

# PHYSICAL SCIENCES

*Programme Code:* PHYS05

*Programme Outcome:*

- Manpower development with the ability to apply basic concepts and methods in physics to research problems.
- Training of manpower with the ability to work in interdisciplinary subjects, particularly those in the interface of different disciplines in physics.
- Developing an understanding of modern mathematical methods and using them in the research environment.
- Training of manpower which has the ability to work in diverse areas and adapt to change in professional and national requirements.

## DETAILED COURSE STRUCTURE

### Semester – I (August – December) (5 core = 15 credits)

Sr.no.	Course Code	Course Title	Type	Hours	Credits
1	07-PHYS05-109-C	Mathematical Methods I	Core	45	3
2	07-PHYS05-110-C	Classical Mechanics	Core	45	3
3	07-PHYS05-111-C	Quantum Mechanics I	Core	45	3
4	07-PHYS05-112-C	Classical Electrodynamics	Core	45	3
5	07-PHYS05-113-L	Lab - I	Core	90	3

### Semester – II (January – May) (5 core = 15 credits)

Sr.no.	Course Code	Course Title	Type	Hours	Credits
1	07-PHYS05-215-C	Statistical Mechanics	Core	45	3
2	07-PHYS05-216-C	Quantum Mechanics II	Core	45	3
3	07-PHYS05-217-C	Classical Field Theory	Core	45	3
4	07-PHYS05-218-C	Mathematical Methods II	Core	45	3
5	07-PHYS05-219-L	Lab - II	Core	90	3

### Semester – III (August – December) (3 core + 2 electives =15 credits)

Sr.no.	Course Code	Course Title	Type	Hours	Credits
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1	07-PHYS05-301-C	Condensed Matter Physics	Core	45	3
2	07-PHYS05-302-C	Atomic Molecular & Nuclear Physics	Core	45	3
3	07-PHYS05-303-C	Electronics & Lab	Core	45	3
4	07-PHYS05-102-E	Quantum Field Theory	Elective	45	3
5	07-PHYS05-103-E	Advanced Statistical Mechanics	Elective	45	3
6	07-PHYS05-304-E	Optics / Photonics	Elective	45	3
7	07-PHYS05-105-E	Many Body Physics	Elective	45	3
8	07-PHYS05-305-E	Thin Films and Interfaces	Elective	45	3
9	07-PHYS05-107-E	Advanced Experimental Techniques	Elective	45	3
10	07-PHYS05-106-E	Soft Condensed Matter Physics	Elective	45	3
11	07-PHYS05-306-E	Basics of Machine Learning & Artificial Intelligence	Elective	45	3
12	07-PHYS05-307-E	Quantum Transport through Nanostructures	Elective	45	3

**Semester – IV (January – May) (1 core+2 electives+1 project=15 credits)**

**High Energy Physics**

Sr.no.	Course Code	Course Title	Type	Hours	Credits
1	07-PHYS05-401-C	Numerical Methods & Research Methodology & Research Publication Ethics	Core	45	3

2	07-PHYS05-402-PR	Project	Core	90	6
3	07-PHYS05-204-E	Quantum Field Theory II	Elective	45	3
4	07-PHYS05-205-E	High Energy Physics	Elective	45	3
5	07-PHYS05-403-E	General Theory of Relativity & Cosmology	Elective	45	3
6	07-PHYS05-203-E	Advanced Nuclear Physics	Elective	45	3
7	07-PHYS05-206-E	Quantum Information & Computation	Elective	45	3

**Condensed Matter Physics (Theoretical)**

Sr.no.	Course Code	Course Title	Type	Hours	Credits
1	07-PHYS05-401-C	Numerical Methods & Research Methodology & Research Publication Ethics	Core	45	3
2	07-PHYS05-402-PR	Project	Core	90	6
3	07-PHYS05-202-E	Advanced Condensed Matter Physics	Elective	45	3
4	07-PHYS05-213-E	Special Topics in Statistical Physics	Elective	45	3
5	07-PHYS05-207-E	Non-linear Dynamics and Chaos	Elective	45	3
6	07-PHYS05-208-E	Special Topics in Condensed Matter Physics	Elective	45	3
7	07-PHYS05-206-E	Quantum Information & Computation	Elective	45	3
8	07-PHYS05-404-E	Physics of Living Matter	Elective	45	3

**Condensed Matter Physics (Experimental)**

Sr.no.	Course Code	Course Title	Type	Hours	Credits
1	07-PHYS05-401-C	Numerical Methods & Research Methodology & Research Publication Ethics	Core	45	3
2	07-PHYS05-402-PR	Project	Core	90	6
3	07-PHYS05-405-E	Special Topics in Experimental Physics	Elective	45	3
4	07-PHYS05-202-E	Advanced Condensed Matter Physics	Elective	45	3
5	07-PHYS05-406-E	Special Topics in Experimental Condensed Matter Physics	Elective	45	3
6	07-PHYS05-206-E	Quantum Information & Computation	Elective	45	3
7	07-PHYS05-407-E	Particle Accelerators: Fundamentals & Applications	Elective	45	3

**Semester – V & VI (January – December) (48 credits)**

Sr.no.	Component	Description
1	Project	The third year of course work will entirely consist of research work for the Master's project

## CORE COURSE CO-ORDINATORS

Course	Coordinators	Email
Mathematical Methods I	<b>Prof. Tapobrata Som</b>	<a href="mailto:tsom@iopb.res.in">tsom@iopb.res.in</a>
Classical Mechanics		
Quantum Mechanics I		
Classical Electrodynamics		
Lab - I		
Statistical Mechanics		
Quantum Mechanics II		
Classical Field Theory		
Mathematical Methods II		
Lab - II		
Condensed Matter Physics	<b>Prof. Tapobrata Som</b>	<a href="mailto:tsom@iopb.res.in">tsom@iopb.res.in</a>
Atomic Molecular & Nuclear Physics		

Electronics & Lab		
Numerical Methods & Research Methodology & Research Publication Ethics		
Project		

## ELECTIVE COURSE CO-ORDINATORS

Course	Coordinators	Email
Quantum Field Theory	<b>Prof. Tapobrata Som</b>	<a href="mailto:tsom@iopb.res.in">tsom@iopb.res.in</a>
Advanced Statistical Mechanics		
Optics / Photonics		
Many Body Physics		
Thin Films and Interfaces		
Advanced Experimental Techniques		
Soft Condensed Matter Physics		
Basics of Machine Learning & Artificial Intelligence		
Quantum Transport through Nanostructures		

Quantum Field Theory II	<b>Prof. Tapobrata Som</b>	<a href="mailto:tsom@iopb.res.in">tsom@iopb.res.in</a>
High Energy Physics		
General Theory of Relativity & Cosmology		
Advanced Nuclear Physics		
Quantum Information & Computation		
Advanced Condensed Matter Physics		
Special Topics in Statistical Physics		
Non-linear Dynamics and Chaos		
Special Topics in Condensed Matter Physics		
Quantum Information & Computation		
Physics of Living Matter		
Special Topics in Experimental Physics		
Advanced Condensed Matter Physics		
Special Topics in Experimental Condensed Matter Physics		

Quantum Information & Computation		
Particle Accelerators: Fundamentals & Applications		

# SEMESTER I

## 07-PHYS05-109-C: Mathematical Methods-I (45 Lecture Hrs)

Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in

### Course Details:

- **Complex variables:**  
Functions of complex variables, single and multiple valued function, limit, continuity, differentiation, Cauchy-Riemann equations and their applications, analytic and harmonic function, complex integrals, Cauchy's theorem, converse of Cauchy's theorem, Integral formula. Taylor and Laurent expansion, classification of singularities, Branch point and branch cut, residue theorem and its application, Conformal mapping.
- **Differential Equations:**  
Ordinary differential equations, hyper geometric equations, partial differential equations, method of characteristics, partial differential equations, classification of PDEs, Laplace and wave equations, boundary value problems.
- **Special function:**  
Special functions, Integral equations and Green functions, Ideas about nonlinear equations, Hypergeometric functions, Bessel functions, Hermite Polynomials, Legendre polynomials, Coulomb functions.
- **Integral transforms:**  
Fourier and Laplace transform and their inverse transforms, Bromwich integral, transform of derivative and integral of a function, solution of differential equation using integral transforms.
- **Linear algebra:**  
Linear Vector spaces, Determinants, Matrices. Special matrices: orthogonal, Hermitian, unitary.
- **Eigenvalue problem:**  
matrix diagonalization, Cayley-Hamilton theorem, Canonical Forms, Infinite-dimensional vector spaces: Hilbert space, Hermitian operators, Numerical solution of linear equations.

### Course Outcomes:

- Understand and apply concepts of complex variables, analytic functions, and conformal mapping.
- Solve ordinary and partial differential equations using standard analytical methods and integral transforms.
- Use special functions, Green's functions, and integral equations in solving physical problems.
- Apply linear algebra and eigenvalue techniques, including Hilbert space concepts, in advanced mathematical analysis.

### References:

1. J. Mathews and R. L. Walker, Mathematical Methods for Physicists, Benjamin, 1964
2. G. Arfken, Mathematical Methods for Physicists, Academic Press, 1995.
3. Methods of Theoretical Physics vol. 1 and 2, Morse and Feshbach
4. R. V. Churchill and J. W. Brown: Complex variables and applications.
5. M. Tinkham, Group theory and Quantum Mechanics

**07-PHYS05-110-C: Classical Mechanics (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **Calculus of variations:**  
Concept of variation - Euler equation - Applications - Variation subject to constraints and Lagrange multipliers.
- **The Lagrangian formulation:**  
Generalized coordinates, the principle of least action and the Lagrange equations of motion - Extension to constrained systems.
- **Conservation laws:**  
Symmetries and Noether's theorem - Conservation of energy, momentum and angular momentum.  
Integration of the Lagrange equations of motion: Motion in one dimension - The two-body problem, reduced mass and the equivalent one-dimensional problem – Motion in a central field - Kepler's problem - Scattering.
- **Small oscillations:**  
Free, damped and forced oscillations in one dimension - Resonance - Damped and forced oscillations - Parametric resonance.
- **Rigid body motion:**  
Angular velocity - The inertia tensor and angular momentum of a rigid body - The equations of motion of a rigid body - Eulerian angles - Euler's equations - Motion of tops - Motion in a rotating frame - Coriolis force.
- **The Hamiltonian formulation:**  
Conjugate momentum - Hamiltonian and Hamilton's equations - Poisson brackets. Canonical transformations - Dynamics in the phase space - Hamilton-Jacobi equation - Separation of variables and solutions - Action-angle variables - Adiabatic invariants.
- **Classical Chaos:**  
Periodic motions and perturbations, Attractors, Chaotic trajectories and Lyapunov exponents, The logistic equation.
- **Special Theory of Relativity:**  
Lorentz transformations, 4-vectors, Tensors, Transformation properties, Metric tensor, symmetric and antisymmetric tensors, 4-dimensional velocity and acceleration, 4-momentum and 4-force, covariant equations of motion, relativistic kinematics (decay and elastic scattering), Lagrangian and Hamiltonian of a relativistic particle.

**Course Outcomes:**

- Apply calculus of variations and Lagrangian formulation to derive equations of motion for physical systems.
- Analyze conservation laws, oscillations, rigid body motion, and central force problems using classical mechanics principles.
- Use Hamiltonian mechanics, canonical transformations, and phase space methods to study dynamical systems.
- Understand concepts of classical chaos and special relativity, including Lorentz transformations and relativistic dynamics.

**References :**

1. H. Goldstein: Classical Mechanics

2. K.C. Gupta: Classical Mechanics of Particles and Rigid Bodies
3. N.C. Rana and P.S. Joag: Classical Mechanics
4. A.P. French: Special Relativity

**07-PHYS05-111-C: Quantum Mechanics-I (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **Fundamentals of Quantum Theory:**

The breakdown of classical physics, the polarization of photons, Wave-particle duality: Particle properties of photons and wave properties of electrons, Schrodinger evolution, Hamiltonian, examples: free particle, one-dimensional potential well, potential barrier, harmonic oscillator, etc., Hilbertspace formulation of Quantum Mechanics: states, observables, measurement, evolution, collapse of wave function, uncertainty relation and its interpretation, Discrete and continuous spectra, canonically conjugate observables, Schrodinger, Heisenberg and interaction pictures, Virial theorem, Ehrenfest's theorem, semi-classical quantization.

- **Theory of spin-1/2 systems:**

Stern-Gerlach experiment for the existence of spin Quantum Mechanics of two-level systems.

- **Three-dimensional problem:**

Three dimensional problems in Cartesian and spherical polar coordinates, 3-d well and Fermi energy; Radial equation of free particle and 3-d harmonic oscillator; Eigenvalue of a 3-d harmonic oscillator by series solution, Schrodinger equation for spherically symmetric potentials, Orbital angular momentum and spherical harmonics, Hydrogen atom problem.

- **Symmetries and conservation laws:**

What is a symmetry, Wigner's theorem, Continuous transformations, Rotation, Euclidean and Galilean groups, Transformations and invariances.

- **Angular momentum theory in Quantum Mechanics:**

Orbital and spin angular momenta, Raising and lowering operators, Addition of angular momenta, Clebsch-Gordon coefficients, Schwinger oscillator model, Spherical tensors and Wigner- Eckart Theorem, Spin-orbit coupling.

- **Exactly solvable models:**

Charged particle in a magnetic field, Landau levels, Quantum Hall effect.

Time-independent perturbation theory: Non-degenerate and degenerate cases, An-harmonic oscillator, Van der Waal's force, Dipole interactions for spin-1/2 systems, Stark effect, Zeemann effect.

**Course Outcomes:**

- Understand fundamental principles of quantum mechanics, including wave-particle duality, Schrödinger equation, and Hilbert space formulation.
- Analyze quantum systems such as spin-1/2 particles, harmonic oscillator, hydrogen atom, and other exactly solvable models.
- Apply angular momentum theory, symmetry principles, and conservation laws in quantum systems.
- Use perturbation theory and magnetic field effects (Stark, Zeeman, Landau levels) to study realistic quantum phenomena.

**References:**

1. R. Shankar: Principles of Quantum Mechanics, Plenum Press, 1994
2. J.J. Sakurai: Modern Quantum Mechanics, The Benjamoin, 1985
3. C.Cohen – Tannoudji: Quantum Mechanics, John Wiley, 1977

4. R.L. Liboff: Introductory Quantum Mechanics, Addison-Wesley, 198

**07-PHYS05-112-C: Classical Electrodynamics (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **Electrostatics and Magnetostatics:**  
Scalar and vector potential, Laplace and Poisson equation, Boundary value problem and uniqueness theorem, multipole expansion, macroscopic media, Ampere's and Faraday's law, boundary value problem in magnetostatics.
- **Maxwell equation:**  
Maxwell equation, gauge invariance, Lorentz gauge and Coulomb gauge, Poynting theorem, Maxwell's stress tensor, magnetic monopole, transformation properties of Maxwell equation under various symmetry operations, ex., rotation, inversion, reflection and time reversion, magnetic monopole.
- **Electromagnetic wave:**  
Solution of Maxwell equation using green function method, Advanced and retarded potentials, plane waves in vacuum and in conducting medium.
- **Radiation:**  
Radiation from localises sources and multipole expansion in the radiation zone, Lienard-Wiechert potentials; dipole and quadrupole radiation and Larmor's formula; spectral resolution and angular distribution of radiation from a relativistic point charge; synchrotron radiation; Rayleigh and Thomson scattering; collision problems; Bremsstrahlung and Cerenkov radiation, Rayleigh and Thomson scattering, radiation reaction from energy conservation, problem with Abraham-Lorentz formula, Limitations of CED.
- **Plasma:**  
Definition of Plasma, dilute and dense plasma, uniform but time dependent magnetic field, magnetic pumping, static non-uniform magnetic field: Magnetic bottle and loss cone; MHD equations, Magnetic Renoyld's number, Pinched plasma, Bennett's relation, Qualitative discussion on sausage and kink instability. Relativistic electrodynamics: Lorentz transformation of electromagnetic fields, Lorentz covariant formulation of electrodynamics; energy-momentum tensor and conservation laws for the fields, Maxwell's equations from action principle.

**Course Outcomes:**

- Apply Maxwell's equations to analyze electrostatic, magnetostatic, and electromagnetic wave phenomena.
- Solve boundary value problems and radiation processes using Green's functions and multipole expansion methods.
- Understand relativistic electrodynamics, gauge invariance, and transformation properties of electromagnetic fields.
- Analyze plasma dynamics, MHD equations, and instabilities in magnetized plasma systems.

**References:**

1. D. J. Griffiths, Introduction to Electrodynamics, Prentice Hall, 1981.
2. L. Landau and E. Lifshitz, The Classical Theory of Fields, Pergamon, 1979.
3. J. D. Jackson, Classical Electrodynamics, Wiley Eastern, 1986.
4. L.D. Landau and E.M. Lifshitz: (i) Electrodynamics of Continuous Media (ii) Classical theory of fields

## 07-PHYS05-113-L: Laboratory I (90 Lab Hrs)

Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in

### *Course Details:*

- **Forced Oscillations-Pohl's Pendulum**
- **Coupled Pendula and Chaotic oscillator**
- **Photoelectric effect**
- **Normal and Anomalous Zeeman Effect**
- **Michelson Interferometer**
- **Mach-Zehnder Interferometer**
- **Faraday Effect**
- **Millikan Oil-drop Experiment**
- **Electron Diffraction**
- **Fine Structure**
- **Gyroscope**
- **Planck's Constant**

### *Course Outcomes:*

- Perform and analyze classical and coupled oscillation experiments, including resonance and chaotic behavior.
- Investigate fundamental quantum phenomena such as photoelectric effect, electron diffraction, and fine structure.
- Study electromagnetic and optical effects using interferometers, Zeeman effect, and Faraday effect experiments.
- Determine important physical constants and properties, including Planck's constant and electron charge, through precision experiments.

## SEMESTER II

### 07-PHYS05-215-C:Statistical Mechanics (45 Lecture Hrs)

Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in

#### Course Details:

- **Review of thermodynamics:**  
Laws, processes, thermodynamic stability.
- **Review of probability:**  
one random variable, probability distributions, random walks, many random variables, central limit theorem, information, entropy and estimation.
- **Kinetic Theory of gases:**  
Liouville's theorem, Boltzmann transport equation.
- **Classical statistical mechanics:**  
Microcanonical, canonical, and grand canonical ensembles.
- **Quantum statistical mechanics:**  
Identical particles, Quantum microstates and macrostates, Bose-Einstein and Fermi-Dirac statistics, quantum ideal gases, example systems.
- **Phase transitions:**  
Cumulant expansion, van der Waals equation, variational methods, corresponding states, phase transitions, critical point behavior.

#### Course Outcomes:

- Apply principles of thermodynamics and probability theory to analyze physical systems.
- Understand kinetic theory and ensemble formulations of classical statistical mechanics.
- Analyze quantum statistical systems using Bose–Einstein and Fermi–Dirac distributions.
- Explain phase transitions, critical phenomena, and real gas behavior using statistical methods.

#### References:

1. Mehran Kardar, Statistical Physics of particles, Cambridge University Press (2007).
2. S.K. Ma, Statistical Mechanics, World Scientific (1985).
3. F. Reif, Fundamentals of Statistical and Thermal Physics, McGraw-Hill International (1987).
4. L. D. Landau & E. M. Lifshitz, Statistical Physics, 03rd edition, Butterworth-Heinemann (1980).
5. C. Kittel and H. Kroemer, Thermal Physics, 2nd edition, W. H. Freeman Inc. (1980).
6. H. B. Callen, Thermodynamics and introduction to thermostatics, 2nd edition, Wiley & Sons (1985).

**07-PHYS05-216-C: Quantum Mechanics-II (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **Review of basics through problem solving:**  
Schrodinger equation, Heisenberg Picture, scattering problem in one dimension, Time- independent perturbation theory, Hydrogen atom, Born Approximation. Ladder operators and coherent states.
- **Time-dependent perturbation theory:**  
Interaction picture, Time ordered perturbation theory, Fermis Golden rule, Floquet.
- **Relativistic Quantum Mechanics:**  
Dirac Equation, Gamma matrices and Lorentz transformation of Dirac wave function, Positive and negative energy solutions and hole theory, Coupling to electromagnetic field, magnetic moment, Klein Paradox. Dirac equation for massless particles, Helicity. Majorana representation, Dirac equation in various space-time dimensions.
- **Path-integral formulation:**  
Derivation of Path-Integral representation, Time-ordered correlators in path-integral formulation, coupling to electromagnetic field, Aharonov-Bohm effect, double well potential in path-integral formulation, Instantons, Tunneling in path-integral formulation. Path-Integral in non-simply connected configuration space.
- **Geometric Phase:**  
Abelian and non-Abelian Berry phase. Some examples (According to the taste of instructor), Aharonov-Bohm effect.
- **Discrete Symmetries:**  
Wigner's theorem, Translation, Rotation, Lorentz Transformation (Group), Parity, charge conjugation and Time-reversal. Kramer's degeneracy.
- **Second quantization:**  
Indistinguishable particles, Bose and Fermi statistics, Many-body quantum mechanics in the second quantized form, Electromagnetic field in the second quantized formalism, Light Atom interaction.

**Course Outcomes:**

- Apply advanced quantum mechanics techniques including perturbation theory, scattering theory, and coherent states to solve physical problems.
- Understand relativistic quantum mechanics, Dirac equation, discrete symmetries, and their physical implications.
- Use path-integral formulation and geometric phase concepts to analyze quantum systems.
- Employ second quantization formalism to study many-body systems and light-matter interactions.

**References:**

1. Sakurai - Modern Quantum Mechanics
2. Landau-Lifschitz - Quantum Mechanics (Non-relativistic theory)
3. Gottfried-Yan - Quantum Mechanics: Fundamentals
4. Feynman-Hibbs - Quantum Mechanics and Path Integrals
5. Sidney Coleman - Aspects of Symmetry, (Chapter: Uses of Instantons)

**07-PHYS05-217-C: Classical Field Theory (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **Continuum Mechanics:**

Coarse graining and continuum limit, The displacement field and strain tensor, The stress tensor and constitutive relations. Hooke's Law, The energy functional, Deformation of thin rods: Stretching, bending and torsion, Equations of motion. Elastic waves, Conservative systems, Lagrangian and Hamiltonian formalisms.

- **Hydrodynamics:**

The velocity and density fields. Continuity equation, Pascals Law and the stress tensor, Bernoulli's principle, Euler equations. Gravity waves, Viscosity, Navier-Stokes equations. Boundary conditions, examples of flow, low Reynolds number flows, Stokes limit.

- **Electrodynamics:**

The electromagnetic field tensor and Bianchi identity, covariant charge density and current, action formalism for electrodynamics, Maxwell's equations and relativistic covariance, Wave solutions. Gauge invariance, Lagrangian and Hamiltonian formalism.

- **Landau-Ginzburg theories:**

Order parameter field, symmetry breaking, Noether theorem, mean-field theory, Gaussian fluctuations, Goldstone modes, generalized stiffness, topological defects, solitons, vortices, O(N) model, Abelian Higgs model (superconductivity).

- **Gravitation:**

Principle of equivalence, curvilinear coordinates, metric, connection, curvature tensor, energy momentum tensor, Einstein equations.

**Course Outcomes:**

- Apply continuum mechanics and hydrodynamics principles to analyze deformation, fluid flow, and wave phenomena.
- Use Lagrangian and Hamiltonian formalisms to describe elastic, fluid, and electromagnetic systems.
- Understand field-theoretic approaches such as Landau–Ginzburg theory, symmetry breaking, and topological defects.
- Explain gravitation using relativistic concepts including metric, curvature, and Einstein's field equations.

**References:**

1. L.D. Landau and E.M. Lifshitz, The classical Theory of Fields, Pergamon Press, 4th Edition, 1980
2. G. Giachetta, L. Mangiarotti and G. Sardanashvily, Advanced Classical Field Theory, World Scientific, 2009

**07-PHYS05-218-C: Mathematical Methods -II (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **Non-linear dynamics and chaos:**  
introduction, logistic map, sensitivity to initial conditions, non-linear differential equations, linear stability analysis, 1d flows and bifurcation, 2d flows, limit cycles, bifurcations, chaos: Lorentz systems, fixed points, attractors, fractals.
- **Differential Geometry:**  
Curves in the plane and space, arc length; Curvature, torsion, Serret-Frenet formulae; Surfaces in three dimensions, smooth surfaces; Tangents, normal; surfaces of revolution; Normal and principal curvatures, Gaussian curvature; Geodesics, geodesic curvature, Gauss' theorem, differentiation of tensors, covariant forms. Calculus of forms, exterior differentiation, Lie differentiation, co-variant derivatives and connections, parallel displacements and geodesics. Torsion and curvature. Cartan's equations of structure and metric tensor. Symmetries of Riemann curvature tensor. Elementary theories of fibre bundles and connection between gravity and gauge theories.
- **Group Theory:**  
Basic definition of groups and subgroups. Homomorphism and isomorphism between groups, finite and infinite groups, conjugate classes, invariant subgroups and coset spaces. Representation of groups. Representation theory, Schur's lemma, Orthogonality theorem, Conjugacy class, Character table, Direct sum, Tensor product, Young tableaux, unitary representation, character of a representation. Elements of Lie Groups, unitary groups, orthogonal groups, homogeneous and inhomogeneous Lorentz groups, Wigner's little group and concept of helicity etc., conformal groups, symplectic groups.
- **Local properties of Lie groups, infinitesimal group generators, Lie algebra, Adjoint representations, simple and semi simple Lie algebras, Casimir operators. Elementary ideas of root vectors, Cartan subalgebra, graphical representations, and weight vectors. Dynkin diagrams and Cartan matrices. Symmetry theory of solid states (crystals) and their band structures Applications of group theory and topology to physical systems.**
- **Probability and stochastic processes:**  
definitions, properties, conditional probability, independence of events, random variables; Moments, Bivariate distributions (discrete and continuous); marginal and conditional distributions; covariance, correlation coefficient, binomial distribution; Poisson distribution; Gauss' normal distribution; central limit theorem; stochastic differential equation, Ito and Stratonovich interpretations, diffusion equation, drift-diffusion.

**Course Outcomes:**

- Analyze nonlinear dynamical systems, bifurcations, chaos, and stability using mathematical methods.
- Apply differential geometry concepts such as curvature, geodesics, tensors, and connections to physical theories.
- Use group theory and Lie algebra techniques to study symmetries in quantum mechanics, relativity, and solid-state systems.
- Apply probability theory and stochastic processes to model random phenomena and diffusion systems.

**References:**

1. George B. Arfken, Frank J. Weber and Frank E. Harris, Mathematical Methods for Physicists, Academic Press

(2012).

2. Philippe Dennery, Andre Krzywicki, Mathematics for Physicists, Dover Publication (1996).
3. Pressley, Elementary Differential Geometry, SUMS, Springer (2001).
4. Rutherford Aris, Vectors, Tensors, and basic equations for fluid mechanics, Dover Publication (1996).
5. K. L. Chung and F. AitSahila, Elementary Probability Theory, Springer (2004). G W Gardiner, Stochastic methods: A handbook, Springer-Verlag (2009). Steven H Strogatz, Nonlinear dynamics and chaos, CRC press (2014).
6. S. Mukhi & N. Mukunda, Introduction to topology, and differential geometry and group theory for physicists
7. D Lichtenberg, Unitary Symmetry and Elementary Particles
8. H Georgi, Lie Algebras in Particle Physics
9. Anthony Zee, Group Theory in a Nutshell for Physicists

## 07-PHYS05-219-L: Laboratory II (90 Lab Hrs)

Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in

### *Course Details:*

- **Ferro to Para Electric Phase Transition (or its Magnetic analogue)**
- **Raman Spectroscopy**
- **ESR**
- **Earth's field NMR gradient**
- **Bragg Diffraction by Microwaves**
- **Hall Effect**
- **G-M counter, Counting Statistics, Gamma-ray absorption cross section**
- **Gamma ray Spectroscopy**
- **STM with Graphene, HOPG, Gold, Semiconductors**
- **Measurement of Speed of Light**
- **Microwave Optics System**
- **Measurement of Susceptibility**
- **X-ray diffraction (XRD)**

### *Course Outcomes:*

- Perform advanced experiments to study phase transitions, magnetic resonance, and spectroscopic techniques.
- Analyze diffraction, interference, and microwave optics to understand wave properties of radiation.
- Investigate electronic and solid-state properties using Hall effect, STM, and X-ray diffraction techniques.
- Apply radiation detection methods and statistical analysis in nuclear and gamma-ray experiments.

## SEMESTER III

### 07-PHYS05-302-C: Atomic Molecular & Nuclear Physics (45 Lecture Hrs)

**Coordinators: Prof. Tapobrata Som**  
**tsom@iopb.res.in**

#### *Course Details:*

- **Atomic and Molecular Physics**

Hydrogen atom including LS coupling and hyperfine interaction. Helium atom introduction to exchange and correlation; variational calculation of ground and excited-states. Introduction to the idea of effective potentials for electrons in many electron atoms (Hartree theory and idea of self-consistency); use of Clementi-Roetti wave-functions.

One-electron atomic systems in an electromagnetic field dipole approximation and associated selection rules; Stark and Zeeman effect (Note: Instructor will have to introduce the students to time-dependent perturbation theory here). Einstein's A and B coefficients, population inversion, laser action, derivation of A and B coefficients from semi-classical treatment of light-atom interaction. Molecular formation: Discussion of atom-atom interaction, Vander Waals force, ionic interaction and covalent bond. Molecular structure: Hydrogen molecule MO and VB pictures; Importance of correlations. Molecular spectra (restricted to two atom molecules) electronic, rotational and vibrational.

- **Nuclear Physics**

- **Nuclear Properties:**

Nuclear size, Rutherford scattering, nuclear radius and charge distribution, nuclear form factor, mass and binding energy, angular momentum, parity and symmetry, magnetic dipole moment and electrical quadrupole moment, experimental determination, Rabi's method.

- **Two body state:**

Properties of deuteron, Schrodinger equation and its solution for ground state of deuteron, r.m.s radius, spin dependence of nuclear forces, electromagnetic moment and magnetic dipole moment of deuteron and the necessity of tensor forces.

- **Twobody scattering:**

Experimental np scattering data, partial wave analysis and phase shifts, scattering length, magnitude of scattering length and strength of scattering, significance of the sign of scattering length, scattering from molecular hydrogen and determination of singlet and triplet scattering lengths, effective range theory, low energy pp scattering, nature of nuclear forces: charge independence, charge symmetry and isospin invariance of nuclear forces.

- **Decay:**

Radio-activity and radioactive decays,  $\beta$ -emission and electron capture, Fermi's theory of allowed  $\beta$  decay, selection rules for Fermi and Gamow-Teller transitions, parity non-conservation and Wu's experiment.

- **Nuclear structure:**

Liquid drop model, Bethe-Weizsacker binding energy/mass formula, Fermi model, Shell model and collective model.

▪ **Nuclear reactions and Fission:**

Different types of reactions, quantum mechanical theory, resonance scattering and reactions – BreitWigner dispersion relation, compound nucleus formation and breakup, statistical theory of nuclear reactions and evaporation probability, optical model, principle of detailed balance, transfer reactions, nuclear fission: experimental features, spontaneous fission, liquid drop model, barrier penetration, statistical model, super heavy nuclei. Passage of charged particle through matter, Detectors and Accelerators. Applications : Effects of radiation on biological systems and nuclear medicine, Industrial applications, Power from fission and fusion : Characteristics of fission, nuclear reactors, Thermonuclear fusion.

▪ **Meson Theory:**

NN-interaction, Relativistic mean field model: Relativistic Mean Field Lagrangian, Equation of Motion, Equation of states (Introductory only)

**Course Outcomes:**

- Understand atomic and molecular structure, light-matter interaction, and spectroscopic techniques including laser physics.
- Analyze nuclear properties, two-body systems, and scattering processes using quantum mechanical models.
- Explain nuclear decay, nuclear structure models, and reaction mechanisms including fission and fusion.
- Apply theoretical models such as shell model, liquid drop model, and meson theory to describe nuclear forces and interactions.

**References:**

1. Elementary Atomic Structure: G.K. Woodgate
2. Atomic Physics: C.J. Foot
3. Atoms, molecules and Photons: W.Demtroder
4. The theory of Atomic Spectra: Condon and Shortley
5. Topics in Atomic Physics: C.E. Butkhardat and J.L.Leventhal
6. Physics of Atoms and Molecules: B.H. Brandsen and C.J. Joachain
7. Nuclear Physics: Principles and Applications, John Lilley
8. The Atomic Nucleus: R.D. Evans
9. Fundamental of Nuclear Reactor Physics – Elmer Lewis, Academic Press
10. An Introduction to the passage of energetic particles through matter- N.J. Caron
11. Accelerator Physics- Shyh-Yuan Lee, World Scientific
12. K.S. Krane: Introductory Nuclear Physics
13. J.S. Lilley: Nuclear Physics
14. M.K. Pal: Theory of Nuclear Structure
15. S.N. Ghoshal: Atomic and Nuclear Physics (Vol. 2)
16. W.E. Burcham and M. Jobes: Nuclear and particle Physics
17. R.K. Bhaduri: Structure of the Nucleus
18. W. Greiner and J.A. Maruhn: Nuclear Models
19. R.D. Evans : The Atomic Nucleus
20. J.M. Blatt and V.F. Weisskopf : Theoretical Nuclear Physics
21. J.D. Walecka: Theoretical Nuclear and Subnuclear Physics

**07-PHYS05-301-C: Condensed Matter Physics (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **Atomic structure:**

Crystals, breaking of translational symmetry, Bravais lattice, primitive cells, Wigner-Seitz cells, space groups, and point groups; Simple cubic lattice, FCC, BCC, etc.; implications of symmetries, piezoelectricity, optical activity; Scattering and structure, reciprocal lattice; Surfaces and interfaces; Simple liquids: pair correlation function, structure factor, long and short-ranged order; Introduction to glasses, liquid crystals, polymers, colloids, quasi-crystals.

- **Electronic structure:**

free Fermi gas, single electron Hamiltonian, density of states, electronic specific heat; free electrons in periodic potential: Bloch's theorem in one and three dimensions, Van Hove singularities, Kronig-Penny model; nearly free electron model; tightly bound electrons: LCAO, Wannier functions, tight binding model.

- **Mechanical properties:**

- **Elasticity:**

isotropic solids, solids with cubic symmetry, normal modes and phonons, phonon specific-heat, Einstein and Debye model, thermal expansion; Dislocations and cracks; Frenkel-Kontorova model of one-dimensional dislocations, Kosterlitz-Thouless transition; Elasticity in liquid crystals, and granular matter; Compressibility and shear viscosity of liquids.

- **Electron transport:**

Drude model, semiclassical dynamics and Bloch oscillations, de Haas-van Alphen effect, Boltzmann transport equation, Onsager relations, thermoelectric phenomena, Wiedemann-Franz law, Seebeck effect, Peltier effect, Hall effect, magnetoresistance; Fermi liquid and quasi-particles, effective mass.

- **Magnetism:**

Magnetic moments, Ferromagnet, Ising model and mean-field theory for Para, Ferro phase transition, Ferrimagnet, Antiferromagnet; Domains, Hysteresis, Spin glass, Landau free energy; Atomic magnetism: Curie's law, Hund's rule, Pauli paramagnetism, Landau diamagnetism, Origin of ferromagnetism: Heitler London, spin Hamiltonian, Heisenberg model.

- **Superconductivity:**

Basic properties, London's theory, Meissner effect, Concept of Cooper pair, Cooper analysis of the Fermi surface instability, Basics of Josephson effect, Landau-Ginzburg theory of Superconductivity.

**Course Outcomes:**

- Understand crystal structure, symmetry principles, reciprocal lattice, and structural properties of solids and complex materials.
- Analyze electronic structure of solids using free electron, nearly free electron, and tight-binding models.
- Apply concepts of phonons, elasticity, electron transport, and magnetism to explain thermal and electrical properties of materials.
- Explain superconductivity, phase transitions, and magnetic phenomena using microscopic and phenomenological theories.

**References:**

1. Michael P Marder, Condensed Matter Physics, Wiley (2010).
2. N. W. Ashcroft & N. D. Mermin, Solid State Physics, Saunders College Publishing (1996).
3. C. Kittel, Introduction to Solid State Physics, 08th edition, John Wiley & Sons, Inc. (2004).
4. Paul Chaikin and Tom Lubensky, Principles of Condensed Matter Physics (Cambridge 1995)

**07-PHYS05-303-C: Electronics & Laboratory (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **Circuit Theory:**  
lumped circuit approximation, circuit elements, Kirchoff's current and voltage laws, resistive Networks, node and loop analysis, Thevenin and Norton's theorem, time domain response of RL, RC and RLC, frequency domain response, impedance, filter and transfer function.
- **Analog electronics:**  
Physics of semiconductor devices, characteristics and operation: Diode, simple diode circuits, Zener diode, LED, photodiode, solar cell, Introduction to plasmonics for optoelectronic devices, Heterojunction devices.
- **Bipolar junction transistor (BJT):**  
biasing, h parameters, small and large signal response, amplifiers, Field effect transistors, Operational amplifiers- device properties, integrator, differentiator, RC active filter, negative and positive feedback, oscillators.
- **Digital electronics:**  
logic gates, truth table, multiplexer, combinational circuits, flip-flop, counters, programmable logic devices, microprocessors.
- Introduction to memristive devices and characteristics, memristor-based memory elements and applications.
- **Experiments at Laboratory for Electronics**
  - Coupled Oscillator Circuits
  - Thermal Equation of state and Critical point
  - Lock-in Amplifier and Signal Processing
  - OpAmps I: Amplifiers and Negative Feedback
  - OpAmps II: Limitations and Applications
  - Diodes: Clamps, Rectifiers, Power Supplie
  - Transistor I: Switch, Common Emitter Amplifier, Push-pull Follower
  - Transistor II: Characteristics, Comparators, MoSFET, CMoS Inverter Logic gates: NAND gate, OR, AND, NOT; Adder, Oscillator
  - Flip-flops: as Memory element, Shift Register, Counters
  - Microcontroller I: Programming to MCU, using the port for input
  - Microcontroller II: Some Applications, Seven Segment Display

**Course Outcomes:**

- Apply circuit theory to analyze DC and AC networks using time and frequency domain techniques.
- Understand and design analog electronic circuits using diodes, transistors, operational amplifiers, and feedback

systems.

- Develop and analyze digital electronic systems including logic gates, flip-flops, counters, and microcontrollers.
- Perform laboratory experiments to design, test, and troubleshoot electronic circuits and signal processing systems.

**References:**

1. Paul Malvino: Electronic Principles
2. Robert Boylestad: Introduction to Circuit Analysis
3. J. Millman and C. Halkias: Integrated Electronics
4. J.D. Ryder: Electronic Fundamental and Applications
5. B.G. Streetman, S. Banerjee: Solid State Electronic Devices
6. Sedra and Smith: Microelectronic Devices
7. Boylestad and Nashelski: Electronic Devices and Circuit Theory
8. S.M. Sze: Physics of Semiconductor Devices
9. R.S. Gaonkar: Microprocessor Architecture, Programming and Application with 8085/808

**07-PHYS05-102-E: Quantum Field Theory-I (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **Canonical quantization of free field theory:**  
Canonical quantization of free (complex) scalar field Retarded, Advanced and Feynman propagator. Causality. Normal-ordering of operators. Concept of (connected) multi-point correlation function. Wicks theorem. Canonical quantization of free Dirac field Feynman Propagator. Wicks theorem for Dirac field Canonical quantization of electromagnetic field Feynman Propagator. Casimir effect.
- **Interacting scalar field:**  
Perturbative evaluation of correlation functions. Time-ordered perturbation theory. Feynman Diagrams. Calculation of some tree-level amplitudes in  $\phi^4$  theory.
- **Path-Integral quantization of Scalar field theory:**  
Derivation of Feynman propagator and Wicks theorem. Path-integral quantization of Maxwell theory. Grassmann numbers and Path-integral quantization of Dirac field Path integral quantization of interacting scalar field theory: Generating functional of connected correlators and derivation of time-ordered perturbation theory.
- **S-Matrix:**  
LSZ reduction. Sample calculations of tree-level S-matrix. Symmetries: Noether's theorem and Ward identity.
- **Miscellaneous topics:**  
Wick rotation. Relation between d-dimensional QFT and (d+1)-dimensional statistical mechanical system. Introduction to Wilsonian-RG and the concept of effective low energy field theory description.

**Course Outcomes:**

- Apply canonical and path-integral quantization methods to scalar, Dirac, and electromagnetic fields.
- Use propagators, Wick's theorem, and Feynman diagrams to compute correlation functions and scattering amplitudes.
- Understand S-matrix formulation, LSZ reduction, and symmetry principles including Noether's theorem and Ward identities.
- Explain advanced concepts such as Wick rotation, renormalization group, and effective field theory frameworks.

**References :**

1. Peskin and Schroeder - An introduction quantum field theory
2. Ramond - Field theory: A modern primer.

**07-PHYS05-105-E:Many Body Physics (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **Preliminaries:**
  - a) First and Second Quantization: Quantum Mechanics with many particles;
  - b) First quantization, many particle systems; Operators in first quantization;
  - c) Second quantization, basic concepts the occupation number representation;
  - d) The general form for second quantization operators; Basis change in second quantization; Examples - Operators for kinetic energy, spin, density, and current; The Coulomb interaction in second quantization.
- **Mean Field Theories:**
  - a) non-interacting many particles system vs interacting many particles system. Examples;
  - b) Concepts of mean field approximation. Idea of broken symmetry;
  - c) Hartree-Fock approximation, Thomas Fermi approximation.;
  - d) Hohenberg-Kohn Theorem: Self-consistent Kohn-Sham Hartree-like theory for exact ground state energy and density of electrons; potential for alternative path to include many-electron effects;
  - e) Application:
    - i) model of ferromagnets, Stoner model of metallic ferromagnets,
    - ii) application to BCS theory of superconductivity,
    - iii) application to nuclear physics. f) short discussion on the limitations of mean field theories.
- **Method of Green functions:**
  - a) Single-particle Greens functions of many-body systems: meaning and significance; Greens function of free electrons; The Lehmann representation; The spectral function; Broadening of the spectral function due to interactions; Measuring the single-particle spectral function – spectroscopy; Two-particle correlation functions of many-body systems.
  - b) Linear response theory and Kubo formalism for response function.
  - c) Imaginary time Greens functions: Matsubara Greens functions; Connection between Matsubara and retarded and advanced Green's functions; Examples: Single-particle Matsubara Greens function; Evaluation of Matsubara sums. Equation of motion for Matsubara Greens functions; Wicks theorem and example of polarizability of free electrons.
  - d) Feynman diagrams and Dyson series
  - e) Application:
    - i) Random impurities in disordered metals.
    - ii) Anderson model for magnetic impurities
    - iii) Random phase approximation for interacting electron system.
    - iv) Application to interacting phonons (i.e beyond the Einstein model of lattice vibrations).
- **Renormalization Group method:**
  - a) Basic concepts;
  - b) Wilsonian Renormalization Group
  - c) Perturbative Renormalization Group
  - d) Functional (or Exact) Renormalization Group method
  - e) Applications.

**Course Outcomes:**

- Apply second quantization formalism to describe interacting many-body quantum systems.

- Use mean-field theories (Hartree–Fock, Kohn–Sham, BCS, Stoner model) to analyze electronic, magnetic, and superconducting systems.
- Employ Green’s function methods, linear response theory, and Feynman diagrams to study many-body interactions and excitations.
- Understand renormalization group techniques and their applications to condensed matter and quantum field systems.

**References:**

1. Many-body quantum theory in Condensed Matter Physics - Karsten Flensberg and Henrik Bruus
2. Condensed Matter Field Theory- Alexander Altland and Ben Simons
3. Introduction to Many Body Physics - Piers Coleman
4. Green functions for solidstate physicist - S. Doniach and E. H. Sondheimer
5. Quantum Theory of Many-Particle system Alexander L fetter and J d Walecka
6. Renormalization methods W. D. McComb
7. Lectures on the Renormalization Group- Peter Kopietz, Lorenz Bartosch and Florian Schutz
8. Phase Transition and Renormalization Group - Jean Zinn-Justin
9. Electronic Structure Calculations for Solids and Molecules-Theory and Computational Methods by Jorge Kohanoff

## 07-PHYS05-103-E: Advanced Statistical Mechanics (45 Lecture Hrs)

Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in

### Course Details:

- **Review of Thermodynamics and Statistical mechanics by problem solving:**
  - a) Quick review of Basic postulates, potentials, Legendre transformation
  - b) Basics of Statistical Mechanics: random walk/Probability, Basics of ensembles, Quantum statistics
- **Dynamics:**

Boltzmann H theorem, its use for transport properties Master equation, Langevin Equation, Fokker Planck equation Simple discussions on Detailed balance, fluctuation-dissipation theorem, Onsager relations, Work theorem, Basics of Monte Carlo.
- **Classical Interacting systems:**

Phase equilibrium, chemical equilibrium, Saha ionization; variational principle, Debye-Huckel theory; Van der Waals, Virial expansion; equilibrium curves, phase diagrams.
- **Phase transitions and critical phenomena:**

First order, continuous transitions; Ising and O(n) models; mean field theory; symmetry breaking, Order parameter; Landau theory (scalar and vector order parameter), Tricritical point, Alexander-McTauge theory; Gaussian model, Ginzburg criterion. Scaling near critical point. Quantum systems: Bosons: Details of Bose condensation of an ideal gas and in a harmonic trap Fermions: Chandrasekhar limit, Pauli paramagnetism, Landau diamagnetism, de Haas-van Alphen effect.

### Course Outcomes:

- Apply thermodynamic and statistical mechanics principles to analyze equilibrium and non-equilibrium systems.
- Use kinetic theory, master equations, and stochastic methods to study transport and dynamical processes.
- Analyze interacting classical systems and phase equilibria using variational and mean-field approaches.
- Explain phase transitions, critical phenomena, and quantum statistical effects in bosonic and fermionic systems.

### References:

1. F. Reif - Fundamentals of Statistical and thermal physics
2. K. Huang - Statistical Mechanics 2nd ed
3. Chaikin-Lubenskly - Principles of condensed matter physics
4. Other books by (a) Pathria, (b) J K Bhattacharjee, (c) Riechl, (d) S.K.Ma, (e) Newman-Barkema

## 07-PHYS05-107-E:Advanced Experimental Techniques (45 Lecture Hrs)

Coordinators: Prof. Tapobrata Som  
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### Course Details:

- **Crystallography:**  
X-ray Diffraction and scattering, X-ray reflection from interfaces and multilayers, Neutron scattering.
- **Optical Spectroscopy:**  
Raman spectroscopy, Photoluminescence spectroscopy, Infrared spectroscopy.
- **Electron Spectroscopy:**  
Revealing the electronic structure via. Synchrotron radiation, Angle integrated and angle resolved Photoemission spectroscopy, X-ray absorption spectroscopy (XAS).
- **Ion Spectroscopy:**  
Introduction to particle accelerator, Ion Implantation, Rutherford back scattering (RBS), particle induced x-ray emission (PIXE).
- **Nuclear Spectroscopy:**  
Basic principles of Resonance spectroscopy and its application: Nuclear magnetic resonance spectroscopy (NMR), electron spin resonance (ESR), muon spin spectroscopy ( $\mu$ SR).
- **Surface Science:**  
Growth of thin film and characterization by Scanning tunneling spectroscopy (STM), Atomic force microscopy (AFM), Low energy electron diffractometer (LEED), transmission electron microscopy (TEM) scanning electron microscopy (SEM).
- **Transport measurements:**  
Understanding magnetic and electronic transport measurements through SQUID-VSM magnetometer, 4 probe resistivity.

### Course Outcomes:

- Apply diffraction and scattering techniques (X-ray, neutron) to determine crystal structure and material properties.
- Use optical, electron, ion, and nuclear spectroscopic methods to investigate electronic and atomic structure of materials.
- Understand surface science techniques (STM, AFM, LEED, TEM, SEM) for thin film growth and nanoscale characterization.
- Analyze transport measurements to study electrical, magnetic, and thermal properties of materials.

**07-PHYS05-106-E: Soft Condensed Matter Physics (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **Basic Introduction:**  
Structure, scattering and correlation functions
- **various structures and scattering:**  
ordered systems, liquids (classical and quantum), polymers, fractals, glasses. Effective forces: van der waals to various time-temperature dependent forces.
- **Liquid crystals, Polymers, and glass:**  
Liquid crystals and colloids: models, phases, and phase diagrams, Polymers: Gaussian (ideal), self-avoiding, semiflexible polymer; scaling and its use; theta point; solutions and melts; topological effects; Response functions (elastic, visco-elastic behavior);
- **Dynamics:**  
single and many chains; Gels, rubber, percolation, Introduction to glass transition. Generalized elasticity: XY model, Liquid crystals, crystals.
- **Hydrodynamic description:**  
Conserved quantities, broken symmetry variables, dynamics near phase transitions (critical dynamics, nucleation, spinodal decomposition, phase ordering).
- **Topological and geometrical problems:**  
topological defects in ordered systems like liquid crystals. Elementary analysis of BKT transition; Fluctuating surfaces, topological invariants.

**Course Outcomes:**

- Understand structure, scattering, and correlation functions in ordered and disordered systems.
- Analyze liquid crystals, polymers, glasses, and their phase behavior using scaling and statistical models.
- Apply hydrodynamic and dynamical descriptions to study phase transitions, critical dynamics, and percolation phenomena.
- Explain topological effects, defects, and geometrical concepts such as BKT transition and fluctuating surfaces in soft matter systems.

**References :**

1. Chaikin-Lubensky, Principles of condensed matter physics
2. Doi-Edwards, Polymer dynamics
3. M Doi, Soft matter physics
4. Richard A. L. Jones, Soft Condensed Matter Review Articles:
5. Gary L Hunter and Eric R Weeks, The physics of the colloidal glass transition Rep. Prog. Phys. 75 (2012) 066501
6. Daan Frenkel, Soft condensed matter, Physica A, Volume 313, Issues 12, 1 October 2002
7. Bray, Theory of Phase ordering kinetics, Adv. Phys. 43,357 (1994)
8. R. D. Kamien, Rev Mod Phys. 84, 497 (2012)

## 07-PHYS05-306-E: Basics of Machine Learning & AI (45 Lecture Hrs)

Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in

### Course Details:

- **Introduction to ML:**
  - i) Motivation and role of machine learning in problem solving
  - ii) Representation (features), linear transformations, matrix vector operations in the context of data and representation.  
Problem formula-tions (classification and regression).
  - iv) the probability distributions in the context of data, Prior probabilities and Bayes Rule.  
supervised, unsupervised learning, a brief overview of semi-supervised, and reinforcement learn-ing.
- **Fundamentals of ML:**
  - i) Principle component analysis and Dimensionality Reduction,
  - ii) Nearest Neighbours and KNN.
  - iii) Linear Regression
  - iv) Decision Tree Classifiers
  - v) concept of Generalization and Overfitting
  - vi) Concept of Training, Validation and Testing; Connect to generalisation and overfitting
- **Selected Algorithms:**
  - i) Basic Ensemble Learning (Random Forest, AdaBoost, Gradient Boosting)
  - ii) Linear Support Vector Machine (SVM),
  - iii) K Means clustering algorithm,
  - (iv) Logistic Regression
  - (v) Naive Bayes algorithm
- **Neural Network Learning**
  - i) Role of Loss Functions and Optimization,
  - ii) Gradient Descent and Perceptron/Delta Learning,
  - iii) Backpropagation
  - iv) MLP for Classification and Regression,
  - v) Regularisation, Early Stopping
  - vi) Introduction to Deep Learning (viii) CNNs
- **Key Concepts from ML:**  
Kernels (with SVM), Bayesian Methods, Generative Methods, Hidden Markov Model (HMM), Expectation maximisation model (EM) etc.
- **Deep Learning Architectures:**  
Popular CNN Architectures, RNNs, GANS and Generative Models,
- **Training Neural Networks:**  
Advances in Backpropagation and Optimization for Neural Networks Adversarial Learning.
- **Brief discussions on advanced architectures:**  
transformer architectures, Graph Neural Network.
- **Example problems for particle physics, condensed matter physics and experimental physics, Handson**

**sessions on Tensor Flow, PyTorch, Scikit-Learn packages.**

***Course Outcomes:***

- Understand core machine learning concepts including supervised and unsupervised learning, probabilistic modeling, and feature representation.
- Apply fundamental algorithms such as regression, SVM, decision trees, ensemble methods, clustering, and dimensionality reduction to real-world datasets.
- Design and train neural networks using backpropagation, optimization techniques, and regularization methods, including CNNs and deep learning architectures.
- Utilize advanced ML concepts (kernels, Bayesian methods, HMM, EM, transformers, GNNs) and implement models using frameworks like TensorFlow, PyTorch, and Scikit-Learn for physics applications.

***References:***

1. Python Machine Learning, Sebastian Raschka and Vahid Mirjalili, Marc Peter Deisenroth, A. Aldo Faisal, Cheng Soon Ong, Mathematics for Machine Learning, Cambridge University Press (23 April 2020)
2. Tom M. Mitchell- Machine Learning - McGraw Hill Education, International Edition
3. Aurélien Géron Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow, O'Reilly Media, Inc. 2nd Edition Reference Books:
4. Additional books:Ian Goodfellow, Yoshoua Bengio, and Aaron Courville - Deep Learning MIT Press Ltd, Illustrated edition
5. Christopher M. Bishop Pattern Recognition and Machine Learning - Springer, 2nd edition Trevor Hastie, Robert Tibshirani, and Jerome Friedman - The Elements of Statistical Learning: Data Mining, Inference, and Prediction - Springer, 2nd edition

**07-PHYS05-307-E: Quantum Transport through Nanostructures (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **Preliminary concepts:**  
Two-dimensional electron gas (2DEG), characteristic length scales, low-field and high-field magnetoresistance, Transverse modes and their origin, Ballistic transport, Phase interference. Quantum confined systems: Nanostructure materials, Quantization of heterojunction system,
- **Lateral confinement:**  
Quantum dots and quantum wires, electronic states in quantum dots and quantum wires, Magnetic field effects in quantum confined systems, Homogeneous transport in low-dimensional systems.
- **Transmission in nano-structures:**  
Tunneling in planar barrier structures, Wave-function treatment of tunneling, Current in resonant tunneling diodes, Landauer formula; derivation, Transmission function and S-matrix, Combining S-matrices, Quantized conductance in nano-structures, Lattice Green's function method.
- **Quantum dots and single electron phenomena:**  
Single electron tunneling and Coulomb blockade, Co-tunneling phenomena, coupled dots and quantum molecules, Transport in anti-dot systems, Qubits and quantum dots.
- **Interference in diffusive transport:**  
Weak localization, Universal conductance fluctuations, The Green's function in transport, Weak localization correction to the conductance, Effect of magnetic field and spin-orbit coupling, Quantum treatment of the fluctuations.
- **Mesoscopic superconductivity:**  
Andreev reflection and Andreev scattering, Transport through a normal metal-superconductor junction, Blonder-Tinkham-Klapwijk formula, Josephson junction arrays, Superconducting Island beyond the Josephson limit, Phase and flux qubits.
- **Interaction, relaxation, and decoherence:**  
Temperature decay of coherence, The role of temperature on the fluctuations, Electron-electron interaction effects, Tunneling in an electromagnetic environment, Electrons moving in an environment, Relaxation and decoherence of Qubits.

**Course Outcomes:**

- Understand quantum transport in low-dimensional and mesoscopic systems, including 2DEG and quantum confinement effects.
- Apply tunneling theory, Landauer formalism, and Green's function methods to analyze transmission and conductance in nanostructures.
- Explain single-electron phenomena, Coulomb blockade, interference effects, and mesoscopic superconductivity.
- Analyze interaction, relaxation, and decoherence processes in quantum devices and qubit systems.

**References:**

1. Quantum transport: Introduction to nanoscience: Y. Nazarov and Y. Blanter
2. Quantum transport: Atom to transistor: Supriyo Datta

3. Transport in Nanostructures: Ferry and Goodnick
4. Mesoscopic electron transport: Supriyo Datta

## 07-PHYS05-304-E: Optics/Photonics (45 Lecture Hrs)

Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in

### Course Details:

Introduction to general lasers and their types, emission, absorption processes and rate equations, Population inversion, gain, optical cavities, three- and four- level lasers, CW and pulsed lasers, Q-switching and mode-locking, Physics of gas discharge, Atomic, Ionic, molecular, liquid, and excimer lasers, optical pumping, Holography, an overview of non-linear Optics, nonlinear polarization, Nonlinear optical susceptibility, Symmetry considerations, Wave Propagation in nonlinear media, electro-optical and magneto-optical effects, higher harmonic generations, Phase matching and quasi-phase matching, Sum and difference frequency generation, Optical parametric amplification and oscillation, Kerr effect, Cross-Phase Modulation, Self-phase modulation, Multiphoton Processes, Self-focusing, Four-Wave Mixing, Laser Spectroscopy, wavefront conjugation Stimulated Raman Scattering, Stimulated Brillouin Scattering, Optical solitons and Optical Pulse Compression, Principles of waveguides and fiber optics.

### Course Outcomes:

- Understand laser physics including emission processes, population inversion, optical cavities, and different types of lasers.
- Analyze nonlinear optical phenomena such as harmonic generation, Kerr effect, multiphoton processes, and parametric interactions.
- Apply concepts of laser dynamics, Q-switching, mode-locking, and laser spectroscopy to practical systems.
- Explain wave propagation in nonlinear media, optical fibers, solitons, and waveguide-based photonic devices.

### References:

1. Lasers by P.W.Milonni and J.H.Eberly, John Wiley and Sons
2. Lasers by A.E.Siegman, University Science Books
3. Principles of Lasers by Orazio Svelto, Springer Verlag
4. The principles of nonlinear optics by Y.R.Shen, John Wiley and Sons
5. Nonlinear Optics by Robert W. Boyd, Academic Press
6. Nonlinear Optics: Basic Concepts by D.L.Mills, Springer Verlag
7. Optical waves in crystals by Amnon Yariv and Pochi Yeh, Wiley-Interscience
8. Laser Spectroscopy by Wolfgang Demtrder, Springer Verlag

**07-PHYS05-305-E: Thin Films and Interfaces (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
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**Course Details:**

- **Definition of thin films:**

Environment, molecular and plasma processes in thin film deposition, Cold and thermal plasma, Requirement for substrate and substrate cleaning, Formation of thin films, Sticking coefficient, Formation of thermodynamically stable cluster – nucleation. Growth process.

- **Properties of thin films:**

Microstructure, Single crystalline films, Polycrystalline films, Nanocrystalline thin films, Amorphous films, Metastable films, Surface morphology, Film density, Stress in thin films, Adhesion, Stoichiometry, Mechanical, electrical, thermal, chemical, and optical properties of thin films.

- **Electrical discharges used in thin film deposition:**

Mechanism of electrical discharges, I-V characteristics of electrical discharges, Townsend discharge, Glow discharge, Arc.

- **Practical electrical discharge configuration for deposition of thin films:**

Direct current electric discharges, Radio-frequency discharges, Microwave discharges, Electron cyclotron resonance plasma, Matching units, Floating potential, Bias potential, Plasma potential, Effective bias, Self-bias.

- **Physical deposition techniques:**

Direct current and radiofrequency sputtering, Magnetron sputtering, Cathodic arc deposition, Filtered cathodic arc deposition. Ion beam sputtering. Ion plating, Thermal evaporation, Resistive evaporation. Electron beam evaporation, Molecular beam epitaxy, Pulsed laser ablation. Synthesis of nanomaterials (nanowires, nanoribbons).

- **Chemical Vapour deposition techniques (CVD):**

Thermally activated CVD, Plasma enhanced CVD, Oxidizing and nitriding, Photo-assisted CVD, Plasma polymerization, Chemical transport in plasma, Hydrogen neutralization in semiconductors.

- **Other processing technologies:**

Pattern transfer, Reactive ion etching, Ion milling, Ion beam dry etching.

**Course Outcomes:**

- Understand the fundamentals of thin film formation, nucleation, growth mechanisms, and plasma processes involved in deposition.
- Analyze structural, mechanical, electrical, optical, and surface properties of different types of thin films.
- Apply knowledge of physical and chemical vapor deposition techniques for fabrication of thin films and nanomaterials.
- Explain plasma-based processing, electrical discharges, and etching technologies used in microfabrication and device manufacturing.

**References:**

1. (E-book) H. Lüth, Solid surfaces, interfaces and thin films, Heidelberg, New York, Springer-Verlag, 2010. (5th ed.)
2. (E-book) D. M. Mattox, Handbook of physical vapor deposition (PVD) processing, Oxford, 2010. (2nd ed.)

3. (E-book) by P. M. Martin (Eds), Handbook of deposition technologies for films and coatings, Oxford, 2009. (3rd ed.)
4. D Clocker, S I Shah (Eds), Handbook of Thin Film Process Technology, Institute of Physics Publishing, London 1995.
5. W N G Hitchon, Plasma Processes for semiconductor Fabrication, Cambridge University Press, Cambridge 1999. J L Vossen, W. Kern (Eds), Thin Film Processes II, Academic Press, Boston 1991.
6. Elshabini-Riad, A. R. Aicha, Thin film technology handbook / New York: McGraw-Hill, 1998.
7. F C Maticotta, G. Ottaviani, Science and technology of Thin Films, World Scientific, New Jersey 1995.
8. Materials Science of Thin Films – Deposition and Structure – Milton Ohring, 2002.

## SEMESTER IV

### 07-PHYS05-401-C: Numerical Methods & Research Methodology & Research Publication Ethics (45 Lecture Hrs)

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

#### *Course Details:*

- **Introduction to computer languages:**  
(Fortran/C/C++/python etc.) Representation of numbers, Numerical pre-cision and estimation of errors. Numerical Interpolation and extrapolations, Sorting and searching, Linear Algebra, eigenvalue and eigenvectors, Root findings algorithms: Bisection method, Newton-Raphsons method, The Secant Method Numerical Integration, Quadratures, Numerical solution to Ordinary and Partial differential equations, Random number generation, Monte Carlo Simulation, Data fitting, chi-square fitting, goodness of fit test, Kolmogorov-Smirnov test.
- **Research Methodology & Research Publication Ethics:**  
Article writing, communication skills, seminar presentation, review of research papers.

#### *Course Outcomes:*

- Apply numerical methods and programming techniques to solve algebraic equations, differential equations, and integration problems.
- Implement algorithms for interpolation, root finding, eigenvalue problems, data fitting, and Monte Carlo simulations.
- Analyze numerical accuracy, error estimation, and statistical tests for scientific data analysis.
- Develop research skills including scientific writing, presentation, and critical review of research literature.

#### *References:*

1. Gerald, C. F. and Wheatly, P. O., " Applied Numerical Analysis", 6th Edition, Wesley.
2. Jain, M. K., Iyengar, S. R. K. and Jain, R. K., "Numerical Methods for Scientific and
3. Engineering Computation", New Age Pvt. Pub, New Delhi.
4. Conte, S. D. and De Boor, C., "Elementary Numerical Analysis", Mc Graw Hill Publisher.
5. Krishnamurthy, E. V. & Sen, S. K., "Applied Numerical Analysis", East West Publication.
6. Tuckman, B. W. & Harper, B. E. (2012). Conducting educational research (6th ed.).
7. Lanham, MD: Rowan & Littlefield Publishers.
8. Doctoral Student Handbook and Dissertation Style Guide. (2011); (<http://web.tamu-commerce.edu/academics/graduateSchool/> for the most current version of this handbook.)
9. Kothari, C. R. and G. Garg (2019), Research Methodology & Research Publication Ethics: Methods and Techniques, Fourth Multi Colour Edition, New Age International Publishers

**07-PHYS05-202-E: Advanced Condensed Matter Physics (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **The electron gas and liquid:**  
the electron gas, Hartree-Fock, The fermi liquid and Landau Parameters, The Random phase approximations, strong interaction (Wigner crystals) Non fermi liquid interactions in the presence of lattice (Mott insulators) d) Electron-Phonon interaction.
- **System of reduced dimensionality:**  
Quantum Dots, The special case of 1D, the Landauer formalism for transport, interactions in 1D: Luttingerliquids the 2D electron gas, the quantum Hall effect (integer and fractional) introduction to topological insulators.
- **Physics of disordered system:**  
Anderson localization, Weak localization, hopping transport, The metal insulator transition interactions in the presence of disorder, many body localization.
- **Superconductivity:**  
Preliminaries, conventional vs unconventional superconductivity. Microscopics of BCS theories, gauge symmetry breaking, Josephson effect. High temperature superconductivity, Cuprate and Pnictides superconductivity, introduction to simple models of High Tc superconductivity. distinction between s-wave, p-wave, d-wave superconductivity, heavy fermionic superconductivity.
- **Magnetism:**  
Basics, Ferromagnetism and Anti ferromagnetism, spin waves, Stoner model, t-J Model. Introduction to frustrated magnetism, Local moments, the Kondo effects and RKKY interactions. Introduction to heavy Fermionic system, The Kondo lattice.

**Course Outcomes:**

- Understand interacting electron systems including Fermi liquid theory, electron–phonon interaction, and strong correlation effects such as Mott insulators and Wigner crystals.
- Analyze low-dimensional systems and quantum transport phenomena including Landauer formalism, Luttinger liquids, and quantum Hall effects.
- Explain effects of disorder such as Anderson localization, metal–insulator transitions, and many-body localization.
- Apply theoretical models to describe superconductivity and magnetism, including BCS theory, high-Tc superconductors, Kondo effect, and frustrated magnetic systems.

**References:**

1. Many-body quantum theory in Condensed Matter Physics - Karsten Flensberg and Henrik Bruus
2. Advanced Solid-State Physics- Philip Philips
3. The quantum theory of Magnetism Majlis
4. Condensed Matter Physics-Michael P. Murdar
5. Many Particle Physics- G Mahan
6. Superconductivity in metal and Alloys-P de Gennes
7. Elementary Excitations in Solids D Pines
8. The Kondo Problem to heavy fermions- A. C Hewson

9. Theory of high Temperature superconductivity- Todor M Mishonov and Evgeni Spenev

## List of Special Topics in Condensed Matter Physics (45 Lecture Hrs)

Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in

### Course Details:

- Topological phases of matter
- Transport in low dimensional system
- Frustrated magnetism and spin liquids
- Quantum phase transition
- Physics of many body localization
- Quantum liquids
- Strongly correlated system and materials
- Unconventional superconductivity and superfluidity
- Physics of cold atoms
- Renormalization group method
- Solid State Physics
- Energy Materials
- Quantum Science & Technology

### Course Outcomes:

- Understand modern concepts in condensed matter physics including topological phases, quantum phase transitions, and many-body localization.
- Analyze transport phenomena, frustrated magnetism, quantum liquids, and strongly correlated systems.
- Explain unconventional superconductivity, superfluidity, and physics of cold atom systems using advanced theoretical methods.
- Apply renormalization group techniques and solid-state physics principles to emerging materials, energy systems, and quantum technologies.

**07-PHYS05-205-E: High Energy Physics (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **Introduction:**  
Broad preview and overview, a bit of discussion of history and current status, basic ingredients of modern theories, colliders and detectors, LHC and main detectors.
- **Symmetries and Lie Groups:**  
Quantum numbers, conservation laws, discrete and continuous symmetries, Lie groups and algebras, SU(n) and SO(n) groups and representations, Young Tableau, hadron spectroscopy, eight-fold way, quark model.
- **S-Matrix, Cross section and Decay rates:**  
General discussion, relativistic kinematics, phase space, basic formulas for  $2 \rightarrow 2$  scattering and decays into 2 or 3 particles, Feynman rules.
- **Gauge Theories and Spontaneous symmetry breaking:**  
Construction of gauge theories, discrete symmetry breaking, breaking of global and local continuous symmetries, Goldstone and Higgs phenomena.
- **Electromagnetic Interactions:**  
Quantum Electrodynamics, Simple processes like Moller Scattering, Bhabha Scattering, Compton scattering, pair annihilation.
- **Weak Interaction:**  
Fermi theory, V-A theory, C, P and CP violation, muon decay, pion, kaon and B/D-mesons decay, neutrino-electron, neutrino-muon, and neutrino-quark scattering, IVB theory, problems.
- **Strong Interaction:**  
Deep-inelastic scattering and structure of hadrons, Bjorken scaling, Quark parton model, sum rules, scaling violation, splitting functions, DGLAP equation,  $\bar{e} e^+ \rightarrow$  hadrons, basic  $2 \rightarrow 2$  processes involving quarks and gluons, glimpse of helicity methods.
- **Standard Model:**  
Motivation for  $SU_C(3) \otimes SU_L(2) \otimes U_Y(1)$  symmetry and its breaking, construction of the action, masses of vector bosons and fermions, CKM matrix and CP violation.
- **Basic processes in the Standard Model:**  
W/Z boson decays, heavy quark production, neutral-current processes, basic Higgs boson production and decays.
- **Beyond Standard Model Scenarios:**  
Neutrino oscillations and neutrino mass, standard model shortcomings, effective field theories, anomalous interactions, GUTs, supersymmetry, large extra dimension, etc.

**Course Outcomes:**

- Understand the fundamental principles of particle physics including symmetries, Lie groups, and the quark model.
- Apply quantum field theory methods to calculate cross sections, decay rates, and scattering processes in electromagnetic, weak, and strong interactions.
- Explain the structure and symmetry breaking mechanism of the Standard Model, including Higgs mechanism and

CKM matrix.

- Analyze physics beyond the Standard Model such as neutrino oscillations, GUTs, supersymmetry, and extra dimensions.

**References:**

1. F. Halzen and A. D. Martin - Quarks and Leptons
2. T-P Cheng and L-F li - Gauge Theory of Elementary Particle Physics
3. V. D. Barger and R. J. N. Phillips - Collider Physics
4. V. Barger, D. Marfatia, and K. Whisnant - The Physics of Neutrinos

**07-PHYS05-204-E: Quantum Field Theory II (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **Loop Calculation in scalar field theory:**  
One-loop calculation of 2 and 4-point functions in interacting scalar field theory, Regularization and Renormalization, Renormalization group equation and beta function, Anomalous dimension, Renormalization of composite operators.
- **Renormalization group flow:**  
Solution of Callan-Symanzik equation, Classification of field points, Multiple couplings and linearized RG-flow in the neighborhood of a field point, Various types of asymptotic behavior of QFT, Wilson-Fisher field point and introduction to E-expansion in large-N vector model.
- **Non-Abelian gauge theory:**  
Non-Abelian gauge theory, Path-Integral quantization of non-abelian gauge theories, BRST symmetry, One loop beta function of non-Abelian gauge theory and asymptotic freedom, Introduction to Wilson loop and confinement.
- **Effective action and global symmetry breaking:**  
1PI effective action and Coleman-Weing using 1PI effective potential, Goldstone Boson.
- **Gauge symmetry breaking:**  
Spontaneous breaking of gauge symmetry and Higgs mechanism. Anomalies: Introduction to anomalies in QFT.
- **Finite temperature field theory:**  
Introduction to field temperature field theory, Coleman-Weinberg effective potential at field temperature, Symmetry restoration at high temperature.
- **Miscellaneous topics:**  
Non-Perturbative techniques in field theory. Solitons and Instantons in field theory.

**Course Outcomes:**

- To develop and produce advanced research skills; and
- Perform one-loop calculations in quantum field theory and apply regularization, renormalization, and renormalization group methods.
- Analyze renormalization group flow, fixed points, and critical behavior in scalar and gauge field theories.
- Understand non-Abelian gauge theories, BRST symmetry, asymptotic freedom, confinement, and anomalies.
- Apply effective action methods and finite-temperature field theory to study symmetry breaking, Higgs mechanism, solitons, and instantons.

**References:**

1. Peskin and Schroeder - An introduction quantum field theory
2. Ramond- Field theory - A modern primer
3. Matthew Schwartz - Quantum field theory and the standard model
4. Weinberg- The quantum theory of field Vol-1 and Vol-2.
5. Sidney Coleman - Aspects of symmetry

## 07-PHYS05-203-E: Advanced Nuclear Physics (45 Lecture Hrs)

Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in

### Course Details:

- **Nuclear Physics General:**

NN interaction: symmetries, basics, low energy scattering and shape independence, meson theory and properties of NN interaction, Nuclear systematics: masses, radii, shapes, magnetic and quadrupole moments, shell structure, radioactivity, fission, halo nuclei.

- **Nuclear Models:**

liquid drop model, semi empirical mass formula, Fermi gas model, Basics of shell model, Hartree-Fock, pairing, Relativistic mean field formalism for finite and infinite nuclear many-body problem (intro.) rotational and vibrational spectra, giant resonance.

- **Nuclear reactions:**

Resonances and compound nucleus, direct reactions (inelastic, stripping, pickup etc.), extracting nuclear information from reactions.

- **Nuclear matter:**

Nuclear equation of state (Relativistic and Non-relativistic Formalisms), neutron stars, Quark models, quark equation of state, relativistic heavy ion collisions, signature of QGP, Big bang and QCD phase transition, hadron and quark, phase transition in neutron stars.

### Course Outcomes:

- Understand nucleon–nucleon interactions, nuclear properties, and systematics including radioactivity and fission.
- Apply nuclear models such as liquid drop, shell model, Hartree–Fock, and relativistic mean field theory to finite and infinite nuclear systems.
- Analyze nuclear reactions and extract structural information from reaction mechanisms and resonance phenomena.
- Explain nuclear matter properties, equation of state, neutron stars, quark–gluon plasma, and QCD phase transitions.

### References:

1. W. Greiner and J. Eisenberg - Nuclear Models, Vol. I, II and III
2. Bohr and B. R. Mottelson - Nuclear Structure, Vol I and II
3. Blatt and Weisskopf - Theoretical Nuclear Physics
4. M. A. Preston and R.K. Bhaduri - Structure of Nucleus
5. Muller - Physics of Quark Gluon Plasma
6. Cheuk-Yin Wong - Introduction to High-Energy Heavy-Ion Collision

## 07-PHYS05-207-E: Non-Linear Dynamics & Chaos (45 Lecture Hrs)

Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in

### Course Details:

- **One- and two-dimensional systems:**  
Fixed points, bifurcation, limit cycles; phase plane analysis; Topological analysis.
- **Interacting Systems:**  
Predator-Prey model/Lotka-Volterra system. Specific Systems: (one or more of the following)
- **Enzyme Kinetics (Michaelis-Menten equation).**
- **Neuron dynamics (Hodgkin-Huxley and FitzHugh-Nagumo models).**
- **Kinematic waves (Belousov-Zabotinski reaction, traffic flow, Singular perturbation/shocks). Travelling waves (Fisher-Kolmogorov problem, kdV equation).**
- **noisy problems (Edwards-Wilkinson/KPZ problem of surface growth). Chaos: Lyapunov exponent, Lorentz equation, Logisticmap, fractals.**
- **Turbulence:** Elementary introduction to Kolmogorov scaling.

### Course Outcomes:

- Analyze one- and two-dimensional dynamical systems using phase plane methods, fixed points, and bifurcation theory.
- Model interacting biological and physical systems such as predator-prey, enzyme kinetics, and neuron dynamics.
- Apply nonlinear wave and reaction-diffusion models to describe traveling waves, shocks, and pattern formation.
- Understand chaos, stochastic growth models, and basic turbulence concepts including Lyapunov exponents and Kolmogorov scaling.

### References:

1. S. Strogatz: Nonlinear dynamics and Chaos
2. J. Murray: Mathematical Biology I, II
3. J. K. Bhattacharjee -Statistical Physics

## 07-PHYS05-206-E: Quantum Information & Computation (45 Lecture Hrs)

Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in

### Course Details:

- **Quantum Mechanics Formalism:**  
Postulates, density matrix, generalized measurements, qubits, no-cloning theorem.
- **Composite Systems:**  
Entangled states, partial trace, Schmidt decomposition, purification. Quantum Entanglement: Detection and quantification of entanglement in bipartite and multipartite systems, monotones, majorization.
- **Quantum Operations:**  
quantum channels, Kraus representation, quantum noise, master equations, tomography.
- **Quantum Nonlocality:**  
EPRparadox, Bell inequality, CHSH inequality, Tsirelson bound, PR box, steering, quantum games.
- **Quantum Communication:**  
superdense coding, teleportation, entanglement swapping, secret sharing.
- **Quantum Cryptography:**  
One-time pad, BB84, B92, Ekert protocols.
- **Quantum Algorithms:**  
Universal quantum gates, Deutsch algorithm, Deutsch-Jozsa algorithms, Quantum Fourier transform.

### Course Outcomes:

- Understand the formalism of quantum mechanics including density matrices, qubits, and generalized measurements.
- Analyze entanglement, composite quantum systems, and quantum nonlocality using Bell inequalities and related concepts.
- Apply quantum operations and noise models to describe quantum channels, decoherence, and tomography.
- Explain key quantum information protocols and algorithms such as teleportation, BB84, and quantum Fourier transform.

### References:

1. M. A. Nielsen and I. L. Chuang - Quantum Computation and Quantum Information
2. J. Preskill - Lecture notes on Quantum Information Theory, online at Caltech Website
3. M. M. Wilde - Quantum Information Theory
4. Peres - Quantum Theory: Concepts and Methods

**07-PHYS05-404-E: Physics of Living Matter (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

**Course Details:**

- **Overview of Soft and Living Matter:**  
Biology by numbers. Statistical physics in biology: active particles, chemical kinetics, feeding by diffusion, membrane potentials. Molecular machines: molecular motors, polymerases, synthases, enzymes, ion-pumps, mitochondria; Macromolecular assemblies: polymers, membranes.
- **Forces, energies, and timescales;**  
colloids, polymers, membranes, liquid crystals; Viscous, elastic, and viscoelastic behavior. Slow variables, Order parameters, phase separation, Landau theory, implication for membrane-less organelles; active Brownian particles, motility-induced phase separation, Vicsek model, flocking transition.
- **Single particle in fluid, Brownian motion;**  
Markov processes; stochastic differential equations; Langevin, Master equation and Fokker-Planck; entropy and information; polymer and random walk; DNA as a semi-flexible polymer; Statistical dynamics, Response and correlation functions Viscous, elastic, and viscoelastic behavior. Hydrodynamics: Navier-Stokes, low Reynolds number flows, swimming, generalized hydrodynamics, active matter, physics of the actomyosin cytoskeleton. Motility of cells, Polar and nematic order; cytoskeleton as active liquid crystal.
- **Pattern formation:**  
morphogen gradients, Turing patterns, mechanochemical patterns, morphogenesis, tissue dynamics.
- **Sensing and signalling:**  
receptor-ligand interactions, MWC model, biochemical pathways, physical limits to sensing.

**Course Outcomes:**

- Apply principles of statistical physics to understand biological systems, molecular machines, and active matter.
- Analyze forces, energy scales, phase behavior, and viscoelastic properties of polymers, membranes, and colloidal systems.
- Use stochastic processes and hydrodynamic models to describe Brownian motion, cell motility, and active cytoskeletal dynamics.
- Explain mechanisms of biological pattern formation, sensing, and signaling using physical and mathematical models.

**References:**

1. Paul Chaikin and Tom Lubensky, Principles of Condensed Matter Physics (Cambridge 1995)
2. Philip Nelson, Biological Physics: Energy, Information, Life (W H Freeman 2014)
3. R Phillips, J Kondev, J Theriot, H Garcia, Physical Biology of the Cell (Garland Science 2013)
4. Antonio Siber and Primož Zihlerl, Cellular Patterns (CRC Press 2018)
5. Cross and Greenside, Pattern formation and dynamics in non-equilibrium systems (Cambridge 2009)

## 07-PHYS05-403-E: General Theory of Relativity & Cosmology (45 Lecture Hrs)

Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in

### Course Details:

- Review of Newtonian Mechanics. Special theory of relativity. Prelude to General relativity, his-torical developments. 4-Vectors and 4-tensors, examples from physics. Principle of Equivalence, Equations of motion, Gravitational force. Tensor Analysis in Riemannian space, Effects of Grav-itation, Riemann- Christoffel curvature tensor, Ricci Tensor, Curvature Scalar. Einstein Field Equations, Experimental tests of GT. Schwarzschild Solution, Gravitational lensing, Gravita-tional waves: generation and detection. Energy, momentum and angular momentum in Gravita-tion. Cosmological principle, Robertson-Walker metric, Redshifts. Big-Bang Hypothesis, CMB. Issues in Quantum Gravity.

### Course Outcomes:

- Understand the foundations of general relativity, including tensor formalism, equivalence principle, and Einstein field equations.
- Apply differential geometry concepts to analyze curvature, spacetime metrics, and gravitational dynamics.
- Explain key predictions of general relativity such as Schwarzschild solution, gravitational lensing, and gravitational waves.
- Describe basic cosmology concepts including expanding universe models, Big Bang theory, CMB, and challenges in quantum gravity.

### References:

1. A first course in General Relativity: B. Schutz
2. Gravity: James B. Hartle
3. The classical Theory of Fields: L.D. Landau and E.M. Lifshitz
4. Gravitation and Cosmology: S. Weinberg
5. Introduction Einstein's Relativity: Ray D'Inverno
6. General Relativity: P.Dirac

### **07-PHYS05-213-E: Special Topics in Statistical Physics (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

#### ***Course Details:***

- **These are special courses as per research requirements, may even be research level topics not covered in other courses or topics of current interest.**

#### ***Course Outcomes:***

- To develop and produce advanced research skills; and
- To be able to deliver original significant contribution to knowledge; and
- To demonstrate mastery in various basic and advanced subject materials; and
- To be able to conduct scholarly activities in an ethical manner and mastering professional ethics and communication.

### **07-PHYS05-405-E: Special Topics in Experimental Physics (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

#### ***Course Details:***

- **These are special courses as per research requirements, may even be research level topics not covered in other courses or topics of current interest.**

#### ***Course Outcomes:***

- To develop and produce advanced research skills; and
- To be able to deliver original significant contribution to knowledge; and
- To demonstrate mastery in various basic and advanced subject materials; and
- To be able to conduct scholarly activities in an ethical manner and mastering professional ethics and communication.

### **07-PHYS05-406-E: Special Topics in Experimental Condensed Matter Physics (45 Lecture Hrs)**

**Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in**

#### ***Course Details:***

- **These are special courses as per research requirements, may even be research level topics not covered in other courses or topics of current interest.**

#### ***Course Outcomes:***

- To develop and produce advanced research skills; and
- To be able to deliver original significant contribution to knowledge; and
- To demonstrate mastery in various basic and advanced subject materials; and
- To be able to conduct scholarly activities in an ethical manner and mastering professional ethics and communication.

## 07-PHYS05-407-E: Particle Accelerators: Fundamentals to applications (45 Lecture Hrs)

Coordinators: Prof. Tapobrata Som  
tsom@iopb.res.in

### Course Details:

- **Introduction to Accelerators:**  
History and basic principle of various particle accelerators, DC Accelerators, Cyclic Accelerators, Linear Accelerators, Synchrotrons and High energy Accelerators, Ion Sources and types.
- **Ion Implanters:**  
Construction, Beam transport, Experimental station.
- **Beam Theory and Optic elements:**  
Vacuum System, Beam Theory, Beam Acceleration, Beam optics calculations, Magnets, Beam steerers, Quadrupoles, Beam profile meters, etc.
- **Control of Accelerators:**  
Control Systems, Devices communication, Fiber Optics communication, Power Supplies (Low and High Voltage, Low and High Currents).
- **Application of Accelerators/Implanters:**  
Accelerators in daily life, Semiconductors, Health Sciences, Pattern formation and its applications, Memory Devices, Quantum Science and Technology, Industry applications, etc.

### Course Outcomes:

- To develop and produce advanced research skills; and
- To be able to deliver original significant contribution to knowledge; and
- To demonstrate mastery in various basic and advanced subject materials; and
- To be able to conduct scholarly activities in an ethical manner and mastering professional ethics and communication.

### References:

1. The physics of particle accelerators: an introduction by Klaus Wille, Oxford Press USA, 2000.
2. Accelerator Physics by S.Y. Lee, World Scientific Publishing Company, 2004.
3. Particle Accelerator Physics by H. Wiedemann, Springer, 2007.
4. Ion-Solid Interactions: Fundamentals and Applications by M. Nastasi, J.W. Mayer, J. K. Hirvonen, 1996.

## SEMESTER V & VI

### 07-PHYS05-402-PR : Project

**Coordinators: Prof. Tapobrata Som**  
**[tsom@iopb.res.in](mailto:tsom@iopb.res.in)**

#### ***Course Outcomes:***

- The students choose a particular topic of his/her choice and work out in details under the guidance of a faculty.
- Learning how to survey literature and approach a problem.
- Acquire capability to understand and explain the problem to the scientific community in written as well as in verbal communication.
- Finding the relevant extension of the problem towards his/her Ph D.