Integrated M.Sc. - Ph.D. Programme:

CORE COURSES		
Course Code	**Name of the Course**	**Credits**
PHY-102.7	Numerical Methods and Algorithms in Chemical Physics	4
PHY-103.7	Mathematical Methods for Physicists	4
PHY-104.7	Classical Mechanics	4
PHY-106.7	Quantum Mechanics – I	4
PHY-107.7	Classical Electrodynamics – I	4
PHY-108.7	Experimental Methods	8
+ All Core courses of Ph.D. Programme		

Ph.D. Programme:

CORE COURSES		
Course Code	**Name of the Course**	**Credits**
PHY-202.7	Numerical Methods-II	4
PHY-205.7	Statistical Mechanics – I	4
PHY-206.7	Quantum Mechanics II / Advanced Quantum Mechanics	4
PHY-207.7	Classical Electrodynamics – II	4
PHY-208.7	Advance Experimental Methods	12

ELECTIVE COURSES		
Course Code	**Name of the Course**	**Credits**
PHY-225.7	Soft Matter and Biological Physics	4
PHY-301.7	Atomic & Molecular Physics	4
PHY-302.7	Computational Methods for Condensed Matter Systems	4
PHY-303.7	Solid State Physics-I / Condensed Matter Physics	4
PHY-304.7	Optics	4
PHY-305.7	Lasers and Nonlinear Optics	4
PHY-313.7	Solid State Physics – II / Condensed Matter Physics – II	4
PHY-325.7	Polymer Physics & Soft Matter	4
PHY-401.7	Advanced Computational Methods	4
PHY-402.7	Advanced Dynamics	4
PHY-403.7	Advanced Statistical Mechanics / Statistical Mechanics – II	4
PHY-404.7	Phase Transitions, Ordering and Dynamics	4
PHY-405.7	Soft Matter: Equilibrium and Dynamics	4
PHY-406.7	Advanced Mathematical Physics	4
PHY-407.7	Advanced continuum Mechanics	4
PHY-408.7	Field Theory	4
PHY-409.7	Nonlinear Dynamics	4
PHY-410.7	Intense laser matter interactions	4
PHY-415.7	Advanced Mathematical Methods	4
PHY-417.7	Magnetism	4
PHY-418.7	Quantum Thermodynamics	4
PHY-419.7	Disordered Systems	4
PHY-422.7	Dynamical system and Chaos	4
PHY-424.7	Dynamics of Statistical Systems	2
PHY-425.7	Dynamics of Statistical Systems in and out of equilibrium	4
PHY-426.7	Modern Topics in Statistical Mechanics	4
PHY-427.7	Nano optics and Plasmonics	4
PHY-428.7	Soft condensed matter physics	4
PHY-429.7	The Quantum Phase of matter	4
PHY-300.7	Departmental Project - I	8
PHY-400.7	Departmental Project - II	8
PHY-399.7	Reading Course on any topic (3xx level)	4
PHY-499.7	Reading Course on any topic (4xx level)	4

Courses offered by other SBs and approved by AAC:

Course Code	Name of the Course	Credits
CHM-222.7	Molecular Dynamics Simulation and application in chemical physics	4
BIO-205.7	Biological Thermodynamics	4
BIO-203.7	Mechanobiology	4
CHM-113.7	Spectroscopy of atoms and molecules	4
CHM-215.7	Molecular and Nonlinear Dynamics	4
CHM-200.7	Principles of NMR Spectroscopy	4
CHM-210.7	Physics and Chemistry of materials: Bulk to Nano	4
CHM-220.7	Electronic Structure theories of Matter	4
CHM-213.7 / BIO-202.7	Fluorescence Methods in Cellular Biophysics	4
CHM-217.7	Solid State NMR	4
CHM-212.7 / BIO-101.7	Basic Cell Biology	4

Compulsory Course:

Course Code	Name of the Course	Credits
PHY-200.7	Research Methodology	4

PHY-102.7: Numerical Methods and Algorithms in Chemical Physics

Syllabus:

1) Python: Writing/running codes: Editors, Ipython; modules, matplotlib, numpy

2) Linear Equations: Gaussian elimination, LU decomposition, Direct/Iterative methods

3) Curve Fitting: Least squares fitting, polynomial interpolation, splines

4) Root finding: Graphical, bisection, Newton-Raphson

5) Numerical Differentiation: Finite difference; Error analysis

6) Numerical Integration: Newton-Cotes formulae, Romberg/Gaussian integration, Multiple integrals

7) Initial Value Problems: Euler/Runge-Ku<a methods; Stability and Stiffness

8) Boundary Value Problems: Shooting Method

9) Symmetric Matrix Eigenvalue Problems: Jacobi rotations, Power/inverse power method, Tridiagonal form

10) Minimization/Optimiztion: 1-D problems, N-D problems, Powell's method, Simplex method

11) Application to Chemical Physics: Molecular thermodynamics (Ideas, harmonic oscillator, rigid rotor partition functions), Equation of states, Schroedinger equation of Hydrogen molecule cation, Hartree Fock for He atom, Linear variational problems in Quantum mechanics (1D potentials, Tunneling prob-lems), Potential energy surface fitting, Time-dependent Schroedinger equation.

12) Optional Topic: Krylov Subspace Techniques, Lanczos iteration

Required Text 1. *Numerical Methods in Engineering with Python 3,* Jaan Kiusalaas, Cambridge university Press (2013).

Evaluation Method: Quizzes based on assignment (4x10%), closed-book mid-term exam (30%), closed-book final exam (30%).

PHY-103.7: Mathematical Methods for Physicists

- **Vectors and Matrices**: Linear vector space, Coordinate transformation, Gradi- ent, Divergence, Curl, Gauss and Stokes theorem, Curvilinear coordinates, tensor, Series, Properties of determinants and matrices, Linear transformation, Eigenvector- Eigenvalue problems, Similarity and unitary transformations.

- **Differential Equations**: Linear and non-linear differential equations, Sturm- Liouville eigenvalue problem, Legendre polynomials and properties, Spherical harmonics, Bessel equations and properties.
- **Complex Analysis:** Cauchy-Riemann conditions, Analytic functions, Contour integrals, Taylor and Laurent series, Singularities, Residue theorem, Gamma and Beta function, Method of steepest descent, Stirling series, asymptotic series, Convergence tests.
- **Integral Transforms:** Fourier series, Fourier transform, Laplace transform, Solution of initial boundary-value problem, Convolution .
- **Calculus of Variations:** Dependent and independent variables, Lagrangian multi- pliers.

Primary text/ References:

1. Mathematical Methods for Physicists by Arfken and Weber
2. Mathematical Physics by V. Balakrishnan
3. Mathematics for Physicists by Dennery and Krzywicki

Evaluation: There will be regular assignments containing 40% weightage on the grades. Apart from these, there will be one mid-term (30%) and one final examination (30%).

Course Outcome:

Sr. No.	On completing the course, the student will be able to:
CO 1	A solid understanding of the basics of different mathematical techniques often used in physics in addition to detailed knowledge of some specific topics such as the complex integrals, solving differential integrals, and integral transforms.
CO 2	General knowledge of some research topics where the analytical techniques can be applied.
CO 3	Gain a basic understanding of some of the biophysics problems where the analytical techniques can be applied to understand the complex problems.
CO 4	Knowledge of the probability theory and randomness. How different types of distribution arises.
CO 5	Demonstration of some simple exercise problems to gain insights of how to gain insights via application of the mathematical techniques.

<u>PHY-104.7: Classical Mechanics</u>

Syllabus:

- One and Two-dimensional dynamical systems : Newton’s laws of motion, Harmonic oscillator, Over-damped oscillator, Simple pendulum, Time period of oscillations, Fixed points, simple bifurcations, Phase plane/space.

- Lagrangian formalism Elements of calculus of variations, Generalised coordinates, Principle of least action, Euler-Lagrange equations, Constraints, Lagrangian for a free particle and system of particles, Conservation laws, Mechanical similarity

- Central force fields and Collisions Motion in one dimension, Reduced mass, Motion in a central field, Kepler’s problem, Elastic collisions, Scattering

- Small Oscillations : Free and forced oscillations, Vibrations of molecules, Damped oscillations, Resonance, Parametric resonance, Regular perturbation theory, Anharmonic oscillator, Motion in a rapidly oscillating field

- Hamiltonian formalism Hamilton’s equation, Poisson brackets, Canonical transformation, Liouville’s theorem, Hamilton-Jacobi theory, Action-Angle variables Integrable and NonIntegrable systems, adiabatic invariants, and elements of timedependent perturbation theory.

Primary Text / Reference Books:

- Mechanics, L.D. Landau and L.M. Lifshitz
- Nonlinear dynamics and Chaos, S.H. Strogatz
- Classical Mechanics, N.C. Rana and P.S. Joag
- Theoretical Mechanics of Particles and Continua, A.L. Fetter and J.D. Walecka

Evaluation Method (Weightage for Internal Assessment, Mid Term / Term End exams, Presentations etc.):

- Mid-semester: 40 %,
- Homework: 20%
- End-semester: 40%.

Course Outcome:

Sr. No.	On completing the course, the student will be able to:
CO 1	Use the formalisms of mechanics- Lagrangian and Hamiltonian – in various physics problems
CO 2	Apply perturbation theory to study the role of nonlinearities.
CO 3	Study necessary techniques to grasp more advanced courses like Nonlinear dynamics.
CO 4	Study effect of interaction between particles in scattering and move to advanced quantum scattering
CO 5	Look at problems involving simple harmonic systems

PHY-106.7: Quantum Mechanics – I

Syllabus:

1) Origins: Wave-particle duality: Blackbody radiation, Compton Effect, de Broglie's hypothesis; Heisen-berg's uncertainty principle; Atom models; Waves

2) Representation of states and operators: Linear vector space and Hilbert space; Operators: Her-mitian adjoint, projection, functions of operators, unitary operators, eigenvalues and eigenvectors of an operators; Discrete basis; Continuous basis; Matrix-vs-wave mechanics

3) Postulates of QM: Probability density; Observables; Measurement; Time-evolution; Symmetries; Connection to classical mechanics

4) 1D problems: 1D Schroedinger equation; Free particle; Potential step; Potential barrier and well; Infi-nite square well; Finite square well; Harmonic oscillator; Numerical solution

5) Angular momentum: Orbital angular momentum; Spin angular momentum; Eigenfunctions and ei-genvalues

6) 3D problems: Variable separation; 3D: free particle, box, harmonic oscillators; Spherical coordinates: Central potential, spherical well, isotropic harmonic oscillators, hydrogen atom, effect of magnetic field on central potentials

7) Rotation and addition of angular momentum: Rotations; Addition of angular momentum; Clebsch Gordon coefficients; Tensor operators; Wigner-Eckart theorem

8) Identical particles: Many-particle systems: Permutation symmetry; Identical particles: Exchange de-generacy, symmetrisation, anti-symmetrisation; Pauli-exclusion principle

9) Approximation methods: Time-independent perturbation theory: Degenerate and non-degenerate versions; Variational method; WKB method

10) Introduction to advanced topics: Time-dependent perturbation theory; Scattering theory; Relativistic quantum mechanics: Dirac equation

Required Text 1. *Quantum Mechanics Concepts and Applications,* Nouredine Zettili, Wiley (Edition-2, 2009).

Evaluation Method: Assignment (6x5=30%), closed-book mid-term exam (30%), closed-book final exam (40%).

PHY-107.7: Classical Electrodynamics – I

Syllabus:

- Single charged particles in E and B fields
- Electrostatic fields, potentials, energy and forces
- Analytical and numerical ways of solving electrostatic potential problems
- Idealized and real charge distributions and their potentials
- Current distributions and magnetic fields
- Magnetic materials
- Maxwell's equations, EM waves and their propagation in free space and in media.
- EM waves in confined spaces

References Books:

1. David J. Griffiths : Introduction to Electrodynamics (Prentice Hall) – 2 Nos
2. J.D. Jackson : Classical Electrodynamics (John Wiley) – 2 nos
3. R.P. Feynman, R.B. Leighton, M.Sands : Lectures on Physics (Addison – Wesley) – 2 nos

Evaluation Method:
Assessment: 40% assignments + 60% Final exam

Course Outcome:

Sr. No.	On completing the course, the student will be able to:
CO 1	comprehend various domains of electrostatics, magnetostatics and steady currents.
CO 2	make use of the uniqueness theorems and Green's identities for problem solving
CO 3	understand the relation between microscopic and macroscopic parameters
CO 4	to pose and solve various boundary value problems.
CO 5	appreciate the use of complex analysis and method of images in solving boundary value problems
CO 6	use extensively methods of separation of variables for different geometries
CO 7	make comprehensive presentations on any assigned topic
CO8	understand the differences between static and dynamic systems and appreciate the physical outcomes of Maxwells equations

PHY-108.7: Experimental Methods

Syllabus:

1. e/m Experiments.
2. Frank-Hertz experiment.
3. Michelson Interferometer.

4. Zeeman effect.
5. Plank Constant measurement.
6. Fiber coupling and profile mapping.
7. 4-probe conductivity measurement.
8. Basic Labview experiment.

Primary Text / Reference Books:

Manuals available with Instructors

Evaluation Method (Weightage for Internal Assessment, Mid Term / Term End exams, Presentations etc.):
Seminars, lab work and the experiment reports for each experiment

PHY-202.7: Numerical Methods-II

- Elements of Computer Programming: Flow-charts, Basic of C language (arrays, pointers, functions), Add/Subtract/Multiply/division, Round of errors with some examples, Data analysis using Matlab, python, gnuplot. (6 lectures)
- Linear algebra: Gauss elimination, Gram-Schmidt orthogonalization, Eigenvalue problem, Examples using lapack.
- Differentiation and Integration: numerical schemes for differentiation (finite differences and spectral methods) and integration (Trapezoidal, Simposon's 1/3, Gaussian Quadratures).
- Ordinary Differential Equations: Euler, Runge-Kutta time integration and velocity verlet scheme, Example elucidating Newton's equation of motion.
- Partial Differential Equation: Diffusion Equation, Advection equation, Advection-diffusion equation, Laplace, Poisson equation, Helmholtz equation.
- Conjugate gradient method. Least square method of fitting data to different functions. Linear, polynomial and non-linear functions (Levenberg-Marquardt algorithm), Interpolation (Linear, polynomial, spline, etc.).
- Advanced topics: Introduction to Molecular Dynamics/Monte Carlo, Lattice Boltzmann and Navier-Stokes Equations

Primary Text / Reference Books:

1. Computational Physics: An Introduction; Authors: F.J. Vesely.

(http://homepage.univie.ac.at/franz.vesely/cp_kluwer/index.html)

2. Numerical Recipes in C/Fortran; Authors: W.H. Press, S.A. Teukolsky, W.T. Vetterling, B.P. Flannery.

(https://www2.units.it/ipl/students_area/imm2/files/Numerical_Recipes.pdf)

3. The art of molecular dynamics simulation; Authors: D. C. Rapaport

Evaluation Method (Weightage for Internal Assessment, Mid Term / Term End exams, Presentations etc.):
50% assignments + 50% final term.

Course Outcome:

Sr. No.	On completing the course, the student will be able to:
CO 1	Learn how to handle finite-precision artithematic, and error propagation. Numerical solution of derivatives and integrals.
CO 2	Learn numerical integration of ordinary and partial differential equations. With applications to Schrodinger and Navier-Stokes equations.
CO 3	Understand the physics-motivated ``Symplectic integrators'' to numerically integrate problems in mechanics.
CO 4	Molecular dynamics simulations to study problems in statistical physics.

PHY-205.7: Statistical Mechanics – I

Short description: An introduction to statistical mechanics with applications to systems in physics and chemistry.

1. **Brief overview of equilibrium thermodynamics:** Extensive and intensive properties, laws of thermodynamics, entropy and free energy, chemical potential, phase equilibrium (3 lectures)
2. **Ensembles in statistical mechanics:** Phase space density in classical systems and its time evolution, introduction of microcanonical, canonical and grand canonical ensembles, partition functions and connections to thermodynamic variables, fluctuations (5 lectures)
3. **Application of statistical mechanics** to the ideal gas, rotational and vibrational spectra, heat capacity of crystals, non-interacting spin systems, chemical reaction equilibrium (4 lectures)
4. **Statistical mechanics of quantum systems:** Fermi and Bose statistics, ideal Fermi gas and ideal Bose gas, discussion of the classical limit, Fermi gases at low temperature, Bose-Einstein condensation (5 lectures)
5. **Statistical Mechanics of Interacting Systems 1**: The configuration integral, virial expansion, the law of corresponding states (3 lectures)
6. **Statistical mechanics of interacting systems 2**: Correlation functions and relation to thermodynamic functions, radial distribution function in simple liquids, correlation functions in magnets (4 lectures)
7. **Computer simulation of statistical systems:** Introduction to Monte Carlo and molecular dynamics, case studies (3 lectures)

Text Books:
1) Statistical Mechanics: Kerson Huang
2) Statistical Mechanics I : M. Kardar
3) Introduction to Modern Statistical Mechanics: David Chandler
4) Statistical Mechanics: Donald McQuarrie
5) Statistical Mechanics: R. K. Pathria and Paul D. Beale
6) Statistical Mechanics: S. K. Ma
7) Statistical Physics: L.D. Landau and E.M. Lifshitz

Mode of Evaluation: 4 or more assignments, 2 exams (1 mid term and 1 end term)

Course Outcome:

Sr. No.	On completing the course, the student will be able to:
CO 1	Learn how to interpret thermodynamic property in terms of molecular properties
CO 2	Will have knowledge on how to derive thermodynamics of imperfect gas and liquid
CO 3	Will get an idea of basic quantum statistics of boson and fermion
CO 4	Will hone analytical skills of solving problems of interest in chemical physics

PHY-206.7: Quantum Mechanics II / Advanced Quantum Mechanics

1. Theory of angular momentum (3L) ˆ
Rotations and spherical tensor operators ˆ
Matrix elements of spherical tensor operators: Wigner-Eckart theorem ˆ
(HW-1)
2. Time Independent Perturbation Theory (2L) ˆ
Projection operator technique ˆ
Examples ˆ
(HW-2)
3. Adiabatic principle and Berry phase (4L) ˆ
Adiabatic principle ˆ
Berry phase ˆ
Modern theory of polarization
4. Time dependent QM (4L) ˆ
Different representations, TDSE in interaction picture: Exact solution for 2-state system V = constant, periodic perturbation
Extension to 1 → continuum, Green operator ˆ
TDPT: with coeff (historical): 1st order, application V = constant, Fermi's golden rule ˆ
examples ˆ
(HW-3)

5. Quantum scattering theory (4L) ˆ
Elastic scattering ˆ
Born Approximation and Born series ˆ
Optical theorem 1 ˆ
Plane wave analysis: method of partial waves ˆ
Some examples: Hard sphere Scattering, Coloumb Scattering
6. Review (1L)
7. Midterm
8. Introduction to QED (12L) ˆ
Quantization of EM field (8L)
- Introduction, Total free field energy density → collection of uncoupled harmonic oscillators
- Second quantization
  * Bosonic and fermionic ladder operators
  * 1- and 2- particle operators in second quantization
  – Lagrangian, conjugate variables, canonical quantization
  – Examples: Spontaneous emission, photoelectric effect
  – (HW-4)
  – Lamb shift (Bethe's derivation)
  – Four vector and Lorentz gauge, other ways of quantization ˆ

Relativistic QM (4L)
– Review of Special relativity
– Relativistic Hamiltonian
– Dirac Equation and Klein Gorden equation
– Free particle solution and Central force problem
– Hole theory
– CPT invariance
– (HW-5)
9. Review (1 extra lecture)
10. Final

Referece Texts (i) Modern Quantum Mechanics, Sakuari (Addison and Wesley) (ii) Advanced Quantum Mechanicw, Sakuari (Addison and Wesley) (iii) Relativistic Quatum Mechanics , Bjorken and Drell (McGraw Hill)

Course Outcome:

Sr. No.	On completing the course, the student will be able to:
CO 1	Understand how to solve model time-dependent problems in quantum mechanics and estimate rate constants for quantum processes
CO 2	Understand how to deal with mixed states
CO 3	Employ the framework of second quantization to study fermionic many-body problems
CO 4	Understand how to quantize the free electromagnetic field and explain spontaneous emission
CO 5	Understand how to treat scattering processes quantum mechanically
CO 6	Comprehend how to treat fast moving particles quantum mechanically

PHY-207.7: Classical Electrodynamics – II

Syllabus:
- Special relativity and relativistic kinematics
- Covariant (Lagrangian) formulation of electrodynamics
- Motion of charges and electromagnetic fields: Leinard Weichert potentials
- Charges in electromagnetic fields: radiation from an accelerated Charge, Bremsstrahlung, Cherenkov, Synchrotron and Transition radiation.
- Radiation reaction: energy loss mechanisms
- Electromagnetic fields propagating through matter: scattering, diffraction.

- Dispersion, causality and Kramers-Kronig relation. Metamaterials: Negative index and hyperbolic media. Perfect lensing. Optical pulses and beams: Fast and slow light. Goos-Hanchen and Feodorov-Imbert shifts. Spin-orbit interaction with light
- **Special topics:** Lasers and nonlinear optics, novel optical phenomena, Plasmonics and nano-optics.

Primary Text / Reference Books:

- W.K.H.Panofsky and M.Phillips : Classical Electricity and Magnetism (Addison Wesley)
- J.D. Jackson, Classical Electrodynamics (John Wiley)
- Landau & Lifshitz : Electrodynamics of continuous media (Pergamon)
- David J. Griffiths, Introduction to Electrodynamics (Prentice Hall)
- S Dutta Gupta, N Ghosh and A Banerjee, Wave Optics – Basic concepts and contemporary trends, (CRC press)

Evaluation Method (Weightage for Internal Assessment, Mid Term / Term End exams, Presentations etc.):

Internal assessment (problem sets) and midterm: 40
Term end exams: 40
Presentation and quiz: 20

Course outcome:

Sr. No.	On completing the course, the student will be able to:
CO 1	appreciate the meaning and consequences of special theory of relativity. Can understand time dilation, Lorentz contraction, notion of simultaneity and synchronization in various inertial frames. Derive and study Lorentz transformation and its consequences.
CO 2	be familier with covariant formulation of electrodynamics, freely use co- and contra- variant vectors and tensors. Can interpret the famous E=mc^2 equation
CO 3	be familiar with radiation from an accelerated Charge, Bremsstrahlung, Cherenkov, Synchrotron and Transition radiation.
CO 4	understand radiation reaction and energy loss mechanisms
CO 5	appreciate the use of complex analysis in obtaining the Kramers-Kronig relations connecting dispersion with losses.
CO 6	introduced to novel optical phenomena in plasmonics and nano-optics, near and far field behavior
CO 7	make comprehensive presentations on any assigned topic
CO 8	solve problems involving electromagnetic fields propagating through matter: deal with scattering, diffraction

<u>PHY-208.7: Advance Experimental Methods</u>

Syllabus:

1. Study the hyperfine spectrum of Rb.
Aim: Studies on Doppler Free atomic absorption spectroscopy of Rb gas. Understanding line broadening mechanisms in atomic spectroscopy

2. Static and Dynamic Mechanical Analyses of polymer membranes
Aim: Calculation of the static mechanical properties of well-known polymer membranes (Hooke's law verification), and studies on the complex modulus of them using dynamic studies. Studies on entropic rubber properties. Verify the transition using DSC measurements.

3. Understanding of Electrochemical Impedance Spectroscopy.
Aim: Understanding different time scales and phenomena of electrode-electrolyte interface.

4. FET Characteristics of Semiconductor Films

Aim: Find out the mobility, type of majority carriers and ON/OFF ratio.

5. Magneto-Resistance & MOKE Measurements of Magnetic Films
Aim: Studying the AMR (%) of a multi-layer thin film using transport measurements in presence of magnetic field. Magneto-Optic Kerr effect (MOKE) measurements of magnetic thin films.

6. Measurement of Q-factor for thin film coatings developed using ECR Gun
Aim: Coating of oxide films on silicon wafers using ECR method. Study the mechanical properties of substrate and coatings by measuring the q-factor for vibration damping.

Evaluation Method (Weightage for Internal Assessment, Mid Term / Term End exams, Presentations etc.):

The students will have to read about the experiment and make a presentation on the theory and methods involved in each before performing the experiment. After the experiment is completed, a report on each experiment has be submitted in the form of a research article. Grades will be based on presentation, experimental performance and the report submitted. All will have equal waitage.

Course Outcome:

Sr. No.	On completing the course, the student will be able to:
CO 1	Explain atomic spectra and hyperfine splitting and will have knowledge of spectroscopy techniques
CO 2	Perform mechanical analyses solids: Static and Dynamic mechanical analyses.
CO 3	Explain Electrochemical Impedance Spectroscopy.
CO 4	Use NMR spectroscopy for chemical analysis
CO 5	Study electron transport properties in magnetic materials and the effect of magnetic field.
CO 5	Use surface tension and surface energy of liquids and solids for their characterisation

PHY-225.7: Soft Matter and Biological Physics

Polymers, Glass Formation and Jamming

- Polymers: Introduction to polymers; Ideal polymer chains; Real Chains: Excluded Volume; Polymer Solutions; Electrostatics; Polyelectrolytes; Networks and gelation; Polymer Dynamics; Rheology of Polymers; Protein Folding
- Glass Formation and Jamming: Glass transition phenomenology; Crystal nuclation and glass forming ability; Description of dynamics; Mode Coupling Theory; Energy landscape approach; Spin glasses; Random First Order Transition theory; Dynamic Heterogeneity; Jamming; Glassy Rheology

PHY-301.7: Atomic & Molecular Physics

- Interaction of one-electron atoms with electromagnetic radiation.
- One-electron atoms: fine structure, hyperfine structure and interaction with external electric and magnetic fields.
- Two-electron atoms: Para and ortho states, Independent particle model, excited states of two-electron atoms.
- Many electron systems: Thomas-Fermi model, the Hartree-Fock method, LS- and jj-couplings.
- The interaction of many-electron atoms with electromagnetic fields. Selection rules, Atoms with several optically active electrons. Zeeman effect and quadratic Stark effect.
- Molecular structure. The Born-Oppenheimer separation for diatomic molecules, rotation and vibration of diatomic molecules. Structure of polyatomic molecules.
- Molecular spectra: Rotational energy levels of diatomic molecules, Vibrational-rotational spectra, electronic spectra, Electronic spectra and Hund's cases, nuclear spin.

PHY-302.7: Computational Methods for Condensed Matter Systems

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PHY-303.7: Solid State Physics-I / Condensed Matter Physics

LIST OF TOPICS

- Drude/Sommerfeld Theory of Metals
- Crystal Lattices, The Reciprocal lattice
- Determination of Crystal Structure by X-Ray Diffraction
- The Free Electron Model and its limitations
- Electrons in Periodic Potentials: General Properties, Electrons in a Weak Periodic Potential
- The Tight-Binding Model
- Calculating Band Structure
- The Semiclassical Model of Electron Dynamics
- The Semiclassical Theory of Conduction in Metals
- Beyond the Independent Electron Approximation
- The Hartree-Fock Equations
- Fermi Liquid Theory
- Diamagnetism and Paramagnetism
- Magnetic Ordering
- Superconductivity
- Field theories, critical phenomena, and the renormalization group
- Hydrodynamic Descriptions

Reference Materials

• Solid State Physics by N. W. Ashcroft and N. Mermin
• Principles of Condensed Matter Physics by P. M. Chaikin and T. C. Lubensky

Grades will be assigned as follows
50% Assignments
25% Midterm Exam
25% Final Exam

Course Outcome:

Sr. No.	On completing the course, the student will be able to:
CO 1	Compute the phonon spectra of crystalline solids
CO 2	Understand the low temperature behavior of solids: heat capacity
CO 3	Compute Electronic properties in Periodic Potentials
CO 4	Calculate Band Structure of solids

PHY-304.7: Optics

Basic properties of EM field: Electro-magnetic field, Maxwell's equations, boundary conditions, energy law of EM field; Scalar waves, plane, spherical and harmonic waves, phase and group velocity; Vector waves, EM plane wave, harmonic EM plane wave; elliptic polarization, characterization of state of polarization, Stokes parameters, Poincaré sphere representation; Reflection and refraction of plane waves, Fresnel formulae, reflectivity and transmissivity, polarization on reflection, total reflection.
Theory of interference and interferometers: Interference of two monochromatic waves, wave-front and amplitude division interferometers, fringes with quasi monochromatic sources, visibility of fringes, coherence; multiple beam interference and interferometers.
Theory of diffraction: Huygens-Fresnel principle, Kirchhof's diffraction theory, Fraunhofer and Fresnel diffraction; Fraunhofer diffraction at apertures and in optical instruments, Fresnel diffraction at a straight edge.
Interference and diffraction with partially coherent light: Polychromatic fields, correlation function of light beams van-Cittert – Zernike theorem; polarization properties of quasi monochromatic light, coherency matrix, degree of polarization.
Optics of metals: Wave propagation in a conductor, reflection, refraction at a metal surface, elementary electron theory
Optics of crystals: Dielectric tensor of anisotropic medium, monochromatic wave in an anisotropic medium, phase and ray velocity, Fresnel's formulae, index ellipsoid, uniaxial and biaxial crystals, measurements.
Advanced topics: Beam shifts, cylindrical vector beams, optical angular momentum, advances in microscopy

PHY-305.7: Lasers and Nonlinear Optics

Part A

- Idea of a LASER. Heuristic description of a single mode laser based on Statz and de Mars equation. Optical feedback, steady states and threshold.

- Optical resonators. Mobius transformation applied to Gassian beams through linear optical elements. Longitudinal and transverse modes. Stable and unstable resonators. Quality factor. Beam and spin optics.

- Semiclassical theory of single mode operation. Density matrix formulation of light-matter interaction. Self-consistency. Maxwell-Bloch equations. Susceptibility and dispersion. Lasing frequency, frequency pushing and pulling.

- Homogeneous and inhomogeneous broadening. Mode-locked and Q-switched operation. Few applications (optical tweezers, EIT, EIA etc.). A brief introduction to the quantum theory of laser fluctuations.

Part B

- The constitutive relation. Response function theory of linear and nonlinear optical susceptibilities. Nonlinear oscillator based models and the density matrix apporach. Local field corrections.
- Wave mixing phenomena. Parametric and non-parametric processes. Harmonic generation, Kerr nonlinearity, four-wave-mixing and optical bistability.
- Parametric downconversion for correlated photon pair generation. Birefringent and quasi phase matching. PPLN. Frequency comb.

Primary Text / Reference Books:

1. **M Sargent, M O Scully and W E Lamb Jr., Laser Physics (Addison-Wesley, New York)**
2. **A E Siegman, Lasers (University Science Books, California, 1986)**
3. **A Yariv, Quantum Electronics, Third Edition, (John Wiley, New York, 1989)**
4. **Stephen C Rand, Lectures on Light: Nonlinear and Quantum Optics using the Density Matrix, (Oxford University Press, Oxford, 2010)**
5. **R. W. Boyd, Nonlinear Optics, Third Edition, (Elsevier, Amsterdam, 2008)**
6. **W. Demtroder, Laser Spectroscopy, Fifth Edition (Springer, 2015)**

Evaluation Method (Weightage for Internal Assessment, Mid Term / Term End exams, Presentations etc.):
2-3 during term exams during the semester and one end term exam.

Course Outcome:

Sr. No.	On completing the course, the student will be able to:
CO 1	comprehend physical principles underlying the operation of a laser, understand its essential components and concepts like threshold, stability, output characteristics, line broadening mechanisms etc.
CO 2	understand and appreciate Saatz de-Mars equations for single mode operation of a laser.
CO 3	understand rays, beams confined in a resonator based on the ABCD law and derive the fundamental properties of the modes of the resonator, its quality factor and resonance frequencies. Calculate the parameter domain of stability of a resonator.
CO 4	learn density matrix approach for light matter interaction and appreciate the importance of the Fermi Golden Rule
CO 5	Derive rate equations for two or higher level systems, understand mode locking and Q switching. Classify lasers in three boad classes, A, B and C types.
CO 6	learn about the domain of nonlinear optics and the new nonlinear optical effects like harmonic generation, parametric amplification, four-wave mixing, phase conjugation, etc.
CO 7	learn about how to satisfy phase matching condition using birefringence, temperature tuning and quasi phase matching using PPLN.
CO 8	learn about nonlinear response function theory and calculate the nonlinear susceptibilityes

	using classical and quantum models.

PHY-313.7: Solid State Physics – II / Condensed Matter Physics – II

A. Special Topics I [14 Lectures] KR
1. Refresher on Second Quantization [3]
2. Quantum Hall Effect, Berry Phases and Topology in Condensed Matter Physics [7]
3. Other Current Topics [4] *B. Special Topics II [12 Lectures] KVR and TNN*
4. Dirac materials: Graphene; Topological Insulators [10] *C. Special Topics III [14 lectures] SRS*
5. Magnetism [4]
6. Superconductivity [10]

Evaluation: Grades will be assigned as follows 50% Assignments 50% Midterm/Final Exam

Course Outcome:

Sr. No.	On completing the course, the student will be able to:
CO 1	The students learn the phenomenology and microscopic of Superconductivity and Magnetism, at the mean field level.
CO 2	There is a detailed treatment of second-quantized BCS theory for superconductivity, that is rarely done at this student level. In a more intuitive treatment, the BCS ground state written as a simple generalization of the free fermi gas of a normal metal,by allowing the step functions to be variational u,v with smooth fall-off.
CO 3	Compute the classical Hall Conductivity of two dimensional materials
CO 2	Compute the Berry phase for adiabatically driven quantum systems
CO 3	Compute the Landau levels for electrons in a magnetic field
CO 4	Compute the quantized Hall conductivity of two dimensional materials

PHY-325.7: Polymer Physics & Soft Matter

- Polymer Science, Soft Matter, Some problems (1 lecture)
- Ideal Chains: Conformations of ideal chain, Ideal chain models, Radius of gyration, free energy, pair correlations, measurements (basic concepts) (3 lectures)
- Real Chains: Excluded volume, Flory theory, Temperature and strain (polymer under shear flow) effects, scaling theory (3 lectures)
- Computer simulation approach using polymer based model (2 lectures)
- Thermodynamics of phase separation, spinodal and binodal. Brief overview of phase separation in biology (2 lectures)
- Polymer solutions, quality of solvent, Alexander-de Gennes brush (2 lectures)
- Percolation, gelation, Flory-Stockmayer theory, phase separation, glass transition (basic overview of the problem and some theoretical models) (8 lectures)
- Dynamics: Rouse model, Zimm model, branched polymers, entanglements, elastic regime (4 lectures)

Evaluation Method:
4 assignments: 25%, Presentation on term-paper based on application of polymer physics in biology: 25%, 2 class-room examinations: 50%

PHY-401.7: Advanced Computational Methods

- Programming primer - C Vs. Fortran Arrays, Memory allocation, Functions and Subroutines, What NOT to do while handling arrays, Debuggers
- Advection equation - Finite difference, Spectral, Boundary conditions

- Diffusion equation - Finite difference, Spectral , Boundary conditions
- Examples of Advection-Diffusion equation - Inviscid and Viscous Burgers equation, Chemical reactions: Advection-Diffusion-Reaction equation (Fisher equation) Poisson equation - Matrix diagonalization , Fast solvers
- A "real" problem: 2D Navier-Stokes simulation in a box - Lid-driven cavity problem, Introducting obstacles: Volume penalization
- A new approach to fluid dynamics: Lattice Boltzmann method - Boltzmann equation and its discretization, From Boltzmann equation to Navier-Stokes: Chapman-Engskok expansion, 2D Navier-Stokes with variety of boudary conditions
- MPI programming of Navier-Stokes and Lattice Boltzmann

PHY-402.7: Advanced Dynamics

- Low-order systems of ordinary differential equations
- maps
- linear stability
- bifurcations
- routes to chaos
- Navier-Stokes and continuity equation, some simple shear flows
- Flow stability: Kelvin-Helmholtz, Rayleigh-Benard, Taylor-Couette
- Routes to turbulence
- Elastic instabilities

PHY-403.7: Advanced Statistical Mechanics / Statistical Mechanics – II

Syllabus:

- A quick summary of different ensembles. Non-interacting Classical Systems - magnetic systems, ideal gas and Harmonic oscillator, Statistical mechanics for interacting systems: Cluster expansion.
- Interacting Magnetic Systems, Ising and Heisenberg Model, Mean Field Theory, Transfer Matrix Method, Phase Transitions: Order Parameter, First and Second Order Phase Transitions, Landau-Ginzburg Theory, Scaling, Critical exponents and Universality class, Generalized Homogeneous function, Hyper Scaling relation, Kadanoff Construction, Renormalization Group Transformation, Momentum Space RG.
- Linear Response, Fluctuation-Dissipation Theorem, Brownian Motion, Langevin Equation, Fokker-Planck Equation.

Primary Text / Reference Books:

1. Pathria and Beale, Statistical Mechanics
2. Chaikin and Lubensky, Principles of Condensed Matter Physics
3. H.E. Stanley, Introduction to Phase Transitions and Critical Phenomena
4. S.K. Ma, Statistical Mechanics
5. Nigel Goldenfeld , Lectures on Phase Transition and The Renormalization Group

Evaluation Method (Weightage for Internal Assessment, Mid Term / Term End exams, Presentations etc.):
Assignments: 30, Mid term presentation: 30 , Final term: 40

Course Outcome:

Sr. No.	On completing the course, the student will be able to:
CO 1	Use basic fluctuation-response relations for magnetic systems
CO 2	Perform cluster expansions for fluid systems

CO 3	Understand the concepts of long range order and broken symmetries
CO 4	Work out the properties of interacting spin systems using mean field theory
CO 5	Calculate critical properties using the renormalization group

PHY-404.7: Phase Transitions, Ordering and Dynamics

- Ordered Phases and Phase Transitions: Phenomenology; Models; Correlation Functions; Mean field theory
- General Results on Ordering: Absence in 1-d; Peierls argument; Spin waves; Lower critical dimension; Mermin-Wagner theorem
- Critical Phenomena: Fluctuations and their growth; Ornstein-Zernike theory; Scaling; Universality; Upper critical dimension, Ginzburg criterion
- Renormalization Group: Basic idea; Real-space RG; Epsilon expansion; Multicriticality Specific Systems: XY Model; Polymers
- The framework of time-dependent statistical mechanics: Linear response theory, fluctuation-dissipation theorem, Kubo formulae
- Brownian motion: Langevin and Fokker-Planck approaches
- Microscopic stochastic dynamics: Kinetic Ising models; Master equation
- Coarse-grained stochastic dynamics: Generalised Langevin equations; Fluctuating hydrodynamics of broken-symmetry systems; dynamics of critical phenomena
- Field-theoretic methods and models: Functional integrals for statistical dynamics; dynamical renormalization group; application of these techniques to selected models at and away from thermal equilibrium.

PHY-405.7: Soft Matter: Equilibrium and Dynamics

- Polymers, Glass Formation and Jamming
- Polymers: Introduction to polymers; Ideal polymer chains; Real Chains: Excluded Volume; Polymer Solutions; Electrostatics; Polyelectrolytes; Networks and gelation; Polymer Dynamics; Rheology of Polymers; Protein Folding
- Glass Formation and Jamming: Glass transition phenomenology; Crystal nuclation and glass forming ability; Description of dynamics; Mode Coupling Theory; Energy landscape approach; Spin glasses; Random First Order Transition theory; Dynamic Heterogeneity; Jamming; Glassy Rheology

PHY-406.7: Advanced Mathematical Physics

1. Advanced vector calculus; electrodynamics as illustration of 4-d; electrodynamics in diverse dimensions; applications to fluid dynamics and elasticity.
2. Green's , Helmholtz and Alfven's theorems; coherence in quantum optics.
3. Matrices; diagonalisation; upper and lower triangular matrices; orthogonal, unitary and Hermitian matrices; normal matrices; LU-decomposition; direct product matrices; eigenvalues and eigenfunctions; generalized eigenvectors; geometric and algebraic multiplicities; defective matrices ; left and right eigenvectors; Schur and Jordan canonical forms; Singular value decomposition; Schmidt decomposition.
4. Elementary differential geometry; metric, connection and curvature; parallel transport, general coordinate transformations and isometries; geodesics.
5. Group theory; rotations and translations; generators and their algebra; unitary unimodular groups in physics;
6. Finite groups; order of the group, order of the element, periods, rearrangement theorem, multiplication tables, subgroups and cosets; Lagrange's theorem; quotient group; conjugacy classes;group characters;
7. Representations of groups.
8. Probability theory; discrete and continuous random variables; mean, variance and higher moments; dependent and independent random variables - joint, marginal and conditional probabilities; uniform distribution, gaussian distribution; central limit theorem; uniform distribution on group manifolds; Bayesian approach to probability.
9. Differential equations, orthogonal polynomials, special functions.
Recommended Books:
1. Mathematical methods of physics, Jon Mathew & R.L. Walker
2. Mathematical methods for physicists, Arfken, Weber and Harris
3. Mathematical methods in Classical and Quantum Physics, Tulsi Dass and Satish K Sharma
4. An introduction to probability, Vol I, William Feller
5. Gravitation and Cosmology, S. Weinberg
6. Mathematical Methods in the Physical Sciences, Mary L. Boas

PHY-407.7: Advanced continuum Mechanics

- Hydrostatics, Surface tension, continuity equation, Euler equation, Bernoulli's theorem. Vorticity equation, inviscid, simple vertical flows, shear stress, simple channel flow. Navier-Stokes, non-dimensionalisation, Stability theory
- The elastic continuum, broken symmetry. Simple elastic free energies of meso-phases and solids. Defects, Volterra constructions, Defect dynamics and elasticity. Time dependent elastic moduli. Elements of plasticity.

PHY-408.7: Field Theory

- Resume of classical mechanics, resume of quantum mechanics, path integral formulation of quantum mechanics, connections to classical statistical mechanics.
- Relativistic quantum mechanics: spin, Klein paradox, antiparticles. Inevitability of many particles even in single particle descriptions. Dirac sea. Simple relativistic processes.
- Fermi sea, particles and holes, nonrelativistic many-body systems, 'relativistic' behaviour in non-relativistic systems, graphene. Point particles to fields. Classical fields in Lagrangian and Hamiltonian formulations, symmetries and conservation laws. Electromagnetic and Gravitational fields. Elasticity as field theory. Hydrodynamics and Field theory, Field theory of liquid crystals.
- Quantisation of scalar fields. Overview of Quantum Electrodynamics. Why atoms radiate? Casimir effect. Examples from Quantum Optics.
- BCS theory of superconductivity. Pions and superconductivity. Higgs bosons and superconductivity.
- Asymptotic freedom in QCD. Kondo effect - asymptotic freedom in condensed matter physics.
- Singular potentials in QM as a guide to renormalisation. Scaling and critical phenomena.

PHY-409.7: Nonlinear Dynamics

The course will consist mainly of homework and project work, with few lectures. The book "Nonlinear dynamics and chaos" by Steven Strogatz will be broadly followed and homework assignments will be based on this. Apart from this, each student (or pair of students) will be assigned a Separate project on a particular aspect of NLD.

PHY-410.7: Intense laser matter interactions

- Conditions for producing a Laser – Population inversions, Gain and Gain Saturation
- Laser Oscillation above Threshold
- Requirements for obtaining Population inversions
- Laser Pumping requirements and techniques
- Laser Cavity Modes
- Stable Laser Resonators & Gaussian Beams
- Introduction to the Theory of Field-Induced Atomic Transitions
- Multiphoton Stimulated Bremsstrahlung
- Multiphoton Compton Scattering and Ponderomotive Forces in an Inhomogeneous Light Field
- Free-Electron Lasers

PHY-415.7: Advanced Mathematical Methods

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PHY-417.7: Magnetism

Syllabus:

Moments and Susceptibility
Local moments; Curie Law; Pauli paramagnetism; General formula for susceptibility

Magnetic Moment of a Single Atom or Ion
Spin and Orbital effects; (A) Hund's Rules; (B) Spin-orbit coupling; (C) Crystal fields
Transition Metals (C>B); Rare Earths (B>C)

Exchange Interactions in Insulators
Direct (potential) exchange; Kinetic exchange; Superexchange; Dzyaloshinski-Moriya interactions

Local Moments in Metals and their Interactions
Anderson impurity Hamiltonian; Kondo limit and the Kondo effect; RKKY interactions; Kondo Lattices

The Hubbard Model
The atomic limit; Half-filling → the spin 1/2 Heisenberg model; Single hole: the Nagaoka result

Magnetic States
Ferromagnets; Antiferromagnets: Neel and Resonating valence bond (RVB) states; Ferrimagnets; Helimagnets; Spin glasses

Magnetism in Metals
Itinerant magnetism

Primary Text / Reference Books:
"Lecture Notes on Electron Correlation and Magnetism" by P. Fazekas (World Scientific)
Evaluation
Homework: 30, Mid Term: 30, Final: 40

PHY-418.7: Quantum Thermodynamics

I. Classical Thermodynamics: temperature, heat, work; first law; entropy and second law; specific heats; heat engines, refrigerators and their efficiencies; entropy of mixing; chemical reactions and entropy constants; Nernst and Nernst-Planck formulations of the third law; cooling rates; dilution refrigerators.
II. Classical Statistical Mechanics: microcanonical, canonical and grandcanonical ensembles; ideal gases.
III. Brief introduction to non-equilibrium stat mech, thermalisation.
IV. Quantum Statistical Mechanics: quantum ideal bose gas; specific heats and entropy.
V. Quantum Thermodynamics of first kind: quantum modifications of classical thermodynamics; third law in the light of QSM;; entropy constants for monatomic and di-atomic ideal gases; He3-He4 mixtures and revision of entropy of mixing; chemical reactions revisited.
VI. Open Quantum Systems.
VII. Classical and Quantum Information
VIII. Quantum Thermodynamics of the other kind: emergence of thermodynamic behavior in quantum systems; quantum-work, quantum-heat and quantum-entropy; quantum first law; many entropies and many second laws; quantum third law; quantum heat engines, refrigerators and their efficiencies.

Primary Text / Reference Books:
- Principles of Thermodynamics by N.D. Hari Dass, CRC Press.
- Statistical Mechanics by R.P. Feynman
- The Principles of Statistical Mechanics by R.C. Tolman
- Elements of Non-equilibrium Statistical Mechanics by V. Balakrishnan
- Advanced Quantum Mechanics by J.J. Sakurai
- Quantum Thermodynamics by Jochen Gemmer and M. Michel

Evaluation Method (Weightage for Internal Assessment, Mid Term / Term End exams, Presentations etc.):
60 percent final exam; 40 percent assignment

PHY-419.7: Disordered Systems

Syllabus:
1) Quenched versus annealed disorder
2) Random structures: Geometrical characterization; Percolation
3) Classical transport in random media
4) Disordered spin systems: Dilute magnets
5) Spin glasses
6) Disordered Bose systems: Helium in vycor
7) Disordered Fermi systems: Anderson localization

Primary Text / Reference Books:

1) Ziman's book on Disordered Systems

2) "Ill Condensed Matter" (Les Houches Proceedings)

3)"Percolation" by Aharony and Stauffer

Evaluation Method (Weightage for Internal Assessment, Mid Term / Term End exams, Presentations etc.):

Weightage 30 (Homeworks), 30 (Mid term) 40 (Final)

PHY-422.7: Dynamical system and Chaos

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PHY-424.7: Dynamics of Statistical Systems

This course will introduce two parallel methods to analyse the time-dependent properties of statistical systems, and illustrate both with several examples. (Some of the topics will be covered in a series of 4 lectures by Prof. Sreedhar Dutta from IISER, Trivandrum, during the first week of February 2019.)

The first method involves the analysis of lattice models whose time evolution is governed by a many-body Master Equation. The second method involves a continuum description in which we describe the time evolution in terms of generalized Langevin equations for extended systems. Connections between the two methods will be illustrated through specific examples.

Topics to be covered include:

Formalism

1. The Master Equation
   Properties of stochastic matrices; Steady states and Equilibrium states; Detailed balance; Kolmogorov criterion; Pairwise balance

2. Continuum Theories
   Landau Ginzburg Wilson Hamiltonians; the approach of Halperin and Hohenberg; Martin-Siggia-Rose formalism; Fluctuating hydrodynamics

Systems

1. Exclusion models: Simple exclusion process; Asymmetric simple exclusion process (ASEP)
2. Interface dynamics: Edwards-Wilikinson model; Kardar-Parisi-Zhang (KPZ) dynamics
3. The Zero-range process
4. Reaction-diffusion processes: Annihilation (A+A → 0 and A+B → 0); Coalescence (A+A → 0; Takayasu and In-out models); Aggregation-fragmentation models
5. Deposition-evaporation Kinetics: Infinite number of conservation laws
6. Dynamics of Ising models: Glauber and Kawasaki dynamics

Reference: “A Kinetic View of Statistical Physics” by P.L. Krapivsky, S. Redner , E. Ben-Naim (Cambridge)

PHY-425.7: Dynamics of Statistical Systems in and out of equilibrium

Syllabus

1. The Random Walk and Diffusion
2. Langevin and Fokker-Planck descriptions
3. The Master Equation
   (a) Formalism; properties of stochastic matrices
   (b) Detailed balance and equilibrium
   (c) Nonequilibrium steady states
4. Interacting random walks
   (a) Simple Exclusion Process
   (b) Asymmetric Simple Exclusion Process
5. Kinetic Ising Models
   (a) Glauber dynamics
   (b) Kawasaki dynamics
6. Interface Dynamics
   (a) Equilibrium interfaces
   (b) Driven interfaces
7. Reaction-diffusion Processes
   (a) Annihilation (A+A→0)

(b) Coalescence (A+A→A)
(c) Competition (A+B → A or B)

8. Approach to an Ordered State
   (a) Growth laws without and with conservation
   (b) Coarsening, scaling and the Porod Law

Primary Text / Reference Books:

(1) S. Chandrasekhar, “Stochastic problems in physics and astronomy”, Reviews of Modern Physics 15, 1 (1943)
(2) “Stochastic Processes in Physics and Chemistry” by N. van Kampen (North Holland)
(3) “Elements of Nonequilibrium Statistical Mechanics” by V. Balakrishnan (Ane Books, New Delhi)
(4) “A Kinetic View of Statistical Physics” by P.L. Krapivsky, S. Redner , E. Ben-Naim (Cambridge)

Evaluation Method (Weightage for Internal Assessment, Mid Term / Term End exams, Presentations etc.):

Internal Assessment	40
Midterm Assessment	40
Presentations/Term End Exams	70

PHY-426.7: Modern Topics in Statistical Mechanics

The importance of statistical analysis in biological research is overwhelming, especially in a time when the consistency and reproducibility of science are under more scrutiny than ever. The conclusion of an experimental effort often depends on the precise statistical method (and its underlying assumptions) that is used to filter significant differences among the samples. However, the fact that the statistical methods can play a defining role even in the design phase of an experiment, remains under-appreciated.

1. Dealing with uncertainty: Fallacy of statistical reasoning, Reproducibility error versus systematic error, laws of large numbers, central limit theorem and hypothesis testing.
2. Working with small sample size: Significance, P values and t-tests, power and sample size, interpreting the error bars, two-sample, one-sample, and paired t-tests.
3. Modern methods in statistics: Nonparametric tests, designing comparative experiments, analysis of variance (ANOVA) and blocking

Materials: Article series entitled “Points of Significance” from Nature journals (https://www.nature.com/collections/qghhqm/pointsofsignificance)

Evaluation Method: 100% written exam.

Microscopy is an essential tool of Cell and Developmental Biology. Going beyond structure in fixed cells and tissues, advancements like Green Fluorescent Protein (GFP) technology have opened up a whole new vista of investigating protein dynamics in live cells. On the other hand, super-resolution techniques have pushed the bounds of structural resolution to well below the diffraction limit of light. So influential have been these methods, that both have won separate Nobel Prizes in a relatively short span of time after their development. This part of the course will discuss both the classic and modern applications of fluorescence microscopy in Biology. Starting from the basics of fluorescence methods, we will go on to discuss methods for measuring dynamics like Fluorescence Recovery After Photobleaching (FRAP), Fluorescence Correlation Spectroscopy (FCS), and also newly developed super-resolution methods that have been garnering a lot of interest. The following topics are proposed to be covered:

1. Basics of fluorescence - Jablonski diagrams, Stokes shifts, structures of fluorophores, quantum yields, fluorescence instrumentation - fluorescence microscopy and spectroscopy, light sources, filters, and detectors.
2. Widefield microscopy, effects of objective numerical aperture on resolution, diffraction limit of resolution of light microscopy.

3. Confocal microscopy - point-scanning and spinning disk confocal microscopy; light sheet microscopy; Total Internal Reflection Fluorescence (TIRF) microscopy; multiphoton microscopy.
4. Basics of Forster Resonance Energy Transfer (FRET), Fluorescence polarization measurements - steady-state and time-resolved fluorescence anisotropy.
5. GFP technology and dynamics measurements in live cells - Single Particle Tracking (SPT), Fluorescence Correlation spectroscopy (FCS), Fluorescence Recovery After Photobleaching (FRAP).
6. Super-resolution microscopy methods - stimulated emission depletion (STED), structured illumination microscopy (SIM), stochastic optical reconstruction microscopy (STORM), photo activated localization microscopy (PALM), and others.
7. Principles and applications of flow cytometry (MV).
Following topics will be covered:
1. Use of various model organism for large scale screens to study fundamental biology and diseases.
2. Technologies for genetic manipulation, genome editing and epigenetics technologies.
3. Utility of IPSC and Organoids.
4. State-of-the-art NGS and 'omics' tools in biology.
As a part of these classes some experts will be invited to deliver lectures/talk. Attending these lectures/talk will be mandatory for the students who have registered this course.
Course Evaluation: Written test 100%

Course Evaluation:
There will be papers assigned after a lecture. The students will be expected to provide written reports on what they understand from the papers. They are expected to convey not just the philosophical content, but the actual methods that led to the conclusions. In addition to these written assignments, there will be a written final examination.
Weightage of marks - 50% from written assignments, 50% from examination.

PHY-427.7: Nano optics and Plasmonics

The main purpose of the following course is to augment the existing course work program of TIFRH and TIFR Mumbai to create a forum for open discussions across a wide platform. The course is modular in structure with exibility built in the modules in respect of duration, depth and complexity. The exibity can be used to accommodate a very broad class of participants having di_erent levels of preparation. The course is designed keeping in view the interdisciplinary nature of research activities at TIFR Institutes, so that irrespective of the discipline any researcher can bene_t from this course.

Course modules and details
(Note: numbers in brackets denote the tentative hours allocated to discuss all the topics.
Bold body text denotes advanced topics).

(1) Structure and motivation of the course(1): How NanoOptics meets Plasmonics.

(2) Introduction to Plasmonics(7): Plane waves and Gaussian beams; Boundary conditions; Layered media and characteristic matrices; Reection and transmission through layered media; Dispersion relations; Resonances as the poles of the scattering coe_cients; Surface and guided modes; Surface plasmons and coupled surface plasmons; Avoided crossings; Resonant tunneling; Wigner delay, Goos-H•anchen shift; Hartman e_ect.

(3) Introduction to Nano-optics (5): Near vs far _eld; Rayleigh limit and how to beat it; Plane wave decomposition of arbitrary beam pro_le; Near-_eld superresolution imaging; NSOM.

(4) Optical properties of composites and metamaterials(7): Linear re-sponse theory; optical response of dielectrics and noble metals; Available experimental data and how to use them; Origin of bright coloring of certain metals; Metal dielectric composites; Maxwell-Garnett and Bruggeman theories; Planar composites; Metal inclusion in dielectric host; percolation threshold. Metamaterials and negative index materials; Perfect imaging with meta-materials (Pendry lensing); Poor man's perfect lens; Major hurdles.

(5) Localized Plasmons(4): Resonances of small particles at micro and nano scales; Mie theory; Quasistatic approximation and localized modes in small metal particles; Dipolar and quadrupolar modes. Modes of spheroids and ellipsoids; Shape and size dependence; Polarization aspects of scatter-ing.

(6) Patterned nanostructures and metasurfaces(4) Dolmen structures and Fano resonances; Quasicrystals . Nanofabrication technqiues for large area patterning and testing using spectroscopic techniques to measure the dispersion, plasmon dynamics using time resolved spectroscopy and near-_eld properties. Quasicrystals and superoscillations. Beating the di_raction limit with propagating
waves.
(7) Other E_ects(5): Extraordinary transmission: Fresnel-Kirchho_ di_raction theory and the aws in approximations; Bull's eye experiment; Role of local-ized and surface modes in extraordinary transmission. Trapping dielectric and plasmonic micro and

nanoparticles: Exploiting plasmonic near_eld enhancement for trapping / manipulating objects; Spin-orbit inter-action and optical spintronics.Light-matter interaction in di_erent regimes covering the weak, strong, ultra- and deep strong coupling regimes. Examples.

(8) Applications(5): Plasmonics for sensing; Surface and nanoparticle enhanced spectroscopy; Single molecule spectroscopy; Photothermal therapy of cancer; Plasmon mediated chemical reactions and catalysis; Plasmon mediated non-linear signal enhancement; SPASERs and Nanolasers; Nano_ber medi-ated entanglement, single photon emitters.

Course Outcome:

Sr. No.	On completing the course, the student will be able to:
CO 1	grasp the structure and motivation of the course, identify the areas and problems covered under nano optics and plasmonics
CO 2	learn the fabrication and characterization methods for metal-dielectric nano and micro structures supporting localized, surface and guided states.
CO 3	understand, derive and visualize the dispersion characteristics for exciting localized and surface plasmons. Appreciate hybridization schemes leading to avoided crossings.
CO 4	appreciate the local field enhancement under excitation of surface and localized plasmons for SERS and other surface enhanced phenomena
CO 5	understand the diffraction limit and learn how to beat it with near field techniques.
CO 6	calculate and understand perfect imaging under Pendry lensing. Understand the physical origin of extraordinary transmission.
CO 7	make comprehensive presentations on any assigned topic
CO 8	take stock of the difficulties in further development of these novel ideas.

PHY-428.7: Soft condensed matter physics

Syllabus:

1. Crystalline solids - symmetry and crystal structure - liquid crystals - isotropic, nematic and cholesterol phases - smectics - hexatic and discsotic phases
2. Symmetry and order parameters - continuous and discrete symmetries - Landau theory of phase transitions - generalized elasticity theory
3. Static properties of liquids - Functionals and functional derivatives - direct correlation functions - response functions - diagrammatic methods - YBG hierarchy and the Born-Green equations - Percus-Yevick equation.
4. Inhomogeneous fluids - nucleation and spinodal decomposition - phase separation - liquid vapour interface - confined fluid - density functional theory of freezing
5. Dynamics and correlations - Navier-Stokes equation and hydrodynamics collective modes - transverse current correlation - Kubo formula - longitudinal collective modes - generalised hydrodynamics - long-time tails - dynamics of supercooled liquids - mode-coupling theory.

Evaluation: There will be projects (40), regular assignments (30) and a final exam (30).

Course Outcome:

Sr. No.	On completing the course, the student will be able to:
CO 1	Have a basic understanding of how to describe the static properties of a liquid using the many-particle distribution function.
CO 2	Understand different types of distribution functions, such as the static structure factor, direct correlation function, two-point correlation function, and how they are related.

CO 3	How to characterise and study the properties of inhomogeneous liquid from the perspective of phase separation.
CO 4	Have a basic understanding of the dynamical properties via time-dependent correlation functions.
CO 5	Understand what is a glassy system and description of glassy dynamics via the mode-coupling theory including its analytical derivation and numerical solutions.

PHY-429.7: The Quantum Phase of matter

The initial part of the course will have in-person lectures in the lecture hall in Bloomberg at IAS Princeton, with Zoom broadcast to other locations. These lectures will be 9:00-10:30 AM (New York Time), Mondays and Wednesdays. Occasionally, the lectures may be moved to a Friday.

The first lecture will be on Wednesday September 1. The course will end mid December, with locations and schedules to be announced.

A provisional list of topics to be covered:

1. Introduction to experiments on the phases of modern quantum materials
2. Boson Hubbard model: superfluids, insulators, and other conventional phases
3. Electron Hubbard model: antiferromagnets, metals, *d*-wave superconductors, and other conventional phases
4. Mott insulators, resonating valence bonds, and the Z_2 spin liquid
5. Gapless spin liquids, and emergent SU(2) and U(1) gauge theories.
6. Kondo impurity in a metal
7. Kondo lattice: the heavy Fermi liquid, and the fractionalized Fermi liquid (FL*). Violations of the Luttinger theorem using emergent gauge fields.
8. The pseudogap metal of the cuprates: FL* theories
9. SYK model of metals without quasiparticles, and emergent gravity
10. Dynamic mean field theories of strong correlation
11. Quantum criticality of Fermi surfaces

PHY-200.7: Research Methodology – SRS, AM & GR:

Scientific research involves a mature understanding of past literature, providing contextual motivation for current work; a judicious analysis of generated data; good presentational skills; and an appreciation of the foundational role of scientific ethics and scientific method. The course will cover diverse areas such as research ethics, literature survey, quantitative methods of data and statistical analysis with practical applications to real- world data, and field visits. Because of the universal need for these research methods, values and skillings, this course is mandatory for graduate students of all the three subject-boards relevant to TIFR Hyderabad (Physics, Chemistry and Biology). The course includes topics below. (Square brackets show [No. of classes]. Smaller font is (informal teacher's notes on the topics to be covered)).

1.SKILLING STUDENTS TO:

* Sketch a Function [2] (Function *and* slope. Symmetries, Special pts, asymptotes, draw segments. Join up!)

* Write a CV [1] (First impression. Show professionalism! CV content. Fonts, topics, and sequencing.)

* Write a Letter [1] (Apply for postdoc. Ask to visit. Request to be cited.)

* Talk about research work [1] (10 minute talk, 1 minute talk, coffee conversation, the elevator pitch,140-character tweet.)

* Give a Research Talk [2] (Judge audience! 1 slide ~ 2 mins. Intro/Motivation/Methods/Results/Takeaways. Questions.)

* Write a Research Paper [2] (Abstract, Text, Fig Caps, Refs, Acknowledgements. Proof-reading. Good/Bad writing examples.)

* Read a Research Paper [1] (Quick-read. Skim text, main refs. Go to Origins, trace Evolutions. Detailed reading.)

* Make Quantitative Estimates [2] (Memorize basic constants, sizes. Internal conversation. Compare others, on Log scale.)

2. METHOD OF SCIENCE [2] (**Theoretical model, predict�Quantitative experimental test�Keep/ Modify model, predict�...Ideas of** Bacon, Occam, Popper, Kuhn.)

3. RESEARCH ETHICS AND AVOIDING PLAGIARISM [2] (Dangers of copy-paste. Plagiarism. Proper citing. Indian Academy of Sciences Report)

4. VISUAL REPRESENTATION OF RESEARCH DATA [2] (Optimal design of plots, charts, schematics, posters etc for graphic display of empirical relationships in complex data.)

5. ERROR ANALYSIS OF RESEARCH DATA [3] (Random and systematic errors. Statistical errors and probability distributions. Error propagation or addition of errors.)

6. STUDENT PRESENTATIONS

(Research Literature. *25+5 min talks,3 per class. Graded. Two cycles, if class-size permits*.)

7. LAB VISITS

(Students split up for Bio/ Chem/ Phys tours, guided by Senior PhD students)

Primary Text / Reference Books:

- Scientific Writing and Communication, Angelika Hofmann, (Oxford 2014).
- Back-of-the-Envelope Physics, Clifford Swartz, (Johns Hopkins 2003).
- The Visual Display of Quantitative Information, Edward Tufte (Graphics Press 1982); Bang Hong, Nature Methods articles.
- Measurements and their Uncertainties, IG Hughes and TPA Hase, (Oxford 2014)
- Advice to a Young Scientist, Peter B Medawar, (Basic Books 2008)
- A PhD Is Not Enough, Peter Feibelman (Basic Books 2011)

Evaluation Method (Weightage for Internal Assessment, Mid Term / Term End exams, Presentations etc.):
Based on student written hand-ins (50%) and student oral presentations (50%)

Course Outcome:

Sr. No.	On completing the course, the student will be able to have a deep perspective on the following topics from emerging literature:
CO 1	Students are taught what senior people already know from experience, namely how to survive a PhD programme, and how to function as an academic professional.
CO 2	There are lectures on Scientific Method and Scientific Ethics. But the core of the course is a series of How To lectures telling them things that, for earlier students at least, were not written down anywhere.
CO 3	How to sketch a function. How to do a CV. How to give a talk. How to write a paper. How to read a paper. How to converse with others about your work. How to write an application letter. How to give an interview, including an online one. How to think,and to feed and keep healthy, your two minds (M1 eats logic. M2 eats analogies.)
CO 4	The course ends with 10 min talks by students on topics that are Not in their area of specialization, that count for 50% of the grade.

CO 5	The RM course is unusual, but seems to work, with students giving quite positive comments