

Statistical Mechanics

Course Code : PAS- 8201/PAS8101H.

Course Name : Statistical mechanics.

Course Instructor : Ayan Chatterjee.

Course Duration : 15 Weeks.

Credits Equivalent: 4 Credits

Course Objectives:

Statistical mechanics is considered essential for every student of physics, irrespective of his/her specialization. The aim of this subject is to study physical macroscopic properties of matter on the basis of dynamical behaviour of its *microscopic constituents*. The basic structure is the use of Hamiltonian mechanics and the principles of mathematical statistics. The aim of PAS-8201 is to study equilibrium states and the principle we shall use is : dynamics of physical states is represented by a set of quantum states and thermodynamics of the system is determined by multiplicity of these states. This connection between microscopic and macroscopic descriptions of a system is uncovered by studying systems in isolation and in thermal contact. Thus, we shall learn how to understand coarse thermodynamic properties of systems from counting of microscopic states.

Course Contents

I. Review of thermodynamics (8 hours)

Equilibrium states and thermodynamic variables, Fundamental relations, Equation of state and free energies, Gibbs- Duhem relation for homogeneous systems, Maxwell's relations, stability of thermodynamic variables.

II. The basic principles of statistical mechanics (12 hours)

Elementary concepts of reversibility, irreversibility and fluctuations, Simple ideas of probability theory, Central limit theorem, Specification of state of a system, Ensemble theory in classical and quantum mechanics, density matrix, the Liouville theorems, Statistical ensembles and probability distributions, The postulates of statistical mechanics.

III. Statistical mechanics of isolated systems (6 hours)

Microcanonical ensemble, Method of counting states, Statistical weights, Applications: ideal gas, Paramagnetism (solids in isolation) and negative temperature.

IV. **Statistical Mechanics of interacting systems** (8 hours)

System in contact with a reservoir: probability distribution, canonical partition function and Helmholtz free energy, Boltzmann distribution and computation of thermodynamic quantities, Fluctuations of the internal energy.

Gibbs distribution, grand canonical partition function and the grand potential, computation of thermodynamics quantities, Examples.

V. **Quantum statistics** (10 hours)

Density matrix for the microcanonical, canonical and the grand canonical ensembles, simple examples: particle in a box, identical particles, ideal gas. Quantum statistics, partition function, grand partition function and thermodynamics quantities, Bose statistics: grand partition function and mean occupation number, Fermi -Dirac statistics: grand partition function and mean occupation number. The Darwin -Fowler method.

VI. **Non- interacting Bose and Fermi gas** (8 hours)

Thermodynamic relations and chemical potential of bosons, Non- relativistic and relativistic Bose gas, Photons, Bose -Einstein condensation.

Thermodynamic relations for Fermi gas at zero temperature: ultra- relativistic and non- relativistic limits, Fermi gas at low temperatures: the Sommerfeld integrals. Applications to stellar matter: Ionisation in stars: the Saha ionisation equation, White dwarfs and the Chandrasekhar limit, Neutron stars.

VII. **Approximation methods and applications to phase transitions** (8 hours)

Perturbation theory and variational techniques, Mean field approximation, the Ising models (1d and 2d) and it's solution.

Criterion for phase transition, Classification of phase transitions: Gibbs phase rule and the Claussius- Clapyeron equation, Order parameter and critical exponents, Landau's theory of continuous phase transition.

Text books:

1. F. Reif: Fundamentals of statistical and thermal physics, McGraw-Hill , NewYork (1965).
2. H. Callen: Thermodynamics and an introduction to thermostatics Wiley, (1985).
3. R. Pathria: Statistical mechanics, Butterworth- Heinemann (1996).
4. L. Landau and E. Lifshitz: Statistical physics (part 1), Pergamon Press, (1980).
5. E. Schroedinger: Statistical thermodynamics, Dover, (1989).
6. C. Kittel: Elementary statistical mechanics, McGraw-Hill (1970).

7. K. Huang: Statistical mechanics, Pearson (1997).
8. D. Schroeder, Thermal physics, Pearson (2010).

Reference Books:

1. J. Walecka: Introduction to statistical mechanics, World scientific, (2011).
2. M. Plischke and B. Bergersen, Equilibrium Statistical Physics, World Scientific.
3. E. Stanley: Introduction to phase transitions, Oxford Univ. press (1987).
4. R. Lindsay: Introduction to physical statistics, Wiley, (1941).
5. M. N. Saha, and B. Srivastava, Treatise on Heat, Allahabad (1951).
6. M. Kardar: Statistical physics of particles, Cambridge Univ. press, (2007).

List of examiners

Statistical mechanics [CODE: PAS 8201, Credit:4]

Course Code: PAS 8201

Course Credits: 4

Theory: 60 Lectures

1. Dr. K. B. Joshi,
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3. Dr. Ranjan Kumar,
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4. Dr. Sourav Sur,
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Advanced Quantum Mechanics

MSc2nd sem/BSc Honors

Course Code: PAS8202A/PAS8202AH

Course Type: Major

Credits: 02

Course Objectives

1. To develop the necessary physics and mathematics background obtained in earlier courses to understand real-life quantum mechanical problems of bound and scattering states.
2. To develop understanding of time-dependent perturbation theory, symmetries, and scattering theory.
3. To study the relativistic version of single-particle quantum mechanics.

Course Outcomes

- CO1: Define symmetries in a quantum system and use them to define conserved quantities.
- CO2: Use conserved quantities to associate quantum numbers and transition probabilities.
- CO3: Define scattering quantum amplitudes and scattering cross-sections.
- CO4: Use relativistic quantum properties to understand modifications of energy levels.
- CO5: Understand the philosophy of quantum mechanics.

Course Content

Unit 1: Identical Particles (5 Hours)

Meaning of identity and consequences; symmetric and antisymmetric wavefunctions; Slater determinant; symmetric and antisymmetric spin wavefunctions of two identical particles; collisions of identical particles.

Unit 2: Time-Dependent Perturbation Theory (5 Hours)

Time-dependent perturbation theory; interaction picture; constant and harmonic perturbations; Fermi's Golden Rule; sudden and adiabatic approximations.

Unit 3: Scattering Theory (8 Hours)

Laboratory and centre-of-mass frames; differential and total scattering cross-sections; scattering amplitude; scattering by spherically symmetric potentials; partial wave analysis and phase shifts; Ramsauer-Townsend effect; relation between sign of phase shift and nature of potential; scattering by rigid sphere and square well; Coulomb scattering; Green's function; Lippmann-Schwinger equation; Born approximation.

Unit 4: Relativistic Quantum Mechanics (10 Hours)

Klein-Gordon equation; interpretation of negative energy states and antiparticles; Dirac equation and covariant form; plane wave solutions; momentum space spinors; spin and magnetic moment of electron; non-relativistic reduction; helicity and chirality; properties of gamma matrices; charge conjugation; normalization and completeness of spinors.

Unit 5: Measurement Problem and Recent Developments (5 Hours)

Copenhagen interpretation; pure and mixed states; Bell states; Bell's inequality and proof; EPR paradox; entanglement.

Prescribed Text Books

1. J.J. Sakurai, Modern Quantum Mechanics, Addison-Wesley.
2. R. Shankar, Principles of Quantum Mechanics, Plenum Press.
3. D.J. Griffiths, Introduction to Quantum Mechanics, Pearson Prentice Hall.
4. B. Bransden and C. Joachain, Quantum Mechanics, PHI.
5. D.J. Griffiths, Introduction to Particle Physics, Pearson Prentice Hall.

Other Resources / Reference Books

1. James D. Bjorken and Sidney D. Drell, Relativistic Quantum Mechanics, McGraw-Hill.
2. E. Merzbacher, Quantum Mechanics, McGraw Hill.
3. L.D. Landau and L.M. Lifshitz, Quantum Mechanics: Non-Relativistic Theory, Butterworth-Heinemann.

Condensed Matter Physics

Course Code: PAS8203/PAS8203H

Course Type:

Major

Credit: 4

Course Objectives:

This course is designed to teach students the relation between the structure and properties of exhibited by the crystalline solids. The details of band theory and effect of periodic potential on energy dispersions of electron. Role of lattice dynamics in thermal properties of solids. This course also aim to introduce the students to various types of properties of materials such as dielectrics, magnetic and superconducting properties.

Course Outcomes:

CO1: *After reading this course, the students will be able to understand how the energy dispersions of the electron are affected when large number of atoms come together to form crystalline materials.*

CO2: *What is the impact of periodic potential on electronic energy states in a crystal?*

CO3: *What causes the magnetism in any material and how one can explain various type of magnetic behaviours exhibited different materials.*

C43: *The students will also be able to understand the dielectric and superconducting materials and underlying mechanisms to explain their properties.*

Course Contents

Unit 1: Structure of solids

(9 hours)

Bravais lattice, primitive vectors, primitive unit cell, conventional unit cell, Wigner-Seitz cell; Symmetry operations and classification of 2- and 3-dimensional Bravais lattices; point group and space group (information only); Common crystal structures: NaCl and CsCl structure, close-packed structure, Zinc blende and Wurtzite structure, tetrahedral and octahedral interstitial sites, Spinel structure; Intensity of scattered X-ray, Friedel's law, Anomalous scattering; Atomic and geometric structure factors; systematic absences; Reciprocal lattice and Brillouin zone; Ewald construction; Explanation of experimental methods on the basis of Ewald construction; Electron and neutron scattering by crystals (qualitative discussion); Surface crystallography; Graphene; Real space analysis — HRTEM, STM, FIM. Non crystalline solids-Monatomic amorphous materials; Radial distribution function; Structure of vitreous silica.

Unit 2: Band theory of solids

(6 hours)

Bloch equation; Empty lattice band; Number of states in a band; Effective mass of an electron in a band: concept of holes; Classification of metal, semiconductor and insulator; Electronic band structures in solids - Nearly free electron bands; Tight binding method - application to a simple cubic lattice; Band structures in copper, GaAs and silicon; Topology of Fermi-surface; Quantization of orbits in a magnetic field, cyclotron resonance — de Haas-van Alphen effect; Boltzmann transport equation - relaxation time approximation, Sommerfeld theory of electrical conductivity.

Unit 3: Lattice dynamics and Specific heat (6 hours)

Classical theory of lattice vibration under harmonic approximation; Dispersion relations of one dimension lattices: monatomic and diatomic cases, Characteristics of different modes, long wavelength limit, Optical properties of ionic crystal in the infrared region; Inelastic scattering of neutron by phonon; Lattice heat capacity, models of Debye and Einstein, comparison with electronic heat capacity; Anharmonic effects in crystals - thermal expansion.

Unit 4: Dielectric properties of solids (6 hours)

Electronic, ionic, and orientational polarization; static dielectric constant of gases and solids; Complex dielectric constant and dielectric losses, relaxation time, Debye equations; Cases of distribution of relaxation time, Cole - Cole distribution parameter, Dielectric modulus; Ferroelectricity, displacive phase transition, Landau Theory of Phase Transition.

Unit 5: Magnetic properties of solids (9 hours)

Origin of magnetism; Diamagnetism: quantum theory of atomic diamagnetism; Landau diamagnetism (qualitative discussion); Paramagnetism: classical and quantum theory of paramagnetism; case of rareearth and iron-group ions; quenching of orbital angular momentum; Van-Vleck paramagnetism and Pauli paramagnetism; Ferromagnetism: Curie-Weiss law, temperature dependence of saturated magnetisation, Heisenberg's exchange interaction, Ferromagnetic domains - calculation of wall thickness and energy; Ferrimagnetism and antiferromagnetism.

Unit 6: Imperfections in solids (6 hours)

Frenkel and Schottky defects, defects by non stoichiometry; electrical conductivity of ionic crystals; classifications of dislocations; role of dislocations in plastic deformation and crystal growth; Colour centers and photoconductivity; Luminescence and phosphors; Alloys, Hume-Rothery rules; electron compounds; Bragg - Williams theory, order-disorder phenomena, superstructure lines; Extra specific heat in alloys.

Unit 7: Superconductivity (6 hours)

Phenomenological description of superconductivity - occurrence of superconductivity, destruction of superconductivity by magnetic field, Meissner effect; Type-I and type-II superconductors; Heat capacity, energy gap and isotope effect; Outlines of the BCS theory; Giver tunnelling; Flux quantisation; a.c. and d.c. Josephson effect; Vortex state (qualitative discussions); High T_c superconductors (information only).

Reference Books:

- Solid State Physics by Neil W. Ashcroft and N. David Mermin
- Introduction to Solid State Physics by C. Kittel
- Introduction to Solids by Azaroff
- Crystallography Applied to Solid State Physics by A. R. Verma and O. N. Srivastava
- Principles of Condensed Matter Physics by P. M. Chaikin and C. Lubensky
- Solid State Physics: A. J. Dekker

Astronomy and Astrophysics

Programme: Post-graduate

Course Code: PAS8204/PAS8204H

Course Type: Minor

Credits: 2

Course Objective:

The prime aim of this course is to provide a pedagogical introduction to astronomy and astrophysics both on the galactic and extragalactic scale at the post-graduation level.

Learning Outcomes:

After completing the course satisfactorily, a student will be able:

- To understand the physical principle of astrophysics, gravitation, radiation and radiative transport.
- Understand distance ladder in the context of the size of the Universe
- Sun and stellar synthesis.
- Milky way Structure and Properties
- Galaxies and their morphology
- Smooth and clumpy universe. The basic mathematical machinery of the background Universe.

Course Contents

Unit 1: Physical principles: Gravitation in Astrophysics, Virial Theorem, Systems in Thermodynamic Equilibrium, Theory of Radiative Transfer (Radiation Field, Radiative Transfer Equation), Optical Depth; Solution of Radiative Transfer Equation, Limb-darkening of Sun **(5 hours)**

Unit 2: Stellar structure: Hydrostatic Equilibrium of a Star, Some Insight into a Star: Sources of Stellar Energy, Modes of Energy Transport. Nucleosynthesis and stellar evolution: Cosmic Abundances, Stellar Nucleosynthesis, Evolution of Stars (Evolution on the Main Sequence, Evolution beyond the Main Sequence), Supernovae. Compact stars: Basic Familiarity with Compact Stars, Equation of State and Degenerate Gas of Fermions, Theory of White Dwarf, Chandrasekhar Limit, Neutron Star Black Hole. Determination of Temperature and Radius of a star; Determination of Masses from Binary orbits; Stellar Spectral Classification, Hertzsprung-Russell Diagram. **(7 hours)**.

Unit 3: The milky way: Basic Structure and Properties of the Milky Way, Nature of Rotation of the Milky Way (Differential Rotation of the Galaxy and Oort Constant, Rotation Curve of the Galaxy and the Dark Matter, Nature of the Spiral Arms), Stars and Star Clusters of the Milky Way, Properties of and around the Galactic Nucleus **(5 hours)**.

Unit 4: Galaxy Morphology, Hubble's Classification of Galaxies. Active galaxies: Classification of the Active Galaxies, Some Emission Mechanisms Related to the Study of Active Galaxies, Behavior of Active Galaxies (Quasars and Radio Galaxies, Seyferts, BL Lac Objects, and Optically Violent Variables), The Nature of the Central Engine, Unified Model of the Various Active Galaxies.**(5 hours)**

Unit 5: Large scale structure & expanding universe: Cosmic Distance Ladder (An Example from Terrestrial Physics, Distance Measurement using Cepheid Variables), Hubble's Law (Distance-Velocity Relation), Friedmann Equation and its Solutions (Newtonian Approach), Early Universe and Nucleosynthesis (Cosmic Background Radiation) **(8 hours)**

Prescribed Text Book:

1. The physical universe: An introduction to astronomy, F.Shu, Mill Valley: University Science Books.
2. Theoretical Astrophysics Volume I : Astrophysical Processes Padmanabhan, T. Published by Cambridge University Press
3. Theoretical Astrophysics Volume II : Star and Stellar Systems Padmanabhan, T. Published by Cambridge University Press...
4. Theoretical Astrophysics Volume III : Galaxies and Cosmology Padmanabhan, T. Published by Cambridge University Press...
5. Introduction to cosmology, by Jayant V. Narlikar Published by Cambridge University Press.
6. Structure formation of the Universe, by T. Padmanabhan Published by Cambridge University Press...

Mathematical Physics

Course Code : PAS- 8205/PAS8205H.

Course Name : Mathematical Physics

Course Instructor : Ayan Chatterjee.

Course Duration : 10 Weeks.

Credits Equivalent: 2 Credits (One credit is equivalent to 10 hours of lectures / organised classroom activity / contact hours; 5 hours of laboratory work / practical / field work / Tutorial / teacher-led activity and 15 hours of other workload such as independent individual/ group work; obligatory/ optional work placement; literature survey/ library work; data collection/ field work; writing of papers/ projects/dissertation/thesis; seminars, etc.)

Course Objectives: The course on mathematical physics is intended to introduce you to the fundamental principles of mathematics important for understanding physics. Most of the problems involve sophisticated mathematical techniques like the linear vector spaces, Sturm- Liouville theory for differential equations, integral equations and other mathematical methods.

Course outcome: You will learn the basics of the tools of mathematical physics for the description of physical world. This course forms the basis of developing the tools required for understanding physics.

Course Content:

I. Linear Vector spaces: (12 hours)

Definition of vector spaces, examples, basis, dimension, completeness. Operators acting on vector

spaces, matrix representation of operators; rank, trace, and determinant of matrices, Kinds of matrices,

Similarity transformations, Cayley-Hamilton theorem for characteristic polynomials, diagonalisation of

matrices, normal matrices, rules for diagonalisation of matrices.

Infinite dimensional vector spaces, function spaces, differential operators on functions spaces, Hermitian

and self adjoint operators, Sturm- liouville theory for differential equations, orthogonality and

completeness of eigenfunctions. Green's functions.

II. Orthogonal functions and their representations (10 hours)

Bessel function of the first kind, Generating functions, recurring relations, orthogonality. Neuman and

Hankel functions, Modified Bessel functions, asymptotic expansions, Spherical Bessel functions.

Legendre polynomials, Generating functions, recurring relations, orthogonality, integral representations.

Associated Legendre functions and spherical harmonics, properties.

Hermite, Laguerre, and Hypergeometric functions.

III. Integral equations (8 hours)

Integral transforms, Generating functions, Neumann series, Seperable kernals, Hilbert-Schidmt theory.

Text books:

1. Mathematical Methods for Physicists, Arfken and Weber 2002, Pearson Education
2. Mathematics for physicists, P. Dennery and A. Kryziwicki,, Dover.
3. Special functions of Mathematical physics and chemistry, Sneddon, Longman, 1980.
4. Tensors and matrices in physics, A.W. Joshi, New Age.
5. The mathematics of classical and quantum physics, Byron and Fuller, 1969, Dover.

Reference Books:

1. Classical Electrodynamics, J.D. Jackson, 3 rd Edn., 1998, Wiley.
2. Introduction to quantum mechanics, D.J. Griffiths, 2012, Pearson Education.

List of examiners

Mathematical Physics [CODE: PAS 8205, Credit:2]

Course Code: PAS 8205

Course Credits: 2

Theory: 30 Lectures

1. Dr. K. B. Joshi,
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3. Dr. Ranjan Kumar,
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4. Dr. Kinjalk Lochan
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5. Dr. Sourav Sur,
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