Outline : Magnetism

Instructor : Subhro Bhattacharjee

Semester: January-April 2019 at ICTS,
Class Timings : *to be decided*

Helpful Prerequisites

Quantum Mechanics II, Statistical Mechanics I, Condensed Matter 1

Tentative Topics

1. **Topic 0 : Introduction to magnetism**

   (a) What is this course about ?

   (b) Recap of basic many-body physics

   (c) Recap of application symmetries in many-body systems

   (d) Summary of the problem of quantum magnetism

   (e) Recap of paramagnetism of free spins in a magnetic field

   (f) Different contributions to magnetism in a material

   (g) Recap of experiments on magnetic insulators
      - (1) Measuring thermodynamic properties
      - (3) Scattering experiments and correlations.

   (h) Recap of phase transitions and idea of spontaneous symmetry breaking in magnetic systems

2. **Topic 1 : Magnetic materials**

   (a) Atomic physics :
      - (1) Atomic orbitals and periodic table
      - (2) Spin-Orbit coupling
      - (3) Coulomb interactions and Hund's rules
      - (4) Atoms in a crystalline solid : Crystal fields

(b) Tight binding model and crystalline symmetries– topological band insulators and Chern insulators.

(c) Hubbard model and the Mott-Insulator

(d) Effective Spin models and strong coupling perturbative expansions

(e) Spin-1/2 models

(f) Spin-orbital models : Kugel-Khomskii models

(g) Experimental examples.

3. **Topic 2 : Mean field theory for magnetic ordering and fluctuations**

   (a) High temperature expansion and Curie-Weiss Mean field theory

   (b) Mermin-Wagner theorem and disordering in low dimensions.

   (c) Symmetry breaking and mean field theory for magnetic ordering.

   (d) Noether theorem and Goldstone modes

   (e) Fluctuations about the mean field and low energy spin waves : Holstein-Primakoff approach and Schwinger boson approach.

4. **Topic 3 : Spin path integral**

   (a) Spin coherent states

   (b) Deriving the spin path integral for long wavelength fluctuations of the magnetic order parameter

   (c) Order parameter, topological defects for magnetic systems

   (d) BKT transition and XY duality

   (e) Renormalisation group for BKT transition.

   (f) Large N approach : O(N) models for magnetism

   (g) Hubbard Model and Non-Linear Sigma model field theories

5. **Topic 4 : Magnetism in one dimensional spin systems**

   (a) Exactly solvable models and fractionalisation in one dimensions

   (b) LSM theorem and restrictions

   (c) Bosonisation methods in context of $J_1 - J_2$ spin-1/2 chain

   (d) Haldane Gap, Berry phase and NLSM field theory with topological term.

6. **Topic 5 : Quantum spin liquid and topological order**

(a) Exactly solvable models of quantum spin liquids
    (1) Toric code
    (2) Quantum spin ice
(b) Topological quantum numbers and topological order.
(c) Symmetry fractionalisation
(d) Parton theory of quantum spin liquids
(e) Many-body Entanglement

7. **Topic 6: Quantum Phase transitions in Magnetic systems**
   (a) Continuous quantum phase transition from a magnetic order state to a trivial paramagnetic state.
   (b) Idea of deconfined critical point.

References

Reference material will be mentioned in class topic-wise. General references include

1. Quantum phase transition, Subir Sachdev
2. Interacting electrons and quantum magnetism, Assa Auerbach
3. Lectures on Many-body physics, P. Fazekas.

Grading

1. **Assignments (50 %) :** Typically one assignment every 2 weeks.
2. **End semester Exam (50%)**