Ideas and methods in condensed matter theory - Web course

COURSE OUTLINE

This is a graduate level course on the modern understanding of phases of quantum matter at low temperature, and phase transitions between these phases.

COURSE DETAIL

S.No	Topics and contents
	Module I. Overview of course
1.	Overview of course and index of topics (this lecture).
	Module II. Conceptual overview and linear response theory.
2	Review of undergraduate Statistical Physics (ensemble theory etc), and preview of new ideas (emergent phenomena).
3	Overview of important ideas needed for a deeper study of phase transitions and critical phenomena in low temperature matter (spontaneously broken symmetry, long range order, Goldstone modes, broken ergodicity, diverging timescales etc).
4	Analysis of thermodynamic fluctuations. Linear response theory: Derivation of linear response kernel from time dependent perturbation theory.

NP-TEL

NPTEL

http://nptel.iitm.ac.in

Physics

Pre-requisites:

Undergraduate

- Quantum Mechanics and
- Statistical Physics (both reviewed when needed in this course)

Coordinators:

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5	Linear response theory: Properties of linear response kernel (analyticity in upper half plane, Kramers-Kronig type dispersion relations).	
6	Linear response theory: Fluctuation-dissipation theorem. Broad-brush introduction to systems of interest in condensed matter physics.	
	Module III. Quantum antiferromagnets: Path integral description and introduction.	
7	Introduction to path integral representation of the partition function. Coherent state basis for quantum spins.	
8	Coherent state path integral for quantum spin systems: Derivation and connection to with statistical mechanics of higher dimensional classical spin system	
9	Coherent state path integral for quantum spin systems: Analysis and characterization of Berry phases for paths.	
10	Introduction to the physics of Mott insulators and derivation of the Heisenberg Hamiltonian for the low energy physics of Mott insulators. Example of parent compounds of high-T$_c$ cuprate superconductors.	
11	Derivation of long-wavelength effective theory for quantum antiferromagnets: Expanding about short-ranged ordered configurations	
12	Derivation of long-wavelength effective theory for quantum antiferromagnets: Role of Berry phases.	
13	Berry phase effects in $d=1$ and $d=2$: Haldane Gap versus gapless power-law antiferromagnetism, and deconfined quantum criticality.	
14	Experimental probes of quantum antiferromagnets: NMR and inelastic neutron scattering.	

	Module IV. Many-body formalism and introduction to strongly correlated bosonic and fermionic systems.
15	Second quantized formalism for representing many-particle bosonic or fermionic systems.
16	Second quantized formalism. Representing external potentials and interactions. Hubbard and tJ models for doped Mott insulators. Qualitative description of the physics of doped Mott insulators.
17	Coherent states for bosonic and fermionic systems and path integral representation
18	Coherent state path integral for bosonic and fermionic systems and Green functions.
19	Boson hubbard model for cold bosonic atoms in optical lattice potentials. Mott-lobes, and superfluid insulator transitions.
20	Effective field theory for superfluid insulator transitions in the bosonic Hubbard model
	Module V. Phase and phase transitions of the quantum rotor model.
21	Phases of the quantum rotor model: ordered phase, and spin wave excitations in the ordered phase.
22	Stability analysis of the ordered phase: Absence of symmetry breaking in dimension $d \leq 2$ at $T>0$, or dimension $d=1$ at zero temperature. Quantum paramagnetic state and its excitations.
23	Proof of Mermin-Wagner theorem for $d=2$ $T>0$ quantum rotor model.

24	Introduction to the renormalization group idea: Poor-man's scaling for the quantum rotor model. Technical aspects of the implementation of this idea.
25	Poor-man's scaling for the quantum rotor model: Derivation of RG flow equations and elementary consequences: Haldane gap for integer spin chains in $d=1$.
26	Field renormalization, critical properties in $2+\epsilon$ expansion. Critical line Consequences for planar rotors in $d=1$ at $T=0$, and for the classical two dimensional xy model.
27	Introduction to quantum critical phenomenology at $T>0$. Relevance to experiment. Poor man's scaling predictions for the effect of temperature fluctuations in rotor model at criticality.
	Module VI. Superfluidity and the Kosterlitz Thouless transition.
28	Planar rotor model as low energy effective model near superfluid insulator transition at commensurate density: Mott Insulator vs superfluid phases of rotor model. Continuum hydrodynamic description of superfluid phase. Sound-wave and plasmon excitations.
29	Vortex excitations in superfluid phase of rotor model.
30	More on vortices: Statistical mechanics of the vortex gas, and renormalization of superfluid stiffness.
31	Kosterlitz-Thouless renormalization group treatment of vortex gas. Consequences for superfluid films.
	Module VII. Outlook: Other applications of renormalization group ideas.
32	Landau Ginzburg theory for classical and quantum phase transitions. Expansion about the upper critical

	dimension. Sketch of $4-\epsilon$ expansion results. Overview of other applications of similar ideas: Kondo problem, renormalization group approach to Fermi-liquid theory.

References:

1. Anderson's `Basic Notions of Condensed Matter Physics'
2. Auerbach's `Interacting Electrons and Quantum Magnetism'
3. Chaikin & Lubensky's `Principles of Condensed Matter Physics' Goldenfeld.
4. Kogut's Reviews of Modern Physics article `Lattice-gauge Theories and Quantum Spin Systems'
5. Landau and Lifshitz's `Statistical Physics: Part I'
6. Negele and Orland's `Quantum Many-particle Systems'
7. Sachdev's `Quantum Phase Transitions'