this course. Purification techniques such as column chromatography will be also included. Synthesized compounds will be characterized using IR, UV, NMR and Mass spectrometer. Put together this organic chemistry lab course will set a platform for students who wish to pursue research in experimental chemistry.

Contents: Separation of ternary quantitative analysis of organic compounds. Electrophilic aromatic substitution reactions: Synthesis of methyl orange (organic dye); Name reactions and rearrangements: Wittig reaction, Beckmann rearrangement: Acetanilide from Acetophenone Oxime; Multi step synthesis: Synthesis of substituted Flavones and characterization of the diketo intermediates and flavones derivatives; Photochemical reaction: Photochemical reaction: Synthesis of benzopinacol from benzophenone using sunlight; Thermal pericyclic reactions: Diels alder reaction: anthracene and maleic anhydride; Copper(I) mediated cycloaddition reaction: Click reaction: Azide and alkyne coupling reaction; Organometallic reactions: Palladium catalyzed cross-coupling reaction: Stereochemistry: Addition of Bromine to trans-cinnamic acid.

Recommended Reading:

1. Experimental procedures will be provided from current literature
2. A Collection of Interesting General Chemistry Experiments: A.J. Elias (2007) Revised Edition, Universities Press
3. Comprehensive Practical Organic Chemistry: V.K. Ahluwalia and R. Aggarwal (2001) Illustrated edition, Universities Press
4. Vogel's Textbook of Practical Organic Chemistry: 5th edition, Prentice Hall

CHM 351 Bioorganic Chemistry 3 credits

Introduction: This course is intended to provide a basic knowledge on the biosynthesis of biomolecule precursors and natural products. The content of this course is a chemistry-based approach to understanding the basic structure, reactivity, biological functions and biosynthesis of precursors—amino acids, nucleotides, fatty acids, lipids and secondary metabolites. This course is also a preamble for Chemical biology course offered in the 8th semester.

Contents: Overview of basic structure of carbohydrates, nucleic acids, proteins, and lipids, Primary and secondary metabolism, bioenergetics, biological and organic reaction mechanisms, coenzymes and cofactors, amino acids: biosynthesis of amino acids promoted by pyridoxal phosphate, Shikimic acid pathway to aromatic amino acids, peptides, depsipeptides antibiotics and their biological activities, biosynthesis of nucleosides. beta-oxidation of fatty acids, biosynthesis of fatty acids, various lipids, polyketides, prostanoids, leucotrienes

and other secondary metabolites, metabolites of mixed biosynthetic origin, from acetate, mevalonate and shikimate pathway, isoprenoids: isoprene unit, monoterpenes, diterpenes, sesquiterpenes and triterpenes, and biological activities, steroids: steroidogenesis, biosynthesis and biological implications.

Recommended Reading:

1. Lehninger Principles of Biochemistry: D.L. Nelson and M.M. Cox (2008) 5th edition, W.H. Freeman
2. Biochemistry: D. Voet and J.G. Voet (2004) 3rd edition, Wiley

CHM 360 Advanced Inorganic Chemistry Laboratory 3 credits

Introduction: This course aims at the integration of chemical synthesis and spectral characterization techniques. Reactions studied in lectures would be explored in laboratory conditions to rationalize synthesis and structural aspects of inorganic molecules and coordination complexes. In this process students, will be encouraged to use advanced instrumentation such as IR and UV-Vis spectrophotometers apart from advanced technique such as multi-nuclear NMR spectroscopy.

Contents: Spectrochemical studies for analysis and stoichiometry, redox reactions. Synthesis, characterization, spectral and magnetic properties of metal co-ordination complexes having different oxidation numbers; determination of their spin-only magnetic moments, Determination of halide concentration by non-spectroscopic methods. Synthesis and evaluation of properties for a silicon polymer, Optical properties of coordination complex. Single crystal-growth and X-ray crystal structural determination.

Recommended Reading:

1. Experimental procedures will be provided from current literature
2. A Collection of Interesting General Chemistry Experiments: A.J. Elias (2007) Revised edition, Universities Press (India) Pvt. Ltd.
3. Vogel's Qualitative Inorganic Analysis: 7th edition, Revised by G. Svehla, Prentice Hall

CHM 410 Advanced Molecular Spectroscopy 4 credits

Introduction: The modern avatar of spectroscopy is a highly interdisciplinary one. Applications are in subjects as diverse as Chemistry, Physics, Astronomy, Materials science and Biology. The developments in spectroscopy now span from ultrafast time-scales to micro and millisecond regimes and a wide range of spatial length scales. The objective of this course is to teach spectroscopy at the advanced level and familiarize the students with the capabilities of these advanced tools. The students will learn fundamentals of laser operation, different types of laser systems, optical techniques that use lasers and various advanced spectroscopic techniques. The students will get practical training in analysis of spectral data.

Modern research topics relevant to this course will be provided to the students and they will make a presentation on that topic at the end of the semester. This course will be useful for those who would like to use advanced spectroscopic techniques in their research.

Contents: Introduction to interaction of radiation with matter, Fundamentals of lasers and laser systems, Advanced spectroscopic techniques and applications, e.g., Raman spectroscopy, Electronic spectroscopy, Fluorescence techniques, Cavity ringdown absorption spectroscopy, Supersonic jet spectroscopy, Laser induced fluorescence, Stimulated emission pumping, Multiphoton ionization spectroscopy, Photoelectron spectroscopy, Ultrafast spectroscopy.

Recommended Reading:

1. Modern Spectroscopy: J.M. Hollas (2004) 4th edition, Wiley, New York
2. High Resolution Spectroscopy: J.M. Hollas (1998) 2nd edition, Wiley
3. Laser Fundamentals: W.T. Silfvast (2008) 2nd edition, Cambridge University Press, Cambridge
4. Laser Chemistry: Spectroscopy, Dynamics and Applications: H.H. Telle, A.G. Urena, R.J. Donovan, (2007) 1st edition, Wiley
5. Physical Chemistry - A Molecular Approach: D.A. McQuarrie and J.D. Simon (1998) 1st South Asian edition, Viva Books Private Limited
6. Spectra of Atoms and Molecules: P.F. Bernath (2005) 2nd edition, Oxford University Press, New York

Prerequisite: Fundamentals of Molecular Spectroscopy (CHM 323)

CHM 411

Organic Synthesis – II

4 credits

Introduction: Builds enough knowledge for independent planning of the total synthesis of an organic molecule. This course would develop research skills and critical thinking by application of course content to practical problem solving. In addition, the course introduces student to variety of strategies in which a molecule can be conceived depending on the intuition of the student. Total synthesis of several molecules from the literature will be discussed in detail which gives students firm understanding of the facts for planning their own synthesis endeavours.

Contents: Formation of carbon-carbon single bonds, Organometallic reagents, synthesis of carbocyclic systems, sketches of synthesis, tactics in organic synthon approach, disconnection approach for multiple step syntheses, functional group interconversions, synthesis of heterocycles: ring-closing reactions; asymmetric synthesis, chiral pool synthesis, chiral auxiliary, organocatalysis, Desymmetrisation, total synthesis of natural products.

Recommended Reading:

1. Organic Chemistry: J. Clayden, N. Greeves, S. Warren and P. Wothers

- (2000) 1st edition, Oxford University Press
2. Organic Synthesis: The Disconnection Approach: S.G. Warren (2008) 2nd edition, Wiley
 3. The Logic of Chemical Synthesis: E.J. Corey and Xue-Min Cheng (1995) 1st edition, Wiley, New York
 4. Classics in Total Synthesis: K.C. Nicolaou and E.J. Sorensen (1996) 1st edition, Wiley-VCH
 5. Advanced Organic Chemistry, Parts A and B: F.A. Carey and R.J. Sundberg, Springer (2007) 5th edition, Springer
 6. Other course material given time to time from literature

Prerequisite: Organic Synthesis □ I (CHM 321)

CHM 413	Bioinorganic Chemistry	4 credits
---------	------------------------	-----------

Introduction: This course will explore the inorganic chemistry behind the requirement of biological cells for metals such as zinc, iron, copper, manganese, and molybdenum. The course comprises of principles of coordination chemistry and spectroscopy topics such as EPR and Mossbauer for metal ions. The reactivity of coordination complexes of metal ions will be discussed in the context of the reaction mechanisms of specific metalloenzymes. A portion of the course will be devoted to the toxicity of metals and also their utility in drugs and in diagnostic agents.

Contents: General aspects of chemistry of dioxygen, Fe, Cu and Co. Nature of M-O₂ linkage, heme proteins, molecular mechanism of oxygenases, catalase and peroxidase, Cu-Zn superoxide dismutase. Electron transferases, Respiration, Photosynthesis, Nitrogen fixation and Vitamin B12. Fe-S proteins, redox behaviour. Metals for diagnosis and chemotherapy, Pt anti-cancer drugs as a case study. ESR and Mossbauer spectroscopy.

Recommended Reading:

1. Bioinorganic Chemistry: I. Bertini, H.B. Gray, J.S. Valentine and J. Lippard (2007) South Asian Edition, Viva Books Private Ltd
2. Biological Inorganic Chemistry: Eds: H.B. Gray, E.I. Stiefel, J.S. Valentine and I. Bertini (2006) University Science Books
3. The Biological Chemistry of the Elements: J.J.R.F. da Silva and R.J.P. Williams (2001) 2nd edition, Oxford University Press

Prerequisite: Transition Metal Chemistry (CHM 322)

CHM 420	Structural Methods and Analysis	4 credits
---------	---------------------------------	-----------

Introduction: The objective of the course is to develop the foundation for important characterization methods (spectroscopic and analytical methods) used routinely by organic/inorganic/physical chemists. Understanding of principles

followed by problem solving sessions involving discussions of spectral data of known and unknown compounds is expected to develop critical thinking and problem solving skills. The course is also important for biology students who want to pursue their research in the chemical biology.

Contents: Infrared Spectroscopy, Ultra-Violet Spectroscopy, Fluorescence Spectroscopy, Elemental Analysis, Mass Spectrometry, Nuclear Magnetic Resonance and multiple problem solving sessions for structure elucidation of natural and synthetic molecules.

Recommended Reading:

1. Spectrometric Identification of Organic Compounds: R.M. Silverstein, F.X. Webster and D.J. Kiemle (2005) 7th edition, Wiley
2. Organic Spectroscopy: W. Kemp (1991) 3rd edition, W.H. Freeman
3. Introduction to Organic Spectroscopy: L.M. Harwood and T.D.W. Claridge (2000) 1st edition, Oxford University Press
4. Principles of Fluorescence Spectroscopy: J.R. Lakowicz (2006) 3rd edition, Springer
5. Introduction to Mass Spectrometry: J.T. Watson and O.D. Sparkman (2007) 4th edition, Wiley
6. Mass Spectrometry a Textbook: J.H. Gross and P. Roepstorff (2011) 2nd edition, Springer

CHM 421

Polymer Chemistry

4 credits

Introduction: This course's emphasis is to provide fundamental knowledge in polymer science. This course is very important for all the students who wish to learn and practice macromolecular and organic chemistry. New physical chemistry concepts in macromolecules, organic synthetic methodologies for polymers and applications of polymers in the industrial applications will be focused. This course is beneficial for students who are interested in polymeric materials, nanomaterials, biology-chemistry interface and macromolecular assemblies in chemical and biological systems.

Contents: Basic concepts, Molecular weight distribution, Linear, Branched, Cross-linked, grafted- Polymers, Polymer Crystallization, Glass Transition, Solution and Melt viscosity, Polymer Rheology, Step-polymerization, Addition Polymers, Radical, Cationic, Anionic Living polymerization, Block copolymers, Liquid crystalline polymers, Ring opening polymerization, Physical and Reactive blends, Nano-composites and synthetic-natural fiber composites, Concepts of conducting polymers and their applications in opto-electronics and sensors, one and 3D dimensional polymeric materials. Dendrimers, hyperbranched polymers, random branched polymers, branching density, influence of branching on the melt, viscosity, rheological and thermal properties of polymers.

Recommended Reading:

1. Principles of Polymerization: G. Odian (2004) 4th edition, Wiley
2. Text Book of Polymer Science: F.W. Billmeyer Jr. (1984) 3rd edition, John Wiley & Sons
3. Polymers: Chemistry and Physics of Modern Materials: J.M.G. Cowie (2007) 3rd edition, CRC Press
4. Review and research articles, communications and notes published in international journals (will be provided)

CHM 422

Statistical Thermodynamics

4 credits

Introduction: Statistical thermodynamics provides a measure to understand classical thermodynamics (energy, entropy, free energy etc.) from microscopic motion of atoms (position, velocity). Therefore, this course provides the tools to explain certain phenomena that are governed by classical thermodynamics (e.g., free energy) from a molecular point of view. The basis of molecular dynamics simulation, which covers a complete research area, is based on statistical thermodynamics. The course requires basic knowledge of mathematics and the concept of probability. This course is essential for a physical chemistry student. However, the knowledge in general will help other branches as well, especially those who would like to think in terms of atoms and molecules. This course will be eventually helpful to pursue a theoretical/computational research

Contents: Thermodynamics postulates, Conditions of equilibrium, Reversible Processes and Maximum Work Postulate, Extremum Principle, Maxwell Relation, Review of Probability Theory, Ensembles and Postulates, Canonical Ensemble, Grand Canonical Ensemble, Microcanonical Ensemble, Other Ensembles, Equivalence of Ensembles, Thermodynamic Connection, Fluctuation, Boltzmann Statistics, Fermi-Dirac Statistics, Bose-Einstein Statistics, monatomic gas, monatomic crystals, Ideal Diatomic Gas, Classical Statistical Mechanics, Ideal Polyatomic Gas, Chemical Equilibrium, Distribution Functions in Classical Monoatomic Liquids.

Recommended Reading:

1. Thermodynamics and Introduction to Thermostatistics: H.B. Callen (1985) 2nd edition, Wiley, [First six chapters]
2. Statistical Mechanics: D.A. McQuarrie, University Science Books, California, USA, Viva Books Private Limited, New Delhi (Indian Edn) [First 7 chapters and some other chapters]
3. An Introduction to Statistical Thermodynamics: T.L. Hill (1987) Dover Publications, Inc, New York

Prerequisite: Basic mathematics

CHM 423**Medicinal Chemistry****3 credits**

Introduction: This course is intended to provide insights into applications of organic chemistry in the field of drug discovery and development. In this course, approaches to new drug discovery including natural product isolation, high-throughput synthesis and screening, and rational drug design will be discussed. We will also compare and contrast these methods of drug discovery and development. We will also learn approaches to lead identification followed by structure-activity determination for optimization of a drug's activity. Some modern methods of drug delivery including formulations and prodrug approaches will be briefly discussed. Finally, we will present a brief introduction to pharmacology, target identification, pre-clinical and clinical development of a drug candidate.

Contents: Enzyme structure and catalysis, types of inhibitors, inhibitors as the basis for drug design, receptors, drug-receptor interactions, ion channels, natural products with drug-like activity, DNA damaging and intercalating agents, RNA-based methods, drug metabolism, biodistribution, drug delivery methods, prodrugs.

Recommended Reading:

1. An Introduction to Medicinal Chemistry: G. Patrick (2001) 2nd edition, Oxford University Press, USA
2. The Organic Chemistry of Drug Design and Drug Action: R. Silverman (2004) 2nd edition, Academic Press
3. Lehninger Principles of Biochemistry: D.L. Nelson and M.M. Cox (2008) 4th edition W.H. Freeman

CHM 430**Advanced Physical Chemistry Laboratory****3 credits**

Introduction: This course comprises of laboratory experiments based on the fundamental concepts in chemistry. Experiments offered in this course provide students an opportunity to learn advanced instrumentation techniques as well as its application to study a variety of physical chemistry and chemical physics problems. One of the main goals of this course is to train students in understanding how physical techniques can be utilized to probe molecular systems and advanced materials.

Contents: Measuring a 1D proton NMR on a standard sample, studying effect of salt on ¹H 90 degree pulse width, studying the effect of solvents on ¹H chemical shifts, experimental demonstration of particle in box model using optical properties of CdS quantum dots, measurement of temperature dependent four-probe sheet resistance of thin films, freely diffusing redox couple- A cyclic voltametric investigation, experimental Demonstration of electrochromic display, contact angle measurement on hydrophobic and hydrophilic surfaces, synthesis and spectroscopic characterization of metal nanoparticles.

Recommended Reading:

1. Basics of NMR, ebook, <http://www.cis.rit.edu/htbooks/nmr/>
2. The Bell System Technical Journal, By F. M. Smits, May 1958, Page 711.
3. Modern Electrochemistry, Bockris and Reddy, 2nd edition (Volume 1 to 3), Springer 1998
4. Electrochemical Methods: Fundamentals and Applications, A. J Bard and L. R Fualkner, 2nd edition, Wiley 2001
5. The Chemistry of Nanomaterials: Synthesis, Properties and Applications, C. N. R. Rao, Achim Müller, Anthony K. Cheetham, Vol. 1, Wiley 2006
6. Nanoscale Materials, Liz-Marzán, L. M.; Kamat, P. V. Vol. 1, Springer 2003

CHM431

Chemical Biology

3 credits

Introduction: Chemical biology is a discipline that integrates principles and experimental techniques drawn from both chemistry and biology to understand biological phenomena. This course will use topics from the current literature to provide an overview of Chemical Biology and will demonstrate the integration of chemical, biochemical and biological approaches. Also, this course will cover the use of modern instrumentation for studying various aspects of biological systems, including structure, dynamics and functions. The course structure will empower both chemists and biologists by providing chemists with relevant new biological targets and biologists with useful new chemical tools.

Contents: The Central Dogma of Molecular Biology, Genes & Genomes, Source of Diversity Beyond Genomes & Diversity through Combinatorial Assembly, Prebiotic Chemistry, Non-bonding Interaction, The Power of Modular Design, Forms of DNA, The Ribonucleotide Subunits of DNA, Elementary Forces in DNA, The Biological Synthesis of DNA by Polymerase Enzyme, Separation of DNA Molecules by Electrophoresis, Recombinant DNA Technology, Nucleic Acid Photochemistry, DNA as Target for Cytotoxic Drugs, RNA Structure, RNA Synthesis, Transcription Control, mRNA Processing in Eukaryotes, Controlled Degradation of RNA, Ribosomal Translation of mRNA into Proteins, Amino Acids and Peptides & Solid Phase Peptide Synthesis, Fundamental Forces that Control Protein Secondary Structure, Protein Domains Have Structural and Functional Roles & Higher Level of Protein Structure, Receptor-Ligand Interaction, A Quantitative View of Enzyme Function, A Mechanistic View of Enzymes that Catalyze Multiple Reactions, Enzymes that Uses Organic Cofactors, Engineering Improved Protein Function, Structure of Carbohydrate Building Blocks, The Chemistry and Enzymology of the Glycosidic Bond, Polysaccharides, Glycoproteins & Glycolipids Glycosylation in the Cytosol, Proteins that Bind to Carbohydrate Ligands, Proteins that Bind to Carbohydrate Ligands, The Claisen Reaction in Polyketide Biosynthesis, The Biosynthesis of Fatty Acid is a Paradigm

for Polyketide Biosynthesis, The Biological Role of Human Polyketide Nonhuman Polyketide Natural Products, Nonribosomal Peptide Synthases & Human Terpenes, Signal Transduction & An Overview of Signal Transduction Pathways in Human Cells, Nuclear Receptors & Receptor Tyrosine Kinase, Cell Surface Receptors that Interact Directly With Transcription Factors, G Protein Coupled Receptors, Ion Channels & Trimeric Death Receptors, Pathways Controlled by Small Diffusible Gas Molecules

Recommended Reading:

This course will use topics from the current literature, and appropriate reference information will be provided to the students.

1. Introduction to Bioorganic Chemistry and Chemical Biology by David Van Vranken and Gregory Weiss, Garland Science, Taylor & Francis Group (Primary Reference)
2. Chemical Biology, A Practical Course: H. Waldmann and P. Janning (2004) 1st edition, Wiley-VCH
3. Chemical Biology: From Small Molecules to Systems Biology and Drug Design: Eds. S.L. Schreiber, T. Kapoor and G. Wess (2007) Volume 2, Wiley-VCH

CHM 432

Solid State Chemistry

3 credits

Introduction: This course is designed to provide the fundamental knowledge of the crystallography, structure and properties. The objective of this course is to lay the foundation for understanding the relationship between the internal structure of matter and the properties of materials that make them attractive for applications. Apart from the familiarity with the routine structure – property correlations, students would be exposed to some of the most recent developments across the spectrum of Solid – State and materials, while at the same time reflecting on key turning points in the evolution of this scientific interdisciplinary course and projecting the knowledge into the directions for future research progress.

Contents: Crystal Structure, Fundamentals of lattice, unit cell, atomic coordinate, Bravais Lattices, Crystal's direction and planes, Symmetry operations, symmetry elements, Point Group, Space group, Crystal Structures, Representation of Crystal Structures, Crystal Diffraction, lattice Vibrations, Electronic Properties and Band theory of solids, metals, insulators and semiconductors, Electronic structure of solids-bond theory, k space and Brillouin zones, Magnetic Properties, Magnetic moment, Curie law, Curie-Weiss law, Mechanism of magnetic ordering, Exchange Interaction, Domain theory, Hysteresis, Anisotropy, Ferromagnetism, Ferrimagnetism, Antiferromagnetism, Classical and Quantum mechanical treatment, Dielectric and Optical Properties, Polarization, Depolarization field, Local electric field at an atom, Ferroelectric domains, Piezoelectricity, Ferroelectricity, Selected examples of materials, structures, properties and applications with respect to structure/property relations, Recent developments,

Thermal Analysis, Thermogravimetric analysis (TGA), differential thermal analysis (DTA) and differential scanning calorimetry, Materials processing and Performances.

Recommended Reading:

1. Basic Solid State Chemistry: A.R. West (1999) 2nd edition, John Wiley & Sons, Ltd
2. Solid State Chemistry and its Applications: A.R. West (1987) John Wiley & Sons, Ltd
3. Solid State Physics: N.W. Ashcroft and N.D. Mermin (2006) 4th edition, CBS Publishing Asia Ltd.
4. Introduction to Solid State Physics: C. Kittel (2005) 8th edition, John Wiley and Sons
5. New Directions in Solid State Chemistry: C.N.R. Rao and J. Gopalakrishnan (1997) 2nd edition, Cambridge University Press
6. Atomic and Electronic Structure of Solids: E. Kaxiras (2003) Cambridge University Press

Prerequisites: Essentials of Physical and Inorganic Chemistry covered during 1st and 2nd semester

CHM 433

Photochemistry

3credits

Introduction: This course will give idea to students how light can take a major role in many natural and chemical processes. Here the students will also get through knowledge about excited state processes (e.g. fluorescence, phosphorescence etc.) and the importance of the above mentioned processes in all fields of science.

Contents: The laws of photochemistry, Primary processes in photochemical reactions, Fluorescence and phosphorescence, Concept of quantum yield, lifetime, anisotropy, Techniques used in measuring fluorescence lifetime, Quenching phenomenon, Electron Transfer Reaction & Marcus Theory, Fluorescence resonance energy transfer (FRET), Concept of Excimer and exciplex, Diffusion controlled rate constants, Flash photolysis, Some typical photochemical reactions: Olefin isomerization, Retinal and Rhodopsin photochemistry of vision, Acid-base chemistry, Reversal of pericyclic selection rules, Woodward-Hoffman rules of electrocyclic reactions, photocycloaddition reactions, UV-DNA damage, breaking aromaticity, Di- π methane rearrangement, oxadi- π -methane rearrangement, Photochemistry of carbonyl compounds, Norrish type I and Norrish type II reactions, Nitrobenzyl photochemistry, Paterno-Buchi reaction, azo compound and diazocompounds, diazirins, azides and photoaffinity labeling, Chemiluminescence and Chemiluminescent reactions, light sticks, photodynamic therapy, photochemistry of transition metal complexes and photosynthesis.

Recommended Reading:

1. Modern Molecular Photochemistry: N.J. Turro (1991) 1st Edition, University Science Books
2. Principles of Fluorescence Spectroscopy: J.R. Lakowicz (2006) 3rd edition, Springer
3. Handbook of Photochemistry: M. Montalti, A. Credi, L. Prodi and M.T. Gandolfi (2006) 3rd edition, CRC Press
4. Modern Physical Organic Chemistry: E.V. Anslyn and D.A. Dougherty (2005) Illustrated edition, University Science Books
5. Synthetic Organic Photochemistry: A.G. Griesbeck and J. Mattay (2004) 1st edition, CRC Press
6. Principles of Molecular Photochemistry: An Introduction: N.J. Turro, J.C. Scaiano and V. Ramamurthy (2008) 1st edition, University Science Books

Prerequisite: Fundamentals of Spectroscopy (CHM 202) / Fundamentals of Molecular Spectroscopy (CHM 323)

CHM 436	Molecular Modelling and Simulation	3 credits
----------------	---	------------------

Introduction: This course will cover various theoretical concepts with hands on Molecular Dynamics simulations experiments. Prior programming experience is desired for writing simulation codes. Students with research interests in computational chemistry are expected to benefit from this course.

Contents: History of Molecular Dynamics simulations, Force-fields, simulation of bulk systems using periodic boundary conditions, minimum image convention, programming of Lennard-Jones potential using generation of system of particles, equations of motions of particles, thermodynamic conditions for simulations using various ensembles, concepts of thermostat and barostat, energy minimization algorithms, Time Correlation Functions: Radial Distribution Functions, Mean Square Displacement, Diffusion coefficients. Hands on Simulations: Molecular Builder, GROMACS Molecular Dynamics Simulations, Molecular Visualization and Data Organization. Analysis and interpretation from simulations will be used for preparation of a research report.

Recommended Reading:

1. Computer Simulations of Liquids: M.P. Allen and D.J. Tildesley (1987) Oxford Science Publications
2. Molecular Modelling: Principles and Applications: A.R. Leach (1997) Addison Wesley Publishing Company
3. Introduction to Computational Chemistry: F. Jensen (2006) 2nd edition, John Wiley & Sons

CHM 441

Advanced Materials Science

3 credits

Introduction: This course would be in two parts. Whist the first part would give an overview of Materials and discuss the structure-property relationships in materials from fundamental perspectives. The second part would introduce you to practical methods and techniques of investigating the properties of these materials for energy applications. Throughout the course there would be sufficient references to state-of-the-art materials and prototypes.

Contents: Overview of Novel Materials, Types of Solids- Metals, Alloys, Insulators, Polymers, Semiconductors, Composites, Liquid Crystals, Quasi Crystals, Defects in Solids – Point, Line and Volume or Bulk Defects, Phase Transformations and Phase Equilibria, Solid Solution, Non-Equilibrium Cooling, Eutectic Systems Properties of Materials- Mechanical, Thermal, Optical and Magnetic. Adsorption Fundamentals, Concepts and Application, Adsorption Kinetics, Chemistry and Physics of Conduction, Primary and Secondary Batteries, Types of Batteries- Charging vs Discharging, Chargeable vs Non-Rechargeable Sources. Physical Limitations of Battery Performance. Solar Cells – Principle, Working and Tuning. Impedance Spectroscopy- Methods for Conductivity Measurements, Electrochemical Kinetics- Butler Volmer Equation, Fick's First Law Of Diffusion, Tafel Equation. Fuel Cells- Design and Measurement, Types of Fuel Cells, Structure of Porous Electrolytes, Electrode Kinetics. Carbon Materials- Nanotubes, Fullerenes, Graphenes as Advanced Functional Materials.

Recommended Reading:

1. Characterization of Porous Solids and Powders: Surface area, Pore Size and Density: S. Lowell, J.E. Shields, M.A. Thomas and M. Thommes (2010) 4th Revised edition, Springer and Kluwer Academic
2. Modern Batteries: C.A. Vincent and B. Scrosati (2003) 2nd edition, Butterworth-Heinemann
3. Grob's Basic Electronics: M.E. Schultz (2007) 10th edition, Tata McGraw-Hill

Prerequisites: Symmetry and Group Theory (CHM 320) and Solid State Chemistry (CHM 432)

CHM 442

Organometallic Chemistry: Principles and Applications

3 credits

Introduction: The main goal of this course is to help the students to learn the principles of organometallic chemistry with emphasis to the understanding of their structure, properties and applications. Organometallic chemistry has served as a bridge between traditional inorganic and organic chemistry and contributed to the development of several important discoveries in synthetic organic chemistry. At the end of this course students will have a thorough understanding of the classification and mechanistic aspects of several organometallic reactions and will be able to identify the role of organometallic complexes in organic synthesis and

industrial applications. This course will be also useful to PhD students working in the area of organic and inorganic chemistry.

Contents: Concepts of structure and bonding: definition, 18 electron rule, classes of ligands, bonding and structural considerations. Fundamental reaction process: oxidative addition and reductive elimination; insertion and elimination; ligand substitution processes, transmetallation, nucleophilic and electrophilic addition and abstraction. Preparative and characterization methods: general methods for the preparation of organometallic compounds and spectroscopic and analytical techniques for the elucidation of structure, properties and reactivities. Synthetic applications: coupling reactions, cyclization reactions, addition reactions, carbonylation, Pauson-Khand reaction, olefin oxidation, carbenes and activation reactions. Industrial applications: hydrogenation, hydroformylation, isomerization, metathesis and polymerization reactions. Bio-organometallics: nitrogen fixation, coenzyme B12, hydrogenase, CO dehydrogenase and methanogenesis.

Recommended Reading:

1. Organometallics: C. Elschenbroich and A. Salzer (1992) 2nd edition, VCH
2. Organometallic Chemistry of the Transition Metals: R.H. Crabtree (2005) 4th edition, Wiley-Interscience
3. Basic Organometallic Chemistry: B.D. Gupta and A.J. Elias (2013) 2nd edition, Universities Press (India)
4. Transition Metals in the Synthesis of Complex Organic Molecules: L. Hegedus and B. Soderberg (2009) 3rd edition, University Science Books

CHM 445

Electrochemistry

3 credits

Introduction: This course deals with the nature of the electrochemical terms and concepts, understanding the nature of electrochemical reactions, kinetics of electrochemical reactions. It also provides an opportunity to plan and perform electrochemical experiments, designing electrochemical cells and modern electrochemical techniques, electrochemical impedance experiments and electric circuits.

Course contents: Electrochemistry Fundamentals, Faraday's laws, Measurement of conductance, theory of electrolytic dissociation, Transport number, degree of dissociation, Activity and activity coefficients of electrolytes, Theories of acids and bases, Common ion effect and solubility product, Mechanism of buffer action, Henderson equation, Acid-base indicators, Galvanic cells, Reversible cells, Reversible electrodes, Thermodynamics of cell reactions. Circuit elements, Capacitors, resistors, inductors, different types of AC circuits, simple capacitor circuit, capacitor resistor circuits, diodes, p-n junction, breakdown voltage, half wave and full wave rectifiers, Transistors, Zener diodes. Electrification of interface, Origin of potential difference across the interface, Accumulation and

depletion regions, Thermodynamics of electrified interface, The structure of electrified interface, Metal/solution & semiconductor solution interfaces, Band bending, Photoelectrochemistry. Electron transfer under an electric field, Butler-Volmer equation, Low potential case/High Potential case, Polarizable and nonpolarizable interface, The equilibrium condition-Nernst's thermodynamic treatment, Symmetry factor and transfer coefficient, Electrode kinetics of semiconductor solution interface, Microelectrodes, lessening diffusion control by microelectrodes and reducing Ohmic errors. Cyclic voltammetry, Impedance spectroscopy concepts and applications, Chrono methods, Scanning Electrochemical Microscopy, Mott-Schottky plot, Determination of flat band potentials and carrier concentration. Corrosion – fundamentals and applications. Electrochemical energy systems, Primary and secondary batteries, fuel cells and electrochemical capacitors, polymer electrolyte membrane fuel cells, solid oxide fuel cells etc. integration of electrochemical energy storage systems with other devices, photo-electrochemical solar cells and conversion of solar energy etc.

Recommended Reading:

1. Modern Electrochemistry, Bockris and Reddy, 2nd edition (Volume 1 to 3), Springer 1998
2. Trends in molecular electrochemistry, Armando and Amatore, 1st Edition, CRC press 2004
3. Electrochemical Methods: Fundamentals and Applications, A. J Bard and L. R Fualkner, 2nd edition, Wiley 2001

CHM 301/302/401/402

Lab Training / Theory Project

3 credits

Introduction: The larger objective of this course is to encourage students to participate in ongoing research at IISER Pune. This may be in the form of a reading/literature review/theoretical or computational project/lab based research project.

Contents: The student has to identify, talk to and mutually agree on a research project before registering for this course. The scope, duration, structure, expectations, and evaluation criteria (also see below) for the course are decided by the project supervisor.

Recommended Reading: As per suggestions of the project supervisor.

MATHEMATICS

Core Courses in the First Two Years of the BS MS Program

Very basic mathematics, by which one means the bare minimum that any scientist should be familiar with, is treated in the following six core courses in the first four semesters: Single Variable Calculus, Multivariable Calculus, Linear Algebra, Probability & Statistics, Introduction to Proofs and Basic Structures of Mathematics.

Philosophy is written in that great book which ever lies before our eyes—I mean our universe—but we cannot understand it if we do not first learn the language and grasp the symbols in which it is written. The Book is written in the mathematical language... without which one wanders in vain through a dark labyrinth. –Galileo Galilei

The Ideology behind the Mathematics Program

The mathematics program at IISER Pune is grouped into five streams: Algebra, Analysis, Geometry & Topology, Discrete Mathematics and Applicable Mathematics. These subjects seamlessly and indistinguishably blend into each other and such a coarse classification is purely for didactic purposes. The courses in the third and fourth year of the BS MS program as well as the courses for the PhD program are all based on this ideology.

Courses in the Third and Fourth Years of the BS MS Program

For each of the above themes, there is a sequence of four courses through the four semesters in the third and fourth years. They are as follows:

1. Algebra: Group Theory; Vector Spaces, Rings and Modules; Galois Theory; Algebraic Number Theory; Commutative Algebra
2. Analysis: Analysis; Complex Analysis; Measure Theory & Integration; Functional Analysis
3. Geometry & Topology: Point Set Topology; Calculus on Manifolds; Algebraic Topology; Differential Geometry
4. Discrete Mathematics: Combinatorics; Graph Theory; Coding Theory; Cryptography; Algorithms
5. Applicable Mathematics: Statistical Inference; Mathematical Biology; Ordinary Differential Equations; Probability; Partial Differential Equations; Stochastic Processes

Suggestions to Students wanting to “Major in Mathematics”

Students wanting to major in Mathematics should choose four out of the above five

sequences and go through all the courses in that sequence for a solid foundation in that theme. All the courses in each of these 5 sequences are for 4 credits. Some examples:

1. A student wanting to focus on what is traditionally called Pure Mathematics could choose Algebra, Analysis, Geometry & Topology, and Discrete Mathematics sequences.
2. A student wanting to focus on what is traditionally called Applied Mathematics could choose Analysis, Geometry & Topology, Discrete Mathematics, and Applicable Mathematics sequences.

The above examples are mere suggestions because the epithets of pure and applied are totally artificial: there is nothing impure about applicable mathematics and much of pure mathematics has evolved out of applications.

Some clusters or prerequisites:

1. Applicable Mathematics sequence needs the Analysis sequence.
2. Geometry & Topology sequence can benefit from the Analysis sequence.
3. Discrete Mathematics sequence can benefit from the Algebra sequence.

For more details about prerequisites see the flowchart below and the individual course descriptions.

The bottom line: Students should choose sequences based on what excites them the most in Mathematics.

Students may take up to one reading project course per semester where they can diversify and explore other subjects within mathematics. Reading projects are all for 3 credits.

Based on students' interests, and available faculty, the course structure has the provision for topics courses. For example, one can have a course on "Representation Theory" under "Topics in Algebra", or a course on "Fourier Analysis" under "Topics in Analysis" in the 7th or 8th semesters. Topics courses will often have certain prerequisites that will be announced by the instructor beforehand. All topics courses are for 3 credits.

Students are also required to take courses from at least two different disciplines in their 5th and 6th semesters (= third year).

Students need a minimum of 84 credits in the third and fourth years. For a student majoring in mathematics, we have for each of the four semesters: $4 \times 4 + 3 = 19$ credits. For four semesters, this adds to 76 credits. The remaining 8 credits may be taken from other disciplines.

Teachers open the door... You enter by yourself – Chinese Proverb

List of Courses in Mathematics

Semester I

1. MTH 100 Introduction to Proofs [2 credits]
2. MTH 101 Single Variable Calculus [3 credits]

Semester II

3. MTH 102 Multivariable Calculus [3 credits]

Semester III

4. MTH 201 Linear Algebra [3 credits]

Semester IV

5. MTH 202 Probability and Statistics [3 credits]
6. MTH 204 Basic Structures of Mathematics [2 credits]

Semester V

7. MTH 310 Group Theory [4 credits]
8. MTH 311 Analysis [4 credits]
9. MTH 312 Point Set Topology [4 credits]
10. MTH 313 Combinatorics [4 credits]
11. MTH 314 Statistical Inference [4 credits]
12. MTH 301 Reading Project [3 credits]

Semester VI

13. MTH 320 Vector Spaces, Rings and Modules [4 credits]
14. MTH 321 Complex Analysis [4 credits]
15. MTH 322 Calculus on Manifolds [4 credits]
16. MTH 323 Graph Theory [4 credits]
17. MTH 324 Mathematical Biology* [4 credits]
18. MTH 328 Coding Theory* [4 credits]
19. MTH 329 Cryptography* [4 credits]
20. MTH 302 Reading Project [3 credits]

Semester VII

21. MTH 410 Galois Theory [4 credits]
22. MTH 411 Measure Theory & Integration [4 credits]
23. MTH 412 Algebraic Topology [4 credits]
24. MTH 413 Algorithms [4 credits]
25. MTH 414 Probability [4 credits]
26. MTH 419 Ordinary Differential Equations [4 credits]
27. MTH 401 Reading Project [3 credits]

Semester VIII

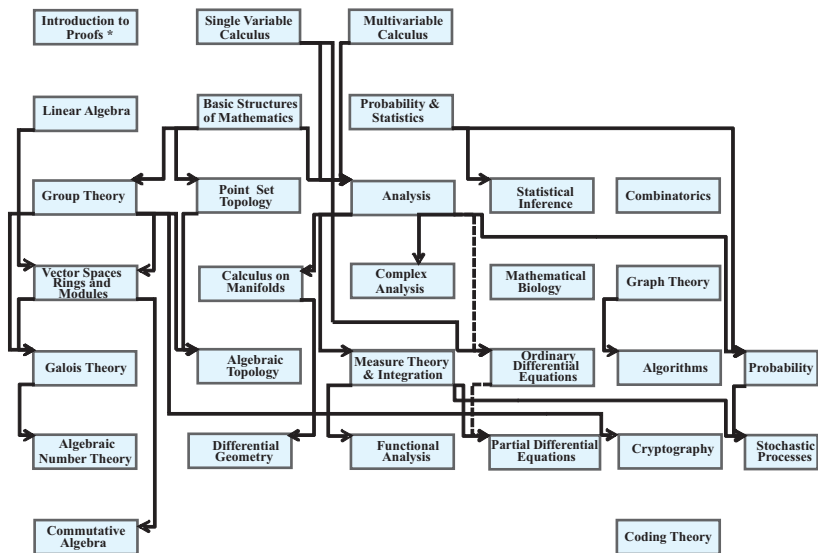
28. MTH 420 Algebraic Number Theory [4 credits]
29. MTH 421 Functional Analysis [4 credits]
30. MTH 422 Differential Geometry [4 credits]
31. MTH 424 Stochastic Processes [4 credits]
32. MTH 425 Commutative Algebra [4 credits]
33. MTH 429 Partial Differential Equations [4 credits]
34. MTH 402 Reading Project [3 credits]

Semester IX-X

MS Thesis

(*): These courses are offered once in every two years.

Flowchart for UG Mathematics Courses



*Introduction to Proofs is needed for all math courses.

Credit System

- **4 credits:** Typically, there will be three lectures a week. Often instructors devote 2 lectures for theory and 1 lecture for tutorial. Students are expected to fill in details of proofs sketched during lectures and will also be expected to solve a lot of exercises.
- **3 credits:** Typically, there will be two lectures a week. In the senior years, these courses require solid background in the prerequisites mentioned for the course. Often students are expected to present proofs or related materials in the class.

Details of Courses in Mathematics

MTH 100	Introduction to Proofs	2 credits
---------	------------------------	-----------

Introduction: This course is meant as a solid first step towards higher mathematics. To deeply understand a body of mathematics, we should know its proofs. This opens up our awareness of the logic underlying the world of mathematics, and brings clarity to our study. In this class we learn the language of mathematical proof and theory building. We survey approaches to proof in different contexts, such as arithmetic, analysis, and geometry, and practice reading and writing in this language. Proof techniques will include proofs by deduction, case analysis, construction, induction, and contradiction.

Contents: Mathematical grammar, elementary logic, truth tables, quantifiers, proof techniques as mentioned in the introduction, theory building, sets, relations, one-to-one and onto functions, inverse functions, strong and weak induction, inductive definitions, natural numbers via Peano arithmetic, divisibility and primes, infinite sets and cardinality.

Recommended Reading:

1. Mathematical Reasoning: Writing and Proof: Ted Sundstrom, (2006) Pearson
2. How to Prove It: A Structured Approach: D.J. Velleman (2006) Cambridge
3. How to Solve It: G. Polya (2004) Princeton University Press
4. How to Read and Do Proofs: D. Solow (2009) Wiley
5. Proof in Mathematics: An Introduction: J. Franklin & A. Daoud (2011) Kew Books
6. What is Mathematics?: R. Courant and H. Robbins (1996) Oxford University Press

MTH 101	Single Variable Calculus	3 credits
---------	--------------------------	-----------

Introduction: This course introduces the basic tools of calculus of functions of one variable. We develop the concepts of continuity, differentiability and integrability together with their geometric and physical meaning. Applications include computing extrema of functions and calculating areas of regions bounded by graphs.

Contents: Properties of real numbers, least upper bound axiom, convergent sequences, limits of functions, continuity, intermediate value theorem, differentiability, product and chain rules, mean value theorem, Taylor's Theorem and Taylor's Expansion, maxima and minima, series, Riemann integration, fundamental theorem of calculus, integration by parts and change of variables, applications to area and volume.

Recommended Reading:

1. Calculus Vol. 1 and 2: T.M. Apostol (2007) Wiley

2. Calculus: M. Spivak (2006) Cambridge
3. Calculus: J. Stewart (2012) Cengage Learning
4. Calculus and Analytic Geometry: G.B. Thomas, R. Finney (1995) Addison-Wesley

MTH 102	Multi Variable Calculus	3 credits
----------------	--------------------------------	------------------

Introduction: This course introduces the basic tools of calculus of functions of several variables. We generalize the notions of continuity, differentiability and integration to functions of several variables and discuss their geometric and physical meaning. We learn the techniques of partial differentiation, integration along curves and surfaces, and indicate a wealth of applications.

Contents: Vectors and 3-dimensional geometry, functions from \mathbb{R}^m to \mathbb{R}^n , derivatives and integrals of vector functions, arclength and curvature of space curves, limits and continuity, partial derivatives, total derivatives, maxima and minima, statement of implicit function theorem. Lagrange multipliers, divergence, curl; iterated integrals, change of variable formula, line integrals, Statement of Green's Theorem, surface integrals, Statement of Stoke's Theorem, Statement of Divergence Theorem. Applications to area and volume.

Recommended Reading:

1. Calculus Vol. 2: T.M. Apostol (2007) Wiley
2. Calculus: J. Stewart (2012) Cengage Learning
3. Calculus and Analytic Geometry: G.B. Thomas, R. Finney (1995) Addison-Wesley

MTH 201	Linear Algebra	3 credits
----------------	-----------------------	------------------

Introduction: The notion of a vector space generalizes our familiar experience of three dimensional space, with its planes and lines, to any dimension. However in higher dimensions our geometric intuition should be supported with the mathematical theory of coordinates. In this course the main objects of study are n -dimensional space, its subspaces, and linear transformations. Our tools are the algebra of matrices and vectors. By introducing the notion of an “inner product”, we may also speak of angles and magnitude in any dimension.

The importance of linear algebra to mathematics cannot be overstated. Along with calculus, linear algebra is one of the two pillars of mathematics, and is fundamental to any student of science.

Contents: Vector Spaces \mathbb{R}^n and \mathbb{C}^n , Matrix operations and systems of linear equations, Gauss-Jordan Elimination, Matrix Inversion, Determinants, Abstract Vector Spaces with Examples, Subspaces, Linear Combinations, Basis and Dimension, Linear Transformations and Geometry, Rank-nullity Theorem, Coordinates and Change of Basis, Inner Product Spaces, Orthogonality and Gram-Schmidt Process, Eigenvalues and Eigenvectors, Diagonalizability, Spectral Theorem for Symmetric Matrices.

Recommended Reading:

1. Linear Algebra: K. Hoffman and R. Kunze (2009) Prentice-Hall
2. Finite Dimensional Vector Spaces: P. Halmos. (2012) Martino Fine Books
3. Introduction to Linear Algebra: G. Strang (2009) Wellesley Cambridge Press
4. Linear Algebra done right: S. Axler (2014) Springer
5. Linear Algebra with applications: Bretscher (2012) Pearson

MTH 202

Probability and Statistics

3 credits

Introduction: This course provides an introduction to probability and statistics with applications. Topics included are basic probability models; random variables; discrete and continuous probability distributions; statistical estimation and testing; confidence intervals.

Contents:

Probability: Random experiments, events, axiomatic definition of probability, equally likely outcomes, conditional probability, independence, Bayes' theorem, random variables, Cumulative distribution function, some standard discrete and continuous variables, mathematical expectation, variance, moments, moment generating function, Chebyshev's inequality, functions of a random variable, their distributions and moments, joint, marginal and conditional distributions, independence of random variables, correlation coefficients, Law of large numbers, Central Limit Theorem, sampling distributions.

Estimation: Organization of data or exploratory data analysis, unbiased estimators with examples, Cramer-Rao bound, maximum likelihood and method of moments, properties of best estimates, confidence intervals for means with known and unknown variance in the normal case.

Recommended Reading:

1. A First Course in Probability: S. Ross (2012) Pearson
2. Introduction to Probability and Statistics: V. Rohtagi and A.K. Saleh (2000) Wiley-Interscience
3. Probability and Statistical Inference: Hogg, Tanis and Rao (2007) Pearson Education

MTH 204

Basic Structures of Mathematics

2 credits

Introduction: This course offers a preview of some fundamental concepts in higher mathematics. Group theory describes the symmetries of objects. A metric gives a notion of distance on a set. Banach and Hilbert space theory allows for convergent series in an infinite-dimensional vector space. These three concepts are illustrated with examples and application. This course complements MTH 100, focusing on ideas rather than proofs.

Contents: Groups: classical linear groups, permutation groups, rigid transformations, groups of symmetries of geometric objects, definition of an abstract group, subgroups and Lagrange's theorem, special unitary group $SU(2)$, special linear groups $SL(2, R)$.

Metric spaces: Definition and basic properties, some examples, closed sets, open sets, continuity, sequences in a metric space. Ideas of compactness, completeness, and connectedness.

Hilbert spaces: Definition of a Banach space, examples, shapes of unit balls under various norms, operators on Banach spaces, Hilbert spaces, orthonormal basis, some classical inequalities (Bessel, Cauchy-Schwartz), the dual space, example of $L^2(S^1)$, adjoint of an operator, self-adjoint operator, statement of spectral theorem.

Recommended Reading:

1. Algebra: M. Artin (1991) Prentice Hall.
2. Introduction to Topology and Modern Analysis: G. Simmons (2003) Krieger
3. Analysis I & II: T. Tao, TRIM series (2006) Hindustan Book Agency

MTH 310

Group Theory

4 credits

Introduction: Groups are collections of symmetries of objects. They are encountered throughout mathematics, for instance in polyhedra, wallpaper patterns, and the irrational roots of polynomials. In this course we introduce abstract groups; that is we study the symmetries without the objects. The emphasis will both be on finite groups, for which cardinality plays a decisive role, and on matrix groups, governed by linear algebra. The notion of a group is one of the basic structures in mathematics, and worthy of study for every scholar. A chemist will later study the linear actions of finite groups, and a physicist will later study those of Lie groups. For mathematicians, group theory is a basic component of their vocabulary.

Contents: Definition of groups, homomorphisms, subgroups, normal subgroups and quotient groups, Lagrange's theorem, examples: cyclic groups, symmetric groups, alternating groups,

Symmetries of geometric objects like regular polyhedra (cubes, tetrahedron etc.), General linear groups and isometry groups, simple groups, group actions, Cayley's theorem, class equation, Sylow theorems, direct and semi-direct products, structure theorem for finite Abelian groups.

Recommended Reading:

1. Abstract Algebra: D.S. Dummit and R.M. Foote (2003) Wiley
2. Topics in Algebra: I.N. Herstein (1975) Wiley
3. Algebra: M. Artin (1991) Prentice Hall

4. Problems in Group Theory: John Dixon (2007) Dover Publications
5. Group Theory Selected Problems: B. Sury (2004) University Press
6. Groups and Symmetry: Armstrong (1987) UTM Springer
7. An Introduction to the Theory of Groups: Rotman (1994) Springer
8. Symmetries: Johnson (2004) SUMS Springer

Prerequisites: None

MTH 311	Analysis	4 credits
----------------	-----------------	------------------

Introduction: A serious student of mathematics must master the epsilon-delta language of “limits”. Familiar ideas from calculus, such as continuity, series, derivatives, and integrals are all describable in terms of limits. In this course we strengthen our analytic technique to the point where we can blend these ideas gracefully. Full proofs are the norm in this course. MTH 311 is very much a prerequisite for courses in the analysis, topology, and applicable math streams; it is also strongly recommended for students pursuing theoretical physics.

Contents: Real Numbers, least upper bound property, sequences, convergence, suprema and infima, Bolzano-Weierstrass theorem, limsup, liminf, limit points, subsequences, Infinite series, rearrangement of series, tests for convergence, Functions on \mathbb{R} , continuous functions, intermediate value theorem, Heine Borel Theorem, uniform continuity, Differentiation on \mathbb{R}^n , definition of total derivative, L'Hospital rule, local maxima and minima, inverse function theorem, implicit function theorem, Riemann integration, basic properties, Riemann integrability of continuous functions, fundamental theorem of Calculus. Point-wise and uniform convergence of sequences of functions, uniform convergence and continuity, Weierstrass approximation theorem, Uniform convergence of series of functions, Weierstrass M-test, convergence of integrals and derivatives of sequences of functions, Introduction to power series and analyticity.

Recommended Reading:

1. Analysis I & II: T. Tao, TRIM Series (2006) Hindustan Book Agency
2. Principles of Mathematical Analysis: W. Rudin (1976) Tata McGraw Hill
3. Mathematical Analysis: T.M. Apostol (1974) Addison-Wesley
4. Introduction to Real Analysis: R. G. Bartle and D. R. Sherbert (2011) Wiley
5. Methods of Real Analysis: Goldberg (1976) Wiley

Prerequisites: None

MTH 312	Point Set Topology	4 credits
----------------	---------------------------	------------------

Introduction: Topology, along with Algebra and Analysis, is one of three foundational areas of pure mathematics. Roughly speaking, Topology can be

thought of as 'rubber-sheet geometry'. Whereas Euclidean notions of lengths between points and angles between lines do not make much sense on a stretchable sheet of rubber, some properties such as that of having a hole in the rubber sheet do not change under any amount of stretching or deformation. Topology is the study of those properties which are invariant under such deformations. It is useful and enriching for all students of science.

Contents: Metric spaces, topological spaces, continuous functions, product topology, quotient topology, compactness, Heine-Borel theorem, Tychonoff's theorem, connectedness and path connectedness, separation axioms such as Hausdorff, normal and regular, Urysohn's Lemma, Urysohn's metrization theorem, Tietze's extension theorem, paracompactness, partition of unity, introduction to CW-complexes.

Recommended Reading:

1. Topology: J. Munkres (2000) Prentice Hall
2. Basic Topology: Armstrong (2004) UTM Springer
3. Introduction to Topology and Modern Analysis: G. Simmons (2004) Tata McGraw Hill

Prerequisites: None

MTH313

Combinatorics

4 credits

Introduction: Combinatorics is concerned with arrangements of the objects of a set into patterns satisfying specified rules. Two general types of problems which occur repeatedly are the existence and enumeration of the arrangements. The idea and techniques of combinatorics are used not only in the traditional area of mathematical application but also in the biological sciences, information theory, computer science, physical sciences and so on.

Contents: Permutations and combinations of multisets, Set partitions, Bell, Catalan, and Stirling numbers, The Pigeonhole Principle (strong form), The Inclusion and Exclusion Method and applications, Mobius Inversion, Recurrence Relations and (Exponential) Generating Functions, Burnside's Lemma, Polya's Counting Theorem; Partial ordered sets, Chains, Lattices; Combinatorial Designs: Block designs, Steiner triple systems, Latin squares; Codes and Designs. Symmetric functions, Ferrers diagrams.

Recommended Reading:

1. Introductory Combinatorics: R. Brualdi (2009) Prentice Hall
2. Combinatorics: P. Cameron (1994) Cambridge
3. Enumerative Combinatorics: R. Stanley (2012) Cambridge
4. A Course in Combinatorics: J. H. van Lint, R. M. Wilson (2001) Cambridge
5. Generating functionality: H. Wilf (2005) A K Peters/CRC Press

6. Combinatorics: Russell Merris (2003) Wiley-Interscience
7. A First Course in Graph Theory and Combinatorics: S. M. Cioaba, M. Ram Murty (2009) Hindustan Book Agency

Prerequisites: None

MTH 314	Statistical Inference	4 credits
---------	-----------------------	-----------

Introduction: The course covers the mathematical development and application of various statistical techniques that are useful in drawing conclusions about a population, based on information obtained from a sample. It is useful for a student wishing to pursue advanced mathematical statistics as well as for a student wishing to analyze commonly collected experimental data in a scientific manner.

Contents: Reduction of data, sufficient statistics, minimal sufficient statistics, Neyman factorization theorem, complete statistics, exponential families. Ancillary statistics, Basu's theorem. Estimation of real and vector parameters. Method of moments and maximum likelihood, Bayes' estimation. Methods of evaluating estimators, Cramer-Rao Inequality, Fisher Information, Rao-Blackwell theorem, Lehmann-Scheffe theorem. Testing of hypotheses, likelihood Ratio tests, Bayesian tests, error probabilities, P-values, power function, most powerful tests, Neyman-Pearson lemma, uniformly most powerful tests, monotone likelihood ratio. Confidence intervals, construction of confidence intervals, one-sided confidence intervals and their relation with UMP tests, pivotal quantities, Bayesian intervals. One and two way analysis of variance, F statistics and their null distributions.

Recommended Reading:

1. Statistical Inference: George Casella, R. L. Berger (2002) Cengage Learning
2. All of Statistics, A Concise Course in Statistical Inference (Springer Texts in Statistics): Larry Wasserman (2004) Springer
3. Linear Statistical Inference and its Applications: C. R. Rao (2001) Wiley
4. Parametric Inference: B. K. Kale (1999) Narosa
5. An Introduction to Probability and Statistics: V. K. Rohatgi, A. K. Md. Saleh (2000) Wiley

Prerequisites: None

MTH 320	Vector Spaces, Rings and Modules	4 credits
---------	----------------------------------	-----------

Introduction: One of the greatest analogies in mathematics is that between integers and polynomials. Both have a rich theory of divisibility, with a Euclidean algorithm and factorization into primes. It is always fruitful to find analogies between the two. The proper context, which generalizes both integers and polynomials, is "ring theory", which we begin in this course. This leads to module

theory, a generalization of vector space theory in which the “scalars” may be elements of a given ring.

A study of modules over the ring Z leads to a classification of finite commutative groups, and relationships between lattices. The analogous study of modules over rings of polynomials brings a deeper mastery of linear algebra than in a first course. We find invariants of a matrix under similarity, in particular the Jordan canonical forms.

In this way, this course is considered a second course in linear algebra, and is therefore invaluable for any serious student of mathematics.

Contents: Vector spaces, linear maps, matrices, characteristic polynomial, minimal polynomial. Commutative rings, homomorphisms, ideals and quotient rings, prime ideals, maximal ideals, integral domains, fields. Chinese Remainder Theorem, Unique factorization domain, Principal ideal domains (PIDs), Modules over commutative rings, submodules, quotient modules, direct sum and tensor products, free modules, structure theory for modules over a PID, invariant factors and elementary divisors for modules over a PID, Jordan canonical forms & Rational canonical forms.

Recommended Reading:

1. University Algebra: N.S. Gopalkrishnan (1986) New Age International
2. Abstract Algebra: Dummit and Foote (2003) Wiley India
3. Algebra: M. Artin (1991) Prentice Hall
4. Algebra: T.W Hungerford (2003) GTM Springer
5. Further Linear Algebra: Blyth and Robertson (2000) SUMS Springer
6. Advanced Linear Algebra: Roman (2008) GTM Springer
7. Finitely Generated Abelian Groups and Similarity of Matrices over a Field: Norman (2012) SUMS Springer

Prerequisites: Group Theory (MTH 310)

MTH 321

Complex Analysis

4 credits

Introduction: Consider a complex-valued function f of one complex variable. If f is complex-differentiable, an analytic condition, then it is locally expressed by convergent power series. Moreover its line integral about a loop in its domain vanishes. These equivalent conditions thus blend topology, analysis, and algebra in the beautiful realm of complex analysis, one of the great stories of mathematics. Its scope of application cannot be overestimated, finding use throughout pure and applied mathematics.

Contents: Complex differentiation, Cauchy-Riemann equations, power series, exponential and logarithms. Complex line integrals, Cauchy's theorem on a triangle, Cauchy's integral formula, power series representations, Morera's

theorem, Schwarz reflection principle. Zeros of an analytic function, singularities, Residue theorem, argument principle, homotopy version of Cauchy's theorem. Conformal mappings, linear fractional transformations, maximum modulus principle, Schwarz lemma, automorphisms of the unit disc, Montel's theorem, Riemann mapping theorem.

Recommended Reading:

1. Function Theory of One Complex Variable: R.E. Greene and S.G. Krantz (2006) AMS
2. Complex Analysis: L. Ahlfors (1979) McGraw Hill
3. Functions of One Complex Variable I: J.B. Conway (1978) GTM Springer
4. Complex Analysis (Princeton Lectures in Analysis): E.M. Stein, R. Shakarchi (2003) Princeton University Press
5. Complex Function Theory: Donald Sarason (2007) AMS

Prerequisites: Analysis (MTH 311)

MTH 322	Calculus on Manifolds	4 credits
----------------	------------------------------	------------------

Introduction: In calculus we found that many important phenomena in the geometry of \mathbb{R} , \mathbb{R}^2 , \mathbb{R}^3 , occur “locally”, that is in small neighborhoods of points. But there are other topological spaces, such as the circle, the sphere, etc. which “locally” look like \mathbb{R} , \mathbb{R}^2 ,... These are manifolds, and on such objects one may generalize familiar concepts from multivariable calculus. This course will lead students through these ideas, up to a very general version of the famous Stokes' theorem.

This course is particularly important for students of geometry and theoretical physics.

Contents: Directional derivatives, Derivative as a linear map, Inverse and implicit function theorems, Immersions, Submersions, Statement of Sard's Theorem, Integrable functions, Fubini's Theorem, Partitions of Unity, Change of variables, vector fields, differential forms in \mathbb{R}^n , Stokes' theorem in \mathbb{R}^n , submanifolds of \mathbb{R}^n , Tensor fields and differential forms for submanifolds, Stokes' theorem on submanifolds.

Recommended Reading:

1. Calculus on Manifolds: M. Spivak (1998) Westview Press
2. Analysis on Manifolds: J. R. Munkres (1991) Westview Press
3. Topology From the Differentiable Viewpoint: J. Milnor (1997) Princeton University Press

Prerequisites: Analysis (MTH 311)

MTH 323

Graph Theory

4 credits

Introduction: This course is an introduction to the theory of graphs intended for students of mathematics and other sciences. The course introduces in an elementary way some basic knowledge and primary methods in Graph Theory. We start from basic definitions and examples, but hope to move on quickly and cover a broad range of topics.

Contents: The Basics: graphs, paths and cycles, connectivity, trees and forests, bipartite graphs, contraction and minors, Euler tours, Hamilton Cycle. Matching and Covers: Maximum bipartite matching algorithms, Konig's Theorem, Independent Set. Cuts and Connectivity: 2-connected Graphs, Menger's theorem; Network Flow: Max-flow Min-cut and the Ford-Fulkerson algorithm. Planar Graphs: drawing, Euler's formula, Kuratowski's theorem, plane duality. Coloring: coloring maps and planar graphs, coloring vertices, coloring edges. Cayley graph, Spectrum of a graph.

Recommended Reading:

1. Introduction to Graph Theory: D.B. West (1996) Prentice Hall
2. Graph Theory: F. Harary (1969) Addison-Wesley
3. Modern Graph Theory: B. Bollobas (2008) Springer
4. Graph Theory: R. Diestel (2006) Springer
5. Graphs: C. Berge (1989) North-Holland
6. Graph Theory and its Applications: J.L. Gross and J. Yellen (2006) CRC Press
7. A First Course in Graph Theory and Combinatorics: S. M. Cioaba, M. Ram Murty (2009) Hindustan Book Agency

Prerequisites: None

MTH 324

Mathematical Biology

4 credits

Introduction: This course is an introduction to modeling biological processes and systems. Classical examples, such as from neuroscience and other topics in physiology, will be used to examine various methods and techniques that are frequently useful. This course will be interesting to applied math students looking to understand how mathematics is useful in biology, and modeling in general. It is now well-recognized that quantitative methods are profoundly important to solving biological problems of the present century; biology students will learn to appreciate how quantitative methods improve understanding of experimental data, and in some cases are indispensable.

Contents: Classical examples will be drawn from the literature that best illustrate the seamless integration of mathematics and biology, such as modeling in neuroscience (the classification of spiking activity based on different bifurcation scenarios), enzyme kinetics (slow-fast analysis and the Michaelis Menten

equations), cell cycle modelling, and others.

Recommended Reading:

1. Dynamic Models in Biology: S.P. Ellener and J. Guckenheimer (2006) Princeton University Press
2. Mathematical Physiology: J. Keener and J. Sneyd (2008) Springer
3. Theoretical Neuroscience: P. Dayan and L. Abbott (2005) MIT Press
4. Mathematical Models in Biology: L. Edelstein-Keshet (2005) Random House

Prerequisites: None

MTH 328	Coding Theory	4 credits
----------------	----------------------	------------------

Introduction: Error-correcting codes are the main systems used to ensure the high degree of reliability required in modern data transmission and storage systems. This course introduces the mathematical theory of error-correcting codes. We will also explore the connections of this subject to other areas of mathematics such as the theory of finite fields, combinatorics, group theory, projective and algebraic geometry.

Contents: Introduction: Need for coding theory. Linear codes: Basic definitions, properties and problems. Basic theory of Finite Fields. The projective geometric point of view of linear codes. The MacWilliams identity and Weight enumerators. Construction and properties of special codes and families of codes like MDS codes and Reed Solomon codes. Structure of finite fields in more detail. A flavour of Algebraic Geometry codes.

Recommended Reading:

1. Fundamentals of Error-Correcting Codes: C. Huffman and V. Pless (2010) Cambridge
2. Introduction to Coding Theory: Ron Roth (2006) Cambridge
3. The Theory of Error-Correcting Codes (North-Holland Mathematical Library): MacWilliams and Sloane (1977) North Holland Publishing Co.

Prerequisites: None

MTH 329	Cryptography	4 credits
----------------	---------------------	------------------

Introduction: Cryptography, especially public key cryptography, is extremely important in modern society. It serves us with the required tools for online transactions and trading, i.e., online commerce. Online commerce is the call of our day and is considered as one of the foundations of a modern civilization. It is the tool that makes it possible for a farmer in a remote village to sell his produce to the city, avoiding the middleman. This course teaches you the mathematical aspects of cryptography. Mathematical aspects of cryptography can be broadly divided into two distinct streams: one, the private key cryptography and, the other, public key

cryptography. This course will try to introduce a student to these two aspects. However the instructor will have leeway in choosing the topics.

Contents: Private key cryptography: DES, differential and linear cryptanalysis, AES. Public Key Cryptography: RSA, Rabin's cryptosystem, discrete logarithm problem, difference between the discrete logarithm problem in the group of rational points of an elliptic curve with that of the group of units of a finite field, protocols using the discrete logarithm problem like the El Gamal cryptosystem and the Diffie-Hellman key exchange. Attacks on RSA, like the factoring algorithms. Attacks on the discrete logarithm problem, like Pollard's rho algorithm and other square-root algorithms. Sub-exponential attacks like the number field sieve and its variants in solving the discrete logarithm problem in finite fields. MOV attack and pairing based cryptosystems.

Recommended Reading:

1. An Introduction to Mathematical Cryptography: J. Hoffstein, J. Pipher and J.H. Silverman (2008) UTM Springer
2. A Course in Number theory and Cryptography: N. Koblitz (1994) Springer
3. Cryptography: Theory and Practice: D.R. Stinson (2005) Chapman and Hall/CRC

Prerequisites: Group Theory (MTH 310)

MTH 410

Galois Theory

4 credits

Introduction: Galois theory arose from the study of “adjoining” roots of polynomials to the rational numbers to generate larger number sets, such as the Gaussian numbers. These larger fields of numbers enjoy the group of symmetries of the irrational roots of these polynomials, which is called the Galois group. Such fields correspond inversely to their Galois groups in a beautiful correspondence beloved to algebraists. A clear understanding of Galois theory allows one to settle classical questions such as whether we can or cannot use radicals to express the roots of various polynomials. It is also prerequisite to modern questions in number theory and algebraic geometry.

Contents: Fields and extensions, examples, algebraic extensions and algebraic elements, transcendental elements, existence of algebraic closure, separable extensions, normal extensions, automorphisms, main theorem of Galois theory, finite fields, Galois groups of finite fields, cyclotomic extensions, impossibility of solving polynomial equations of degree 5 or more by radicals.

Recommended Reading:

1. Abstract Algebra: Dummit and Foote (2003) Wiley India
2. Galois Theory: I. Stewart (2003) Chapman Hall/CRC Math. Series
3. Algebra: S. Lang (2005) GTM Springer
4. Field and Galois Theory: Patrick Morandi (2011) GTM Springer

5. Galois Theory (lectures delivered at the University of Notre Dame): E. Artin (1997) Dover
6. Galois Theory: Edwards (1984) Springer
7. Field Theory: Roman (2006) Springer
8. Galois Theory of Algebraic Equations: J.P. Tignol (2001) World Scientific
9. Lectures on the Algebraic Theory of Fields: K.G. Ramanathan, TIFR Lecture notes (available online)
10. Galois Theory: Murthy, Ramanathan, Seshadry, Shukla and Sridharan, TIFR Pamphlets (available online)

Prerequisites: Group Theory (MTH 310), Vector Spaces, Rings and Modules (MTH 320)

MTH411	Measure Theory & Integration	4 credits
--------	------------------------------	-----------

Introduction: Measure theory is a generalization of the theory of volumes, one which is reconciled with the subtleties of analysis. Sets which are negligible for the purposes of integration have “measure zero”, and it is central to determine which these are. For instance, sets of rational numbers, and the Cantor set have measure 0, but the set of *irrational* real numbers has infinite measure.

The theory of integration is central to analysis, being a method to assimilate quantities. Delicate problems with integrals, such as those arising in Fourier series, require more sophistication than Riemann's naive integral. The Lebesgue integral focuses attention on the domain of a function, and defines the integral in terms of measures of subsets of that domain. The Lebesgue theory is now standard, and gives a robust way to handle limits of integrals.

In particular this course introduces the famous “ L^2 ”-spaces comprised of square-integrable functions. This is the basic example of a Hilbert space, spaces which are studied more thoroughly in Functional Analysis. Many concepts in probability theory may be expressed in terms of measure theory, so this course is also prerequisite for Stochastic Processes.

Contents: Lebesgue Integration: Algebra and σ -algebra of sets, Lebesgue measure, real valued measurable functions of a real variable, existence of a non-measurable sets, nowhere dense sets with positive measure, Cantor sets, Integrability, Littlewood's three principles, Monotone and Dominated convergence theorems, Fatou's lemma, Vitali convergence theorem, Egorov's theorem and Lusin's theorem, functions of bounded variation, change of variable, Jensen's Inequality, General Measure & Integration theory: Definition and examples of general measures, integration of measurable functions, absolute continuity of measures, Radon-Nikodym theorem, outer measure, the extension theorem, L^p spaces, Hölder's inequality, Minkowski's inequality, convolution, differentiation of measures, monotone class lemma, product measure and Fubini's theorem.

Recommended Reading:

1. Real Analysis: H. L. Royden (1997) Prentice-Hall
2. Measure Theory: V. L. Bogachev (2006) Springer
3. Measure Theory: K. B. Athreya & S. N. Lahiri (2006) TRIM Hindustan Book Agency
4. Real Analysis: Measure Theory, Integration and Hilbert Spaces: E. M. Stein & R. Shakarchi (2005) Princeton University Press
5. Real and Complex Analysis: W. Rudin (2006) McGraw Hill

Prerequisites: Analysis (MTH 311)

MTH 412	Algebraic Topology	4 credits
---------	--------------------	-----------

Introduction: It is possible to detect “holes” in a topological space in the following manner. You trace out a path with some string, but make it a closed path, meaning it starts and ends at the same point. (All of this must happen within the space.) If you can contract the string to a point, then you have not found any hole, but if you cannot, then that says something about your space. For instance, on a sphere you can contract any closed path, but on a torus, or on a “punctured plane” you can detect such holes.

The fundamental group of a topological space is a group obtained by manipulating such paths. Moreover a continuous map between topological spaces corresponds to a homomorphism between groups. In this way, one can transform questions in topology into questions in algebra.

In this same spirit, the abelian groups of “homology” quantify how simplices fit together in your space, and can also be used to apply algebra to the world of topology.

Contents: Paths and homotopy, fundamental groups, fundamental group of a circle, free groups and free products, Van Kampen Theorem, application to CW complexes, covering spaces, lifting criteria, deck transformations, Introduction to homology theory, definition of singular homology, Hurewicz isomorphism, Axioms of homology, homology groups of spheres, Applications of homology: Brouwer fixed point theorem, Invariance of domain theorem.

Recommended Reading:

1. Algebraic Topology: Allen Hatcher (2002) Cambridge
2. Topology: J. Munkres (2000) Prentice Hall
3. Elements of Algebraic Topology: J. Munkres (1996) Westview Press
4. Topology and Geometry: G. Bredon (1995) GTM Springer
5. Algebraic Topology: Spanier (1996) Springer

Prerequisites: Point Set Topology (MTH 312), Group Theory (MTH 310)

MTH413**Algorithms****4 credits**

Introduction: This course covers the core material of algorithms and computational complexity. The subject matter is essential for all students wishing to continue in computer science or discrete mathematics. It is moreover suitable for all mathematics students since computational questions are ubiquitous throughout pure and applied mathematics.

Contents: Asymptotic order of growth: big O notation and its relatives. Data structures: Priority queues, heaps, queues, stacks, Union-Find. Basic Graph Algorithms: breadth first search, depth first search, DAGs (directed acyclic graphs) and topological ordering, strongly connected components. Greedy Algorithms: interval scheduling, Dijkstra's algorithm for finding shortest paths in a graph, minimum spanning trees, Huffman codes for data compression. Divide and Conquer and Recurrences: The master theorem, application to the complexity of recursive algorithms, example of an algorithm with running time $O(n^{\{1.59\}})$.

Recommended Reading:

1. Algorithm Design: J. Kleinberg and E. Tardos (2006) Pearson Education
2. Introduction to Algorithms: H. Cormen, C.E. Leiserson and R.L. Rivest (2009) MIT Press
3. Design and Analysis of Algorithms: A.V. Aho, J.E. Hopcroft and J.D. Ullman (1975) Addison-Wesley
4. Fundamentals of Computer Algorithms: E. Horowitz and S. Sahni (1999) Galgotia Publishers
5. Algorithms and Data Structures: K. Mehlhorn and P. Sanders (2008) Springer
6. Combinatorial Optimization: Algorithms and Complexity: C.H. Papadimitriou and K. Steiglitz (1982) Prentice Hall

Prerequisites: Graph Theory (MTH 323)

MTH414**Probability****4 credits**

Introduction: This course gives an introduction to probability theory. The goal of this course is to start with some basic notions in probability and then move to important topics like Martingales, Markov chain etc. The topics included in this course are essential for those who are interested in advanced probability theory, mathematical finance, mathematical biology, time series analysis etc.

Contents: The Probability Space, Events, properties of probability measures, independence, Bayes' formula, Kolmogorov 0-1 law. Random variable, distribution functions, examples of discrete and continuous distributions, joint distributions, independence of random variables, Borel-Cantelli lemmas. Limit theorems: Weak/Strong Law of Large numbers, Central limit theorem. Conditional probability, Martingales, Stopping time, Azuma's inequality, Doob's inequality. Discrete time discrete space Markov chain, Chapman-Kolmogorov equation,

classification of states, and limit theorems.

Recommended Reading:

1. Introduction to Probability Models: S. M. Ross (2014) Academic Press
2. Introduction to the Theory of Probability and its Applications, Vol. 1: W. Feller (2008) Wiley
3. Introduction to Stochastic Processes: P. G. Hoel, S. C. Port and C.J. Stone (1986) Waveland Press Inc.
4. Probability: A Graduate Course (Springer Texts in Statistics): A. Gut (2010) Springer

Prerequisites: Analysis (MTH 311)

MTH 419	Ordinary Differential Equations	4 credits
----------------	--	------------------

Introduction: The laws of physics are written in differential equations, providing an eternal challenge for mathematicians. In this course we consider ordinary differential equations (ODEs), those only depending on one parameter (time). Students are likely to have seen methods for producing explicit solutions for sanitized classes of ODEs, particularly linear ones with constant coefficients. But nature usually gives differential equations for which we do not have explicit solutions. One nonetheless has a robust theory which qualitatively describes the behavior of common ODEs. We will analytically prove existence, uniqueness, and stability, and rigorously discuss the dynamic behavior of solutions to ODEs (meaning their long-term evolution).

All of this demands mathematical sophistication on the part of the student. We highly recommend that the student has taken a course like Analysis (MTH 311), but this is not a formal prerequisite.

Contents: Brief review of methods in solving common ODEs. Higher order constant coefficient linear ODEs, matrix exponentials and the Linearity Principle, Wronskian theory, inhomogeneous systems, Sturm-Liouville theory, phase plane analysis, stable, unstable and center subspaces, stability, asymptotic stability. Non-autonomous Linear Systems. Non-linear Systems: Dynamical Systems, local existence and uniqueness, Peano's Theorem, Gronwall's Inequality: Continuous dependence of solutions, Contraction mappings, Picard approximations, Extending Solutions, the maximal interval of existence, global existence theorem, Differentiability of the flow. Linearization, The Stable Manifold Theorem, The Hartman-Grobman Theorem, Stability and Lyapunov functions, Introduction to the Poincare map, Statement of the Poincare-Bendixson Theory.

Recommended Reading:

1. An Introduction to Ordinary Differential Equations, Dover Books on Mathematics: E. Coddington (1990) Dover
2. Differential Equations and Dynamical Systems: L. Perko (2010) Springer
3. Differential Equations with Applications and Historic Notes,

- International Series in Pure and Applied Mathematics: George F. Simmons (1991) McGraw Hill
4. Differential Equations, Dynamical Systems, and an Introduction to Chaos: Hirsch, Smale and Devaney (2004) Elsevier Academic Press
 5. Theory of Ordinary Differential Equations: Coddington and Levinson (1987) Tata McGraw Hill
 6. Geometrical Methods in the Theory of Ordinary Differential Equations: V.I. Arnold (1988) Springer Science and Business Media

Prerequisites: None, but see the Introduction

MTH 420

Algebraic Number Theory

4 credits

Introduction: Algebraic number theory is a major branch of number theory where one studies various algebraic properties related to algebraic integers. The ring of algebraic integers O in an algebraic number field K is the basic object in algebraic number theory. This course aims at the discussion of algebraic properties of O such as factorization, the behavior of ideals, and field extensions. The usual properties of the integers such as unique factorization need not hold in this general setting. This course is essential for a student studying branches of modern mathematics such as modular forms, arithmetic geometry, automorphic forms and analytic theory of L- functions.

Contents: Algebraic numbers and algebraic integers: definitions and basic properties, Dedekind domains, prime ideals, ideal factorization, ramification index and inertial degree, Decomposition groups and inertia groups, proof of the law of quadratic reciprocity using number fields, finiteness of class groups, Dirichlet's Unit Theorem, Riemann and Dedekind zeta functions, class number formula, Dirichlet L-functions.

Recommended Reading:

1. Number Fields: Marcus (1995) Springer
2. Problems in Algebraic Number Theory: Esmonde, Ram Murthy (2005) Springer
3. Algebraic Number Theory: J.W.S. Cassels and A. Frohlich (1993) Academic Press
4. Algebraic Number Theory: Lang (1984) Springer
5. Algebraic Number Theory: Neukirch (1999) Springer
6. Algebraic Number Fields: Janusz (1996) AMS
7. Algebraic Number Theory and Fermat's Last Theorem: I. Stewart and D. Tall (2001) AK Peters
8. Algebraic Number Theory: Narasimhan, Raghavan, Rangachari and Lal, TIFR Pamphlets (available online)
9. Algebraic Number Theory: J. Milne (available online)

Prerequisites: Galois Theory (MTH 410)

MTH 421

Functional Analysis

4 credits

Introduction: Pure linear algebra does not itself suffice in the study of infinite-dimensional vector spaces.

Linear combinations are typically replaced with infinite series or integrals of vectors. To make sense of such series or integrals, one can use an inner product or norm, leading to the theory of Hilbert spaces or Banach spaces. Functional analysis thus investigates this interplay between analysis and linear algebra. One major discovery is that many important operators between these spaces have a theory of eigenvectors akin to that of symmetric matrices. This course especially finds application in the representation theory of Lie groups and in mathematical physics.

Contents: Normed linear spaces: Definition and examples, bounded linear operators, Hahn-Banach theorem, Banach spaces, Definition and examples, L^p spaces, Arzela-Ascoli theorem, uniform boundedness principle, open mapping theorem, closed graph theorem, quotient spaces, projections, dual spaces, weak and weak* convergence, reflexivity, compact operators, spectrum of compact operators, Hilbert spaces: Definition and examples, geometry of Hilbert spaces, orthonormal sets, orthogonal projections, Riesz representation theorem, Spectral theory: Adjoint of an operator, unitary operators, normal operators, spectral theorem for compact self-adjoint operators.

Recommended Reading:

1. Functional Analysis: B. V. Limaye (1996) New Age International Publishers
2. Real and Complex Analysis: W. Rudin (2006) McGraw Hill
3. Notes on Functional Analysis: R. Bhatia (2009) Hindustan Book Agency
4. Introduction to Topology and Modern Analysis: G.F. Simmons (2003) Krieger
5. A Course in Functional Analysis: J. Conway (1990) GTM Springer
6. Introductory Functional Analysis with Applications: E. Kreyszig (1989) Wiley
7. Essential Results of Functional Analysis: R. Zimmer (1990) Chicago University Press
8. Functional Analysis, Sobolev Spaces and Partial Differential Equations: H. Brezis (2010) Springer

Prerequisites: Measure Theory & Integration (MTH 411)

MTH 422

Differential Geometry

4 credits

Introduction: This capstone class in geometry completes the treatment of manifolds from MTH 327, and continues into the deeper terrain of Riemannian Geometry and Lie Theory. A manifold M is called “Riemannian” once it is endowed with a (locally defined) metric. This Riemannian metric can be used to define the geometry of lengths and area on submanifolds of M , and moreover

notions of geodesics, curvature and parallel transport. This course leads up to Gauss' celebrated Theorem Egregium of the intrinsic nature of curvature.

A group may be given a manifold structure so that it becomes a “Lie Group”; naturally a manifold with many symmetries. Lie groups and their quotients, called homogeneous spaces, furnish a wealth of interesting examples in geometry. Their infinitesimal generators form interesting algebraic objects called “Lie algebras”. The beautiful correspondence between Lie groups and Lie algebras is described in this course.

This is an important course for both future topologists and theoretical physicists.

Contents: Smooth manifolds, tangent spaces, Lie groups and Lie algebras, Homogeneous spaces, examples, Derivatives of functions on manifolds, Immersions and submersions, vector fields,

Frobenius theorem Flows and exponential map, matrix exponential function on a linear Lie group, Lie subgroups and subalgebras, Adjoint representation, Tensor fields, differential forms, Exterior derivatives, Orientation, Integration on manifolds, Connections, Parallel transport, Covariant derivatives, Riemannian metrics, Levi-Civita connection, Geodesics, First and second fundamental form for surfaces, Gaussian curvature, Theorema Egregium, Examples of negatively/positively curved/flat manifolds, Isometry groups of Riemannian manifolds.

Recommended Reading:

1. Foundations of Differentiable Manifolds and Lie Groups: F. Warner (1983) GTM Springer
2. Differential Geometry, Lie Groups and Symmetric Spaces: S. Helgason (2001) AMS
3. An Introduction to Manifolds: L. Tu (2011) Springer
4. Introduction to Differentiable Manifolds and Riemannian Geometry: W. M. Boothby (2003) Academic Press
5. Differential Geometry of Curves and Surfaces: Manfredo P. do. Carmo (1976) Prentice Hall
6. A Course in Differential Geometry and Lie Groups: S. Kumaresan (2002) Hindustan Book Agency

Prerequisites: Calculus on Manifolds (MTH 322)

MTH 424

Stochastic Processes

4 credits

Introduction: This course introduces the measure theoretic aspects of probability. This course also introduces Brownian motion which serves as the backbone to the stochastic analysis. This course will benefit anyone interested in studying queuing theory, mathematical finance, stochastic control theory and other fields of stochastic analysis.

Contents: Measure theoretic probability, Kolmogorov consistency theorem, notion of convergence, Monotone class theorem, weak convergence, Prokhorov theorem, Skorohod representation theorem, tightness and compactness, characteristic functions and its properties. Conditional expectation and Jensen's inequality, regular conditional expectation. Markov processes. Definition of Brownian motion, Levy's Theorem, construction of Brownian motion, Some properties of Brownian motion, Geometric Brownian motion. Stochastic calculus, Ito integration, Ito's formula, stochastic differential equations, strong/weak solutions.

Recommended Reading:

1. Measure Theory and Probability Theory (Springer Texts in Statistics): K. B. Athreya, S.N. Lahiri (2010) Springer
2. Brownian Motion (Cambridge Series in Statistical and Probabilistic Mathematics): Peter Moerters and Yuval Peres (2010) Cambridge
3. Brownian motion and stochastic calculus: I. Karatzas and S. E. Shreve (1991) GTM Springer

Prerequisites: Probability (MTH 414), Measure Theory & Integration (MTH 411)

MTH 425

Commutative Algebra

4 credits

Introduction: Commutative algebra is essentially the study of commutative rings. Roughly speaking it has developed from two sources (1) algebraic geometry and (2) algebraic number theory. In (1) the prototype of the rings studied is $k[X_1, X_2, \dots, X_n]$, the polynomial ring in n variables over a field k ; and in (2) it is the ring of integers of a number field. Commutative algebra is now one of the foundation stones of algebraic geometry. It provides the local tools for the subject in the same way that differential analysis provides the local tools for differential geometry.

Contents: Commutative rings with 1, prime ideals, maximal ideals, existence of maximal ideals, prime avoidance lemma, nilradical and Jacobson radical. Basic constructions for modules, like direct sums, direct products, short exact sequences, Homfunctor, definition of projective module, tensor products, definition of flat module. Cayley-Hamilton theorem for endomorphisms of a finitely generated R -module and Nakayama's Lemma. Localization, correspondence of prime ideals under localization, other important properties of localization like localization is an exact functor, it commutes with tensor product, etc. Noetherian rings, Hilbert basis theorem. Integral extensions, going up theorem.

Recommended Reading:

1. Commutative algebra: Atiyah and MacDonal (1994) Westview Press
2. Commutative algebra: Gopalkrishnan (1984) Oxonian Press
3. Commutative ring theory: Matsumura (1989)

Prerequisites: Vector Spaces, Rings and Modules (MTH 320)

Introduction: A solution of an ODE is typically specified by finitely many constants. In contrast, a solution to a PDE is typically specified by finitely many *functions*. Both initial conditions of time and boundary conditions of space play a decisive role. PDE theory is thus much vaster than the theory of ODEs. This course focuses on four primary PDEs arising from nature: the transport equation, Laplace's equation, heat equation, and wave equation, representing first order PDEs, second order elliptic, parabolic, and hyperbolic PDEs, respectively. Each of these leads to its own branch of mathematics that one could study for a lifetime. As well as being an engaging mathematical topic in its own right, PDE theory is essential for many topics in analysis, geometry, probability theory, mathematical physics, etc. Students of PDEs may go on to study topics like harmonic analysis, geometric analysis, operator theory, control theory, differential geometry, and the calculus of variations.

Familiarity with the contents of MTH 417 (ODEs) is helpful but not mandatory.

Contents:

A. Introduction and Classification of PDEs

B. Four important Linear PDEs:

- (1) Transport Equation: Initial Value Problem, Non-homogeneous problem,
- (2) Laplace's Equation: Fundamental Solution, Mean Value Property, Maximum Principles, Properties of Harmonic functions, Green's function, Energy Methods,
- (3) Heat Equation: Fundamental Solution, Mean Value Property, Maximum Principles, Properties of solutions, Energy Methods,
- (4) Wave Equation: Solution by Spherical Means, Non-homogeneous problem, Energy Methods.

C. Solution via Separation of Variables

Recommended Reading:

1. Partial Differential Equations, Methods and Applications: R. McOwen (2002) Pearson Education
2. Partial Differential Equations: L. Evans (2010) Graduate Studies in Mathematics, AMS
3. Introduction to Partial Differential Equations: G. Folland (1995) Princeton University Press
4. Partial Differential Equations: F. John (1995) Springer
5. An Introduction to Partial Differential Equations: Y. Pinchover and J. Rubinstein (2005) Cambridge

Prerequisites: Measure Theory & Integration (MTH 411), and see the Introduction.

PHYSICS

The courses offered in Physics at IISER Pune form part of a comprehensive program at the level of a Bachelor's and Master's degree (BS and MS). The Physics program aims to enable students to understand the basic laws of nature and develop the necessary skills and tools to apply this understanding to other areas and disciplines. Here students are prepared for careers in basic physics as well as in related applied sciences or technology.

The courses offered in Physics for the BS MS program are structured in two levels.

Courses in Semesters I-IV: Introduction to the World of Physics

The first level spans courses offered during the first four semesters of the BS MS Program. These courses are common and mandatory for all students. Based on their interests, the students specialize after completing the fourth semester. For this reason, the first level courses are designed to cover the basic concepts in physics in a very comprehensive manner, since they could be the only physics courses taken by students specializing in other disciplines. These courses are meant to give a flavor of the various approaches and analyses in Physics as well as to prepare them for advanced courses in later years of study.

The four World of Physics courses in the first four semesters offer all students an exposure to both the rigour and breadth of physics, concentrating mainly on mechanics, waves and matter, electricity and magnetism, and quantum physics. There are three Laboratory Courses that expose them to key experiments and teach them skills in handling basic equipment. In addition, there are two Interdisciplinary Courses offered during this period: Mathematical Methods that provides the basic mathematical tools needed for a program in science, and Thermodynamics that provides an introduction to the concepts needed for the further study of physics and chemistry.

Courses in Semesters V-VIII

The courses at the second level of the program are designed for students who have chosen to specialize primarily in physics. These are in-depth courses with a strong emphasis on developing problem-solving skills.

The basic requirements for graduation during semesters V-VIII, consist of 12 courses of 4 credits each, as well as a number of courses of 3 credits each, to add up to a minimum total of 84 credits. The 4-credit courses are core courses meant for detailed and in-depth study covering all the basic areas of Physics. A student planning a career in Physics is expected to take all of them. These include Mathematical Methods, Classical Mechanics and Electrodynamics, two courses in Quantum Mechanics, Statistical Mechanics, Condensed Matter Physics, Nuclear and Particle physics, Atomic and Molecular Physics and Classical and Quantum

Optics. In addition, advanced courses in Statistical Mechanics, Condensed Matter Physics, Quantum Information and Gravitation and Cosmology are offered as courses of 3 credits that are a sequel to some of the basic courses. Four Laboratory courses are offered, one in each semester, which will train students in advanced-level experiments and the use of modern equipment.

The courses at this level are designed to train students to enter into a career as experimental or theoretical physicists. For this purpose, students are encouraged to follow their own inclinations and can take any combination of basic theoretical courses including current research topics, as well as advanced laboratory courses, along with courses like electronics and experimental methods.

Interdisciplinary Courses

The pattern of course work followed at IISER Pune permits students specializing in other disciplines or areas, also to take courses from Physics. Some of the 3-credit courses are introductory courses, meant for this purpose. Thus courses in Mathematical Methods, Nonlinear Dynamics, Fluid Dynamics, Nanoscale Physics and Material Science are offered such that students interested in other disciplines also benefit from them.

Similarly, a student interested in a career in Physics and interdisciplinary areas related to Physics, can take courses from other disciplines. Some such courses are Neurobiology, Genetics, Biophysics etc from Biology; Statistical Thermodynamics, Symmetry and Group Theory, Quantum Chemistry etc from Chemistry; and Differential Geometry, Statistics, Complex Analysis etc from Mathematics. During Semesters V and VI, students have to take at least one course from another discipline.

Semester Projects

Unique to the IISER Pune undergraduate program is the laboratory training/theory project offered in each semester during the four semesters V-VIII. This gives an opportunity to work under the guidance of a faculty member on a topic of mutual interest to earn three credits. This allows students to slowly build a solid platform from which they may launch themselves into a more challenging fifth-year research project later on. Any specialization or advanced training needed, in addition to the courses offered, can be achieved through careful choice of this lab training/theory project course.

Semester IX-X

During the final two semesters of the program, students do an extended project for 36 credits that result in the MS thesis.

The structure of the program with the sequence and organization of the courses in the various semesters is given in the flow chart below. The prerequisites for later courses, as the students advance in their program, are indicated in the chart.

List of Courses in Physics

Semester I

1. PHY 101 World of Physics I – Mechanics [3 credits]

Semester II

2. PHY 102 World of Physics II – Waves and Matter [3 credits]
3. PHY 121 Physics Lab [3 credits]

Semester III

4. PHY 201 World of Physics III – Electricity & Magnetism [3 credits]
5. PHY 221 Physics Lab II [3 credits]

Semester IV

6. PHY 202 World of Physics IV – Quantum Physics [3 credits]
7. PHY 222 Physics Lab III [3 credits]

Semester V

8. PHY 310 Mathematical Methods in Physics [4 credits]
9. PHY 311 Classical Mechanics [4 credits]
10. PHY 312 Electrodynamics [4 credits]
11. PHY 313 Quantum Mechanics [4 credits]
12. PHY 330 Physics Lab IV [3 credits]
13. PHY 334 Astronomy & Astrophysics* [3 credits]
14. PHY 335 Electronics I* [3 credits]
15. PHY 340 Methods of Experimental Physics [3 credits]
16. PHY 301 Lab Training / Theory Project [3 credits]

Semester VI

17. PHY 320 Physics Lab V [4 credits]
18. PHY 321 Statistical Mechanics I [4 credits]
19. PHY 322 Quantum Mechanics II [4 credits]
20. PHY 341 Physics at Nano Scale [3 credits]
21. PHY 342 Nonlinear Dynamics* [3 credits]
22. PHY 350 Electronics II* [3 credits]
23. PHY 351 Gravitation and Cosmology* [3 credits]
24. PHY 356 Group Theory in Physics* [3 credits]
25. PHY 361 Quantum Information* [3 credits]
26. PHY 302 Lab Training / Theory Project [3 credits]

Semester VII

27. PHY 410 Physics Lab VI [4 credits]
28. PHY 411 Condensed Matter Physics [4 credits]
29. PHY 412 Statistical Mechanics II [4 credits]
30. PHY 414 Biophysics I [4 credits]
31. PHY 452 Fluid Dynamics* [3 credits]
32. PHY 453 Computational Physics [3 credits]
33. PHY 462 Plasma Physics* [3 credits]
34. PHY 401 Lab Training / Theory Project [3 credits]

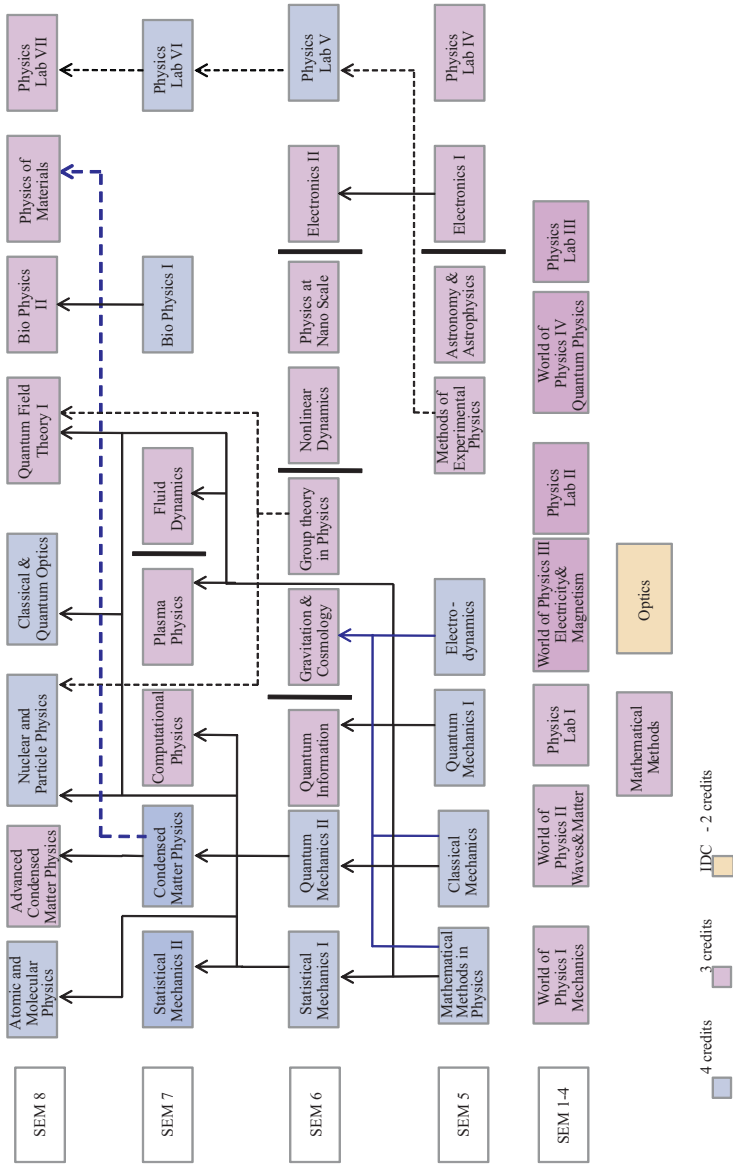
Semester VIII

35. PHY 420 Atomic and Molecular Physics [4 credits]
36. PHY 421 Classical and Quantum Optics [4 credits]
37. PHY 422 Nuclear and Particle Physics [4 credits]
38. PHY 430 Physics Lab VII [3 credits]

- | | |
|---|-------------|
| 39. PHY 444 Biophysics II | [3 credits] |
| 40. PHY 446 Physics of Materials | [3 credits] |
| 41. PHY 461 Quantum Field Theory I | [3 credits] |
| 42. PHY 463 Advanced Condensed Matter Physics | [3 credits] |
| 43. PHY 402 Lab Training / Theory Project | [3 credits] |

* Courses offered once in two years

BS MS Program: Curriculum in Physics



Full arrows indicate prerequisites , dotted arrows show recommended sequence

Details of Courses in Physics

PHY 101	World of Physics I – Mechanics	3 credits
----------------	---------------------------------------	------------------

Introduction: Overview of basics of mechanics and some important applications, introduced at a level which will help the students with succeeding courses.

Contents:

Section 1: Place of mechanics in physics, Range of validity of classical mechanics. Kinematics and mathematical tools, Newton's laws, Examples of one, two and three dimensional motion under forces.

Section 2: Central force motion and application to planetary motion, Rotational motion of a rigid body, Potential energy, multiparticle systems and conservation laws.

Section 3: Frames of reference, Galilean relativity, non-inertial frames, basic special relativity, Least action principle, Hamiltonian and phase space.

Recommended Reading:

1. Mechanics: C. Kittel, W.D. Knight, M.A. Ruderman, C.A. Helmholtz and B.J. Moyer (2008) Berkeley Physics Vol 1, Tata McGraw-Hill Ltd
2. Classical Mechanics: R.D. Gregory (2008) Cambridge University Press
3. Introduction to Classical Mechanics: D. Morin (2009) Cambridge University Press
4. Classical Mechanics: J.R. Taylor (2005) University Science Books
5. Mechanics: L.D. Landau and I.M. Lifshitz (2007) 3rd edition, Butterworth-Heinemann

PHY 102	World of Physics II – Waves and Matter	3 credits
----------------	---	------------------

Introduction: To develop familiarity with classical phenomenology relating to deformable media and oscillatory phenomena which are ubiquitous in nature.

Contents: Oscillations and waves in one and many dimensions, Damped and driven oscillations. Resonances. Oscillations of continuous string and Fourier analysis, Traveling waves, pulses and wave packets, phase and group velocity, reflection, refraction and transmission, Properties of deformable media, Hooke's law, stress and strain. Torsion and bending of rods, deflections of rods. Compression waves in solids and fluids. Generalised deformations, introduction to stress, strain and elasticity tensors.

Recommended Reading:

1. Waves: F.S. Crawford Jr (2008) Berkeley Physics volume 3, Tata McGraw-Hill Ltd
2. Physics of Waves and Oscillations : H. J. Pain (2005) Wiley
3. Classical Mechanics: N. Rana and P. Joag (2001) Tata McGraw-Hill Education

4. Classical Mechanics: J.R. Taylor (2005) University Science Books
5. Feynman Lectures in Physics, Vol I, II, Addison-Wesley.

PHY 121	Physics Lab	3 credits
----------------	--------------------	------------------

Introduction: To learn how to approach experiments in physics: design, observations, data analysis and interpretation.

Contents: Torsional pendulum, physical pendulum, Young's modulus, coefficient of friction, Euler's relation, Faraday's and Lenz's law of electromagnetic induction, Biot-Savart's law, Stoke's law, numerical experiments.

PHY 201	World of Physics III– Electricity and Magnetism	3 credits
----------------	--	------------------

Introduction: To introduce the basics concepts of electricity and magnetism and motivate students about the importance of understanding the behaviour of materials subjected to electric and magnetic fields.

Contents: Electrostatics, Coulomb's law, Gauss's law and its applications, method of images, magnetostatics, electric fields in matter, dielectrics, polarisation, magnetic fields in matter, magnetic materials, Biot-Savart law, Ampere's law, Faraday's law, Lorentz force law, displacement current, Maxwell equations, plane electromagnetic waves, polarised light

Recommended Reading:

1. Electricity and Magnetism: E.M. Purcell (2008) Berkeley Physics Course, Vol 2, Tata McGraw-Hill Ltd
2. Feynman Lectures on Physics: R.P. Feynman, R.B. Leighton and M. Sands (2011) The Millenium edition, Vol 2, Basic Books
3. Introduction to Electrodynamics: D.J. Griffiths (2012) Pearson Education

PHY 202	World of Physics IV – Quantum Physics	3 credits
----------------	--	------------------

Introduction: To introduce students to the fundamental laws of nature operating at the atomic scale and below.

Contents: Historical background, discrete spectra, wave-particle duality, wave packets, uncertainty principle, postulates of quantum mechanics, Schrodinger equation, expectation values, particle in a box, potential well and barrier in one dimension, Hydrogen atom

Recommended Reading:

1. Quantum Physics: S. Gasiorowicz (2003) 3rd edition, Wiley India Edition
2. Quantum Physics: E.H. Wichman (2008) Berkeley Physics Course, Vol 4, Tata McGraw-Hill Ltd
3. Quantum Physics of Atoms, Molecules, Solids, Nuclei and Particles: R.

- Eisberg and R. Resnick, 2nd edition, John Wiley and Sons
4. Quantum Mechanics: C. Cohen-Tannoudji, B. Diu and F. Laloe (1977) Vol 1, Wiley-Interscience
 5. Introduction to Quantum Mechanics, David J. Griffiths, Pearson Education
 6. Introductory Quantum Mechanics, Richard Liboff, Addison-Wesley; 4 edition
 7. A Modern Approach to Quantum Mechanics, John Townsend, Viva Books

PHY 221	Physics Lab II	3 credits
----------------	-----------------------	------------------

Introduction: Meant for students to gain exposure to experiments in basic Physics, as a continuation of experiments in Semester I.

Contents: Thermal expansion of solids, thermal conductivity by Lee's method, specific heat of solids, Stefan's law of radiation, temperature dependence of a thermistor, resolving power of a telescope, diffraction grating and prism spectrometer, Newton's rings, Malus's Law.

PHY 222	Physics Lab III	3 credits
----------------	------------------------	------------------

Introduction: This lab course is for introducing students to Modern Physics. The experiments include measurement of fundamental constants such as Plank's constant, e/m ratio. We aim to give basic introduction to optical spectroscopy and interferometry. Some experiments on sound will also be performed.

Contents: Photo-electric effect, Cornu's method to determine Young's modulus, e/m by Thomson's method

Rydberg's Constant, Millikan's oil drop Methods, G-M Counter Characteristics, Constant Deviation spectrometer, Michelson interferometer, Standing waves in pipes, Wavelength of acoustic waves in liquids by diffraction, Kundt's Tube, Measuring the velocity of sound by phase shift.

Recommended Reading:

1. Advanced Practical Physics: B.L. Worsnop and H.T. Flint, Asia Publishing House
2. Analytical Experimental Physics: Michael Ference Jr., Harvey B. Lemon, Reginald J. Stephenson (1970) University of Chicago Press
3. The Art of Experimental Physics: D.W. Preston and E.R. Dietz (1991) John Wiley

PHY 310	Mathematical Methods in Physics	4 credits
----------------	--	------------------

Introduction: To provide the key mathematical tools needed for a physics student.

This is a core course for physics students. Students from other disciplines may also find it useful, especially the module on partial differential equations.

Contents: Complex analysis; Ordinary differential equations; Sturm-Liouville theory, Special functions: Hermite, Legendre, Laguerre, Bessel and Green's functions; partial differential equations, introduction to tensors.

Recommended Reading:

1. *Mathematical Methods for Physicists:* G. Arfken and H. Weber (2012) 7th edition, Academic Press
2. *Fundamentals of Complex Analysis:* E.B. Staff and A.D. Snider (2008) Dorling Kinderley (India) Ltd
3. *Ordinary Differential Equations:* G. Birkhoff and G.C. Rota (1989) 4th edition, Wiley India
4. *Differential Equations with Applications and Historical Notes:* G. Simmons (2003) Tata McGraw Hill
5. *Linear Partial Differential Equations for Scientists and Engineers:* Tyn Myint-U and Lokenath Debnath (2006) 4th edition, Birkhauser

PHY 311

Classical Mechanics

4 credits

Introduction: To provide a detailed survey of the basic formalism and practical applications of classical mechanics. This is a foundational course for physics students but could also appeal to those majoring in other disciplines, including mathematics.

Contents: Euler-Lagrange equation from variational principle, constraints and Lagrange multipliers, integrals of motion, symmetries and conservations laws. Hamiltonian formalism: Hamilton equations, Poisson brackets, symplectic formulation, canonical transformations, Hamilton-Jacobi theory, action-angle variables.

Central force motion: integrals, Kepler problem, classical scattering. Small oscillations, normal modes. Continuous systems: wave equation, classical fields, classical perturbation theory. Nonlinear oscillators, hamiltonian chaos.

Recommended Reading:

1. *Classical Mechanics:* H. Goldstein, C. Poole and J. Safko (2002) 3rd edition, Pearson
2. *Classical Dynamics of Particles and Systems:* Thornton and Marion (2003) Thomson Learning EMEA Ltd
3. *Classical Mechanics:* R.D. Gregory (2008) Cambridge University Press
4. *Mechanics:* L.D. Landau and E.M. Lifshitz (2007) 3rd edition, Butterworth-Heinemann
5. *Classical Mechanics A Contemporary Approach:* J.V. Jose and E.J. Saletan (2006) Cambridge University Press

PHY 312	Electrodynamics	4 credits
----------------	------------------------	------------------

Introduction: To provide a basic understanding of electric and magnetic fields in matter, electromagnetic waves in vacuum and in matter and the electromagnetic field equations in a covariant way.

Contents: Review of electro- and magnetostatics, Maxwell's equations, conservation laws, electromagnetic waves in vacuum and in matter, guided waves, dipole radiation, scalar and vector potentials, retarded potentials, gauge transformations, relativistic electrodynamics, electromagnetic field tensor, covariant formulation of Maxwell's equations.

Recommended Reading:

1. Introduction to Electrodynamics: D.J. Griffiths (2012) Pearson Education
2. Modern Electrodynamics: A. Zangwill (2013) Cambridge University Press
3. Feynman Lectures on Physics: R.P. Feynman, R.B. Leighton and M. Sands (2011) The Millenium edition, Vol 2, Basic Books
4. Electrodynamics of Continuous Media: L.D. Landau and E.M. Lifshitz (2007) 3rd edition, Butterworth-Heinemann

PHY 313	Quantum Mechanics I	4 credits
----------------	----------------------------	------------------

Introduction: This course is a pre-requisite for many advanced courses in physics and chemistry, and is indispensable for understanding the behavior of molecules, atoms and elementary particles.

Contents: Vector spaces, linear operators, eigenvalue problems; postulates of quantum mechanics, Heisenberg uncertainty relations; time evolution; Schroedinger equation; harmonic oscillator; creation and annihilation operators; orbital angular momentum; central force problems; Hydrogen atom; spin angular momentum; identical particles; General properties of Schroedinger equation.

Recommended Reading:

1. Modern Quantum Mechanics: J.J. Sakurai (1999) Revised Edition, Addison-Wesley
2. Quantum Mechanics: C. Cohen-Tannoudji, B. Diu and F. Laloe (1977) Vol 1 and 2, Wiley-Interscience
3. Principles of Quantum Mechanics: R. Shankar (2010) 2nd edition, Springer
4. Introduction to Quantum Mechanics: D.J. Griffiths (2004) 2nd edition, Addison-Wesley

PHY 320	Physics Lab V	4 credits
----------------	----------------------	------------------

Introduction: The objective of this course is to introduce students to a variety of standard experiments in physics. The lab also covers introduction to solid state

devices such as diode, transistor and operational amplifiers. Various test and measurement techniques used in advanced experimental labs will be introduced.

Contents: BH curve, Solar cell, Verification of Curie Weiss Law, Magnetic susceptibility by Quinkes method, Measurements of thermal and electrical conductivities. Diodes, Bipolar/Field emission transistors, Logic gates, Op-amps and their basic applications, Voltage regulators and oscillators.

Recommended Reading:

1. Advanced Practical Physics: B.L. Worsnop and H.T. Flint, Asia Publishing House
2. Analytical Experimental Physics: M. Ference Jr., H.B. Lemon, R.J. Stephenson (1970) University of Chicago Press
3. The Art of Experimental Physics: D.W. Preston and E.R. Dietz (1991) John Wiley
4. The Art of Electronics: P. Horowitz and W.Hill (1989) 2nd edition Cambridge University Press

PHY 321

Statistical Mechanics I

4 credits

Introduction: This is a basic course for students wanting to major in physics. It provides an introduction to the microscopic understanding of thermodynamic systems via the laws of statistical mechanics and applies this to various ideal and non-ideal systems.

Contents: Review of classical thermodynamics: Laws of Thermodynamics, Carnot engines, approach to equilibrium, thermodynamic potentials, Maxwell relations, Stability conditions, description of phase transitions. Principles of statistical mechanics : Ergodic hypothesis, postulate of equal *a priori* probability, phase space, Liouville's theorem, microcanonical ensemble, canonical ensemble, grand canonical ensemble, Boltzmann entropy, partition function, microscopic definition of temperature and calculation of other thermodynamic quantities, fluctuations of energy/particles in canonical/grand canonical ensembles, classical spins: paramagnetism, ferromagnetism, Curie's law. Bose and Fermi statistics, quantum ideal gas, Bose-Einstein condensation, black body radiation spectrum, Einstein and Debye model of specific heat.

Recommended Reading:

1. Statistical Mechanics: K. Huang (1987) 2nd edition, Wiley
2. Fundamental of Statistical and Thermal Physics: F. Reif (2008) Waveland Pr Inc
3. Statistical Physics of Particles: Mehran Kardar (2007) Cambridge University Press
4. Statistical Mechanics: R.K. Pathria (1996) 2nd edition, Butterworth-Heinemann

PHY 322	Quantum Mechanics II	4 credits
----------------	-----------------------------	------------------

Introduction: The course will cover standard but relatively advanced topics that are required for every physicist.

Contents: Approximation methods: time-independent and time dependent perturbation theory, variational and WKB approximation; angular momentum and Clebsch-Gordan coefficients; symmetries of quantum systems; Landau levels; scattering theory; coherent states; relativistic quantum mechanics.

Recommended Reading:

1. Quantum Mechanics: Vol I and 2, C. Cohen-Tannoudji, B. Diu and R. Laloe (2005) John Wiley and Sons
2. Modern Quantum Mechanics: J.J. Sakurai (2009) Revised edition, Addison Wesley
3. Principles of Quantum Mechanics: R. Shankar (2010) 2nd edition, Springer
4. Introduction to Quantum Mechanics: D.J. Griffiths (2004) 2nd edition, Addison-Wesley

Prerequisites: Quantum Mechanics I (PHY 313)

PHY 330	Physics Laboratory IV	3 credits
----------------	------------------------------	------------------

Introduction: This lab covers experiments in basic quantum physics and the interaction of radiation with matter.

Contents: Skin depth measurement, Generation and transmission of electromagnetic waves (Lecher Wire)

Magnetic Susceptibility measurement by Gouy's method, Blackbody radiation, Franck Hertz experiment, Faraday effect, Ionic conductivity, Determination of ionization potential, Constant deviation spectrometer, Microwave propagation.

Recommended Reading:

1. Advanced Practical Physics: B.L. Worsnop and H.T. Flint, Asia Publishing House
2. Analytical Experimental Physics: M. Ference Jr., H.B. Lemon and R.J. Stephenson (1970) University of Chicago Press
3. The Art of Experimental Physics: D.W. Preston and E.R. Dietz (1991) John Wiley
4. The Art of Electronics: P. Horowitz and W. Hill (1989) 2nd edition, Cambridge University Press

PHY 334	Astronomy and Astrophysics	3 credits
----------------	-----------------------------------	------------------

Introduction: To introduce students to the basic concepts of astrophysics. The

course is intended both for students interested in pursuing a career in this general area, and for those specialising in some other area who would like an overview of astrophysics.

Contents: Electromagnetic processes, thermal and synchrotron emission, spectral lines; stellar physics: structure, composition, evolution; active galactic nuclei, radio galaxies, quasars, galaxies and galaxy clusters, galaxy structure and composition; X-ray clusters, cluster radio sources; dark matter, gravitational lensing, rotation curves; cosmology, big bang model, cosmic microwave background, reionisation. Other topics (time permitting): pulsars, extra solar planets, telescopes.

Recommended Reading:

1. Galaxies in the Universe: An Introduction: L.S. Sparke and J.S. Gallagher III (2000) Cambridge University Press
2. Galactic and Extragalactic Radio Astronomy: G.L. Verschuur and K.I. Kellermann (1988) Springer-Verlag
3. The Physics of Stars (Manchester Physics Series): A.C. Phillips (1999) John Wiley & Sons

PHY 335

Electronics I

3 credits

Introduction: To provide an overview of the design principles of electronic circuits. By the end of this course, students are expected to be able to understand simple circuits, and also design new circuits on their own.

Contents: Voltage & current sources, Thevenin & Norton's theorems, semiconductors, diodes, rectifiers, Zener diode, LEDs, transistors, AC and DC biasing, amplifiers, JFETs, MOSFETs, thyristors, op-amps and related circuits, positive and negative feedback, oscillators, TTL.

Recommended Reading:

1. Electronic Principles: A. Malvino and D. Bates (2006) 7th edition, McGraw-Hill
2. The Art of Electronics: P. Horwitz and W. Hill (1989) 2nd edition, Cambridge University Press

PHY 340

Methods of Experimental Physics

3 credits

Introduction: To build up the necessary background required to design and carry out important experiments, exposure to the physics behind recent experimental techniques.

Contents: Error analysis and the value of "zero" in experimental physics, measurement of noise and analysis of noise, electrical measurements and precautions: I-V, C-V, resistivity. Magnetic measurements and precautions: vibrating sample magnetometer, SQUID; Vacuum techniques: units, gauges,

pumps, materials; Techniques of temperature measurements: very low, medium and very high-temperature thermometers, thermocouples, thermistors, pyrometer, spectroscopy etc; Thin film deposition methods: physical, e-beam, sputter, chemical vapor deposition, molecular beam epitaxy, spin coatings, dip coating, electroplating, electroless plating etc; Techniques of optical spectroscopy and optoelectronic devices: UV-Vis absorption, photoluminescence, electroluminescence, light-emitting diodes, solar cells; Advanced experimental techniques: AFM, atomic and molecular traps, superconductivity, astronomy, NMR, nano-materials and devices, time-resolved measurements etc.

Recommended Reading:

1. Practical Physics: G.L. Squires (2001) 4th edition, Cambridge University Press
2. Astronomical Optics: D.J. Schroeder (1999) 2nd edition, Academic Press
3. Experimental Physics: R.A. Dunlap (1988) 1st edition, Oxford University Press
4. Characterization of Materials: J.B. Wachtman and Z.H. Kalman (1992) Butterworth-Heinemann

PHY 342

Nonlinear Dynamics

3 credits

Introduction: This is an introductory course in the subject. Although all the novelties of nonlinear dynamics will be introduced, the emphasis is to provide a basic training to students to work out the fixed points, their stability and bifurcations in dynamical systems and apply these to real-world systems like population dynamics, epidemics, chemical reactions, lasers, neurons, nonlinear oscillators etc. The course will run in parallel with computer laboratory sessions so that students will also receive training in the analysis of time series data, power spectra, bifurcation diagrams, fractals and so on.

Contents: Nonlinear dynamical systems: classification, chaos, features of chaos, continuous and discrete dynamical systems; 1-d flows: fixed points and stability, linear stability analysis, bifurcations, flows on a circle, population dynamics; 2-d flows: classification of fixed points, stability analysis, limit cycles, bifurcations, predator-prey systems; higher-dimensional systems: stability, attractors, bifurcations, chaos, Lorenz system, Rossler system, pendulum.

Discrete dynamical systems, 1-d systems: logistic map, bifurcations, period doubling, chaos, Lyapunov exponent, circle map; 2-d systems: Henon map, quasiperiodicity, Arnold tongue; measures of chaos, Poincare map, basin boundary, FFT, Lyapunov exponents; Fractals: dimensions, multi-fractals, f-alpha spectrum.

Special topics: control of chaos, stochastic resonance, synchronization, spatio-temporal chaos, time series analysis, complex networks.

Recommended Reading:

1. Nonlinear Dynamics and Chaos: Steven Strogatz (2001) Westview Press
2. Chaos and Nonlinear Dynamics: Hilborn (2009) Oxford University Press
3. Chaos: An Introduction to Dynamical Systems: K.T. Alligood, T.D. Sauer and J.A. Yorke (1996) Springer
4. Chaos in Dynamical Systems: E. Ott (2003) Cambridge University Press
5. Nonlinear Dynamics: M. Lakshmanan and S. Rajasekar (2003) Springer

PHY 350

Electronics II

3 credits

Introduction: A continuation of the first course, focusing on advanced topics in electronics like microprocessors, instrumentation and signal processing.

Contents: Advanced electronic devices (Photo diodes, Light emitting diodes, Solar cells, Schottky diodes, Tunnel diodes, Gunn diodes, IMPATT diodes); Practical Electronic circuits: Using BJT, FET and MOSfets, High power switching; Circuit Design: Voltage and Power regulation, BJT and FET amplifier circuits, Audio and high frequency amplifier circuits, Modulators and demodulators; Filters and oscillators: Filter Theory, Low pass, High pass and notch filters, Active filters, Oscillators; Signal measurement and signal processing: Noise in electronic circuits, Noise sources, Interference and shielding, Noise reduction techniques, Phase sensitive detection and Phase locked loops, Modulation techniques, Heterodyne and superheterodyne demodulation, Fourier transform and Fast Fourier transform. Communications systems: Fundamentals of signal transmission, Transmission lines and wave guides, Antennas; Digital electronics: Introduction to various Digital signal standards, interfacing of signals between various logic level signals, Gates, Flipflops, Counters, Multiplexers, Demultiplexers, Registers, Analog to Digital conversion, Digital to Analog conversion, Digital signal processing; Introduction to Microcontrollers and Microprocessor

Recommended Reading:

1. The Art of Electronics: Paul Horowitz & Winfield Hill (2011) Cambridge University Press
2. Digital Principles and Their Applications: Donal P. Leach, Albert Paul Malvino and Gautam Saha (2006) Tata McGraw Hill
3. Solid State Electronic Devices: B.G. Streetman & S.K. Banerjee (2005) 6th edition, Prentice
4. Electronic Devices and Circuits: Robert L. Boylestad & Louis Nashelsky (2009) Pearson

Prerequisite: Electronics I (PHY 335)

PHY351	Gravitation and Cosmology	3 credits
---------------	----------------------------------	------------------

Introduction: This course will introduce students to general relativity, its predictions, tests and applications, particularly cosmology and black holes. The interplay between mathematics and physics in relativity will be stressed and students will get a flavor of the exciting open research problems in gravitation at the end of the course. This course is also expected to be useful to students who want to learn astrophysics, theoretical physics and mathematics, and differential geometry.

Contents: Introduction to four-vectors, Principle of equivalence, Einstein's equation from action principle and its basic properties, Schwarzschild solution and classical tests of relativity; basic ideas of black hole physics, introduction to gravitational waves .Basic introduction to contents and scales in the universe, Friedmann metric, dynamics of the FRW universe and elements of cosmology.

Recommended Reading:

1. Gravity: An Introduction to Einstein's General Relativity: J.B. Hartle (2003) Benjamin Cummings
2. Spacetime and Geometry: An Introduction to General Relativity: S. Carroll (2003) Benjamin Cummings

PHY356	Group Theory in Physics	3 credits
---------------	--------------------------------	------------------

Introduction: This course will focus broadly on the role of symmetries in nature, with a special emphasis on the important relationship between continuous symmetries and conserved quantities. Students of physics and mathematics may find the course useful. This course will be particularly useful for students intending to specialize in theoretical physics.

Contents: Introduction to discrete groups, Lie groups and Lie algebras, Lie algebras in particle physics, discrete and continuous symmetries in nature, symmetries and conserved quantities, gauge symmetries and fundamental forces.

Recommended Reading:

1. Group Theory: A Physicist's Survey: P. Ramond (2010) 1st edition, Cambridge University Press
2. Lie Algebras in Particle Physics: H. Georgi (1999) Westview Press, 2nd edition

PHY361	Quantum Information	3 credits
---------------	----------------------------	------------------

Introduction: Involves a theoretical treatment of quantum information, the goal is to prepare students towards understanding (and contributing to) current research in the area.

Contents: Section 1: Fundamental Concepts-Qubits and their measurements,

superdense coding, ensembles, Schmidt decomposition, Bell inequality.

Section 2: Quantum Computation-Circuits, quantum Fourier transform, search and factorization, physical implementations.

Section 3: Quantum Information-Noise, fidelity measures, error-correction, entropy and information.

Recommended Reading:

1. Quantum Computation and Quantum Information: M.A. Nielsen and I.L. Chuang(2011) Cambridge University Press
2. Preskill's lecture notes on Quantum Information and Quantum Computation, <http://www.theory.caltech.edu/people/preskill/ph229/>
3. An Introduction to Quantum Computing: P. Kaye, R. Laflamme and M. Mosca (2007) Oxford University Press

Prerequisite: Quantum Mechanics I (PHY 313)

PHY 410

Physics Lab VI

4 credits

Introduction: The aim is to teach experiments with light and electron emission and study the spin resonance phenomenon.

Contents: Field emission, Zeeman effect, Electron diffraction, characteristics of X-rays and X-ray absorption, Electron spin resonance, Principle of phase sensitive detection, Thermionic emission, Field-emission microscopy and Lock-in amplifiers.

Recommended Reading:

1. Advanced Practical Physics: B.L. Worsnop and H.T. Flint, Asia Publishing House
2. Analytical Experimental Physics: M. Ference Jr., H.B. Lemon, and R.J. Stephenson (1970) University of Chicago Press
3. The Art of Experimental Physics: D.W. Preston and E.R. Dietz (1991) John Wiley

PHY 411

Condensed Matter Physics

4 credits

Introduction: This is a basic course for all students intending to major in physics. The objective is to understand the properties of solids on the basis of the principles of quantum and statistical physics.

Contents: Crystal structure, diffraction, reciprocal lattice, chemical bonding, Bloch theory and band-structures, beyond band theory: Mott insulator, nearly free electron model, tight binding theory, Hall effect and magneto-resistance, conduction in metals, Hartree-Fock approximation, dynamic lattice model and harmonic approximations, phonon and specific heat, anharmonic effects, insulators and semiconductors, superconductivity, optical properties, magnetic properties.

Recommended Reading:

1. Solid State Physics: N.W. Ashcroft and N.D. Mermin (1976) College edition, Harcourt College Publishers
2. Introduction to Solid State Physics: C. Kittel (2004) 8th edition, John Wiley and Sons
3. Advanced Solid State Physics: Philip Phillips (2012) Cambridge University Press

Prerequisites: Quantum Mechanics I (PHY 313) and Statistical Mechanics I (PHY 321)

PHY 412**Statistical Mechanics II****4 credits**

Introduction: Modern developments in statistical physics have diverse applications in several areas of science including physics, chemistry and biology. This course will provide an exposure to a number of these developments as well as exposure to stochastic methods in physics.

Contents: Section 1: Introduction to non-ideal classical gas: second virial coefficient and van der Waals equation, introduction to modern theory of phase transitions and critical phenomena, concept of renormalization group.

Section 2: Introduction to non-equilibrium processes, diffusion, transport, Brownian motion, review of probability distributions, stochastic processes, Markov processes, master equation, Fokker-Planck equation, Langevin equation, normal and anomalous diffusion, Levy flights and fractional Brownian motion.

Recommended Reading:

1. Statistical Mechanics: K. Huang (2005) 2nd edition, John Wiley and Sons
2. Statistical Mechanics of Phase Transitions: J. Yeomans (1992) Oxford University Press
3. Introduction to Modern Statistical Mechanics: D. Chandler (1979) Oxford University Press
4. Elements of Non-equilibrium Statistical Mechanics: V. Balakrishnan (2009) Ane Books
5. Statistical Physics of Particles: Mehran Kardar (2007) Cambridge University Press
6. Stochastic processes in Physics and Chemistry: N.G. van Kampen (2007) 3rd edition, North Holland

Prerequisites: Quantum Mechanics I (PHY 313) and Statistical Mechanics I (PHY 321)

PHY 414 **Biophysics I** **4 credits**

Introduction: Students will be introduced to the new and interdisciplinary field of physical biology of the cell. This topic is at the intersection of physics and biology, with connections to mathematics, physical chemistry and cell physiology.

Content: Order of magnitude physics applied to biology, molecular biophysics, cellular biophysics, physics in development, and biophysical techniques with special emphasis on light in biology. Laboratories will be conducted for measuring molecular thermodynamics of biological macromolecules, quantifying cellular dynamics and measuring diffusion.

Recommended Reading:

1. Biological Physics: Energy, Information, Life: P. Nelson (2003) W.H. Freeman
2. Physical Biology of the Cell: R. Philips, J. Kondev and J. Theriot (2008) Garland Sciences
3. Biological Physics of the Developing Embryo: G. Forgacs (2005) Cambridge University Press

PHY 420 **Atomic and Molecular Physics** **4 credits**

Introduction: To learn the basic physics of atoms, molecules, their spectra and the interaction of light with matter.

Contents: Electronic structure of atoms, models of many-electron atoms, spin-orbit interaction-coupling schemes, emission and absorption of electromagnetic radiation by atoms, transition probabilities and selection rules, induced and spontaneous emission, Einstein coefficients, broadening of spectral lines, continuous absorption and emission spectra, rotation and vibration spectra of molecules, experimental techniques, optical cooling and trapping of atoms, atom interferometer, quantum measurement and decoherence, THz spectroscopy.

Recommended Reading:

1. Physics of Atoms and Quanta: H. Haken and H.C. Wolf (2005) Springer
2. Physics of Atoms and Molecules: B.H. Bransden and C.J. Joachain (2003) Pearson Education India
3. Atoms, Molecules and Photons: W. Demtroder (2010) Springer

Prerequisites: Quantum Mechanics I (PHY 313), Quantum Mechanics II (PHY 322), Electrodynamics (PHY 312), Statistical Mechanics I (PHY 321)

PHY 421 **Classical and Quantum Optics** **4 credits**

Introduction: To give a broad survey of Classical optics and an introduction to quantum aspects of light, from a modern perspective, keeping in mind the emerging applications of optical techniques in many fields and to prepare a subset

of students for more advanced and specialised work in optical techniques and/or quantum optics

Contents: Review of electromagnetic plane waves in vacuum and in media. Polarisation – Stokes parameters. Fresnel -Kirchoff diffraction theory with examples. Fresnel coefficients, optics of metals, bulk and surface plasmons, Scattering of light

Optical imaging systems. Fourier viewpoint in optics, Telescopes, microscopes, gratings, holography. Longitudinal and transverse coherence - Wiener Khinchin theorem and Zernike-van Cittert theorem Michelson, Fabry-Perot. Stellar interferometers.

Electromagnetic modes and quantization of the electromagnetic field. Photons. Coherent states Interaction of light with matter – dipole approximation. Polarizability and elastic scattering. Spontaneous emission, stimulated emission and absorption. Non linear processes.

Recommended Reading:

1. Optics: E. Hecht (2001) 4th edition, Addison-Wesley
2. Optical Physics: A. Lipson, S.G. Lipson, and H. Lipson (2010) 4th edition, Cambridge University Press
3. Fourier Optics: J.W. Goodman (2004) 3rd edition, Roberts and Company
4. Principles of Nano-optics: L. Novotny and B. Hecht (2012) 2nd edition, Cambridge University Press
5. Quantum Theory of Light: R. Loudon (2000) 3rd edition, Oxford University Press
6. Principles of Optics: M. Born and E. Wolf (1999) 7th edition, Cambridge University Press

Prerequisites: Quantum Mechanics II (PHY 322), Classical Electrodynamics (PHY 312)

PHY 422

Nuclear and Particle Physics

4 credits

Introduction: Introduction to the fundamental constituents of matter and their interactions.

Contents: Overview of particle interactions, Review of relativistic kinematics, Dirac equation, electromagnetic interactions, weak and strong interactions (introductory), properties of nuclei, mass, spin, charge, magnetic moment, classification, fermions and bosons, leptons and hadrons, mesons, quarks, gluons, intermediate vector bosons, structure of subatomic particles, scattering form factors, conservation laws, angular momentum and isospin-invariance, parity, conservation and breakdown of parity, CPT and breakdown of CP invariance, quark models of mesons and baryons, nuclear models: liquid drop, Fermi gas, shell and collective models.

Recommended Reading:

1. Introduction to Elementary Particles: D. Griffiths(1987) 2nd edition, Wiley
2. Quantum Field Theory in a Nutshell: A. Zee (2010) 2nd edition, Princeton University Press
3. Particle Physics: R.R. Martin and G. Shaw (2008) John Wiley & Sons
4. An Introduction to Nuclear Physics: W.M. Cottingham and D.A. Greenwood (2001) 2nd edition, Cambridge University Press

Prerequisites: Quantum Mechanics II (PHY 322)

PHY 430	Physics Lab VII	3 credits
----------------	------------------------	------------------

Introduction: Introduction to advanced experiments in atomic physics, solid-state physics, interaction of radiation with matter.

Contents: Zeeman effect, Field emission microscopy, Scanning tunnelling microscopy, beta-ray, gamma-ray and scanning-tunnelling spectroscopy, Compton and Rutherford scattering, X-ray diffraction and Thermoluminescence.

Recommended Reading:

1. Advanced Practical Physics: B.L. Worsnop and H.T. Flint, Asia Publishing House
2. Analytical Experimental Physics: M. Ferenc Jr., H.B. Lemon and R.J. Stephenson (1970) University of Chicago Press
3. The Art of Experimental Physics: D.W. Preston and E.R. Dietz (1991) John Wiley

PHY 443	Physics at Nanoscale	3 credits
----------------	-----------------------------	------------------

Introduction: An introduction to nanoscience and its applications, provides a flavour of the current excitement in the field of nanoscience. This course should be of interest to physics, chemistry and biology students.

Contents: Why nanoscience? What is nanotechnology? Historical perspective. size effect (colour, melting, magnetism etc. and Lotus effect, Gecko effect). Clusters: noble metal, semiconductors, magnetic. Magic numbers. Quantum confinement: quantum wells, wires and dots. Effective mass, excitons, plasmons, scaling laws. Hydrophobic-hydrophilic surfaces, self assembly. Some special materials: fullerenes, CNTs, graphene, porous materials (po-Si, MCM-41, SBA, MOF). Synthesis of nanomaterials: physical, chemical, biological methods. Nanofabrication. Analysis techniques: microscopy techniques, electron microscopes, scanning probe microscopes, diffraction techniques, X-ray and electron, spectroscopy techniques, optical and electron, Properties of nanomaterials: mechanical, thermal, structural, optical, electrical, magnetic, introduction to spintronics, GMR, CMR etc.

Recommended Reading:

1. Optical Properties of Semiconductor Nanocrystals (Cambridge Studies in Modern Optics): S.V. Gaponenko (1997) Cambridge University Press
2. Nanotechnology: Principles and Practices: S.K. Kulkarni (2009) Capital Pub. Co., New Delhi
3. Introduction to Nanotechnology: C.P. Poole, Jr. and F.J. Owens (2008) Wiley-India edition
4. The Physics of Micro/NanoFabrication: I. Brodie and J.J. Murray (1992) Springer, Plenum Press
5. Handbook of Nanofabrication: Ed. G. Wiederrecht, (2010) Elsevier B.V.

PHY 444

Biophysics II

3 credits

Introduction: This course, Biophysics II, will deal with molecules, cells and tissues. The novelty of this course will be an introduction to the non-equilibrium aspects of biophysics applied to molecules. The course will begin with a detailed treatment of the role of water and its biophysics and end with physics of developmental pattern formation. Assessment will be based on research paper reading, assignments, laboratories and a term paper. The term paper topic will be chosen by the student within two-weeks of the start of the course, a mid-semester update and an end-semester submission.

Content: Mathematics of water and crowding, dynamics of macromolecules particular molecular motors and the cytoskeleton, non-equilibrium approaches, mechano-biology of cells with a focus on muscles, nerves and stem cells, tissue dynamics and development (embryology), literature review, term paper, labs on macromolecular crowding and pattern formation.

Recommended Reading:

1. Mechanics of the Cell: D. Boal (2001) Cambridge University Press
2. Physical Biology of the Cell: Philips, Kondev, Theriot & Orme (2009) Garland Science, Taylor and Francis Group LLC.3
3. Biological Physics of the Developing Embryo: G. Forgacs and S. Newman (2005) Cambridge University Press
4. Biological Physics: P. Nelson (2007) W.H. Freeman
5. Biophysics: An Introduction: R. Glaser (2010, 2012) Springer
6. Life in Living Fluids: S. Vogel (1996) Princeton University Press
7. Lehrbuch Der Biophysik: E. Sackmann and R. Merkel (2010) Wiley-VCH Verlag GmbH & Co KGaA

Prerequisite: Biophysics I (PHY 414)

PHY 446

Physics of Materials

3 credits

Introduction: Material Science is an important area of research in modern

science. This is a highly interdisciplinary area where knowledge of Physics, Chemistry and Engineering is used to understand property of materials and that knowledge is used to design new materials with desired properties or improve/modify properties and functionalities of existing materials in response to the challenges in areas of energy, environment, medicine and manufacturing. As a physicist, one studies Condensed Matter, Quantum Mechanics, Thermodynamics and Statistical Physics. In this course the students will use these concepts to understand the physics of materials.

This course will be useful for BS MS students, and PhD and Int. PhD students, both in Physics and Chemistry, who are interested in the area of Material Science.

Contents: Introduction to material science; building crystals from atoms, structure property relationship, Electronic structure and phonons, Stability of structures: (a) thermodynamic stability (b) dynamic stability, Material properties: Mechanical; electrical; optical; magnetic and thermal, Defects, non crystalline solids and finite structures.

Types of materials: Metals, semiconductors, ceramics, polymers, composites, multi-functional materials.

Characterization techniques: Experimental: X-ray & neutron diffraction, electron microscopy, scanning probe microscopy, spectroscopy and surface analysis techniques, optical spectroscopy, magnetic spectroscopy

Computational: multi-scale modeling

Recommended Reading:

1. Atomic and Electronic Structure of Solids, E. Kaxiras, Cambridge
2. Physical Chemistry, Engel and Reid, Pearson
3. Other Recommended Reading from journals will be provided in class.

Prerequisites: Quantum Mechanics I (PHY 313), Statistical Mechanics I (PHY 321), Condensed Matter Physics (PHY 411)

PHY 452

Fluid Dynamics

3 credits

Introduction: This course will be useful for students wishing to gain an overview of the vast field of fluid dynamics. The course is aimed at imparting basic knowledge of the subject to facilitate research career in plasma physics, astrophysics, soft matter, biophysics, and computational fluid dynamics.

Contents: Conservation equations, The equation of continuity, energy and momentum flux; The Lagrangian and Eulerian description of fluid mechanics, Euler's equation of motion for Ideal flows, Potential flow and related problems, vorticity, Gravity waves. Deformation of continuous media, strain rate tensor, viscous stress tensor, the equation of motion for viscous flows (Navier-Stokes equation), Laminar flow and exact solution of Navier-Stokes such as flow in a pipe and rotating cylinder, the law of similarity and its use in solving unsteady flows. Reynolds's number and other dimensionless numbers in fluid mechanics, Prandtl's

formulation of boundary layers and related problems, Non-Newtonian flows.

Recommended Reading:

1. Fluid Mechanics, P. K. Kundu, I. R. Cohen and D. R. Dowling, Elsevier, 5th edition
2. Fluid Mechanics films produced by National committee on fluid Mechanics Films at MIT.
3. Fluid Mechanics: L.D. Landau and E.M. Lifshitz (2007) 2nd edition, Pergamon Press

Prerequisite: Electrodynamics (PHY 312)

PHY 453	Computational Physics	3 credits
----------------	------------------------------	------------------

Introduction: This advanced course aims to give the students competence in the methods and techniques of calculations using computers. The student can expect to get a hands-on experience in modeling, algorithm development, implementation and calculation of physical quantities of relevance in interacting many body problems in physics. Both quantum and classical computational tools will be introduced.

Contents: Introduction to Fortran 90; Numerical integration: *basic integration algorithms and schemes, Stochastic methods for multi-dimensional integrals*; Numerical solutions to differential equations: *Classical equations of motion, chaotic dynamics, time independent and time dependent Schrodinger equations*; Simulations of molecular dynamics, Monte Carlo simulations: *Metropolis algorithm for equilibrium statistical mechanics, classical models of magnetism, Ising model*; and exact diagonalization of many-body Hamiltonians.

Recommended Reading:

1. Computational Physics: J. Thijssen (1997) Cambridge University Press
2. Computational Physics, by N. J. Giordano and H. Nakanishi (Pearson Prentice Hall, 2006)
3. Fortran 90/95 for Scientists and Engineers, by S. Chapman (McGraw Hill, 2004)
4. Fortran 90/95 Explained, by M. Metcalf and J. Reid (Oxford university Press, 2002)
5. Numerical Recipes, by W. H. Press, S. A. Teukolsky, W. Vetterling, and B. P. Flannery (Cambridge University Press)
6. Computer simulation of liquids by M. P Allen, D. J. Tildesley , (Clarendon Press, 1987)
7. Understanding Molecular Simulation: From Algorithms to Applications by Daan Frenkel, Berend Smit (Academic Press, 2002)

Prerequisites: Quantum Mechanics I (PHY 313), Statistical Mechanics (PHY 321), Mathematical Methods (PHY 310)

PHY 461 **Quantum Field Theory** **3/4 credits**

Introduction: The goal of this course is to make students familiar with canonical Quantization formalism for scalars, fermions and gauge fields. This course will be useful for students in theoretical physics and students in experimental high energy physics. This course will be 4 credits for PhD students, and 3 credits for BS MS students.

Contents: Classical theories of fields, symmetries; Scalar field theory; Dirac field; Electromagnetic field; Quantum Electrodynamics

Recommended Reading:

1. An introduction to Quantum Field Theory, M. Peskin & D. Schroeder
2. Quantum Field Theory, Ryder
3. Quantum Field Theory in a Nutshell, A. Zee

Prerequisites: Classical Mechanics (PHY 311), Quantum Mechanics I & II (PHY 313, PHY 322)

PHY 462/656 **Plasma Physics** **3/4 credits**

Introduction: Plasmas in various forms constitute over 95% of the observable universe. An understanding of plasma physics in the laboratory context is key to the important push towards harnessing energy from nuclear fusion. This course will provide an overview of the theory of magnetohydrodynamics and plasma physics with a view to applications in astrophysics and in the laboratory. This course will be 4 credits for PhD students, and 3 credits for BS MS students.

Contents: Basics of plasma physics: Kinetics: Particle orbits, guiding center theory, the BBGKY hierarchy, Moments of the distribution function, wave-particle interactions (e.g., Landau damping), transport coefficients, Transition to the fluid description: Magnetohydrodynamics: basic governing equations, instabilities (sausage instability, kink instability, two stream instability, etc), waves in plasmas, applications to astrophysics (the solar dynamo, the solar wind, jets from compact objects) and laboratory plasma (column pinches, confinement)

Recommended Reading:

1. Plasma Physics: An Introduction to the theory of astrophysical, geophysical and laboratory plasmas: Peter A Sturrock (Cambridge)
2. The physics of plasmas: T J M Boyd, J J Sanderson (Cambridge)
3. The Physics of Fluids and Plasmas; Arnab Rai Choudhuri (Cambridge)

Prerequisites: Electrodynamics (PHY 312), Classical Mechanics (PHY 311)

PHY 463 **Advanced Condensed Matter Physics** **3/4 credits**

Introduction: This course will cover various interacting many-body phenomena, which will be a good foundation for those who are interested in theoretical,

experimental, and computational research in condensed matter. Lecture notes will be provided for most of the course content. This course will be 4 credits for PhD students, and 3 credits for BS MS students.

Contents: Interacting electrons (Many-body problem, Hartree-Fock approximation in second quantization, Brief overview on Density Functional Theory); Linear response theory (Fluctuation-dissipation theorem, Scattering, F-sum rule); Physics of disorder (Kubo formula for conductivity, Scaling theory of localization, Quantum hall effect); Magnetism (Local moment magnetism, exchange interaction, Band magnetism- Stoner theory, spin density wave, Anderson model, Kondo problem); Fermi liquid theory (Electron spectral function, Quasi-particles and Landau interaction parameter, Fermi liquid in Kondo problem); Superconductivity (Landau diamagnetism, London equation and effect of disorder, Ginzburg-Landau theory, vortices, Type II superconductor)

Recommended Reading:

1. Advanced Solid State Physics – Phillip Phillips
2. Solid State Physics, by N W Ashcroft and N D Mermin, Harcourt College Publishers. (College Ed.)
3. Theory of Quantum liquid, Pines and Nozieres, Westview Press
4. Theory of Superconductivity. J. Robert Schrieffer, Westview Press

Prerequisites: Condensed Matter Physics (PHY 411), Quantum Mechanics I & II (PHY 313, PHY 322)

PHY 301/302/401/402	Lab Training / Theory Project	3 credits
----------------------------	--------------------------------------	------------------

Introduction: This provides an opportunity for the student to work under the guidance of a faculty member on a topic of mutual interest over a semester. This can be a reading/literature review/theoretical or computational project/lab based research project. Any specialization or advanced training needed, in addition to the courses offered, can be achieved through careful choice of this lab training/theory project course.

Contents: The student has to identify, talk to and mutually agree on a research project before registering for this course. The scope, duration, structure, expectations, and evaluation criteria for the course are decided by the project supervisor.

Recommended Reading: As suggested by the project supervisor.

EARTH AND CLIMATE SCIENCE

The recently introduced courses in Earth and Climate Science at IISER Pune aim to enable students understand the basic principles and controlling factors of various geological, oceanic and atmospheric processes. These inter-disciplinary courses present combined applications of various branches of science (i.e. geology, physics, chemistry and mathematics) in yielding useful information on structure and evolution of our planet, magmatic and aqueous processes, and recent climatic changes through natural and man-made activities.

The courses offered in Earth and Climate Science are structured in two levels. The mandatory courses taught in the first two years introduce various geological reservoirs and feedback processes associated with them. The advanced courses deal with geophysical and geochemical approaches in understanding the internal dynamics of our planet and yielding quantitative information for processes responsible for reshaping the Earth and its resources.

The Earth and Climate Science program also offers semester-long laboratory training/theory project to the V-VIII semesters students. The main goal of these training/project courses is to provide students hand-on research experience in their topic of interest. During the final two (IX-X) semesters of the BS MS program, students can work on their MS thesis by carrying out an extended research projects for 36 credits.

List of Courses in Earth and Climate Science

Semester III

- | | | | |
|----|---------|----------------|-------------|
| 1. | ECS 201 | Earth System I | [2 credits] |
|----|---------|----------------|-------------|

Semester IV

- | | | | |
|----|---------|-----------------|-------------|
| 2. | ECS 202 | Earth System II | [2 credits] |
|----|---------|-----------------|-------------|

Semester V-VII

- | | | | |
|----|---------|-------------------------------|-------------|
| 3. | ECS 311 | Physics of the Earth | [4 credits] |
| 4. | ECS 312 | Isotope geochemistry | [4 credits] |
| 5. | ECS-301 | Lab Training / Theory Project | [3 credits] |
| 6. | ECS-302 | Lab Training / Theory Project | [3 credits] |
| 7. | ECS-401 | Lab Training / Theory Project | [3 credits] |
| 8. | ECS-402 | Lab Training / Theory Project | [3 credits] |

Details Of Courses In Earth And Climate Science

ECS 201	Earth System-I	2 credits
---------	----------------	-----------

Introduction: The Earth System operates through some fundamental cycles such as the Water, Energy, and the Carbon Cycles. This course deals with concept of feedbacks within the Earth System, global energy balance and the Greenhouse Effect. A brief introduction to the atmospheric and oceanic circulation will lead to the water cycle connecting the land, ocean, and atmosphere to the Earth System. Introduction to the Global carbon, nitrogen, and sulfur cycles will be followed by the concept of long-term climate regulation and short-term climate variability.

Contents: Global change on short and long time-scales: Global warming and Greenhouse Effects, role of long-term variability of solar luminosity. Introduction to Systems and feedbacks: Systems, components, Daisy World. Global Energy balance, Greenhouse effect: Greenhouse gases, clouds, radiation balance. Oceans and the Atmosphere: Wind-belts, ocean currents, Coriolis Effect, Solar forcing. Atmospheric and oceanic circulation, cells, seasons, deserts. Global Carbon Cycle: Recycling elements: Life on Earth, marine productivity, in/organic carbon, warm/cold waters, residence/response times, missing sink. Global Carbon Cycle: Ecosystems, biological pump, biomass, biodiversity, stability, and interactions with the environment. Other elemental cycles: Nitrogen, Phosphorus, Silica. Long-term Climate Regulation: Faint Young Sun Paradox.

Recommended Reading:

1. The Earth System by L. Kump, J. Kasting, and R. Crane, Prentice Hall, 3rd Edition, 2009.
2. Earth System Science by M. Jacobson, R. Charlson, H. Rodhe, and G. Orians, Academic Press, 1st Edition, 2000.

ECS 202	Earth System-II	2 credits
---------	-----------------	-----------

Introduction: Continuing with The Earth System-I, this course provides an integrated view of the Planet Earth dealing with the Earth's internal structure and processes (Earth materials, earthquakes, volcanism, plate movement), and surface processes.

Contents: Structure and composition of planets: a comparative study of the Earth and other planets; Understanding Earth Processes: Earth material, Rock formation processes and its deformation; Earthquakes and Earth Structure: Earthquakes due to brittle fracture; elastic wave propagation and detection; retrieving physical properties of the Earth's interior; Models of chemical constitution of the layered Earth; Earth's thermal state; convection in the outer core and the geomagnetic field; Plate Tectonics: A unique planetary mechanism for the outward flow of the Earth's internal heat (spreading center, transform fault, subduction).

Recommended Reading:

1. The Earth System by L. Kump, J. Kasting, and R. Crane, Prentice Hall, 3rd Edition, 2009.
2. Understanding Earth by J. Grotzinger and T J Jordan, W H Freeman and Co., 6th Edition, 2010.

ECS 311	Physics of the Earth	4 credits
----------------	-----------------------------	------------------

Introduction: This course is an essential introduction to how the solid Earth evolves, through tectonics, volcanism and near- surface activity as well as processes deep within our planet. It provided the physical and mathematical basis for understanding the processes and quantification of their response.

Contents: Earth surface topography, lithostatic equilibrium; Stress and Strain in solids: Body and surface forces, stresses and strain, transformation of stresses under rotation, local strain from the displacement field; Elasticity and Flexure of lithosphere; Fundamental of elasticity, 2-d bending of plates, Plate equation, thin plate limit, bending moment, Application to the Earth's lithosphere; Faulting and Deformation in the earth: Rheology, Rock fracture and friction, Mohr-Coulomb failure criteria, Strength of the lithosphere, Anderson theory of faulting, Earthquakes: magnitude, energy, global earthquake distribution, block-spring model of earthquakes; Heat Transfer and Temperature distribution in the earth: Earth surface heat measurement, Heat conduction and diffusion equation, Thermal structure of ocean and continental lithosphere, Past climate reconstruction.

Recommended Reading:

1. Geodynamics, by D. Turcotte and G. Schubert, 3rd Edition, 2014, Cambridge University Press.

ECS 312	Isotope Geochemistry	4 credits
----------------	-----------------------------	------------------

Introduction: This inter-disciplinary course aims to present application of (inorganic) chemistry in Earth and Climate sciences. We will discuss in detail how abundance and distribution of chemical elements (and their isotopes) can be used to understand various geological processes. The goal is to understand the behavior of selected isotopes in different geochemical reservoirs and applying these properties in the field of hydrology, ocean and climate sciences.

Contents: Properties of chemical elements; Stable and radioactive isotopes; Geochemical cycles; Mass dependent and independent fractionation; Analytical methods and isotope dilution; Binary Mixing; Solid Earth and magmatic processes; Chemical geodynamics; Radiogenic tracers and Geochronology; Paleothermometry; Reconstruction of past climate; Isotopes in the hydrology; Sub-marine groundwater; Application of isotopes in oceanography; Atmospheric chemistry.

Recommended Reading:

1. Geochemistry: An introduction by F. Albarede (2009), Cambridge University Press, 342 pp.
2. Isotope Geology, C. Allegre (2008), Cambridge University Press, 512 pp.

INTERDISCIPLINARY COURSES

IDC 101**Introduction to Computation****3 credits**

Introduction: The goal of this course is to teach the student to think like a computer scientist. This way of thinking combines some of the best features of mathematics, engineering, and natural science. Like mathematicians, computer scientists use formal languages to denote ideas (specifically computations). Like engineers, they design things, assembling components into systems and evaluating tradeoffs among alternatives. Like scientists, they observe the behavior of complex systems, form hypotheses, and test predictions. The single most important skill for a computer scientist is problem solving. Problem solving means the ability to formulate problems, think creatively about solutions, and express a solution clearly and accurately. As it turns out, the process of learning to program a computer is an excellent opportunity to practice problem-solving skills.

Contents: Variables, expressions and statements; Values and types; Variable names and keywords; Operators and operands; Expressions and statements; Order of operations; String operations; Functions; Function calls; Type conversion functions; Math functions; Composition; Adding new functions; Flow of execution; Parameters and arguments; Variables and parameters are local; Stack diagrams; Fruitful functions and void functions; Encapsulation; Generalization; Conditionals and recursion; Modulus operator; Boolean expressions; Logical operators; Conditional execution; Alternative execution; Chained conditionals; Nested conditionals; Recursion; Infinite recursion; Composition; Iteration; Multiple assignment; Updating variables; The while statement; break; Square roots; Algorithms; Strings; Lists; List operations; List slices; List methods; Map, filter and reduce; Dictionaries; Dictionary as a set of counters; Looping and dictionaries; Reverse lookup; Memos; Global variables; Long integers; Sequences of sequences; Random numbers; Files; Reading and writing; Filenames and paths; Classes and methods; Object-oriented features; Operator overloading; Polymorphism; Debugging; Inheritance; Card objects; Class attributes; Class diagrams; Analysis of Algorithms; Order of growth; Analysis of basic Python operations; Analysis of search algorithms.

Recommended Reading:

1. Think Python: How to Think Like a Computer Scientist: A. Downey (2012) O'Reilly
2. Python Programming: An Introduction to Computer Science: J. Zelle (2003) Franklin Beedle & Associates
3. Programming Pearls: J. Bentley (1999) 2nd edition, Pearson
4. How to Solve It by Computer: R.G. Dromey (2006) Pearson
5. Thinking in Java: B. Eckel (2000) Pearson
6. Structure and Interpretation of Computer Programs: H. Abelson, G.J. Sussman and J. Sussman (1996) MIT Press
7. Introduction to Computing: Explorations in Language, Logic, and Machines: D. Evans (1996) Createspace

IDC 102

Mathematical Methods

3 credits

Introduction: This course surveys the basic mathematical methods required by any undergraduate student of the natural sciences.

Contents: Basic calculus with emphasis on trigonometric, exponential and log functions; sketching functions of one variable; basics of complex numbers; vectors and matrices; partial differentiation; vector calculus; line integrals, surface integrals, volume integrals; ordinary differential equations; Fourier series and transforms.

Recommended Reading:

1. Mathematical Methods for Physics and Engineering, K.F. Riley, M.P. Hobson and S.J. Bence
2. Mathematical Methods in the Physical Sciences, M. L. Boas

IDC 202

Optics

2 credits

Introduction: To introduce students to fundamental effects of light (as a wave) such as diffraction, interference – and to introduce the fundamentals of optical instruments such as microscopes and telescopes.

Contents: Modern day classical optics – an introduction, Interference, Diffraction, Polarization, Scattering of light, Introduction to lasers, Optical techniques and instrumentation, Introduction to optical imaging, Microscopes, Telescopes, Interferometry, Holography, Polarimetry, Optics in physics, chemistry, biology and engineering

Recommended Reading:

1. Optics, Eugene Hecht, Addison-Wesley; 5th edition, (2015)
2. Classical Optics and its applications, Masud Mansuripur, Cambridge University Press; 2nd edition, (2009)

HUMANITIES AND SOCIAL SCIENCES

HSS 102	Critical Reading and Communication (Topic: Science and Society)	2 credits
----------------	--	------------------

Introduction: This course has dual aims. The first is to develop skill sets applicable to a wide variety of settings for (1) critical reading and thinking; (2) effective writing in terms of appropriate language, organizational structure and sound content; and (3) oral presentations (including PowerPoint presentations). The second is to explore the natural sciences in the broader context of the philosophy and implications of Science, the impact of the sciences on society and vice-versa, and to study the relationships between Science, the Humanities, and the Social Sciences.

Contents: The course content includes assigned non-technical articles and videos on variety of topics related to science and society: the history of science & technology; biographies of scientists; the interactions between sciences and humanities; overlaps of and differences between the social sciences and natural sciences; the impact of social differences (e.g. gender/ class/ region etc.) and social institutions (e.g. nationalism/ politics/ religion) that affect scientific practice. Students are expected to analyze these topics through the study material provided, complete written assignments, and make presentations on a variety of topics.

Material: All study material and tasks will be provided by the instructors.

HSS 201	An Introduction to the History of Science, Technology and Medicine	2 credits
----------------	---	------------------

Introduction: 1) To introduce key concepts in the history of science, technology and medicine and to place them in their social contexts. 2) To develop analytical skills that allow students to recognise, test and deploy arguments in a logical, methodical and stepwise manner as they evolve.

Contents: Selected case studies in the history of science, technology and medicine drawing upon the four Greek elements, water, air, earth and fire, as points of departure. For instance, the making of the Panama Canal in the early 20th century in the context of architectural innovation, political will and advancements in germ theory. Included are field components, discussions and short writing projects that involve bibliographic searches, both print and web-based, in order to enable students to get a basic grasp through real-life examples of what is at stake in the study of science and its applied allies, technology and medicine.

Material: Recommended course readings and audio-visual content will either be provided by the instructor and/or will be available in the library. Exemplary sources are:

1. Jared Diamond, *Guns, Germs and Steel: The Fates of Human Societies* (New York/London: W. W. Norton & Co., 1997)

2. Roy Porter, *The Greatest Benefit to Mankind: A Medical History of Humanity* (New York: Norton, 1997)
3. Jon Agar, *Science in the Twentieth Century and Beyond* (Cambridge, UK/Malden, MA: Polity Books, 2012)
4. Carl Charlson (Director), *Panama: A Man, A Plan, A Canal* Nova Films (USA), 2004

HSS 311

**Other Ways of Seeing:
Introduction to Qualitative Research**

3 credits

Introduction: This course will introduce students to qualitative research, some of its methodological approaches, and its rationales and philosophies. We will discuss in a historical context how various research methods have developed over past three centuries and understand qualitative research in comparison to quantitative methods. We will get acquainted with qualitative research approaches used in disciplines such as Anthropology, Sociology, History, Science and Technology Studies, etc. and their relevance in traditional science topics.

Contents: The course content includes readings on approaches such as ethnography, historical research, actor-network theory, cultural studies, etc. We will discuss methods and case studies that will cover science-related topics as studied through these approaches. The course involves readings (out of class) and in-class discussions of assigned articles/book excerpts. Students are expected to participate in discussions, conduct research (library and/or field) and write one essay and two two-page assignments.

Material: All readings will be provided by instructor as pdfs. They will include articles/book excerpts such as: Bruno Latour, “The Historicity of Things: Where Were Microbes before Pasteur”; Thomas Kuhn, *The Structure of Scientific Revolutions*; Joan Roughgarden, *Evolution's Rainbow*; Steven Mithen, *The Singing Neanderthals*, etc.

HSS 301/302/401/402

Topics in the History of Science

3 credits

Introduction: 1) To approach themes and topics in the history of science and locate them socio-culturally 2) To read extensively on such themes for weekly discussions 3) To develop written skills in analyzing and presenting arguments both synthesized (from the readings) and original in a cogent framework.

Content: Topics are chosen for analysis. The tutorial will involve the reading of texts for deliberation with the instructor on a weekly basis, with a final 12-15 page essay on a topic developed by the student, drawing upon course material as well as further reading of his/her choice, responding to what has been gleaned in the class.



Indian Institute of Science Education & Research (IISER) Pune

Dr Homi Bhabha Road, Pashan, Pune - 411008

Tel: +91 20 2590 8001 Fax: +91 20 2586 5086

www.iiserpune.ac.in