Syllabus template

Semester: VII	
Programme : PHYSICS	
Course : Advanced Thermal Physics and Advanced Quantum Mechanics I	
Paper code: M2C4PH26011T	**Credits: 2+2**
Hours/week : 4	
Category: Core/MDC/SEC/VAC : CORE(Major)	
Theory / Practical / Composite : THEORY	
No of Modules : 2	

Course Overview: Advanced Thermal Physics

Thermal Physics III introduces advanced topics in quantum statistical mechanics, focusing on density matrix formalism, quantum statistics of indistinguishable particles, and interacting spin systems. The course bridges microscopic quantum mechanics with macroscopic thermodynamic behavior and lays the foundation for modern condensed matter physics. Emphasis is placed on formal development, physical interpretation, and applications to real physical systems such as electron gases, white dwarfs, and magnetic materials.

Course Overview: Advanced Quantum Mechanics I

This course introduces approximation methods and many-particle concepts in quantum mechanics for analyzing realistic physical systems. Topics include time-independent and time-dependent perturbation theory with applications to the Zeeman and Stark effects, the variational method and the helium atom, and the quantum theory of identical particles, spin, and statistics.

Course Outcome: Advanced Thermal Physics

1. Formulate statistical mechanics using density matrices
2. Derive quantum statistical distributions
3. Analyze quantum gases in various regimes
4. Understand degeneracy pressure and astrophysical applications
5. Solve basic interacting spin models
6. Develop readiness for research in condensed matter and statistical physics

Course Outcome: Advanced Quantum Mechanics I

1. Apply time-independent perturbation theory to non-degenerate and degenerate energy levels and calculate first- and second-order corrections to energy eigenvalues and eigenstates.

2. Analyze physical effects of external perturbations such as the Zeeman effect (without electron spin) and the Stark effect in hydrogen.

3. Use the variational method to estimate ground-state energies of quantum systems.

4. Employ time dependent perturbation theory to compute transition probabilities for systems under harmonic perturbations. 5. Evaluate and compare quantum states of identical particles, distinguish symmetric and antisymmetric wavefunctions and justify the connection between spin and quantum statistics with application to the helium atom.				
Prerequisites: ***Basic knowledge about any prior course***				
SYLLABUS				
UNIT/ Module	**CONTENT**	**HOURS of NUMBER OF CLASSES**	**CO Mapping**	**COGNITIVE LEVEL**
I.	**Advanced Thermal Physics** **A) Density matrix:** Idea of quantum mechanical ensemble. Statistical and quantum mechanical approaches, Properties. Quantum Liouville's theorem, density matrices for microcanonical, canonical, grand canonical Pure and Mixed states. Density matrix for stationary ensembles. Application to a free particle in a box, an electron in a magnetic field**.** Density matrix for a beam of spin ½ particles.	**10L**	**CO1**	**K2, K3, K4**
	B) Systems of indistinguishable particles: BE and FD distributions, Ideal Bose and Fermi gas, statistics of occupation number, equation of state, BE condensation, Thermodynamic behaviour of an ideal Bose gas, blackbody radiation, thermodynamic behaviour of ideal Fermi gas, the electron gas in metals, statistical equilibrium of white dwarf stars.	**8L**	**CO2** **CO3**	**K2, K3, K4, K5**
	C) Interacting systems: Ising model. Idea of exchange interaction and Heisenberg Hamiltonian. Exact solution of one-dimensional Ising system. Applications	**6L**	**CO4** **CO5** **CO6**	**K1, K2, K3, K4, K5, K6**

II.	**<u>Advanced Quantum Mechanics I</u>** **A)** Time independent perturbation theory: Non-degenerate case. First order perturbation. Second order perturbation. Perturbation of an oscillator. Degenerate case. Zeeman effect without electron spin. First order Stark effect in hydrogen. Introduction to the variational method.	**10L**	**CO1, CO2, CO3**	**K2, K3, K4, K5**
	B) Time dependent perturbation theory: First order perturbation. Harmonic perturbation. Transition probabilities.	**6L**	**CO4**	**K3**
	C) Identical particles and spin: Indistinguishability of identical particles. Symmetric and antisymmetric wavefunctions. Connection between spin and statistics. Spin matrices and eigenfunctions. The helium atom.	**8L**	**CO5**	**K4, K5**

Text Books

Module A

1. F. Reif, Fundamentals of Statistical and Thermal Physics (McGraw-Hill).
2. K. Huang, Introduction to Statistical Mechanics (John Wiley & Sons)
3. R. K. Pathria, Statistical Mechanics (Butterworth - Heinemann)
4. David Chandler, Introduction to Modern Statistical Mechanics (Oxford University Press)

Module B

1. R. Shankar, Principles of Quantum Mechanics (Springer)
2. Cohen Tannoudji, Diu and Laloe, Quantum Mechanics (Wiley VCH)
3. L. I. Schiff, Quantum Mechanics (McGraw-Hill)
4. S. Gasiorowicz, Quantum Physics (John Wiley)
5. J. J. Sakurai and Jim Napolitano, Modern Quantum Mechanics (Cambridge University Press)

Suggested readings

1. L. P. Kadanoff, Statistical Physics (World Scientific).
2. R. Kubo, Statistical Mechanics. (North - Holland)

3. M. Kardar, Statistical Physics of Particles (Cambridge University Press)
Web Resources (OER)
1. *Tong, D., Statistical Physics.* *Department of Applied Mathematics and Theoretical Physics, University of Cambridge.* *Available at: http://www.damtp.cam.ac.uk/user/tong/statphys.html*
2. *MIT OpenCourseWare* *8.044 Statistical Physics I.* *Massachusetts Institute of Technology.* *Available at: https://ocw.mit.edu/courses/8-044-statistical-physics-i-spring-2013/*
3. *Fitzpatrick, R.* *Statistical Mechanics.* *University of Texas at Austin (Lecture Notes).* *Available at: https://farside.ph.utexas.edu/teaching/sm1/lectures/*
4. MIT OpenCourseWare *8.06 Quantum Physics III.* *Massachusetts Institute of Technology.* *Available at: https://ocw.mit.edu/courses/8-06-quantum-physics-iii-spring-2018/*
Evaluation Theory CIA: 30 (2 x 10 + 5/assgn.+ 5/attn.) Semester Exam:70
Paper Structure for Theory Semester Exam Module : For each module of 35 Marks: 15 Marks from 3 marks questions (5 out of 7) 20 Marks from 10 marks questions (2 out of 3)

Course outcomes (COs) for Advanced Thermal Physics and Cognitive Level Mapping

COs	CO Description	Cognitive levels
CO1	Formulate statistical mechanics using density matrices	K2,K3,K4
CO2	Derive quantum statistical distributions	K2,K3,K4,K5
CO3	Analyze quantum gases in various regimes	K4,K5
CO4	Understand degeneracy pressure and astrophysical applications	K1,K2,K3,K4

CO5	Solve basic interacting spin models	K4,K5
CO6	Develop readiness for research in condensed matter and statistical physics	K1,K2,K3,K4,K5,K6

Course outcomes (COs) for Advanced Quantum Mechanics I and Cognitive Level Mapping

COs	**CO Description**	**Cognitive levels**
CO1	Apply time-independent perturbation theory to non-degenerate and degenerate quantum systems and calculate first- and second-order corrections to energy levels and eigenstates.	**K2,K3,K4,K5**
CO2	Analyze physical effects of external perturbations such as the Zeeman effect (without electron spin) and the Stark effect in hydrogen using appropriate quantum mechanical methods.	**K3, K4, K5**
CO3	Use the variational method to estimate ground-state energies of quantum systems.	**K3**
CO4	Employ time dependent perturbation theory to compute transition probabilities for systems under harmonic perturbations.	**K3**
CO5	Evaluate and compare quantum states of identical particles, distinguish symmetric and antisymmetric wavefunctions and justify the connection between spin and quantum statistics with application to the helium atom.	**K4, K5**