PHY 616(A) (Soft Matter Physics) 2014-15 IInd

Course objective:
Soft condensed matter is a rapidly expanding discipline in the interface between physics, chemistry and chemical engineering, often including biophysics and biochemistry. The area encompasses many surface phenomenon and materials such as polymers, gels, colloids and biological macromolecules (e.g. proteins). The aim of this course is to provide a foundation for understanding and utilization of properties and behavior of soft matter. After the course the students should be able to define and discuss the basic concepts and physics of soft matter and explain universalities between and within subclass of soft matter and how they are interrelated.

Course content:
Introduction to Soft Matter, Forces, energies and timescales in soft matter, Thermodynamic aspects of intermolecular forces, van der Waals force, Hydrophobic and hydrophilic interaction, Interfacial phenomenon; wetting, adhesion and friction, Mechanical properties, Introduction to complex fluids, Fluid flow and hydrodynamic instabilities, Foams and emulsions, Polymers, colloids and Surfactants, Liquid crystals, Self-assembly in soft matter, Experimental tools for soft matter.

Books recommended:
1. *Intermolecular and Surface Forces* by Jacob N. Israelachvili (Academic Press, 1998)
2. *Soft Condensed Matter* by R. A. L. Jones (Oxford University Press, 2002)
3. *Principles of Condensed Matter Physics* by P. M. Chaikin and T. C. Lubensky (Cambridge University Press, 1995)
4. *Hydrodynamic and hydromagnetic stability* by S. Chandrashekhar (Oxford University Press, 1981)
5. *Structured Fluids* by Thomas A. Witten (Oxford University Press, 2004)
6. *Structure and Rheology of Complex Fluids* by Ronald G. Larson (Oxford University Press, 1999)

INDIAN INSTITUTE OF TECHNOLOGY KANPUR
Department of Physics

PHY618A: **Physics of Life**
Instructor: Debashish Chowdhury
Pre-requisite: Basic Thermodynamics/Thermal Physics

Course objective:

Living matter is no different from matter that constitutes non-living systems. What makes living systems different from non-living ones are some ``processes'' that occur only in living systems. These dynamic processes are governed by the same laws of physics (and chemistry) that were discovered in non-living systems. The movements of biological systems are caused by real physical forces (and not by any `vital force'), the laws of thermodynamics impose constraints on which processes are possible, and laws of kinetics impose constraints on the rates of those processes. Life, which originated in aqueous environment, depends on the delicate balance of hydrophilic and hydrophobic interactions. The signaling in living systems depends on traffic of ions. Therefore, understanding of life as a process cannot be complete without insight into the physics of these processes. This course is an elementary introduction to the physical principles underlying the key dynamic processes in living systems.

Course Contents:

(1) **Inter-molecular interactions, binding and bonding in living systems**: Introduction to conservative, dissipative and random forces; molecular binding events, covalent and non-covalent bonds; interaction of macromolecules with small ligands; protein-nucleic acid interactions- specific versus non-specific interactions; ligand-receptor interaction- slip bond versus catch bond.

(2) **Statistical thermodynamics for living systems**: Concepts of conformation and structure of a macromolecule of life; free energy change and generalized chemical force; concepts of thermodynamic equilibrium and non-equilibrium steady-state; coupled processes and energy transduction in a living system; efficiency at maximum power; power stroke versus Brownian ratchet.

(3) **Stochastic kinetics of mechano-chemical processes in living cells**: Stochastic stepping of a motor protein; stochasticity in enzymatic reactions in a living cell- fluctuations around Michaelis-Menten rate; substrate specificity of an enzyme- role of fluctuation and conformational selection, kinetic proofreading for specificity amplification and role of energy dissipation.

(4) **Cellular and intracellular movements** : Diffusion- transport in bacterial cells; transport by motor proteins in eukaryotic cells; cooperativity of motors in vesicular transport; bi-directional movements of organelles by competing motors; motor-driven export/import of polymers of life across internal membranes; movements of chromosomes in metaphase and anaphase; swimming and gliding of bacteria; crawling of cells and collective migration.

(5) **Polymers of life and template-directed polymerization**: curvature and bending elasticity, thermal fluctuations and persistence length; stochastic elongation of a growing polymer, competing demands of speed and fidelity; stall, backtracking and slippage of polymerization machinery; collision of polymerization machines in traffic on a template.

(6) **Entropy, information, self-organization and emergence of life**: Shannon entropy and information; evolution of genetic information encoding and processing mechanisms; essential signatures of life and its definition- debates and controversies; plausible pathways for emergence of life- roles of energy and information.

Text Books and References:

1. "Physical Biology of the Cell", by R. Phillips et al. (Taylor & Francis, 2009)
2. "Biological Physics: Energy, Information, Life", by P. Nelson (Freeman, 2014).
3. "Mechanics of the Cell", by D. Boal (Cambridge Univ. Press, 2012).
4. "Biophysics: searching for principles", by W. Bialek (Princeton Univ. Press, 2012)

PHY 621

Electronic Structure of Materials

Prereq. (For M.Sc. and Undergraduate students PHY 543, None for Ph.D. students)

Instructor: R. Prasad
Office: FB 373, Phone: 7065, email: rprasad@iitk.ac.in

Knowledge of electronic structure is essential to understand electronic, magnetic, transport, optical and various other properties of materials. The course aims to give an overview of basic concepts involved and various approaches for calculating electronic structure. These approaches are based on the density functional theory. The course will be particularly useful for Ph.D. students who want to work in this area or want to understand their experimental results using electronic structure calculations. Project work will form an important component of the course. The students should have some knowledge of computer programming.

Course content:

One electron model, Born-Oppenheimer approximation, Hartree & Hartree-Fock approximation, density functional theory, local density approximation, beyond LDA. electrons in periodic solids, Bloch's theorem, nearly-free electron model, energy bands, Fermi surface, The tight-binding method, APW method, OPW method, pseudo-potential method, KKR method, LMTO method, the full-potential methods. applications to different types of solids; electron in disordered solids, mean-field theories, coherent potential approximation, KKR-CPA. Applications of KKR-CPA, tight-binding molecular dynamics, applications to clusters and solids, Car-Parinello methods and its applications to clusters and amorphous semiconductors, applications of electronic structure methods to materials design.

Reference Books:

1. Electronic Structure of Materials by R. Prasad
2. Electronic Structure by R. M Martin

Course contents of PHY 644 Quantum Electronics:
Gaussian beams and optical resonators
Semi-classical theory of lasers
Interaction of radiation with atomic systems
Physics of laser oscillation, Q-switching and mode-locking
Noise and spectra of optical amplifiers and oscillators
Coherence in lasers and coherent effects (superradiance, photon echoes)
Nonlinear optical effects (second- and third-order)

General Relativity and Cosmology (PHY660)

Instructors: Pankaj Jain and Suratna Das

Pre-requisite: PHY407, Special and General Relativity (or consent of the instructor)

Course Content:

Mach's principle, Riemannian geometry, energy-momentum tensor and Einstein's equations. Schwarzchild metric and singularities of space time, post-Newtonian approximations, gravitational radiation, Introduction to cosmology.

Note: roughly half the course will be devoted to cosmology.

Pankaj Jain

First Handout for PHY-680/680A: Particle Physics

Instructor: Kaushik Bhattacharya[1]
Office: FB-387, Phone: 7306

The course is designed according to the syllabus set by the Institute. Throughout the course the emphasize will be on the inherent symmetries in nature as parity, charge-conjugation and time-reversal. More over we will try to focus our attention on global as well as local gauge symmetries which dictates much of the nature of particle physics. The subject will be built up by referreing to, and interpreting the results, of the various pathbreaking experiments which shaped the history of modern particle physics. The course will end with a brief encounter with the standard model of particle physics. I will assume that the students have an understanding of the following:

- special theory of relativity.
- Very basics of quantum field theory.
- Some amount of group theory.

People who are not aware of these topics are requested to go through them once such that they can understand the class proceedings. The very basic books they can consider to brush up their basics are as follows.

- **Introduction to Elementary Particles**, by David Griffiths.
- **A First Book of Quantum Field Theory**, by Amitabha Lahiri and Palash Baran Pal.

As particle physics requires a moderately fair amount of knowledge of special relativity and group theory the students are advised to look up to these topics before the actual classes start.

The grading pattern for the course is as follows:

1. First quiz 10 marks.
2. Midsem examination will have 80 marks.
3. Second quiz will have 10 marks.
4. Final examination will have 100 marks.

[1]Email: kaushikb@iitk.ac.in

There will be homeworks given in the class which the students are supposed to solve. If they find any difficulty with the problems they can always meet the instructor at any convenient time. Some of the problems in the exams will come from the homeworks.

The students are required to attend each and every class of the course, as missing some of them will become a heavy burden at the time of examinations. The books which can be consulted:

1. **Quarks and Leptons**, by F. Halzen and D. Martin.

2. **Gauge Theory of elementary particle physics**, by Ta-Pei Cheng and Ling-Fong Li.

3. **An Introduction to Quantum Field Theory**, by Michael E. Peskin and Daniel V. Schroeder.

These are only some books out of many good books. The students are free to consult any book of his/her choice. The main course may or may not follow any of the particular books, listed above, in great detail but the above set of books offers a comprehensive understanding of the topics which will be covered in the particle physics course.

Gauge Theory and Renormalization (PHY690N)
Instructor: Sayantani Bhattacharyya

Prerequisite: Quantum Field Theory-I (PHY681/681A)

1. In the first part, we shall start with the formal aspect of path integral methods in Quantum mechanics and field theory. In particular we shall study the the convergence of the path-integral, how to take the classical limit and how to systematically move away from the classical picure in loop expansion.

2. Next we shall use this method to study systems with local symmetry (called gauge symmetry) in detail.

3. In the final part we shall study how, depending on the 'length scale' or the 'energy scale' of our description, we can use an effective field theory to study the properties of the system. This is what we call 'renormalization'.

PHY693: Introduction to Spintronics (2014-15-II)

Instructor*:* Amit Agarwal, Physics Department, IIT Kanpur

Prerequisite:

The students should have a background in quantum mechanics at least at the level of PSO201 or Phy204 or Phy431 . Some basic understanding in condensed matter physics is also desirable.

Course Content:

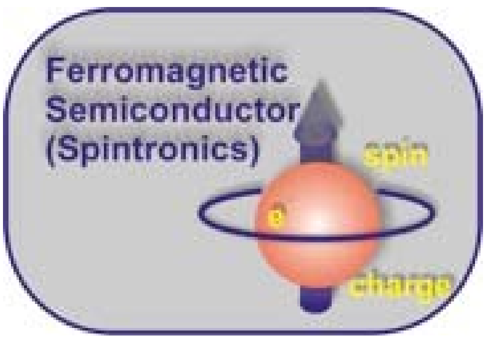
The aim of this course is to systematically develop the theory of spin-based device applications from basic principles to an advanced level. We will introduce the essential theoretical formalism at an accessible level with illustrations of experimental results. This course will be useful for PG as well as advanced UG students.

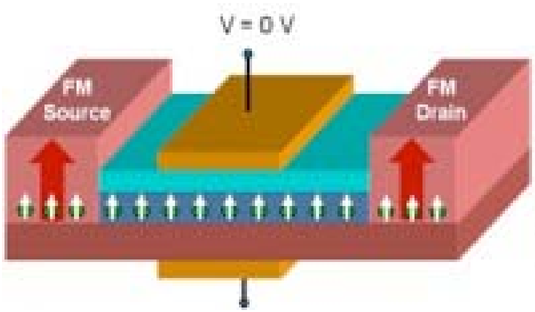
We plan to discuss the following topics in this course:

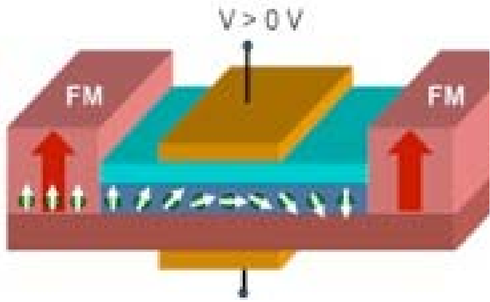
1) Introduction, quantum mechanics of spin, Density matrix and Bloch sphere etc.
2) Review of magnetism in condensed matter systems (Ferro, para and diamagnetic materials and basic models).
3) Spin-orbit interactions in condensed matter systems (Rashba, Dresselhaus etc, Dutta-Das transistor)
4) Spin Dynamics and variuos relaxation mechanisms (D'yakonov-Perel, Elliott-Yafet etc.)
5) Spin transport (Spin current, spin torque, spin Hall effect, spin Hanle effect, Drift Diffusion model etc.)
6) Spin Based Devices (Spin Valves, Magnetic Tunnel junction, GMR, spin transfer torque, spin FET, other topics of recent interest.)

References:

1) Introduction to Spintronics by S. Bandyopadhyay and M. Cahay, CRC Press, 2008
2) Semiconductor Spintronics (Tutorial Review) by J. Fabian, A. Matos-Abiague, C. Ertler, P. Stano, and I. Zutic, arXiv:0711.1461
3) Spintronics: Fundamentals and applications, I. Zutic, J. Fabian, and S. Das Sarma, Reviews of Modern Physics 76, 323 (2004)

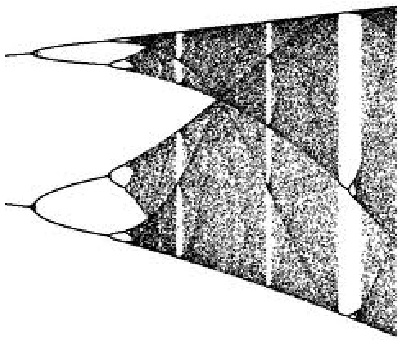






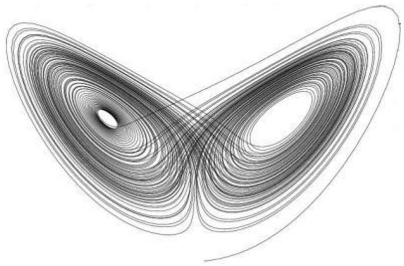
PHY695: Nonlinear Systems and Dynamics

Instructor: *Sagar Chakraborty, Department of Physics, IITK.*



Prerequisite: ***NONE*** but a background in Lagrangian and Hamiltonian mechanics would be helpful for some parts of the course.

Course contents (broadly): Dynamics in phase space, low dimensional flows (1D, 2D, 3D), Stability analysis, Attractors, Perturbation methods, Central manifold theory, Bifurcation theory, Normal forms, Maps (1D, 2D), Quasiperiodicity, Renormalization, Routes to Chaos, Hamiltonian chaos, Multifractals.



References (among others):

(1) *S. H. Strogatz*, Nonlinear Dynamics And Chaos, Westview Press (2001).
(2) *R. C. Hilborn*, Chaos and Nonlinear Dynamics, Oxford University Press (2001).
(3) *J. Arg*yris*, G. Faust, & M. Hasse*, An Exploration of Chaos, North Holland, Elsevier (1994).
(4) *M. Tabor,* Chaos and Integrability in Nonlinear Dynamics, Wiley-Interscience (1974).
(5) *J. Banks, V. Dragan, & A. Jones*, Chaos: A Mathematical Introduction, Cambridge University Press (2003).
(6) *S. Wiggins*, Introduction to Applied Nonlinear Dynamical Systems and Chaos, Springer (2003).
(7) *H. G. Schuster*, Deterministic Chaos, Wiley-VCH (1995).
(8) *E. A. Jackson*, Perspective of Nonlinear Dynamics (Vol. I & II), CUP (1992).
(9) *A. Lichtenberg & M. Lieberman,* Regular and Chaotic Dynamics, Springer (1992).