

Outline :
Condensed Matter Physics-1

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

Helpful Prerequisites

Quantum Mechanics II, Statistical Mechanics I.

Tentative Topics

1. Topic 0 : Introduction to quantum condensed matter (3-4 lectures)

- (a) What is this course about ?
- (b) Recap of the idea of identical quantum particles
- (c) Recap of free bosons and free fermion gas
- (d) Recap of application symmetries in quantum systems
- (e) Basic types of condensed matter experiments–
 - (1) Measuring thermodynamic properties
 - (2) Measuring transport properties.
 - (3) Scattering experiments and correlations.
- (f) Recap of phase transitions and idea of spontaneous symmetry breaking
- (g) Elements of second quantization

2. Topic 1 : Electron Gas (7 lectures)

- (a) Jellium Model of electrons
- (b) Drude and Sommerfeld theory of electrons
 - (1) Ohm's law and conductivity
 - (2) Hall effect and Hall coefficient

- (c) Boltzmann equation and idea of linear response
- (d) Coulomb interactions among electrons
- (e) Hartree-Fock theory of interacting electrons
- (f) Screening on interactions
- (g) Phenomenological theory of fermi liquids
- (h) Idea of quasi-particle and single-particle lifetime vs. transport lifetime
- (i) Landau Level and Integer Quantum Hall effect of a free electron gas in two dimensions

3. **Topic 2 : Lattice (8 lectures)**

- (a) Crystallisation as spontaneous symmetry breaking
- (b) Description of a crystal
 - (1) Bravais lattice and description of crystal in real space
 - (2) Reciprocal lattice and description of crystal in momentum space
- (c) Experimental detection of crystal through X-ray diffraction
- (d) Lattice vibrations
 - (1) Phonons as goldstone modes
 - (2) Harmonic theory of phonons
 - (3) Bloch theorem and Bloch states
 - (4) Detecting phonons in inelastic scattering experiments
 - (5) Raman and Infrared spectroscopy
 - (6) Anharmonic effects and thermal expansions
- (e) Theory of elasticity

4. **Topic 3 : Electrons in crystalline solids (6 lectures)**

- (a) Electron orbitals
 - (1) Atomic orbitals and periodic table
 - (2) Spin-Orbit coupling
 - (3) Hund's rules
 - (4) Crystal fields
- (b) Hopping of electrons on a lattice
 - (1) Tight-binding models
 - (2) Role of symmetries
 - (3) Electron band structure
 - (4) Wanniner Orbitals

- (5) Band Insulators, Band metals and semi metals
- (6) Fermi surfaces
- (7) Magnetic oscillations
- (8) Topological Band Insulators
- (9) Graphene
- (10) Pierl's substitution and Hofstadter Model, Chern Insulator
- (c) Semiclassical Dynamics of electrons
- (d) Time dependent variation principle of electron dynamics
- (e) Conductivity in metals
- (f) Umklapp scattering
- (g) Electromagnetic response of electrons in a solid
 - (1) Dielectric properties
 - (2) Plasmons

5. Topic 4 : Magnetism (2 lectures)

- (a) Origin of magnetism
 - (1) Recap of Dirac theory of spins and the non relativistic limit
 - (2) Single spin in a magnetic field as a model of dilute paramagnet
 - (3) Different contributions to magnetism in a material
 - (4) Magnetic susceptibility
 - (5) Neutron scattering
- (b) Magnetic insulators
 - (1) Spin model and their origin
 - (2) Spin rotation symmetry breaking and magnetic orders– Ferromagnetism, Antiferromagnetism.
 - (3) spin waves
 - (4) Ising Model
 - (5) Toric code as example of topological order

6. Topic 5 : Superconductivity (4 lectures)

- (a) What is superconductivity ?
- (b) Electron-phonon interactions and Cooper instability
- (c) Cooper pairs
- (d) Landau theory of superconductivity
- (e) Electromagnetic response of a superconductor
 - (1) Meissner effect
 - (2) Josephson effect

References

To be added

Grading

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