Course Content

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Physics Courses

Mathematical Physics 1
Learning Outcomes:

- To develop computational models using Python
- Ability to use concepts of vector spaces and linear transformation in physics and for mathematical modelling
- Geometrical understanding of calculus of many variables and ability to apply it in physics and mathematics

Lab 1: Introduction to Physics through Experiments
Learning Outcomes:

- Design experiments and make observations
- Analyse the information collected
- Match them against theory-based expectations, and in general draw inferences.

Classical Mechanics
Learning Outcomes:

- Learning how Euler, Lagrange, Hamilton, and Jacobi reformulated the laws of motion
- Learn to solve problems more comfortably using scalar equations of motion
- Understand the appearance and importance of the symmetries in physics

Electromagnetism in Light of Relativity
Learning Outcomes: Understanding the fundamentals of -

- Electrostatics: Fields, potentials, work and energy,
- Potentials: Laplace equation, method of images, multipole expansion
- Magnetostatics: Forces, role of currents, vector potential
- Special theory of relativity: Lorentz transformation, four vectors

- Unification of E and B, Maxwell's equations
- Electric field in matter: conductors, dielectrics, superconductors
- Magnetic field in matter: Diamagnets, paramagnets and ferromagnets

Lab 2: Classical Mechanics and Electromagnetism
Learning Outcomes:

- This laboratory based course is designed to accompany the theoretical courses namely, Classical Mechanics and Electricity in Magnetism in Light of Relativity. We will try to understand the Newton's law of motions, terminal velocity, Eddy current damping, basic electronics etc.
- List of experiments:
  1. Kater's pendulum
  2. Free fall
  3. Air track
  4. Electromagnetic damping
  5. Equipotential curves
  6. Electronics circuits

Mathematical Physics 2
Learning Outcomes:

- This mathematical physics course aims to be an introduction to differential equations with a view towards physical applications (especially in later physics courses).
- Ordinary differential equations (first order): Overview and importance. Rate of change problems, modeling simple systems, population growth, logistic curve. First order linear equations, Integrating factors. linear ODEs with constant coefficients. Phase plane, coupled systems of linear first order ODEs.
- Nonlinear ODEs and Dynamical systems: phase portraits, flows and vector fields, phase plane analysis, linearisation about fixed points, stability analysis, limit cycles and bifurcations. Brief discussion of chaos.
- Second order ODEs: Power series solutions, some special functions (Bessel, Legendre and Hermite). Fourier Series and Fourier integrals with a few physical applications
- Partial differential equations: Linear first and second order PDEs, separation of variables, illustration through Laplace's equation/ wave equation/ diffusion equation.

- A familiarity with linear differential equations and analytical ways of solving them; Also an acquaintance with basic geometric/qualitative ways of understanding nonlinear systems (linearisation, stability, fixed points, flows, phase portraits etc.)

Oscillations, Waves and Optics
Learning Outcomes:

- Harmonic oscillator: undamped, damped, forced; Coupled oscillators: Normal modes and normal coordinates; Standing wave: Fourier series and decomposition into normal modes; Travelling waves: Sound waves, Doppler effect, Transmission of energy and momentum; Dispersive systems: Phase and group velocity; transmission of waves presence of a boundary between different media
- Electromagnetic waves: unbounded medium, Boundary conditions, Reflection and transmission, Total internal reflection, conductors; Optical waveguides: TE and TM modes; Polarization electromagnetic waves: linear and circular polarization; Interference: Amplitude division, Wave-front division; Diffraction: diffraction integral, Fraunhofer and Fresnel diffraction

Thermal Physics
Learning Outcomes:

- Topics that this course will cover include: the history of thermodynamic thought, fundamental relations in the energetic and entropic representations, the first, second and third law of thermodynamics, the Gibbs and Euler relations, Legendre transformations and free energies, Maxwell relations, Carnot cycles and their interpretation, useful work and the relation to statistical physics.
- The emphasis will be on the development of the right intuition in its historical context, the codification of this intuition in terms of the laws of thermodynamics and how to understand them and, actual calculations of relevance to real life

Lab 3: Optics, Oscillations and Thermodynamics
Learning Outcomes:

- This laboratory based course is designed to accompany the theoretical courses namely, Optics, Oscillations and Thermodynamics
- List of experiments:
    1. Coupled pendulum
    2. Acoustics
    3. Diffraction

4. Polarisation.
5. Interferometry
6. Thermometry
7. Wein's Displacement Law

Statistical Mechanics
Learning Outcomes:

- In this course we will use statistical mechanics to study simple classical and quantum systems, with and without interactions. We will begin by understanding how the thermodynamic description of a simple system like an ideal gas in equilibrium can be found from statistical mechanics, and go on to more complex systems, both classical and quantum, that would be difficult to grasp using thermodynamics alone.
- We will learn to describe fluctuations about equilibrium, which tell us about the stability of equilibrium states and are also related to equilibrium properties like specific heat and compressibility. And we will try to understand the basic ideas of equilibrium between phases, and, through computational exercises, of transformation between them.

Quantum Mechanics
Learning Outcomes:

- Learning Quantum Mechanics opens up a world of possibilities, given its range of applications throughout physics (and beyond).
- By the end of this course, it is expected that students will have a firm foundation in the fundamental concepts of QM, will be familiar with both the state-vector and wave mechanics based approaches
- Gain the relevant background to explore and understand the manifold applications of QM to explain diverse physical phenomena, be it in Atomic, Molecular, Nuclear, Particle Physics or Quantum Information or Condensed Matter physics.

Lab 4: Quantum Mechanics and Statistical Mechanics
Learning Outcomes:

- The Lab-4 will have the following experiments and these experiments are broadly based on the principles of quantum mechanics and statistical mechanics.
- List of experiments:
  1. Hall effect
  2. Magnetic susceptibility by Quincke's Method

3. Zeeman effect
4. Brownian motion
5. e/m by Thomson's method and Helmholtz coil
6. Millikan's oil drop experiment

Computational Physics
Learning Outcomes: Techniques Learned -

- Review of basics of computations: integers, floating point numbers, errors
- Hand-warming exercises: machine precisions, quadratic equation, series summation, stability analysis of programs
- Recursive programming
- Interpolation, Root finding, fractals
- Use of random numbers: shuffling, probability distributions
- Integration: Basic rules and Monte Carlo
- Monte Carlo methods in physics, economics, epidemics
- Curve fitting
- Differential equations: 1st order equation, diffusion equation (focus on stability), general methods
- More on fractals, other problems involving random numbers, matrix problems

Physics of Matter (ongoing)

- Drude theory of metals:Basic assumption of theory, Equation of motion, DC conductivity, Hall effect, AC conductivity, thermal conductivity, Wiedemann-Franz law
- Sommerfeld theory of metals: Free electron(Quantum picture), Periodic boundary condition, Density of state, Fermi energy, Fermi temperature, Ground state energy Fermi pressure, thermal properties of free electron gas (specific heat), Wiedemann-Franz law
- Crystal structure: Bravais lattice, primitive vectors, 2d and 3d lattices, primitive unit cell, Wigner Seitz cell and conventional cell, packing fraction
- Reciprocal lattice: Diffraction from periodic structure, Laue condition, Reciprocal lattice vector, Brillouin zone, Lattice plane and Miller indices, Bragg formulation of diffraction, Von Laue formulation of diffraction, Bragg planes, Ewald construction

- Lattice vibrations: 1-d mono-atomic Bravais lattice, Dispersion relation, Specific heat of solid: High and low temperature, Boltzmann and Einstein model, Normal mode and phonon, Debye model for specific heat, 1-d diatomic chain, optical and acoustic branches and gap, Lattice thermal conductivity: Elementary kinetic theory

- Electrical properties of material: periodic potential and Bloch's theorem, crystal momentum, band gap (perturbation theory), Energy Band, mixing waves, Reduced and extended zone scheme, Semiconductor

- Magnetic Properties of Matter, Superconductivity, Soft Matters

Mathematical Physics 3 (ongoing)
Learning Outcomes:

- The course (MP3) will cover Complex analysis (functions, singularities, multivalued functions, differentiation, integration, analytic continuation, etc.), theory of distributions, Integral transforms like Fourier and Laplace transforms, Green's functions, second order differential equations and special functions

- Learning basic concepts and methodologies, which form the backbone of advanced topics in physics and allied subjects

Non-Equilibrium Statistical Mechanics (ongoing)
Learning Outcomes:

- This course explores different approaches to studying non-equilibrium systems and topics such as the Langevin equation, Fokker-Planck formalism, Martin-Siggia-Rose field theory, master equation, Boltzmann equation, and hydrodynamics to develop a broader understanding of non-equilibrium systems. Additionally, the course will cover established results such as the fluctuation-dissipation theorem, work theorem, linear response theory, and Onsager relations.

- Learning about problems and methodology at the frontiers of research.