University of Pune

Proposed Ph.D. Course work in Physics

Course Work will consist of Four courses

1. Each Course will be of 5 Credits.
2. Each Department head will appoint coordinator for Ph. D. teaching program.
3. Course 4 will be handled by concerned guide.

Course 1 : RESEARCH METHODOLOGY

Mode of study includes : Assigning the topic to students based on their basic background and presentation in the form of seminar which will be followed by discussion and submission of the write-up. This will be evaluated by group of teachers. There will not be any formal classroom teaching.

INTRODUCTION : Definition of Research, Qualities of Researcher, Components of Research Problem, Various Steps in Scientific Research : Hypotheses, Research Purposes, Research Design, Literature searching

DESIGN AND PLANNING OF EXPERIMENTS, TIME SCHEDULING : Aims and Objectives, Expected outcome, Methodology to be adapted, planning of experiments for achieving the aims and objectives, Importance of reproducibility of research work.

DATA COLLECTION : Sources of Data: Primary Data, Secondary Data; Sampling Merits and Demerits of Experiments, Procedure and Control Observations, Sampling Errors - Type-I Error - Type-II Error.

STATISTICAL ANALYSIS AND FITTING OF DATA : Introduction to Statistics - Probability Theories - Conditional Probability, Poisson Distribution, Binomial Distribution and Properties of Normal Distributions, Estimates of Means and Proportions; Chi-Square Test, Association of Attributes - t-Test - Standard deviation - Co-efficient of variations. Correlation and Regression Analysis. Introduction to statistical packages, plotting of graphs.

SCIENTIFIC WRITING : Structure and Components of Research Report, Types of Report: research papers, thesis., Research Project Reports, Pictures and Graphs, citation styles,

References:

1. “How to write and Publish” by Robert A. Day and Barbara Gastel, (Cambridge University Press).

2. “Survival skills for Scientists” by Federico Rosei and Tudor Johnson, (Imperial College Press).

3. “How to Research” by Loraine Blaxter, Christina Hughes and Malcum Tight, (Viva Books).

4. “Probability and Statistics for Engineers and Scientists” by Sheldon Ross, (Elsevier Academic Press).

5. “The Craft of Scientific Writing” by Michael Alley, (Springer).

6. “A Students's Guide to Methodology” by Peter Clough and Cathy Nutbrown, (Sage Publications).

COURSE 2 AND 3

Advanced courses I and II

Each course has several topics; out of these 5 are to be covered as per the background and requirement of students. Each topic is equivalent to 1 credit.

❖ **Course No. 2** **(5 Credits)**

There will be following eight modules. Each module is of 1 credit. Any five modules may be given.

- Quantum Mechanics
- Classical Mechanics
- Statistical Mechanics
- Electrodynamics
- Mathematical Methods in Physics
- Solid State Physics
- Nuclear Physics
- Atoms and Molecules

Students can opt any five modules to obtain five credits. Each module consists of 15 lectures, assessment and evaluation through seminars, assignments,tests etc.

QUANTUM MECHNAICS

One dimensional problems: potential wells, steps and barriers. Harmonic oscillator, Hydrogen Atom, Spherically symmetric potentials: Bound States and scattering. Partial wave method, the Born approximation. Time-independent and Time-dependent perturbation theory. WKB approximation. Symmetry in Quantum Mechanics, Identical particles and spin.

Quantization of the electromagnetic field in the Transverse gauge, Kramers-Heisenberg formula with applications to Thomson, Raleigh and Raman scattering.

Elementary introduction to relativistic quantum mechanics: the Klein Gordon and Dirac equations. Interpretations; Antiparticles.

Recommended Books:

Quantum Mechanics: L.I. Schiff (McGraw Hill)
Quantum Mechanics: A.S. Davydov (Pergamon)
Quantum Mechanics: Cohen-Tannaudji *et al.* (Wiley VCH)
Modern Quantum Mechanics: J.J. Sakurai (Addison-Wesley)
Relativistic Quantum Mechanics: J. Bjorken and S. Drell (McGraw Hill).
Advanced Quantum Mechanics, J. J. Sakurai (Addison-Wesley)
Relativistic Electron Theory, M. E. Rose (John-Wiley & Sons).
Quantum Electrodynamics, R. P. Feynman (Benjamin Cummings).
Lectures on Quantum Mechanics, G. Baym (Benjamin).
Quantum Field Theory, L. Ryder (Academic).

CLASSICAL MECHANICS

i) Newton's Laws and their meaning, simple applications conservation laws. Constraints and constraint forces. Principle of virtual work and D'Alembert's principle. Lagrange's equations, Integrals of motion.

ii) Rotating frames of reference, terrestrial applications.

iii) Central forces, Conservation of energy and angular momentum. Characteristics of resulting motion. Characteristics of bounded orbits. Kepler problem, planetary orbits, kepler equation. Conservation of electricity vector. Rutherford scattering formula. Conserved qualities.

iv) Legendre transformations and Hamilton's equations. Phase portraits of simple systems.

v) Principle of least action. Hamilton's principle. Noether's theorem. Hamilton's principal and characteristics functions.

vi) Canonical transformations. Generating functions examples.

vii) Hamilton – Jacobi theory. H-J equation. Connection with CT. Examples. Action-angle variables.

viii) Stable and unstable equilibria. Small oscillations. Normal mode analysis. Normal coordinates.

ix) Rigid body dynamics. Euler's theorm. Moment of Inertia calculations and theorems. Euler's equations of motion. Symmetric top.

x) Classical fields.

The teacher should cover the material worth 15 lectures spread over this syllabus.

Books - a) Classical Mechanics – Rana – Joag. TMH

b) Mathematical Methods of Classical Mechanics – V. I. Arnold. Springer.

STATISTICAL MECHANICS

UNIT-I

Probability distribution functions: Binomial, Gaussian, Poisson distribution functions. Probability density, probability for continuous variables. Brownian motion using 1-d Langevin equation, calculation of mean square displacement (MSD), (4 lectures)

UNIT-II

Maxwell-Boltzmann gas velocity and speed distribution. Chemical potential, Free energy and connection with thermodynamic variables, First and Second order phase transition; phase equilibria. (3 Lectures)

UNIT -III

Maxwell-Boltzmann, Bose-Einstein, Fermi-Dirac gases. Statistics of occupation numbers, Evaluation of partition functions, Ideal gases in the classical limit. (2 Lectures)

UNIT -IV

Thermodynamics of Black body radiation, Stefan-Boltzmann law, Wien's displacement law. Specific heat of solids (Einstein and Debye models). (3 Lectures)

UNIT -V

Ideal Fermi System : Thermodynamic behavior of an ideal Fermi gas, degenerate Fermi gas, Fermi energy and mean energy, Fermi temperature, Fermi velocity of a particle of a degenerate gas, (3 Lectures)

Reference books:

1. *Fundamentals of Statistical and Thermal Physics,* F. Reif (International Student Ed.) McGraw Hill.
2. *Statistical Mechanics*, K. Huang, John Wiley & Sons, 2nd Ed.
3. *Statistical Mechanics,* R. K. Pathria, (Pergamon Press).
4. *Fundamentals of Statistical Mechanics,* B. B. Laud, (New Age International Edition).
5. *Heat and Thermodynamics*, by Mark W. Zemansky and Richard H. Dittman (McGraw Hill)
6. *Statistical Physics*. (Vol. V) by Frederick Reif and R. A. Sevenich (Berkeley Physics Course)
7. *Statistical Mechanics* (Parts I and II) by. L. D. Landau and E. M. Lifshitz .
8. *Statistical Mechanics* (Frontiers in Physics) by Richard P. Feynman
9. *Thermodynamics and Statistical Physics* by P. V. Panat (Narosa)

ELECTRODYNAMICS

Electrostatics :

Coloumb’s law, Gauss’s law, Electrostatic potential energy (2 lectures)

Poisson and Laplace’s equations, Boundary value problems (2 lectures)

Magnetostatics:

Biot Savart’s law, Ampere’s law, Magnetostatic potential energy (2 lectures)

Multipole expansions of potentials, Linear dielectric and linear magnetic materials (2 lectures)

Motion of a charged particle in uniform, static, electric, magnetic and combined fields (2 lectures)

Time varying fields, Faraday’s law, Maxwell’s displacement current, Maxwell’s equations, Poynting’s theorem. (2 lectures)

Wave equations, Electromagnetic plane waves, Linear, circular and elliptic polarization Reflection and refraction of plane waves (3 lectures)

Books:

J. D. Jackson - Classical Electrodynamics

D. J. Griffiths – Introduction to Electrodynamics

J. R. Reitz, F. J. Milford, W. Christy – Foundations of Electromagnetic Theory

MATHEMATICAL METHODS OF PHYSICS

Problem solving using analytical and numerical methods

Vector calculus; Vector spaces, Linear transformations, Self-adjoint and unitary transformations, Inner product, orthogonality and completeness, matrices, similarity transformations, Eigenvalues and Eigenvectors of Hermitian and Unitary transformations, diagonalization using analytical and numerical methods. (5 lectures)

Linear differential equations and introduction to Special functions (Hermite, Bessel, Laguerre and Legendre); Solutions of differential equations using numerical techniques like Runge-Kutta method and other predictor-corrector methods (4 lectures)

Fourier series, Fourier and Laplace transforms; Numerical evaluation (2 lectures)

Elements of complex analysis: Cauchy-Riemann conditions, Laurent series-poles, residues and evaluation of integrals; (4 lectures)

Books:

Complex Analysis by Churchil

Mathematical Methods for Physicist by Arfken and Weber

Finite dimensional Vectror Spaces, P. Halmos

Mathematics of Classical and Quantum Physics by F. W. Byron and R.. W. Fuller

SOLID STATE PHYSICS

High Tc superconductors, Electrodynamic of superconductors, tunneling and Josephson effect.

Magnetic ordering, anisotropy, Thermal excitations of Magnons. Spin waves. FMR and NMR. Magneto-resistance effect, Spintronics.

Thermodynamics and ferroelectric domain formation. Piezoelectric effect. Multiferroics.

Books.

1. Introduction to Solid State Physics by C Kittel
2. Solid State Physics by N W Ashcroft and N D Mermin
3. Solid State Physics by A.J. Dekker

NUCLEAR AND PARTICLE PHYSICS

Basic nuclear properties: size, shape, charge distribution, spin and parity; Binding energy, semi-empirical mass formula; Liquid drop model;

Fission and fusion; Nature of the nuclear force, form of nucleon-nucleon potential; Charge-independence and charge-symmetry of nuclear forces; Isospin;

Deuteron problem; Evidence of shell structure, single- particle shell model, its validity and limitations; Rotational spectra;

Elementary ideas of alpha, beta and gamma decays and their selection rules;

Nuclear reactions, reaction mechanisms, compound nuclei and direct reactions; Classification of fundamental forces;

Elementary particles (quarks, baryons, mesons, leptons); Spin and parity assignments, isospin, strangeness; Gell-Mann-Nishijima formula; C, P, and T invariance and applications of symmetry arguments to particle reactions, parity non-conservation in weak interaction; Relativistic kinematics.

1) Concepts of Nuclear Physics, B. L. Cohen (Tata McGraw Hill)
2) Nuclear Physics - An Introduction, S. B. Patel
3) Subatomic Physics, Frauenfelder and Hanley (Prentice-Hall)
4) Nuclear Physics, I. Kaplan
5) Nuclei and Particles, Emilio Segre
6) Nuclear Radiation Detectors, S. S. Kapoor, V. S. Ramamurthy
7) Techniques for Nuclear and Particle Physics Experiments, W R Leo
8) Radiation Detection and Measurement, G F Knoll

ATOMS AND MOLECULES

Quantum states of an electron in an atom; Electron spin; Stern-Gerlach experiment;

Spectrum of Hydrogen, helium and alkali atoms;

Relativistic corrections for energy levels of hydrogen; Hyperfine structure and isotopic shift; width of spectral lines; LS & JJ coupling; Zeeman, Paschen Back & Stark effect;

X-ray spectroscopy; Electron spin resonance, Nuclear magnetic resonance, chemical shift; Rotational, vibrational, electronic, and Raman spectra of diatomic molecules; Frank – Condon principle and selection rules;

Spontaneous and stimulated emission, Einstein A & B coefficients; Lasers, optical pumping, population inversion, rate equation; Modes of resonators and coherence length.

1. Quantum Physics of Atoms, Molecules, Solids, Nuclei and particles by R. Eisberg and R. Resnick (John Wiley)
2. The elements of Physical Chemistry by Atkins (Oxford)
3. Quantum Chemistry, by I. N. Levine (Prentice Hall)
4. Atomic and Molecular Physics by H. E. While (East-West Press)

- **<u>Course No. 3</u>** **(5 Credits)**

- Physics & Application of Advanced Materials
- Experimental Techniques - (1) Material Characterizations.
- Experimental Techniques - (2) Spectroscopy & Other Techniques.
- Electronics & Instrumentation.
- Signal Processing & Analysis.
- Synthesis of Materials.
- Methods of Computational Physics

Students can opt any five modules to obtain five credits. Each module consists of 15 lectures, assessment and evaluation through seminars, assignments,tests etc.

PHYSICS AND APPLICATIONS OF ADVANCED MATERIALS

The unit will cover the underline physics and applications of advanced materials:

Quantum dots and 1-D nanostructures, Nanocomposites of inorganic and organic systems, Self-assembly hierarchic structures and advanced functional materials for applications in energy harvesting, nano/microelectronic devices, catalysis, sensors etc.

Reference Books:

1. Handbook of Advanced Materials, Enabling new designs Edited by James K Wessel, publisher: Wiley Interscience, 2004
2. Precursors Chemistry of Advanced Materials, Edited by lR. A. Fischer, Publisher: Springer.

EXPERIMENTAL TECHNIQUES -1

I Structural and Composition Characterization

a) Basics of radiation matter interaction, Basics of electron matter interaction, Basic properties of Fourier Transform, Elastic Scattering, Diffraction of electrons, photons and neutrons, Basic principle, advantages and limitations.

b) X-ray diffraction (φ scan, ω scan), Scanning Electron Microscopy- Energy Dispersive X-ray Analysis, Extended X-ray Absorption Fine Structure, X-ray Fluorescence, etc.

(5 lectures)

II Optical Characterization

a) Review of molecular structure and band structure, Basic principle, instrumentation, advantages and limitations.

b) Fourier Transform Infrared Spectroscopy (FTIR), UV- Vis. Spectroscopy, Room temperature as well as low temperature Photoluminescence, Cathode Luminescence.

(5 lectures)

III Magnetic and dielectric measurements

a) Review of magnetic materials, dielectric materials. Underlying principles, instrumentation, etc.

b) Vibrating Sample Magnetometer (VSM), Mössbauer spectroscopy, Impedance spectroscopy (Including case analysis for each technique)

(5 lectures)

EXPERIMENTAL TECHNIQUES -2

1. X- Ray Photoelectron Spectroscopy:-
   Basic principle, Brief idea of set up with significance of different parameters such as calibration using carbon C1s peak, Au $4F_{7/2}$, Resolution of energy analyzer etc and its influence on the spectra recorded. Sample handling and preparation, Depth profiling and interpretation of the spectra recorded after deconvolution – case study ZnO, MnO_2 (assignment to students)

   (3 – Lectures)

2. Raman Spectroscopy:-
   Basic principle, Brief idea of set up (includes source, detector, operating conditions (back scattered geometry, etc) excitation wavelength choice, Deconvolution of the peaks, analysis of the spectra based on peak position, FWHM of the vibrational modes, area etc.

   (3 – Lectures)

3. Scanning Probe microscopy –
   a) Atomic Force Microscopy: -Basic principle, Brief idea of set up –contact mode, tapping mode etc. Different modes of AFM and its importance. Other modified operation such as MFM etc.
   b) Scanning Tunneling Microscopy: -Basic principle, Brief idea of set up – details of components etc. Different modes of STM and its importance

   (6 – Lectures)

4. Transmission Electron microscopy:-
   Basic principle, Brief idea of set up, Sample preparation, imaging modes bright field imaging, dark field imaging, Selected area electron diffraction etc. (3 – Lectures)

Books:

1. XPS hand book by Briggs
2. IR and Raman spectra by Herzberg
3. Encyclopedia of analytical chemistry. Instrumentation and application (pg 9 – 84) Chapters by Prof. C. V. Dharmadhikari and R. A. Meyer, John Wiley U.K. (2000)
4. TEM: a text book for Material Science; by David B. Williams and C. Barry Carter (Springer Verlag) – 2009
5. Introduction to conventional TEM by Marc DeGraef (Cambridge Solid State Science) 2007

ELECTRONICS AND INSTRUMENTATION

Semiconductor device physics, including diodes, junctions, transistors, field effect devices, homo and heterojunction devices, device structure, device characteristics, frequency dependence and applications; Optoelectronic devices, including solar cells, photodetectors, and LEDs; High-frequency devices, including generators and detectors; Operational amplifiers and their applications; Digital techniques and applications (registers, counters, comparators and similar circuits); A/D and D/A converters; Microprocessor and microcontroller basics.

1. Fundamentals of Electronics, Malvino and Leach
2. Semiconductor Devices by S. M. Sze
3. Essentals of Semiconductor Physics by T. Wenckebach (Wiley)

SIGNAL PROCESSING AND ANALYSIS

Unit 1 Definition and classification of signals –continuous and discrete, Periodic non-periodic, deterministic and non-deterministic random signals with examples.
Operation on signals .Sine, cosine, unit impulse, sum, product, Time scaling, Integration and differentiation Linear and non-linear, Time variant and Non-Variant

Unit 2 Introduction to Linear Time Invariant systems, convolution Integral, Impulse response, Stability and Impulse response to standard signal

Unit 3: Definition and Properties of Laplace Transform , Fourier series and Fourier Transform, Wavelet transform, Application to LTI systems and relevant physical systems

Unit 4: Correlation Function, auto and cross Correlation Function, Properties of auto and cross Correlation Function, Correlation of Fourier series , Energy Spectral Density, Power Spectral density, applications to various types of signals.

Unit 5: Probability and Random Variables
Random Variables, Discrete Random Variables, probability density function, statistical average, standard derivation and variance, Binomial, Poisson , Gaussian Distributions

Unit 6: Signal conversions, Sampling basics, simple signal conversions systems, sampling theorem, Aliasing conversion of specific signals , A to D conversions and D to A conversions. Basics of Digital filtering, types of digital filters, FIR Filters and IR filters and their characteristics, Signal averaging ,a typical average.

Unit 7: Frequency Domain analysis of Discrete Time systems, DFT (Discrete Fourier Transform) Relation between impulse response and frequency response, Frequency selective systems and filters, Energy /Power spectral density
The Parsleys theorem: Specific for frequency domain
FFT: Determination and partitioning in time and frequency, FFT algorithms for a power of two number of points, Spectral analysis of real life signals
Unit 8: Wavelet Basics, Types of Wavelets-D4 and Meyer, Multi resolution analysis using pyramidal filter schemes, wavelet analysis of real life signals

Recommended Books

1.Alan V. Oppenheim, Ronald W. Schafer-"Discrete Time Signal Processing", Prentice Hall of India(Private) Limited, New Delhi,1994
2.Joan G. Proakis, Dimitris G. Manolakis-"Digital Signal Processing-Principles, Algorithms and Applications", Third Edition ,Prentice Hall of India(Private) Limited, New Delhi,1997.
3.Sanjit k. Mitra -"Digital Signal Processing Laboratory using MATLAB".:MC Graw Hill International Edition ,2000,Computer Science Series.
4. David J.DeFatta, Joseph G. Lucas, Williams S. Hodgkiss, "Digital Signal Processing-A systems Design Approach", John Willey and Sons, Inc. Pte Ltd., Singapore
5. W.J.Tomkins, "Biomedical Digital Signal Processing", EEE, 2003

SYNTHESIS OF MATERIALS

Fundamentals of materials synthesis (3 Lectures)

Nucleation and growth, diffusion, Thermodynamic and chemical effects phase diagrams

Bulk Synthesis (2 Lectures)

Solid State Route, Sol Gel, Milling, etc.

Thin Film and Thick Film synthesis (6 Lectures)

Physical methods (Vacuum evaporation, sputtering, PLD, MBE, etc.)

Chemical methods (Chemical and electrochemical methods, spin coating, etc.)

Nano-materials synthesis (4 Lectures)

Top down and bottom up approach

Solid Phase (Physical) methods

Liquid Phase (Chemical) methods

Gas phase methods

Reference Books:

3. Materials Science and Engineering (John Wiley & Sons, Inc.) By William D. Callister, Jr.
4. Handbook of Thin Film Technology (McGraw-Hill Handbooks) By Leon I. Maissel and Reinhard Glang
5. Nanotechnology: Principles and Practices (Capital Publishing House) By S. K. Kulkarni
6. Solid State Physics, Kittle
7. The Physics and Chemistry of Materials, J. L. Gersten and F. W. Smith

METHODS OF COMPUTATIONAL PHYSICS

Module No. 1 is compulsory; Any two modules out of 2 to 8 may be offered depending on the instructor)

Module-1 : Numerical Methods : Solution of differencial equations, Applications to potential well problem. Understanding of special functions, Generation and graphs, Random number generators, various tests.

Module-2 : Stochastic processes, Markov chain, Metropolis sampling, Simple idea of Monte-Carlo integration, Application to 2dimensional Ising model.

Module-3 : Hubbard model : Motivation, representation of Sz basis, Generation of basis states, construction of Hamiltonian. Exact diagonalization, Calculation of correlation function.

Module-4 : Lanczos method and applications to tight binding Hamiltonians, Calculation of spectral properties.

Module-5 : Numerical solution of Schrödinger equation for spherically symmetric potentials - scattering states, Calculation of phase shifts, Resonance.

Module-6 : Quantum Monte Carlo, Variational Monte Carlo, Diffusion Monte Carlo.

Module-7 : Electrons in Periodic potential, Calculation of band structure by using plane wave methods.

Module-8 : Molecular dynamics, Interacting particles with Lennard-Jones potentials.

Books :

1. A first course in computational Physics, Paul, L. Pavries, Pub. John Wiley and Sons, 1994.

2.Monte Carlo Methods, M. H. Kalos and P. A. Whitelock, John Wiley & Sons, NY 1986.

3. Understanding Molecular Simulation, Daan Frenkel and B. Smit, Academic Press, 1996.

4. Computational Physics, J. M. Thijssen, Cambridge Univ. Press, 1999.

Course No. 4 **(5 Credits)**

This will be monitored by the respective guide and students can obtain credits by any of the following ways.

- Two posters/papers presentation in national conference : 1 credit
- One poster/paper presentation at international conference : 1 credit
- Attending workshop which is of minimum 3days with cummulative10 days duration : 1 credit
- Training in the laboratory outside the department at least for 15 days. : 1 credit
- 5 Seminars given on a topic other than the main topic of Research which is attended by at least 3 members of the research committee : 1 credit
- Members of the Organizing Committee of Raman Memorial Conference or national & international conference : 1 credit