DEPARTMENT OF PHYSICS

I Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits (AL/3)
PHY 101	Mechanics	2	1	4.5	0	0	7.5	4	O to F	3
PHY 103	General Physics Laboratory-I	0	0	1	3	0	4	3	O to F	1

II Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits (AL/3)
PHY 102	Modern Physics	2	1	4.5	0	0	7.5	4	O to F	3

III Semester:

	Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits (AL/3)
DC	PHY201	Waves and Optics	3	1	4.5	0	0	8.5	4	O to F	3
	PHY203	Electrodynamics	3	1	4.5	0	0	8.5	4	O to F	3
	PHY205	General Physics Laboratory-II	0	0	1	3	0	4	3	O to F	1
MD	ECS203	Basic Electronics	3	0	4.5	0	0	7.5	3	O to F	3
RD	MTH201	Multivariable Calculus	3	1	4.5	0	0	8.5	4	O to F	3

IV Semester:

	Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits (AL/3)
DC	PHY202	Physics by Numerical Analysis	3	1	4.5	0	0	8.5	4	O to F	3
	PHY204	General Properties of Matter	3	1	4.5	0	0	8.5	4	O to F	3
	PHY206	General Physics Laboratory-III	0	0	1	3	0	4	3	O to F	1
MD	CHM222	Classical Thermodynamics	3	1	4.5	0	0	8.5	4	O to F	3
RD	MTH202	Probability and Statistics	3	1	4.5	0	0	8.5	4	O to F	3

DC: Departmental Compulsory Course; **MD:** Mandatory Course from Other Department; **RD:** Recommended Course from Other Department

V Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits
PHY 301	Mathematical Methods I	3	0	7.5	0	0	10.5	3	O to F	4
PHY 303	Quantum Mechanics I	3	0	7.5	0	0	10.5	3	O to F	4
PHY 305	Classical Mechanics	3	0	7.5	0	0	10.5	3	O to F	4
PHY 307	Physics Laboratory I	0	0	3	6	0	9	6	Oto F	3
*** ***	Open Elective I	3	0	4.5/7.5	0	0	7.5/10.5	3	O to F	3/4
Total Credits		**12**	**0**	**30/33**	**6**	**0**	**48/51**	**18**		**18/19**

VI Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits
PHY 302	Mathematical Methods II	3	0	7.5	0	0	10.5	3	O to F	4
PHY 304	Quantum Mechanics II	3	0	7.5	0	0	10.5	3	O to F	4
PHY 306	Statistical Mechanics	3	0	7.5	0	0	10.5	3	O to F	4
PHY 308	Physics Laboratory II	0	0	3	6	0	9	6	Oto F	3
*** ***	Open Elective II	3	0	4.5/7.5	0	0	7.5/10.5	3	O to F	3/4
Total Credits		**12**	**0**	**30/33**	**6**	**0**	**48/51**	**18**		**18/19**

VII Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits
PHY 401	Electrodynamics and Special Theory of Relativity	3	0	7.5	0	0	10.5	3	O to F	4
PHY 403	Condensed Matter Physics	3	0	7.5	0	0	10.5	3	O to F	4
PHY 405	Condensed Matter Physics Laboratory	0	0	3	6	0	9	6	Oto F	3
*** ***	Open Elective III	3	0	4.5/7.5	0	0	7.5/10.5	3	O to F	3/4
*** ***	Open Elective IV	3	0	4.5/7.5	0	0	7.5/10.5	3	O to F	3/4
Total Credits		**12**	**0**	**27/33**	**6**	**0**	**45/51**	**18**		**17/19**

VIII Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits
PHY 402	Atomic and Molecular Physics	3	0	7.5	0	0	10.5	3	O to F	4
PHY 404	Nuclear and Particle Physics	3	0	7.5	0	0	10.5	3	O to F	4
PHY 406	Nuclear Laboratory	0	0	3	6	0	9	6	Oto F	3
*** ***	Open Elective V	3	0	4.5/7.5	0	0	7.5/10.5	3	O to F	3/4
*** ***	Open Elective VI	3	0	4.5/7.5	0	0	7.5/10.5	3	O to F	3/4
Total Credits		**12**	**0**	**27/33**	**6**	**0**	**45/51**	**18**		**17/19**

IX Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits
PHY 501	Project Work	-	-	-	-	-	35	-	O to F	14
*** ***	Open Elective VII	3	0	7.5	0	0	10.5	3	O to F	4
*** ***	Open Elective VIII	3	0	7.5	0	0	10.5	3	O to F	4
HSS 503	Law Relating to Intellectual Property and Patents	1	0	2.5	0	0	3.5	1	S/X	1
Total Credits		**7**	**0**	**17.5**	**0**	**0**	**59.5**	**7**		**23**

X Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits
PHY 501	Project Work	-	-	-	-	-	35	-	O to F	14
*** ***	Open Elective IX	3	0	7.5	0	0	10.5	3	O to F	4
*** ***	Open Elective X	3	0	7.5	0	0	10.5	3	O to F	4
Total Credits		**6**	**0**	**15**	**0**	**0**	**56**	**6**		**22**

PHY 101: Mechanics (3)

Learning Objectives

Students will learn the concepts related to Newton's laws of mechanics and their application to many particle systems, small oscillations. Although the students are assumed to be familiar with basic calculus, required mathematical tools will be reviewed whenever needed.

Course Content

Kinematics: Introduction to coordinate systems, Cartesian and polar coordinate systems, velocity and acceleration in polar coordinate system.(4)

Kinetics: Force, Newton's laws of motion, frames of reference, statics, dynamics, rotational motion about a single axis and moment of inertia. (7)

Momentum, momentum of a system of particles, conservation laws, center of mass, variable mass systems.(5)

Work and energy, conservation of energy, collisions, conservative and non-conservative forces.(4)

Simple harmonic oscillator, small oscillations, damped harmonic oscillation, differential equation for waves in one dimension and its solution.(4)

Brief introduction to motion under central force. (2)

References

1. D. Kleppner and R. Kolenkow, An Introduction to Mechanics
1. R. Shankar, Fundamentals of Physics
2. David Morin, Introduction to Classical MechanicsR. P. Feynman, R. B. Leighton and M. Sands, The Feynman Lecture on Physics Vol 1.
3. C. Kittel, W. D. Knight, M. A. Ruderman, A. C. Helmholz and B. J. Moyer, Mechanics (Berkeley Physics Course) Vol 1
4. D. Resnick, R. Halliday and K. S.Krane, Physics, Vol 1, 5thEd.
5. M. K. Verma, Introduction to Mechanics.

PHY 102: Modern Physics (3)

Learning Objectives

Students will learn basic modern physics including wave mechanics, duality of wave and particle nature and applications of quantum mechanics to some simple problems in physics.

Course Content

Introduction to wave mechanics: wave equation, solutions of wave equation, frequency and period, superposition of waves, double-slit experiment, interference, dispersion relation, definition of group and phase velocities.(4)

Bohr model : Review of Bohr atom model, its successes and failures. (2)

Particle properties of waves : black body radiation, photoelectric effect, Compton effect, X-ray diffraction, pair production.(4)

Wave properties of particle: de Broglie wavelength, wave particle duality, phase and group velocities, particle/electron diffraction, particle in a box, uncertainty principle.(4)

Quantum Mechanics: Schrödinger equation, linearity, superposition, operators, eigenvalues and eigenfunctions of operators, expectation values, particle in a box, finite well potential, tunnelling, harmonic oscillator.(10)

Hydrogen atom: energy states and quantum numbers. (2)

References

1. A.Beiser, Concepts of Modern Physics.
2. H. C.Verma, Quantum Physics.
3. R. P. Feynman, R. B. Leighton and M. Sands, The Feynman Lectures on Physics Vol 3.
4. H. S. Mani and G. K. Mehta: Introduction to Modern Physics.
5. R. Shankar, Fundamentals of Physics II

PHY 103: General Physics Laboratory (1)

Learning Objectives

The laboratory course demonstrates and tests the fundamental concepts of mechanics through real life examples, and helps the students form lasting connections between theory and experiments. This course enables the students to devise and design reliable methods for obtaining experimental data and learn error analysis techniques including distinguishing significant figures and representing the data graphically. In addition, the course will help the students to acquire and practice skills needed for making concise technical presentations, both oral and written, making effective use of graphical techniques.

List of experiments

1. Least count, observation and data-analysis, measurements of length, error analysis, graph plotting
2. Determination of g by free fall
3. Determination of g by bar pendulum
4. Moment of inertia of a gyroscope
5. Young's modulus by bending of a beam
6. Torsional pendulum
7. Pohl's pendulum
8. Surface tension
9. Balmer series
10. Photoelectric effect

PHY 201: Waves and Optics (3)

Learning Objectives

In this course, students will be introduced to fundamental concepts of waves and classical optics with particular reference to the phenomena of interference and diffraction.

Course Content

Oscillations: Review of simple harmonic motion and damped oscillations, coupled oscillators and normal modes.(4)

Waves: wave equation, superposition of waves with same and different frequency, Lissajous figures, standing waves, dispersion relations and group velocity.(4)

Maxwell's equations: Wave equation, plane, spherical, cylindrical and beam like solutions of the wave equation.(3)

Boundary conditions: reflection and transmission at the boundary.(2)

Propagation of light in anisotropic media.(2)

Coherence: Spatial and temporal.(2)

Polarization and double refraction, quarter and half wave plates.(2)

Geometrical optics: Paraxial approximation, lens aberrations, ray matrix approach to Gaussian optics, optical systems and resolving power.(8)

Interference: Division of wavefront (Young's double slit) and amplitudes (Newton's rings, Michelson interferometer), multi-wave interference-Fabry-Perot interferometer, thin optical coatings (single and multilayer), interference filters.(6)

Diffraction: Huygen-Fresnel and Kirchhoff's theories.(2)

Fresnel diffraction: rectangular, circular and zone plates.(2)

Fraunhoffer diffraction: Slits (single, double) and grating and circular aperture.(2)

Introduction to metamaterials.(1)

References

1. A. P. French, Waves and Oscillations
2. N. K. Bajaj, The Physics of Waves and Oscillations
3. A. K. Ghatak, Optics
4. F. A. Jenkins and H. E. White, Fundamentals of Optics
5. R. S. Longhurst, Geometrical and Physical Optics

PHY 203: Electromagnetism (3)

Learning Objectives

In this course students will learn properties of electric and magnetic fields in the presence of static charge and current distributions. They will also learn Maxwell’s equations which govern the dynamics of electric and magnetic fields.

Course Content

Introduction to vector calculus: Gradient, divergence and curl of fields, Divergence theorem, Stokes Theorem, Dirac delta function.(5)

Cylindrical and Spherical coordinate systems: Line, surface and volume elements.(2)

Electrostatics: Coulomb’s Law, Gauss’s law (integral and differential forms) and its applications, Electric potential, Laplace’s and Poisson’s equations (no solutions), Method of images, Energy of a charge distribution, Field and potential due to a dipole. Polarization in a dielectric, D, P and E fields, linear dielectrics, force on dielectrics.(12)

Motion of charged particles in electric and magnetic fields.(1)

Electric currents: Line, surface and volume currents and current densities, electrical conductivity and Ohm’s law, equation of continuity, energy dissipation.(2)

Magnetostatics: Biot-Savart and Ampere’s law, divergence and curl of B, integral and differential form of Ampere’s law, vector potential, Magnetic dipoles, Magnetization in materials, H, B and M, Dia-, para- and ferro-magnetism, B and H in a bar-magnet.(7)

Electrodynamics: Electromagnetic induction, motional emf and Faraday’s law, inductance and energy in a magnetic field, the displacement current, Maxwell's equations.(6)

References

1. D. J. Griffiths, Introduction to Electrodynamics 4thEd.
2. E. M. Purcell, Electricity and Magnetism (Berkeley Physics course) 2ndEd.
3. R. P. Feynman, R. B. Leighton and M. Sands, The Feynman Lectures on Physics Vol 2.

PHY 202: Physics by Numerical Analysis (3)

Learning Objectives

Students will learn to solve various problems in physics numerically. Numerical methods related to integration, differentiation, ordinary differential equations will be discussed in detail.

Course Content:

Dimensional analysis and physics of magnitudes. (3)

Data Analysis and Numerical Error: Mean, standard deviation, histogram, roots of polynomials.(3)

Curve fitting and interpolation.(2)

Iterations: Dynamical systems, Logistic map, Lyapunov exponents.(3)

Numerical differentiation: Electric force and charge density from a potential.(3)

Numerical integration: Center of mass, moment of inertia, trajectory of a particle, potential from a force.(3)

Numerical methods for ordinary differential equations: Runge-Kutta methods, Newton's laws, Motion in a central force, anharmonic oscillator, Lorenz attractor, phase space diagrams.(7)

Numerical methods for partial differential Equations: Poisson equation, Schr**ö**dinger equation, Diffusion equation. (4)

Random numbers and introduction to Monte Carlo methods: Area enclosed by a curve, simple simulations. (3)

System of linear equations: Normal modes of coupled oscillators. (3)

Matrix diagonalisation: Eigenvalue problems in quantum mechanics. (4)

References

1. Numerical Recipes
2. W. Kinzel and G. Reents, Physics by Computer

PHY 204: General Properties of Matter (3)

Learning Objectives

This course aims at providing an introduction to general properties of solids, liquids and gases largely at a phenomenological level and forms the basis for courses on condensed matter physics later.

Course Content

States of Matter, length, mass, density, pressure. (2)

Solids: Crystalline and Amorphous solids, Crystal structure, Defects in crystals, Covalent bond, Ionic bond, Metallic bonds, Classification of electronic materials: metals, insulators and semiconductors. Magnetic materials: para-, dia- and ferro-magnetism. (8)

Elastic Properties of materials: Elasticity, Hooke's law, Elastic constants, Bending moment, Cantilever, Beams, Elastic energy. (6)

Liquids: Origin of surface tension and surface energy, Molecular theory, Angle of contact, Capillarity, Liquid surface, Liquid drops, Ripples. (6)

Fluid Dynamics and Statics: Archimedes’s principle, Continuity equation and its applications, Navier-Stokes equation and applications, Bernoulli's equation. (6)

Gases: Gas laws, Brownian motion, Turbulence, Viscosity, Compressibility, Thermodynamic equilibrium. (8)

References

1. D. S. Mathur, General Properties of Matter
2. B. Brown, General Properties of Matter
3. A. Beiser, Modern Physics
4. C. J. Smith, Properties of Matter
5. F. H. Newman and V. H.L. Searle, General Properties of Matter,
6. M. A. Wahab, Solid State Physics Structure and Properties of Materials
7. A.J. Dekker, Solid State Physics

PHY 205: General Physics Laboratory-II (1)

Learning Objectives

The laboratory course demonstrates and tests the fundamental concepts of Electrodynamics through real examples, and helps students form lasting connections between theory and experiments. Upon successful completion of this course, the students, through hands-on experience, will be able to get conceptual clarity on topics learnt in theory courses, acquire proficiency in error analysis, and apply critical thinking in interpreting scientific data. Besides this, the course will help the students to learn and practice skills needed for making concise technical presentations, both oral and written, through effective use of graphical representations of the data.

List of Experiments

1. Electron Diffraction
2. Franck Hertz experiment
3. Electromagnetic induction (EMI)
4. Magnetic field of paired coils in Helmholtz arrangement with a Teslameter
5. Malus law
6. Determination of refractive index of a prism using Spectrometer
7. Magnetic Moment using a pair of Helmholtz coils
8. Newton's Rings
9. e/m ratio using a pair of Helmholtz coils
10. Charging and discharging curve of a capacitor

PHY 206: General Physics Laboratory – III (1)

Learning Objectives

The laboratory course provides experimental demonstrations of concepts in general properties of matter through weekly hands-on experiments, especially on the topics taught in the theoretical course PHY 206. Upon successful completion of the course, students will be able to apply critical thinking in interpreting scientific data, work in groups to study and apply quantitative measures to answer questions, and solve problems through experiments.

List of experiments

1. Band gap of semiconductors by four probe method
2. Torsional vibrations and torsion modulus
3. Viscosity of Newtonian and non-Newtonian liquids
4. Ferromagnetic hysteresis (BH Curve)
5. Mechanical hysteresis
6. Surface tension with the ring method (Du Nouy method)
7. Seebeck effect
8. Curie temperature
9. Young's modulus
10. p-n junction diode, Zener diode and light emitting diode

PHY 301: Mathematical Methods I (4)

Learning Objectives

The main objective of the course is to equip the students with the tools of mathematics as required in various courses of the physics curriculum, in particular, quantum mechanics and electrodynamics.

Course Content

Finite dimensional vector spaces**:** Linear independence, basis, dimension. Subspaces.Notions of sum, direct sum and the dual of a vector space.Tensor product of vector spaces.Tensors.Linear operators on vector spaces.Null space and Rank of a linear operator.Representation of vectors and operators in a chosen basis.Matrices.Transformation properties of the representation of vectors and linear operators under change of basis. Eigenvalues and eigenvectors. Diagonalizability of linear operators.Cayley-Hamilton theorem. Statement of basic results on Jordan canonical form.Inner product on a vector space. Orthonormal bases. Gram-Schmidt orthogonalization procedure. Adjoint of an operator. Self adjoint, Unitary, projection and positive operators and their special properties. (10)

Fourier series. Fourier and Laplace transforms and their properties. Dirac delta function. Elementary introduction to Generalized functions. (9)

Introduction to Groups **:** Finite Groups, subgroups, normal subgroups, conjugacy relations, Permutation Groups, Continuous Groups, Lie groups, generators, example : SO(3) (6)

Introduction to representation theory, representation of unitary and rotation group. (4)

Ordinary differential equations of second order: Ordinary and regular singular points. Power series and its interval of convergence. Gamma function. Frobenius method for solving general second order ordinary differential equations around regular singular points and in particular, its application for solving Bessel, Legendre, Laguerre, Hermite differential equations. (10)

References

1. P. R. Halmos Finite Dimensional Vector Spaces
2. J. E. Marsden and A. Tromba, Vector Calculus
3. A. L. Rabenstein, Introduction to Ordinary Differential Equations
4. P. Dennery and A. Krzywicki, Mathematics for Physicists
5. B. Arfken and H. J. Weber, Mathematical Methods for Physicists, 6^{th}Ed
6. M. L. Boas, Mathematical Methods in Physical Sciences
7. S. D. Joglekar, Mathematical Physics: Advanced Topics
8. J. Mathews and R. L. Walker, Mathematical Methods of Physics
9. P. K. Chattopadhyay, Mathematical Physics
10. S. Hassani, Mathematical Physics
11. A. K. Ghatak, Mathematical Methods of Physics
12. H. W. Wyld, Mathematical Methods for Physics
13. F. B. Hildebrand, Methods of Applied Mathematics
14. S. Mukhi and N. Mukunda, Lectures on Advanced Mathematical Methods for Physicists

PHY 302: Mathematical Methods II(4)

Learning Objectives

The main objective of the course is to equip the students with the tools of mathematics as required in various courses of the physics curriculum, in particular, quantum mechanics and electrodynamics.

Course Content

Complex Analysis: Complex numbers, functions of a complex variable. Notions of differentiability and analyticity.Cauchy-Riemann conditions.Pole singularities.Calculation of residues at poles.Multiple valued functions, branch point singularities and branch cuts.Cauchy integral formula, Laurent expansion.Cauchy residue theorem.Evaluation of integrals along the real line using methods and results from complex variable theory.Multiple valued function, branch cuts and branch points.Evaluation of integrals, saddle point method. (15)

Partial differential equations: Method of separation of variables. Solution of Laplace, Poisson and the Wave and the diffusion equations. Green's functions, Dirichlet and Neumann problems for three dimensional Laplacian, wave equation (10)

Sturm-Liouville theory. Second order differential equations of Sturm-Liouville form admitting orthogonal polynomial systems as solutions. Orthogonal expansions and its application to Bessel, Legendre, Hermite functions. (10)

Integral equations: Fredholm equation of 1st and 2nd kind, Volterra equation of 1st and 2nd kind. Solution of integral equations. (5)

References

1. B. Arfken and H. J. Weber, Mathematical Methods for Physicists, 6thEd
2. M. L. Boas, Mathematical Methods in Physical Sciences
3. S. D. Joglekar, Mathematical Physics: Advanced Topics
4. J. Mathews and R. L. Walker, Mathematical Methods of Physics
5. P. Dennery and A. Krzywicki, Mathematics for Physicists
6. P. K. Chattopadhyay, Mathematical Physics
7. S. Hassani, Mathematical Physics
8. A. K. Ghatak, Mathematical Methods of Physics
9. H. W. Wyld, Mathematical Methods for Physics
10. F. B. Hildebrand, Methods of Applied Mathematics
11. A. K. Kapoor, Complex variables

PHY 303: Quantum Mechanics(4)

Learning Objectives

The course will lay down the foundations of quantum mechanics via wave-particle duality, uncertainty principle and Schrödinger equation. Operator formalism will be developed and applied to various problems in one-dimensional and central potentials. Particularly, hydrogen atom problem and angular momentum algebra be discussed in detail.

Course Content

Uncertainty Principle, Schrödinger Equation, Probability interpretation and probability current; Coordinate and momentum representations; Expectation values of dynamical variables; Descriptions of wave packets and its evolution. (5)

One Dimensional Problem: Harmonic Oscillator – creation and annihilation operators; Brief descriptions of potential step, barrier and well – Ideas of bound states, scattering states and resonances; Dirac-delta function potential, Applications to alpha-decay. (9)

Central Potential: Bound states in three dimensions; Hydrogen atom. (4)

Operator formalism: Vector spaces, Hermitian operators; Eigenvalues; Classical limit – Ehrenfest's theorem; Stationary states, Generalized uncertainty principle; Simultaneous eigenstates of commuting operators; Introduction to Dirac's notation. Heisenberg picture, and equivalence with Schrödinger picture. (6)

Theory of Angular Momentum: Orbital angular momentum and their eigenvalue problems; Spherical harmonics, addition of angular momenta, Clebsch-Gordon coefficients. Theory of spin: Stern-Gerlach experiment, Formulation of spin ½ states, Spin angular momentum; Pauli matrices. (10)

Identical particles: Fermions, Bosons. (3)

Foundational Issues: Measurements and interpretations of quantum mechanics; Bell's inequality; EPR paradox. (2)

References

1. D. J. Griffiths, Introduction to Quantum Mechanics
2. N. Zettili, Quantum Mechanics: Concepts and Applications
3. H. C. Verma, Quantum Physics

4. R. P. Feynman, R. B. Leighton and M. Sands, The Feynman Lectures on Physics Vol 3
5. J. J. Sakurai, Modern Quantum Mechanics
6. B. H. Bransden and C. J. Joachain, Quantum Mechanics 2ndEd
7. P. A. M. Dirac, The Principles of Quantum Mechanics.
8. C. Cohen-Tannoudji, Quantum Mechanics, (Vol I and II)
9. R. Shankar, Principles of Quantum Mechanics, 2ndEd
10. A. I. M. Rae, Quantum Mechanics, 4thEd.
11. E. Merzbacher, Quantum Mechanics, 3rdEd.
12. L. D. Landau and L. M. Lifshitz, Quantum Mechanics: Non-relativistic Theory, 3rdEd.

PHY 304: Quantum Mechanics II (4)

Learning Objectives

Students would get an introduction to applications of quantum mechanics theory learned in part one, to some real-world-motivated problems. A great deal of emphasis would be placed on developing approximate methods to solve the Schrödinger equation. In particular, perturbation theory approaches, scattering theory, and an introduction to concepts of symmetry.

Course Content

Approximation methods for stationary states: Time Independent Perturbation Theory: Formalism; Applications to relativistic corrections (‘fine structure corrections’) to atom (a) Relativistic K.E, (b) Spin-Orbit couplings, (c) Darwin term; WKB method: Descriptions of tunnelling, Variational method: Application to He atom ground state. (12)

Time Dependent Phenomena: Formalism; Fermi’s Golden rule; Adiabatic approximation; Application to matter-radiation interaction; Emission and absorption of photons; Selection rules for electric dipole transitions; Applications to Lasers. (9)

Charged particle in an electromagnetic field: Gauge invariance of Schrödinger equation; Larmor frequency; Brief discussions on normal and anomalous Zeeman effect (5)

Scattering by a Potential: Formalism; Born approximations; Partial wave analysis. (6)

Introduction to relativistic quantum mechanics. (2)

References

1. D. J. Griffiths, Introduction of Quantum Mechanics
2. N. Zettili, Quantum Mechanics: Concepts and Applications
3. H. C. Verma, Quantum Physics
4. R. P. Feynman, R. B. Leighton and M. Sands, The Feynman Lectures on PhysicsVol 3
5. J. J. Sakurai, Modern Quantum Mechanics
6. B. H. Bransden and C. J. Joachain, Quantum Mechanics
7. P. A. M. Dirac, The Principles of Quantum Mechanics
8. C. Cohen-Tannoudji, Quantum Mechanics, (Vol I and II)
9. R. Shankar, Principles of Quantum Mechanics
10. I. M. Rae, Quantum Mechanics
11. E. Merzbacher, Quantum Mechanics
12. L. D. Landau and L. M. Lifshitz, Quantum Mechanics Non-Relativistic Theory
13. D. J. Tannor, Introduction to Quantum Mechanics

PHY 305: Classical Mechanics(4)

Learning Objectives

The course deals with the advance concepts of mechanics. It gives a good understanding of Lagrangian mechanics, conservation principles, oscillations, gravitation, central force, scattering, rigid body. The tools learnt in this course will be extremely useful to understand wide variety of branches in physics including condensed matter physics, high energy physics and cosmology.

Course Content

Review of Newtonian mechanics. Lagrangian mechanics, generalized coordinates, constraints, principle of virtual work, Hamilton's principle, some techniques of the calculus of variations, Derivation of Lagrange’s equation from Hamilton's principle, Conservation theorems and Symmetry principles, Noether theorem. (12)

Central forces, Planetary motions, Collisions, Scattering. (6)

Small oscillations, Normal modes, Forced oscillators, Anharmonic oscillators, Perturbation theory. (6)

Rigid body dynamics, Orthogonal transformations, Euler angles, Cayley-Klein parameters, Inertia tensor and Moment of Inertia, Principal axis transformation, Motion of a symmetrical top. (9)

Hamilton's equations, phase space and phase trajectories, Poisson brackets, canonical transformations, Hamilton-Jacobi theory. (7)

References

1. H. Goldstein, Classical Mechanics
2. L. D. Landau and E. M. Lifshitz, Mechanics
3. S. T. Thronton and J. B. Marion, Classical Dynamics of Particles and Systems
4. R. G. Takwale and P. S. Puranik, Introduction to Classical Mechanics
5. K. C. Gupta, Classical Mechanics of Particles and Rigid Bodies
6. N. C. Rana and P. S. Joag, Classical Mechanics
7. C. Percival and D. Richards, Introduction to Dynamics
8. D. Morin, Classical Mechanics.
9. L. N. Hand and J.D. Finch, Analytical Mechanics
10. V. B. Bhatia, Classical Mechanics

PHY 306/604: Statistical Mechanics (4)

Learning Objectives

This course contains a review of classical laws of thermodynamics and their applications, postulates of statistical mechanics, statistical interpretation of thermodynamics. The methods of statistical mechanics are used to develop the statistical description of Bose and Fermi systems.

Course Content

Motivation: Why do we need statistical mechanics? Thermodynamic description of a system.Microscopic origin of thermodynamic results - introduction of statistical description. (2)

Phase space: Introduction and definition of phase space. Examples. Phase space density, Time average and ensemble average. Equivalence between time average and ensemble average. Ergodic hypothesis, Liouville's equation. (4)

Micro-canonical ensemble: Definition, Volume of phase space, Definition of entropy, Definition of temperature, Physical interpretation of temperature. Validity of the statistical description. Definition of pressure, 1st law of thermodynamics. Statistical interpretation of entropy. Classical ideal gas in microcanonical ensemble. Gibbs paradox. (6)

Canonical ensemble: Definition, Average in canonical ensemble, Partition function, Equivalence between canonical and microcanonical ensemble average. Definition of free energy.Ideal gas in canonical ensemble. (5)

Grand-canonical ensemble: Definition, Grand-canonical partition function, Definition of chemical potential, Equivalence between canonical and grand-canonical average. Ideal gas in grand canonical ensemble. (3)

Quantum statistical mechanics: Pure and mixed ensembles. Examples of pure and mixed ensemble.Quantum ensemble average.Introduction of density matrix.Properties of density matrix.Examples of density matrix.Micro-canonical, Canonical and Grand-canonical ensembles and partition functions. (7)

Three different statistics : Boltzmann statistics - Partition function for ideal Boltzmann gas. Equation of state.Bose and Fermi statistics. (3)

Ideal Fermi gas: Partition function. Equation of state.High temperature Fermi gas.Low temperature Fermi gas.Fermi energy, Fermi temperature and Fermi surface.Pressure of low temperature Fermi gas.Zero point pressure. (5)

Pauli paramagnetism. (2)

Ideal Bose gas: Partition function. Equation of state. Gas of photon - Black body radiation (3)

References

1. F. Reif, Fundamentals of Statistical and Thermal Physics
2. R.K. Pathria, Statistical Mechanics, 2nd Ed.
3. M. Plischke and B. Bergersen, Equilibrium Statistical Physics
4. J. K. Bhattacharjee, Statistical Physics: Equilibrium and Non Equilibrium Aspects

5. K. Huang, Statistical Mechanics
6. S-K. Ma, Statistical Mechanics
7. L. D. Landau and E. M. Lifshitz, Statistical Physics
8. R. Kubo, M. Toda and N. Hashitsume, Statistical Physics I and II
9. M. Kardar, Statistical Physics of Particles
10. C. Kittel, Elementary Statistical Physics

PHY 307: Physics Laboratory I (4)

Learning Objectives

The laboratory course provides experimental demonstrations of concepts in physics complementing the theoretical courses taught in the classes. Students will be able to get conceptual clarities with hands-on experience, learn experimental techniques and the process of data analysis, and apply critical thinking in interpreting scientific data.

List of Experiments

1. Franck Hertz experiment
2. Planck's constant
3. Cavendish experiment
4. Chua's circuit
5. Ferromagnetic Hysteresis
6. Atomic spectra of Iodine vapor
7. Inelastic electron collision
8. Millikan's oil drop experiment
9. Viscosity of Newtonian and non-Newtonian liquids
10. Microwave based waveguide measurement.

PHY 308: Physics Laboratory II (3)

Learning Objectives

The laboratory course provides experimental demonstrations of concepts in physics, especially in microscopy, spectroscopy, and optics, complementing the theoretical courses taught in the classes. Students will be able to get conceptual clarities with hands-on experience, learn experimental techniques and the process of data analysis, and apply critical thinking in interpreting scientific data.

List of Experiments

1. STM
2. AFM
3. Raman Spectrometer
4. Characteristics of He-Ne laser.
5. Fiber optics
6. Spectroscopy with fibers [Ocean optics*]
7. Michelson Interferometer
8. Fabry Perot Interferometer
9. Optical detection of weak source using a lock-in laser gyroscope

PHY 309: Thermal Physics (4)

Learning Objectives

The course aims to lay down the foundations of thermodynamics along with introduction to phenomenon of phase transitions and critical phenomenon.

Course Content

Kinetic theory of gases: Statistical definition of temperature, Boltzmann function, Maxwell-Boltzmann distribution, molecular distribution, molecular effusion, mean free path and collisions, transport and thermal diffusion: viscosity, thermal conductivity and diffusion, the Prandtl number. (8)

Review of basic thermodynamics: Thermodynamic systems, first law of thermodynamics, second law of thermodynamics, Claussius theorem, thermodynamic and statistical definition of entropy, entropy of mixing (Gibbs paradox), entropy and probability, internal energy and heat capacity equations and their applications. (6)

Thermodynamics in action : Entropy and information theory (Shannon's entropy), Thermodynamic potential functions and their applications, Maxwell relations, Throttling/Joule-Thomson expansion, Liquefaction of gases, adiabatic demagnetization for milli/micro Kelvin temperatures, entropy of elastic rod (rubber and wire), third law of thermodynamics and its implications, chemical potential, energy maximum and entropy minimum principle, the Gibbs-Duhem relation. (10)

Phase transitions: Claussius-Clapeyron equation, stability and metastability, Le Chatelier's and Le Chatelier-Braun principle, latent heat, chemical potential and phase changes, classification/order of phase transitions, order parameter, Gibbs phase rule, colligative properties, phase transitions of single and multi-component systems, eutectic point, Landau theory of phase transitions, universality and scaling, renormalization (introduction). (13)

Special topics: Brownian motion and fluctuations: Brownian motion, Johnson noise, fluctuations and availability. (3)

References

1. S. J. Blundell and K. M. Blundell, Concepts in Thermal Physics
2. M. Zemansky and R. Dittman, Heat and Thermodynamics
3. D.V. Schroeder, An Introduction to Thermal Physics
4. H. B. Callen, Thermodynamics and an Introduction to Thermostatistics
5. E. Fermi, Thermodynamics
6. C. Kittel and H. Kroemer, Thermal Physics

PHY 401/605: Electrodynamics and Special Theory of Relativity (4)

Learning Objectives

Maxwell's equations will be discussed in detail with application to physical problems relating to electromagnetic fields including those in free space and in a medium. Special relativity will be studied in context of Maxwell's equations, gauge invariance and radiation by accelerating charged particles.

Course Content

Boundary problems, Formal solution with Green functions, Method of image, Electric fields in matter, Boundary-Value problems with dielectrics, polarizability and susceptibility, Energy density in a dielectric, Multipole expansion. (7)

Vector potential, Magnetic fields of a localized current distribution, Magnetic moment, Force and Torque on and energy of a localized current distribution, Boundary conditions on B and H, Boundary value problems in magnetostatics, Multipole expansion. (3)

Maxwell equations, Gauge transformations, Green functions for the wave equation, Poynting's theorem, Transformation properties of electromagnetic fields and sources under rotations, spatial reflections, and time reversal. (5)

Plane electromagnetic waves and wave propagation, polarization, Stokes parameters, Reflection and refraction of electromagnetic waves at a plane interface between dielectrics, wave propagation in conductors and dielectrics, dispersion, complex refractive index, waveguides. (5)

Radiation from an accelerated charge, Larmor formula, Fields and radiation of a localized oscillating source, Electric dipole fields and radiation, Linear antennas, Scattering at long wavelengths, Rayleigh scattering. (5)

Introduction to Special Theory of Relativity, Minkowski space and four vectors, concept of four-velocity, Four acceleration and higher rank tensors, Relativistic formulation of electrodynamics, Maxwell equations in covariant form, Gauge invariance and four-potential, the action principle and electromagnetic energy momentum tensor, Liénard-Wiechert potentials. (10)

References

1. D. J. Griffiths, Introduction to Electrodynamics, 4thEd.
2. A. Zangwill, Modern Electrodynamics, 1stEd.
3. J. D. Jackson, Classical Electrodynamics
4. L. D. Landau and E. M. Lifshitz, Classical Theory of Fields
5. R. P. Feynman, R. B. Leighton and M. Sands, The Feynman Lectures on Physics Vol 2
6. W. K. H. Panofsky and M. Philips. Classical Electricity and Magnetism

PHY 402: Atomic and Molecular Physics (4)

Learning Objectives

To understand the hierarchy of atomic and molecular energy levels, what implications these have for the interaction with electromagnetic radiation and which practical applications arise from which transitions. To appreciate the challenge in the quantum-many body problem of many electron atoms and molecules, the order arising through the Pauli exclusion principle and to have a rough idea about possible advanced solution techniques.

Course Content

Brief review of the Hydrogen atom and periodic table; Significance of the four quantum numbers; Concept of atomic orbitals. (3)

Single valence electron atoms: Review of Orbital magnetic dipole moment; Orbital, spin and total angular momenta; Spin-orbit interaction and fine structures; Lamb shift; Hyperfine structure. General selection rules; Details of Stark, Zeeman (normal and anomalous) and Paschen-Beck effects. (6)

Many valence electron atoms: Two valence electron atoms: Para- and ortho states and the role of Pauli's Exclusion principle; He atom; Identical particles; Slater determinant; LS and JJ coupling scheme; Outlook on advanced methods such as Hartree-Fock and Density Functional Theory. (6)

Width and shape of spectral lines; Selection rules; Intensity of spectral lines; Principle of ESR with experimental setup; Chemical shift; Rabi oscillations; Optical Bloch equations; Photo-ionisation; Light scattering. (9)

Molecules: Concept of valance and bonding; Born-Oppenheimer approximation; Hydrogen molecule – Heitler-London method. (6)

Molecular orbital and electronic configuration of diatomic molecules (e.g H2, C2,); Vibrational structure and vibrational analysis; Frank-Condon principle; Dissociation energy; Rotational spectra; Raman spectra. (6)

Overview of modern atomic physics; Laser cooling; Bose-Einstein Condensation; Atomic clocks; High Harmonic Generations; Attoscience. (3)

References

1. P. W. Atkins and R. S. Friedman, Molecular Quantum Mechanics 3rdEd.
2. W. Demtroder, Atoms, Molecules and Photons
3. G. W. Woodgate, Elementary Atomic Structure
4. H. S. Friedrich, Theoretical Atomic Physics
5. R. Eisberg and R. Resnick, Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles
6. B. H. Bransden and C. J. Joachain, Physics of Atoms and Molecules
7. F. A. Cotton, Chemical Applications of Group Theory
8. C. N. Banwell, Fundamentals of Molecular Spectroscopy
9. J. M. Hollas, Modern Spectroscopy

PHY 403/607: Condensed Matter Physics (4)

Learning Objectives

The course objective is to introduce to the students the physical properties of solids including the electrical, magnetic, optical, thermal and mechanical properties. The goal of this course is to develop student's understanding of the impact the structure, symmetry, and bonding in solids have in determining their properties.

Course Content

Bonding in solids, van der Waal and Repulsive interactions, Lennard Jones potential, Cohesive energy and compressibility, Ionic crystals, Madelung constant, Covalent crystals, Metals, atomic and ionic radii. (4)

The Drude theory of metals: DC electrical conductivity of a metal; Hall effect and magnetoresistance; AC electrical conductivity of a metal and propagation of electromagnetic radiation in a metal; Thermal conductivity of a metal, The Sommerfeld theory of metals: Density of states; Fermi-Dirac distribution; Specific heat, thermal, and electrical conductivity of degenerate electron gases. (8)

Structure of solids, Symmetry, Bravais lattices, Unit cell, Miller indices, Simple crystal structure, Reciprocal lattice, Laue equations and Bragg's law, Brillouin Zones, Diffraction of x-rays, Atomic scattering and structure factors, Defects and dislocations. (8)

Free electron theory, Kronig-Penney Model, Crystal lattices: Periodic potential, Band theory, Tight binding, Classification of metals, insulators and semiconductors, Cellular and pseudopotential methods, Symmetry of energy bands, Density of state, Fermi surface. (8)

Vibrations of one dimensional monoatomic and diatomic chain, Normal modes and Phonons, Phonon spectrum, Long wavelength acoustic phonons and elastic constants, specific heat capacity, Density of states, thermal expansion and conductivity, Phonons: Vibrational Properties, normal modes, acoustic and optical phonons. (6)

Dia-, Para-, and Ferromagnetism, origin of magnetism, Langevin's theory of paramagnetism, Weiss Molecular theory (6)

References

1. L. V. Azaroff, Introduction to Solids
2. C. Kittel, Introduction to Solids State Physics
3. N. W. Ashcroft and N. D. Mermin, Solids State Physics
4. J. Decker, Solids State Physics
5. O. Madelung, Introduction to Solid State Theory
6. P. M. Chaikin and T. C. Lubensky, Principles of Condensed Matter Physics
7. H. Ibach and H. Lutz, Solid State Physics
8. J. Weertman and J. R. Weertman, Elementary Dislocation Theory
9. M. J. Buerger, Crystal Structure Analysis
10. J. Callaway, Quantum Theory of Solid State

PHY 404: Nuclear and Particle Physics (4)

Learning Objectives

Students will be able to learn theory of nuclear forces through applications of quantum mechanical principles and different types of nuclear emissions. They will learn the theoretical and experimental aspects of elementary particles.

Course Content

Properties of nucleon-nucleon interaction, general forms of N-N potential, description of low energy neutron-proton scattering to show spin dependence of nuclear force, ground state properties of deuteron, simple considerations of deuteron using central potential. (6)

Compound nucleus theory, shell model potential and shell theory, liquid drop model, electromagnetic interaction in nuclei, parity and angular momentum selection rules, internal conversion. (7)

Nucleon emission, separation energy, alpha decay and its energy spectrum, Q-value, Gamow's theory of alpha decay, Beta decay and its energy spectrum, selection rules, Need for neutrinos, Q-value of Beta decay, Gamma decay, Selection rules for gamma transitions (no derivation). (7)

Basic interactions in nature, elementary particles, quantum numbers and conservation laws, concepts of isospin, quark flavors and colors, quark model, eightfold way, mesons and baryons, bound states and resonance states. (5)

Feynman diagrams and interactions in the standard model, CKM matrix, neutrino mixing, introduction to decay channels, branching fractions and decay times, OZI rule. (8)

Relativistic Kinematics, Four vectors, relativistic energy-momentum conservation and collisions.Noether's theorem, symmetries and conservation laws, discrete symmetries (CPT). (4)

Brief review of Experimental Methods: Gas Filled counters (ionization Chamber), Scintillation counter, Spark Chambers, Cerenkov detectors, Ion Sources. (3)

References

1. S. S. M. Wong, Introductory Nuclear Physics
2. V. Devanathan, Nuclear Physics
3. B. L. Cohen, Concepts of Nuclear Physics
4. B. B. Srivastava, Fundamentals of Nuclear Physics
5. H. A. Enge, Introduction to Nuclear Physics

PHY 405: Condensed Matter Physics Laboratory (3)

Learning Objectives

The course aims to complement the theoretical knowledge gathered in PHY 403 by means of hands on experience with experiments relating to condensed matter physics.

***Course Contents*:**

1. Lattice dynamics
2. Abbe refractometer
3. Curie Temperature
4. Dielectric constant
5. Thermal expansion of quartz crystal
6. Hall effect
7. Thin film preparation and thickness measurement
8. Raman effect
9. Interfacing a multimeter through GPIB
10. X-ray diffraction
11. Electro-optic effect (Kerr effect)

12. Fabry-Perot and Mach-Zenhder Interferometer
13. Fiber Optics (Estimation of numerical aperture, bending loss)
14. Holography

PHY 406: Nuclear Laboratory (3)

Learning Objectives

The course aims to complement the theoretical knowledge gathered in PHY 404 by means of hands on experience with experiments relating to nuclear and particle physics.

Course Contents

1. Half life and radioactive equilibrium
2. Balmer series/Determination of Rydberg's constant
3. GM counter.
4. Gamma - Ray Spectroscopy Using NaI (Tl) detector.
5. Alpha Spectroscopy with Surface Barrier Detector.
6. Determination of the range and energy of alpha partcles using spark counter.
7. Study of gamma ray absorption process.
8. X-Ray Fluorescence.
9. Neutron Activation Analysis Measurement of the Thermal Neutron Flux.
10. To Study the Solid State Nuclear Track Detector.
11. Fission Fragment Energy Loss Measurements from Cf252.
12. Gamma - Gamma Coincidence studies.
13. Compton Scattering: Energy Determination.
14. Compton Scattering: Cross-Section Determination.
15. Determination of energy of mu-mesons in pi-decay using Nuclear Emulsion Technique.
16. Identification of particles by visual range in Nuclear Emulsion.
17. Study of Rutherford Scattering.

PHY 411: Nonlinear Dynamics and Chaos (4)

Learning Objectives

This course introduces fundamental concepts of dynamical systems, dynamical flows, non-linearity and chaos.

Course Contents

Introduction to Dynamical Systems: Overview, Examples and Discussion. (4)

One-dimensional flows: Flows on the line, Fixed points and stability, Population growth, Linear stability analysis, Saddle-node, Transcritical and Pitchfork bifurcations, Flow on the circle. (9)

Two-dimensional flows: Linear system: Definitions and examples, Phase portraits, Fixed points and linearization, Limit cycles, Poincare-Bendixson theorem, Lienard systems, Bifurcations revisited: Saddle-node, Transcritical and Pitchfork bifurcations, Hopf bifurcations, Oscillating chemical reactions, Poincare maps, Global bifurcation of cycles, Coupled Oscillators and Quasiperiodicity. (12)

Chaos: Lorenz equations: Properties of Lorenz equation, Lorenz Map; One-dimensioanl map: Fixed points, Logistic map, Liapunov exponent, Fractals: Countable and Uncountable Sets, Cantor Set, Dimension of Self-Similar Fractals, Box dimension, Pointwise and Correlation Dimensions; Strange Attractors: Baker's map, Henon map Chaos in Hamiltonian systems. (13)

References

1. S. H. Strogatz, Nonlinear Dynamics and Chaos with Applications to Physics, Biology, Chemistry and Engineering
2. E.Ott, Chaos in dynamical systems
3. R. C. Hilborn, Chaos and Nonlinear Dynamics
4. M. Lakshmanan and S. Rajasekar, Nonlinear dynamics: Integrability Chaos and Patterns

PHY 412: Computational Physics (4)

Learning Objectives

The course introduces the basic simulation techniques to the students. The techniques learnt will then be explored in the conext of various problems in physics.

Course Contents

Introduction: Computer simulations and problems in material science, Numerical methods and programming in Fortran 90/95, Brief review of classical mechanics, statistical mechanics and quantum mechanics as a starting point. (5)

Monte Carlo simulations: Importance sampling and the metropolis method, basic Monte Carlo algorithm, trial moves, random number generators, estimators. Applications and hands-on sessions–solid-liquid phase-transition in the Lennard-Jones fluid and the magnetic transition in the Isingmodel.Advanced applications–Monte Carlo in various ensembles, Kinetic Monte Carlo, Monte Carlo methods for rigid molecules and polymers. (12)

Molecular Dynamics: The basic idea of MD, numerical integration of equations of motion – Verlet and velocity Verlet algorithms, classical force-fields – bonded and non-bonded interactions, parameterization of force-fields. Applications and hands-on sessions – determining the diffusion constant and radial distribution functions of a Lennard-Jones fluid using an Anderson thermostat, end-to-end distance and radius of gyration of a solvated polymer using bead-spring model. Advanced applications – MD in various ensembles – thermostats and baro-stats, constrained MD. (12)

Some Tricks of the trade: Neighbour lists, Multiple time step methods, How to handle long-range forces. (6)

Advanced techniques: Biased Monte Carlo Schemes, Rare Event, Brownian dynamics, Dissipative particle dynamics. (5)

References

1. D. Frenkel and B. Smit, Understanding Molecular Simulations (ed. 2)
2. A. R. Leach, Molecular Modeling
3. M. P. Allen and D. J. Tildesley, Computer Simulation of Liquids
4. J. M. Thijssen, Computational Physics

5. T. Pang, An introduction to computational physics
6. V. Rajaraman, Computer Programming in Fortran 90 and 95

PHY 413/503: Introduction to Astrophysics (4)

Learning Objectives

The main objective here is to use our prior knowledge of physics (Classical, Statistical, Quantum mechanics and General relativity) to understand the fundamental processes that occur in celestial objects ranging from interstellar dust to stars and galaxies.

Course Content

Introduction: Brief overview of our Universe (1)

Motion in the sky: Celestial sphere, Coordinate system and time, distance to stars, velocity and distance measurement, proper motion, Kepler's problem and its parametric solution. (3)

Radiative processes: Radiative transfer, Blackbody radiation, Bremsstrahlung, Cyclotron and Synchrotron radiation, Thompson and Compton scattering, Inverse Compton Scattering. (4)

Physics of Stars: Equation of stellar structure, Polytropes and modeling, Nuclear reaction rates and burning of stars, Nucleosynthesis, Stellar evolution, White Dwarfs, Neutron stars, Black holes, Collapsars, gamma ray bursts. (14)

Interstellar medium: Composition, Radiative heating and cooling, Shocks and supernovae, supernovae remnant, star formation. (5)

Galaxies: Morphological classification, spiral and elliptic galaxies, galactic dynamics, galaxy disc, rotation curve and dark matter, galaxy formation, active galactic nuclei and quasars. (9)

Gravitational waves: Generation of gravitational waves, measurement. (2)

References

1. B. W. Carroll and D. A. Ostlie, Introduction to Modern Astrophysics
2. M. Zeilik and S. A. Gregory. Introductory Astronomy and Astrophysics
3. S. L. Shapiro and S. A.Teukolsky, Black Holes, White Dwarfs and Neutron Stars

4. B. James and S. Tremaine, Galactic Dynamics
5. G. B.Rybicki and A. P.Lightman, Radiative Processes in Astrophysics
6. J. E. Dyson and D. A. Williams, The Physics of Interstellar Medium

PHY 414: Advanced Condensed Matter Physics (4)

Learning Objectives

Students will learn structural, electronic and magnetic properties of some exotic materials of contemporary relevance, namely, the colossal magneto-resistive materials,magnetoelectric and multiferroic materials, high temperature superconductors, low dimensional systems, etc.

Course Content

Review of basic postulates of magnetism, direct and indirect exchange interaction, Zener-double exchange interactions, super-exchange interactions, ferro-, antiferro-, ferri-magnetism, spin glasses. (8)

Oxide based modern magnetic materials: Ferrites and magnetic technology based on it, Giant magnetoresistance: Exchange in magnetic multilayers; Colossal magnetoresistance materials, charge- and orbital-ordering, phase-separation; electric, magnetic and photo control of physical properties. (10)

Dilute magnetic semiconductors, Introduction to spin electronics and technology based on it. Thin film technology of magnetic materials. (8)

Review of basic postulates of superconductivity, High temperature supercondtivity, Josephson junctions, SQUID magnetometer, recent advances in superconductors: MgB2, Fe-based superconductors, etc. (6)

Ferroelectricity, Multiferroicity, magnetoelectricity (5)

Introduction to nanotechnology and nanoscience: Carbon nanotubes and fullerenes. (3)

References

1. M.Getzlaff, Fundamental of Magnetism
2. N. W. Ashcroft and N. D. Mermin,Solids State Physics
3. O. Madelung, Introduction to Solid State Physics

4. P. M. Chaikin and T. C. Lubensky, Principles of Condensed Matter Physics:
5. H. Ibach and H. Luetz, Solid State Physics – An Introduction to Theory and Experiment:
6. J. Callaway.Quantum Theory of Solid State
7. B. D. Cullity, Introduction to Magnetic Materials
8. N. A. Spaldin, Magnetic Materials: Fundamentals and Device Applications

PHY 415/615: Quantum Field Theory I (4)

Learning Objectives

Students will be able to understand the basics of quantum field theory and will be able to read and understand advanced texts on the subject. Students will be able to apply analytical problem solving skills in the areas of relativistic quantum mechanics

Course Content

Classical Field Theory: Introduction; Lagrangian Field Theory; Lorentz Invariance; Noether's Theorem and Conserved Currents; Hamiltonian Field Theory. (8)

Canonical Quantization: The Klein-Gordon Equation, The Simple Harmonic Oscillator, Free Quantum Fields, Vacuum Energy, Particles, Complex Scalar Fields, The Heisenberg Picture, Causality and Propagators, Applications, Non-Relativistic Field Theory. (8)

Interacting Fields: Types of Interaction, The Interaction Picture, Dyson's Formula, Scattering, Wick's Theorem, Feynman Diagrams, Feynman Rules, Amplitudes, Decays and Cross Sections, Green's Functions, Connected Diagrams and Vacuum Bubbles, Reduction Formula. (10)

Quantizing the Dirac Field: Spin-Statistics Theorem, Fermionic Quantization, Fermi-Dirac Statistics, Propagators, Particles and Anti-Particles, Dirac's Hole Interpretation, Feynman Rules. (6)

Quantum Electrodynamics: Gauge field, Gauge Invariance, Quantization, Inclusion of Matter - QED, Lorentz Invariant Propagators; Feynman Rules; QED Processes. (8)

References

1. M. Schwartz, Quantum Field Theory
2. M. E. Peskin and D. V. Schroeder, An Introduction to Quantum Field Theory
3. L. H. Ryder,Quantum Field Theory
4. S. Weinberg, Quantum Field Theory Part 1

PHY 416: General Theory of Relativity (4)

Learning Objectives

This course covers the basic principles of Einstein's general theory of relativity, tensor algebra, experimental tests of general relativity, black holes, and cosmology.

Course Content

Review of special theory of relativity. (2)

Mathematical aspects: Tensor algebra, Transformation of coordinates, Lie derivative, covariant derivative, affine connections, Riemann tensor, Curvature tensor. (8)

Inertial frames, Gravitational mass and inertial mass, Equivalence principle: weak form, strong form, Principle of general covariance. (4)

Field equations in general relativity: Geodesic deviation, Vacuum Einstein equations. (6)

Action formulation of GTR. (3)

Solution of Einstein equations: Tests of GTR, Black holes, Schwarzschild black hole. (12)

Penrose diagram of Schwarzschild black hole. (2)

Cosmology: FRW Universe. (4)

References

1. S. Carroll,Spacetime and Geometry: An Introduction to General Relativity
2. R. M. Wald,General Relativity
3. J. B. Hartle, Gravity: An Introduction to Einstein's General Relativity
4. S. Weinberg, Gravitation and Cosmology

PHY 421: Quantum Field Theory II (4)

Learning Objectives

Students will be able to calculate tree level processes in quantum electrodynamics. Students will be able to understand and apply path integral methods to quantum field theory. Students will be able to understand basics of non-abelian gauge theories

Course Content

Introduction: Why should we study "Path integral quantization"? (2)

Review of path integral formulation of quantum mechanics. (3)

Path integral formulation of interacting scalar field theory: Correlation functions, Feynman Rules, Functional derivatives, Generating functional. (5)

Path integral for Fermion fields: Anti commutating numbers, the Dirac propogator, Generating functional. (5)

Path inegral for QED. (4)

Non-abelian gauge theories and quantization: Gauge invariance, Yang-Mills action, Feynman rules, Faddeev-Popov ghost fields, BRST. (8)

UV divergences and renormalization: explicit one loop renormalization for interacting gauge theory. (6)

Renormalization Group : calculation of beta function. (3)

Spontaneous symmetry breaking: Goldstone boson, Higgs mechanism. (4)

References

1. M. Schwartz,Quantum Field Theory
2. M. E. Peskin and D. V. Schroeder,An introduction to Quantum Field Theory

3. L. H. Ryder, Quantum Field Theory
4. A. Lahiri and P. B. Pal,A First Book of Quantum Field Theory
5. M. Kaku, Quantum Field Theory: A Modern Introduction by M. Kaku
6. J. D. Bjorken and S. D. Drell,Relativistic Quantum Field Theory
7. T-P Cheng &L-F Lee,Gauge Theory and Elementary Particle Physics
8. F. Halzen and A. D. Martin, Quarks and Leptons: An Introductory Course in Modern Particle Physics

PHY 423/523: Electronic Structure of Materials (4)

Learning Objectives

This course is aimed at introducing concepts and methods in modern electronic structure theory as applied to materials science. The course will begin with a review of one-electron theories and illustrate their usefulness through some common applications. An introduction to many electron problem along with a description of state of the art techniques, such as density functional theory, quantum Monte Carlo, many body perturbation theory, will follow. Practical aspects of the methods will be discussed in the context of problems of contemporary interest.

Course Content

Revision of one electron theory: Periodic systems, Bloch theorem, Tight binding method, application to 1 dimensional crystals: chain of atoms, 2-dimensional systems (e.g. graphene), 3-dimensional systems (e.g. silicon). (3)

Many electron systems: Crystal Hamiltonian, Born Oppenheimer approximation, Variational principle, brief introduction to Hartree-Fock theory. (3)

Density Functional Theory: Fundamental theorems, Kohn-Sham formalism, practical aspects - basis sets, pseudopotential, Brillouin zone sampling, approximate exchange-correlation functionals. (6)

Description of metals and insulators: Density of states, band dispersion, work function, smearing. (5)

Spin density functional theory: magnetism, exchange interaction, strongly correlated materials and the DFT+U approach. (8)

Advanced topics:Phonons, Berry phase approach to electric polarization, NEB, kinetic Monte Carlo, Ab initio MDQuantum Monte Carlo, Perturbation theory methods – GW. (8)

Nanomaterials, surfaces, interfaces. (2)

References

1. R. Martin, Electronic Structure: Basic Theory and Practical Methods
2. A. P. Sutton, Electronic Structure of Materials
3. D. Scholl, Density Functional Theory
4. W. A. Harrison, Electronic Structure and the Properties of Solids
5. D. Khomskii, Basic Aspects of Quantum Theory of Solids
6. G. Grosso and G. PastoriParravicini, Solid State Physics
7. J. Thijssen, Computational Physics
8. M.-C. Desjonqueres, Concepts in Surface Physics

PHY 504: Magnetism and Superconductivity (4)

Learning Objectives

Students will learn fundamentals and theoretical foundations of ordered and disordered magnetic phases, different types of magnetic exchange interactions and magnetic materials exhibiting such properties. Basic principles and theoretical foundations of superconductivity, and different types of superconductors comprise second part of the course.

Course Content

Magnetism: Orbital and spin magnetism without interactions; Exchange interactions; Ferromagnetism, anti-ferromagnetism, ferrimagnetism, helical order and spin glasses; Measurement of magnetic order; Broken symmetry, Landau theory of ferromagnetism, Heisenberg and Ising model, consequences of broken symmetry, phase transitions and spin waves; Domains and the magnetization process; Itinerant magnetism of metals; Giant, colossal and tunneling magneto resistance; Nuclear magnetic resonance and technological aspects of magnetic materials.

Superconductivity: Properties of conventional (low temperature) superconductors, Meissner-Ochsenfeld effect, perfect diamagnetism, London and Pippard equation;

Type I superconductors and type II superconductors, vortex state, critical fields, interaction of vortices, magnetic properties, surface superconductivity; Ginzburg-Landau theory; BCS theory of superconductivity- electron-phonon interaction, ground state of the superconductor, spectrum of elementary excitations, tunnel effects and measurement of the energy gap; Josephson effect and the quantum interferometers; High Temperature superconductivity.

References

1. S. Blundell, Magnetism in Condensed Matter
2. J. M. D. Coey, Magnetism and Magnetic Materials
3. A. Aharoni, Introduction to the Theory of Ferromagnetism
4. M. Tinkham, Introduction to Superconductivity
5. J. F. Annett, Superconductivity, Superfluids and Condensates
6. T. P. Sheahen, Introduction to High- Temperature Superconductivity

PHY 505: Advanced Topics in Condensed Matter Physics (4)

Learning Objectives

This course aims to provide a blend of theoretical background with experimental observations covering the recent trends in condensed matter physics.

Initially, some basic concepts of condensed matter physics will be revised. This will be followed by the current trends in condensed matter physics covering special topics, such as; oxide electronics, emergent phenomena at the oxide interfaces and heterostructures. Later, novel properties of 2D materials (graphene and transition metal dichalcogenides (TMDCs)) will also be discussed.

An important goal of this course is to prepare the participants to know when to be surprised – that is - how/when do you know you have discovered a new species or something remarkably new?

Course Contents

Review of basic concepts: Free electron and tightly bound electrons, electron-electron interaction, band structure, Bloch electrons and transport phenomena, metal-insulator transition, semiconductors and dilute magnetic semiconductors, magnetism and superconductivity; phonons, quasi-particle couplings (electron-phonon, spin-phonon).

Recent trends in condensed matter physics:

(a) Oxide electronics: Novel properties of complex oxides; oxide thin films, interfaces and heterostructures; emergent phenomena at the interfaces - two dimensional electron gas, magnetism, superconductivity; experimental techniques to grow and probe interfaces / heterostructures; experimental observations and relevant theoretical models; etc.

(b) 2D materials: Graphene and TMDCs; lattice structure and band diagram; lattice vibrations, Landau levels; novel electronic, optical and magnetic properties as well as superconductivity.

References

1. N. W. Ashcroft and N. D.Mermin,Solid State Physics
2. M. P. Marder, Condensed Matter Physics
3. H. Y. Hwang et al, Emergent phenomena at oxide interfaces, Nature Materials vol-11, pp-103, 2012 (and reference therein).
4. J. Mannhart et al, Two-Dimensional Electron Gases at Complex Oxide Interfaces, Annual Review of Materials Research vol-44, pp-151, 2014 (and reference therein).
5. M. Xu et al, Grahene-like Two-Dimensional Materials, Chemical Review vol-113, pp-3766, 2013 (and reference therein).
6. J-W Jiang, Graphenevs MoS2, arXiv:1408.0437v1 (and reference therein).
7. S. Das et al, Beyond Graphene: Progress in Novel Teo-Dimensional Materials and van der Waals Solids, Annual Review of Materials Research vol-45, pp-1, 2015 (and reference therein).
8. MoS2: Materials, Physics and Devices; Zhiming M. Wang (Editor), Lecture Notes in Nanoscale Science and Technology 21 (Springer, 2014).

PHY 506: Advanced Topics in Theoretical Condensed Matter Physics (4)

Learning Objectives

Current trends in condensed matter physics will be discussed in this course. Some of the topics to be taught include topological insulators, topological superconductors, quantum hall effect and phase transitions.

Course Contents

Second quantization for bosons and fermions.

Lattice vibrations: waves and phonons in graphene. Different bending modes of graphene, Landau levels, oscillations of magnetization (de Haas van Alphen), diamagnetism Landau and magnetic susceptibility of electron gas in graphene.

Graphene: band structure and Dirac spectrum.

Various generalizations: bilayer graphene, edge modes in ribbons, the birth of topological insulators, Berry phase, topological indices, topological order and the quantum spin hall effect, adiabatìc transport.

References

1. A. Altland and B. Simons, Condensed Matter Field Theory
2. R. Saito, Physical Properties of Carbon Nanotubes

PHY 510/630: Cosmology I (4)

Learning Objectives

This is an elective course which introduces cosmology to undergraduate students. Cosmology is the study of the origin, evolution, structure and composition of the universe as a whole.

Course Content

Brief introduction of cosmological distant scales - Astronomy and cosmology, galaxies, radio sources, Quasars, coordinate systems, Hubble expansion Brief review of general theory of relativity:

Relativity to Cosmology: Einstein field equation, luminosity distance, horizon and Hubble radius, angular size redshift relation.

Relics of big-bang: radiation dominated universe, thermodynamical treatment of early universe, nucleosynthesis, cosmic microwave background addition,.

Problems with standard big-bang theory: inflationary paradigm, Formation of large scale structure of universe.

Theory of Cosmic microwave background radiation.

References

1. S. Dodelson, Modern Cosmology
2. J. V. Narlikar, An Introduction to Modern Cosmology
3. P.J.E. Peebles, Physical Cosmology
4. J. A Peacock, Cosmological Physics
5. S. Weinberg, Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity

PHY 519: Experimental Techniques (4)

Learning Objectives

Students will learn the fundamentals of various techniques used in thermometry, vacuumsystems, cryogenics, magnetometry, radiation detection and measurement, and determination of electrical andthermal properties.

Course Content

Basics of vacuum technique: vacuum generation, gauging.

Cryogenics: generation of low temperature and it measurements, Structure and composition analysis by x-ray and electron diffraction based techniques: X-Ray Diffraction, Energy dispersive X-Ray (EDX), Transmission electron microscopy (TEM), X-Ray Fluorescence (XRF).

Electronic structure of Solids: X- ray and ultraviolet photoemission spectroscopy, angle resolved photo-emission spectroscopy, auger electron spectroscopy, and x-ray absorption techniques.

Radiation and particle detectors: gas detectors, scintillator detectors and semiconductor detectors,Thin film, polycrystalline and single crystal sample preparation techniques.

Magnetometry and electrotransport : ac and dc magnetization techniques, two-probe and four probe resistivity measurements, magnetoresistance, Hall, thermal conductivity, thermopower, and heat capacity.

Ultrafast spectroscopy: transient absorption, two photon absorption and terahertz spectroscopy Neutron and Muons in condensed matter.

References

1. S.Dushman, Scientific Foundations of Vacuum Technique
2. G. White, P. J. Meeson, Experimental Techniques in Low-Temperature Physics
3. B. D. Cullity, Elements of X Ray Diffraction
4. R. F. Egerton, Physical Principles of Electron Microscopy: An Introduction to TEM, SEM, and AEM
5. K. K. Schuegraf, Handbook of Thin-film Deposition Processes and Techniques: Principles, Methods, Equipment, and Applications
6. K. Byrappa, T. Ohac, Crystal Growth Technology
7. S.Hüfner, Photoelectron Spectroscopy by Principles and Applications
8. B. D. Cullity,Introduction to Magnetic Materials
9. K. Sakai, Terahertz Optoelectronics
10. W. E. Fischer, R. Morf, X-Rays, Neutrons and Muons

PHY 527: Quantum Engineering (4)

Course Content

Quantum confined semiconductors –physics and devices.

Introduction to semiconductors; electrons and phonons in quantum wells, quantum wires, and quantum dots. Quantum well diode lasers, inter-sub-band transitions and detectors based on them, excitons in quantum wells and self-electro-optic-effect devices, quantum dots for quantum computing.

Laser cooling and trapping of ions and their use in quantum information processing: Laser cooling, Paul ion trap, other ion traps, coherent light atom interaction, quantum computing with trapped ions.

Superconducting systems for quantum information processing, Josephson effect, Phase qubits and flux qubits, circuits, examples.

References

1. P.Yeh and M.Cardona, Fundamentals of Semiconductors
2. D. A. B. Miller, Quantum Mechanics for Scientists and Engineers
3. P. Harrison ,Quantum Wells, Wires and Dots: Theoretical and Computational Physics of Semiconductor Nanostructures

4. B.R. Nag, Physics of Quantum Well Devices
5. J. Stolze, D. Suter Quantum Computing: A Short Course from Theory to Experiment
6. H. O. Everitt,ed, Experimental Aspects of Quantum Computing
7. L.-M. Duan and C. Monroe, Rev. Mod. Phys. 82, 1209 (2010)
8. A. M.Zagoskin Quantum Engineering: Theory and Design of Quantum Coherent Structures

PHY 531: Special Topics in Theoretical Physics (4)

Course Content

Course title and contents will be dynamic and change year to year according to emerging interesting areas in theoretical physics. *Course Content* will be approved by Academic Senate upon recommendation from DUGC and DPGC.

PHY 534: Advanced Statistical Mechanics (4)

Learning Objectives

This course is about theoretical understanding of the various phases of matter using statistical mechanics. Phase transitions of the first order and second order will be discussed using a phenomenological model and the renormalization group approach. This course will also introduce non-equilibrium statistical mechanics.

Course Contents

Revision of statistical mechanics, Thermodynamics of various ensembles, General properties of partition function, Lee-Yang theorem.

Thermodynamics of phase transitions, metastable states, First and second order transitions, phenomenology of liquid-gas and paramagnetic-ferromagnetic transition, Van der Waals' equation of state critical point exponent.

Classical mean field theories, mean field theory for Ising model, Landau theory. Setting up the transfer matrix, Calculation of free energy and correlation functions, Results of Ising model in one and two dimensions.

Critical phenomena at second-order phase transitions, spatial and temporal fluctuations, scaling hypothesis, critical exponents, and universality classes.

Ginzburg-Landau free-energy functional, momentum-space renormalization group.

Systems out of equilibrium, kinetic theory of a gas, approach to equilibrium and the H-theorem, Boltzmann equation and its application to transport problems. Brownian motion, Langevin equation, fluctuation-dissipation theorem, Einstein relation, Fokker-Planck equation.

References

1. K. Huang, Statistical Mechanics
2. R.K.Pathria, Statistical Mechanics
3. E.M. Lifshitz and L.P. Pitaevskii, Physical Kinetics
4. D.A. McQuarrie, Statistical Mechanics
5. L.P. Kadanoff, Statistical Physics: Statistics, Dynamics and Renormalization
6. P.M. Chaikin and T.C. Lubensky, Principles of Condensed Matter Physics
7. H. E. Stanley, Introduction to Phase Transitions and Critical Phenomena

PHY 535/635: Many-body Quantum Mechanics of Degenerate Gases (4)

Learning Objectives

To master the practical use of the second quantised/ Fock space framework. To understand how macroscopic quantum coherence arises in BEC and use mean field theory. To understand the implications of quantum degeneracy pressure for Fermions and its various practical manifestations. To obtain an overview of the diverse quantum simulation prospects of ultracold gases.

Course Content

The course introduces the essential foundations of quantum many-body physics, and uses it to build the theory of Bose-Einstein condensates and degenerate Fermi gases. This allows a brief discussion of a variety of interesting physical phenomena such as superfluidity, superconductivity or white dwarf stars. After pointing out the general impossibility of comprehensive solutions of quantum-many-body systems, it concludes with two paradigmatic applications of the idea of “quantum simulators”: the ultracold atom Bose-Hubbard model and BEC-BCS cross-over.

Motivation and Review

Context, applicability; single-particle quantum-mechanics, maths and statistical physics.Quantum Many-Body Formalism

Symmetries of identical particles, creation- and destruction operators, coherent states, Pauli blocking and Bose enhancement, field operators. Bose-Einstein condensates

Bose-Einstein statistics, critical temperature and condensate fraction, Gross-Pitaevskii equation, Bogoliubov theory, quasi- particles, Superfluidity.Degenerate Fermi gases

Fermi-Dirac statistics, critical temperature, Fermi surface, Superconductivity, Fermi-pressure in white dwarf stars. Quantum Simulators

Quantum many-body Hilbert space challenge.Feynman’s vision of quantum simulations, Bose-Hubbard model (for cold Bose- atoms), BEC-BCS crossover (for cold Fermi-atoms).

References

1. C. J. Pethick and H. Smith, Bose-Einstein Condensation in Dilute Gases
2. L. Pitaevskii and S. Stringari, Bose-Einstein Condensation
3. J. J. Sakurai, Modern Quantum Mechanics
4. J. W. Negele and H. Orland, Quantum many particle systems

PHY 613: Ultrafast Optics and Spectroscopy (4)

Course Content

Basics laser theory: Einstein coefficient and light amplification, laser rate equations, cavity modes, transverse and longitudinal mode selection, coherence properties.

Ultrashort pulse generation: Active and passive mode-locking, mode-locking using optical Kerr Effect.

Ultrafast-pulse measurement methods: Electric field auto-correlations and power spectrum, Intensity autocorrelations, frequency resolved optical gating (FROG).

Manipulation of ultrashort pulses: Pulse shaping techniques.

Ultrafast time-resolved spectroscopy: Forced wave equations, second harmonic generation, Propagation equation for nonlinear refractive index media, nonlinear Schroedinger equation, self-phase modulation, modulation instability and solitons.

Ulatrafast time-resolved spectroscopy: Degenerate and non-degenerate pump-probe transmission measurements, stimulated Raman scattering.

Terahertz electromagnetic radiations: THz generation and detection, THz time domain spectroscopy and imaging.

Introduction to atto-second science.

References

1. A.Weiner, Ultrafast Optics by Andrew Weiner
2. P. H. Ford ed., Laser Spectroscopy
3. A. K. Ghatak and K. Thyagarajan, Laser Theory and Applications
4. R. Trebino and J.Squiereds., Ultrafast Optics

PHY 617: Soft Condensed Matter (4)

Course Objective

Students will be able to learn the basics for the area of soft condensed matter physics. Course will introduce colloids, polymer, liquid crystals and amphiphiles to the students.

Course Content

Introduction and Overview: What is soft condensed matter, forces, energies and timescales in soft condensed matter.

Colloids: A single colloidal particle in a liquid (Stoke's law and Brownian motion), forces between colloidal particles (Van der Waals, electrostatic double layer, stearic, depletion interaction), stability and phase behaviour of colloids (hard sphere, long ranged repulsion, weakly attractive, strongly attractive), flow in concentrated dispersions.

Polymers: Polymeric materials, freely jointed chains and its Gaussian limit, real polymer chains, excluded volume, theta temperature, viscoelastic behaviour of polymers, linear viscoelasticity, time-temperature superposition, entanglements, tube model and theory of reptation.

Liquid Crystals: Types of liquid crystals, characteristics and identification of liquid crystal phases, nematic/isotropic transition, rigidity and elastic constants of a nematic liquid crystal, boundary effects, disinclination, dislocation and other topological defects, polymer liquid crystals.

Amphiphiles: Self-assembled phases in solutions of amphiphilic molecules, spherical micelles and critical micelle concentration, cylindrical micelles, bilayers and vesicles, phase behaviour of concentrated amphiphile solutions, complex phases in surfactant solutions and microemulsions.

Biological Soft Matter: DNA (structure, condensation), proteins (structure, folding, crystallization), membranes (lipid membranes, instabilities).

Experimental Techniques in Soft Matter: Rheology (shear rheometry, microrheology), light scattering (dynamic light scattering, static light scattering), microscopy (optical microscopy, video microscopy and particle tracking).

References

1. R. A. L. Jones, Soft Condensed Matter
2. W. Hamley, Introduction to Soft Matter: Synthetic and Biological Self-Assembling Materials
3. T. A. Witten and P. A. Pincus, Structured Fluids: Polymers, Colloids and Surfactants

PHY 632: Quantum Entanglement in Many-Body Systems (4)

Learning Objectives

The course will develop the notion of entanglement with the aim of exploring its consequences in the field of many-body physics. The ideas of pure and mixed states, and various appropriate measures of entanglement will be introduced. Second quantization formalism will be developed for free fermions and free bosons. Techniques for computing entanglement in such systems will then be described. An attempt will be made to make contact with current research where familiar phenomena of many-body physics are being studied afresh from a quantum entanglement perspective.

Course Contents

Quantum Theory: Linear algebra, the postulates of quantum mechanics, measurement.

Entanglement: Density operators, Schmidt decomposition, Einstein- Podolsky-Rosen, Bell inequality.

Measures of entanglement: Entropy of entanglement, Concurrence, Tangle, Positive Partial Transpose, Mutual information, Quantum discord etc.

Second Quantization: States of many-particle system, Fock space: creation and destruction operators, Identity of particles and the Pauli principle, Representation of Symmetric operators in Fock space, Independent particle states, Coherent states, Canonical Transformations, Bogolyubov transformation, Canonical form of the generalized density matrix, Diagonalization of quadratic Hamiltonians.

Entanglement in Solvable Many-Particle Models: Reduced density matrices, Note on application to DMRG, Entanglement entropy: von Neumann, and Renyi entropy, Free-particle models: fermionic hopping models, coupled oscillator models, correlation functions, Entanglement hamiltonians, correlator matrix approach to computing entanglement entropy, Schmidt form for fermions, Integrable models: Transverse field Ising models, Relation to a 2D partition function, Entanglement entropies for various chain models.

Outlook: Recent and current activity in the field of many body physics, open questions, hints on possible directions for research. Other models and questions that are being investigated.

References

1. M. A. Nielsen and I. L. Chuang, Quantum Computation and Quantum Information
2. J. P. Blaizot and L. Ripka, Quantum Theory of Finite Systems
3. J. J. Sakurai, Modern Quantum Mechanics
4. D. J. Griffiths, Introduction of Quantum Mechanics, 2nd Ed
5. I. Peschel, Special Review: Entanglement in Solvable Many- Particle Models
6. V.Vedral, Entanglement in the Second Quantization Formalism, CEJP 2, 289-306 (2003)