FOUR YEAR UNDERGRADUATE PROGRAMME

STATISTICAL MECHANICS

WITH INTRODUCTION TO PLASMA PHYSICS

As Per 5th Semester (D.U.), 6^{th} Semester (G.U., A.U., Bhattadev University, & Other Indian Universities and Autonomous Colleges syllabi under FYUGP (NEP).

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PREFACE

Welcome to *Statistical Physics***.** This book is designed as a gateway into the fascinating and mathematically rich world of probability, energy, and matter at the microscopic scale. As you begin this intellectual journey, you will uncover the fundamental principles that explain how the behavior of countless particles gives rise to the macroscopic properties of physical systems—from the warmth of sunlight to the stability of stars.

The text opens with the classical foundations of statistical mechanics, where the concepts of microstates, macrostates, and the distribution of particles are introduced alongside key ideas such as phase space, ensembles, and entropy. We explore how thermodynamic quantities like internal energy and free energy emerge naturally from microscopic statistics, and how classical assumptions lead us to familiar laws like the Maxwell-Boltzmann distribution and the law of equipartition of energy.

Building upon these ideas, we move into the realm of quantum statistics, where the distinction between bosons and fermions reshapes our understanding of heat, pressure, and radiation. You'll engage with topics such as blackbody radiation, the ultraviolet catastrophe, Planck's law, and the quantum mechanical derivation of thermal phenomena. From the peculiar behaviors of a Bose-Einstein condensate to the thermodynamic stability of white dwarf stars governed by Fermi-Dirac statistics, the book demonstrates how quantum mechanics revolutionizes statistical interpretation.

Throughout the book, emphasis is placed on both conceptual understanding and mathematical rigor. You will not only learn how to calculate thermodynamic functions but also why these methods matter in interpreting the natural world. Applications span condensed matter systems, astrophysics, and radiation theory, offering a comprehensive foundation for future study or research.

Our goal is not just to teach formulas but to nurture a deeper intuition for how large systems behave through the lens of probability and statistics. Approach each topic with a sense of inquiry and imagination. Let the patterns in randomness and the elegance of statistical laws inspire your journey into the heart of thermal and statistical physics.

June, 2025
Assam,

With best regards
Dr. Rajesh Kumar Verma
Dr. Pushpender Kumar Gangwar
Dr Atul Kumar Pandey

B.A/B.Sc in Physics Programme (NEP)

Detail syllabus of 6th Semester (Gauhati Univerisity)

Nature of Course : Core, Credit : 4

Title of Course: Statistical Mechanics – I

Course Code: PHY354

CONTENTS

Unit No.	Unit Content	No of Classes	Marks/ Credit
Theory			
Unit I: Classical Statistics	Microstate and macrostate, distributions of particles in compartments, principle of equal a priori probability. Phase space, volume of phase space. Elementary concept of ensembles, Types of ensembles. Ergodic hypothesis. Entropy and thermodynamic probability, Stirling's approximation, Maxwell-Boltzmann distribution function, Partition functions. Gibbs Paradox, Sackur Tetrode equation, Law of Equipartition of Energy (with proof) - Applications to specific heat and its limitations. Thermodynamic parameters (internal energy, entropy, free energy, enthalpy) using partition functions.	**15**	**Credit 4**
Unit II: Classical and Quantum Theory of Radiation	Properties of thermal radiation. Blackbody radiation. Spectral distribution of Blackbody radiation, Kirchhoff's law. Stefan-Boltzmann law: Thermodynamic proof. Radiation pressure (for Normal and diffused case). Wien's Displacement law. Wien's Distribution Law. Saha's ionization formula. Rayleigh-Jean's Law (with proof). Ultraviolet catastrophe. Need of quantum statistics. Planck's quantum	**12**	

	postulates. Planck's law of blackbody radiation: Experimental verification. Deduction of (1) Wien' s Distribution Law, (2) Rayleigh Jeans Law, (3) Stefan-Boltzmann Law, (4) Wien's Displacement law from Planck's black body radiation formula		
Unit III: Bose-Einstein Statistics	Bose-Einstein (BE) distribution, Pressure of a Bose gas, Bose Einstein Condensation (qualitative description only), Properties of liquid Helium (qualitative discussion only), Radiation as a photon gas and Bose's derivation of Planck's blackbody radiation formula, Thermodynamic functions of photon gas - energy, entropy, and free energy	**8**	
Unit IV: Fermi-Dirac Statistics	Fermi-Dirac (FD) distribution, FD function and Fermi Energy, Degenerate Fermi gas, strongly degenerate case (qualitative discussion only), Thermodynamic functions - energy and pressure of a completely degenerate Fermi gas, Heat capacity at low temperature, Free electron gas in metals and electronic specific heat, Relativistic Fermi gas, thermodynamics of white dwarf star (qualitative discussion only).	**10**	

B.A/B.Sc in Physics Programme (NEP)

Detail syllabus of 5th Semester (Dibrugarh Univeristy

Nature of Course : Core, Credit : 4

Title of Course: Statistical Mechanics – I

Course Code: PHY-C-11

CONTENTS

UNIT 1: CLASSICAL STATISTICS

Macrostate and Microstate, Phase Space, Elementary Concept of Ensemble, Postulates of classical statistical mechanics, Liouville's theorem, Number of microstates, Connection between Entropy and Thermodynamic Probability: Boltzmann entropy formula, Microcanonical ensemble, Classical Ideal Gas in Microcanonical ensemble, Classical Entropy Expression, Gibbs Paradox, Sackur Tetrode equation, Canonical ensemble, Classical Canonical Partition Function, Classical Ideal Gas in Canonical ensemble, Grand canonical ensemble, Chemical Potential, Classical Grand canonical Partition Function; Maxwell-Boltzman distribution law

(L 18, H 18, M 18)

UNIT 2: PARTITION FUNCTION

Quantized systems and discrete energy levels, Canonical and Grand Canonical Partition Functions (PF), Boltzman factor, Free Energy and Entropy in terms of PF, Average energy and Average number of particles; PF of a two-level system, PF of linear harmonic oscillator, Single particle PF, N particle PF (non-interacting); Degeneracy, Density of states.

(L 12, H 12, M 12)

UNIT 3: BOSE - EINSTEIN STATISTICS

Bose-Einstein distribution law, Thermodynamic functions of a Strongly Degenerate Bose Gas, Bose Einstein condensation, Properties of liquid He (qualitative description), Radiation as a Photon Gas, Thermodynamic functions of Photon Gas, Derivation of Planck's law..

(L 15, H 15, M 15)

UNIT 4: FERMI - DIRAC STATISTICS

Fermi-Dirac Distribution Law, Thermodynamic functions of a Completely and Strongly Degenerate Fermi Gas, Fermi Energy, Electron gas in a Metal, Specific Heat of Metals, Relativistic Fermi gas,White Dwarf Stars, Chandrasekhar Mass Limit

(L 15, H 15, M 15)

(Total Lectures 60, Total Contact Hours 60, Total Marks 60)

B.A/B.Sc in Physics Programme (NEP)

Detail syllabus of 3rd Semester (Assam University)

Title of Course : Statistical Mechanics

Course Code : PHYDSC-352T (30 CCA)

CONTENTS

UNIT 1

Microstates and macrostates, Phase Space, Entropy and Thermodynamic Probability, Maxwell- Boltzmann Distribution Law, Concept of statistical ensemble - Micro-canonical, Canonical and Grand canonical ensemble. Basic idea of partition functions, Expressions of different thermodynamical quantities (e.g. Free energy, pressure, average energy, entropy, Specific heat) in terms of partition function **(12 Lectures)**

UNIT 2:

Properties of Thermal Radiation. Kirchhoff's law. Blackbody Radiation, Spectral Distribution of Black Body Radiation. Wein's law & Rayleigh Jeans law (No derivation), Ultraviolet catastrophe. Planck's Quantum Postulates. Planck's Law of Blackbody Radiation and its derivation. Deduction of (1) Wien's Distribution Law, (2) Rayleigh-Jeans Law, (3) Stefan-Boltzmann Law, (4) Wien's Displacement law from Planck's law. Saha's Ionization Formula (qualitative idea only). **(12 Lectures)**

UNIT 3:

Entropy of mixing and Gibb's paradox, Resolution of Gibb's paradox, Concept of identical particles, Limitation of classical statistics. Fermions and Bosons. Bose-Einstein distribution function and its behaviour with temperature, Basic idea of phenomenon of Bose-Einstein condensation (Qualitative description), Calculation of various thermodynamical quantities of photon gas (black body radiation). **(13 Lectures)**

UNIT 4: KINETIC THEORY OF GASES

Fermi-Dirac distribution function and its behaviour with temperature, Basic idea of Fermi surface and fermi energy, Calculation of various thermodynamical quantities of free electron gas; Classical limits and distinguishing features of classical and quantum statistics. Basic idea of degenerate Fermi gas. Comparison of three distribution laws and their properties. **(13 Lectures)**

UNIT 5:

Plasma: Its definition, composition and characteristics, microscopic and macroscopic descriptions of plasma. Difference between ordinary gas and plasma, Plasma Parameters, Concept of Debye shielding distance, Quassi-neutrality in plasma, Dielectric constant of plasma, Production of plasma through collisions, Plasma Diagnostics - Single probe method, magnetic confinement of plasma. Solar corona and Solar wind. **(11 Lectures)**

B.A/B.Sc in Physics Programme (NEP)

Detail syllabus of 3rd Semester (Bhattadev Univeristy)

Title of Course: Statistical Physics

Course Code: PHY6204C (4 Credit)

CONTENTS

SECTION I : CLASSICAL THEORY OF RADIATION (Lectures 10)

Properties of Thermal Radiation. Blackbody Radiation. Pure temperature dependence. Kirchhoff ’ s law. Stefan-Boltzmann law: Thermodynamic proof. Radiation Pressure. Wien ’ s Displacement law. Wien ’ s Distribution Law. Sahas Ionization Formula. Rayleigh-Jean ’ s Law. Ultraviolet Catastrophe.

SECTION II : CLASSICAL STATISTICS (Lectures 12)

Macrostate & Microstate, Elementary Concept of Ensemble, Phase Space, Entropy and Thermodynamic Probability, Maxwell-Boltzmann Distribution Law, Partition Function, Thermodynamic Functions of an Ideal Gas, Classical Entropy Expression, Gibbs Paradox, Sackur-Tetrode equation, Law of Equipartition of Energy (with proof) - Applications to Specific Heat and its Limitations, Thermodynamic Functions of a Two-Energy Levels System, Negative Temperature.

SECTION III : QUANTUM THEORY OF RADIATION (Lectures 11)

Spectral Distribution of Black Body Radiation. Planck ’ s Quantum Postulates. Planck’s Law of Blackbody Radiation: Experimental Verification. Deduction of (1) Wiens Distribution Law, (2) Rayleigh-Jeans Law, (3) Stefan-Boltzmann Law, (4) Wiens Displacement law from Planck ’ s law.

SECTION IV : QUANTUM STATISTICS (Lectures 12)

B-E distribution law, Thermodynamic functions of a strongly Degenerate Bose Gas, Bose Einstein condensation, properties of liquid He (qualitative description), Radiation as a photon gas and Thermodynamic functions of photon gas. Bose derivation of Plancks law. Fermi-Dirac Distribution Law, Thermodynamic functions of a Completely and strongly Degenerate Fermi Gas, Fermi Energy, Electron gas in a Metal, Specific Heat of Metals

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