489 S 04 Lecture 28

Review of Course - Incomplete!

1. Fundamental principles
   (a) Quantum Statistics
      - Partition Function
      - Fermi Distribution for non-interacting Fermions - Fermi Energy
      - Bose-Einstein Distribution for non-interacting Bosons
      - Interacting particles

   (b) Periodicity - Ordered State of matter
      - Crystal Structure = Lattice + Basis
      - Primitive Cells, e.g., Wigner-Seitz Cell
      - Reciprocal Lattice
      - Laws for elastic scattering - Bragg Law
      - Brillouin Zone

   (c) Conservation Laws for inelastic scattering
      - Energy
      - Momentum ($\pm$ reciprocal lattice vector)

   (d) Bloch theorem
      - Electron states - Bands - $\epsilon_n(k)$, n=1,2, ... ∞
      - Fermi Surface in a metal
      - Lattice vibrations - Dispersion curves - ω_n, n=1,2, ... $3N_{atoms-per-cell}$ in 3 dimensions
      - Counting of states in bands
      - Density of states

   (e) Dynamics of electrons in electric/magnetic fields
      - Equations of motion: h v = grad ϵ, h dk/dt = force
      - Filled bands
      - Electrons and holes
      - Effective mass
      - Classical orbits in a magnetic field

   (f) Quantization of orbits in a magnetic field
      - Flux quantization, de Hass van Alphen (and other) effects
      - Landau Levels in 2d - Quantized Hall Effect

   (g) Magnetic Solids have long range magnetic order
      - Ferromagnets, Antiferromagnets
      - Magnons

(h) Superconductors have subtle long range order
- Exclusion of magnetic field
- Instability of Fermi Surface to attractive interactions (Cooper pairs)
- Relation of currents to phase of complex order parameter
- Flux Quantization hc/(2e)
- Persistent currents

2. Properties of Condensed Matter

(a) Cohesive Energy: Four types of bonding

(b) Equilibrium Thermal properties
- Internal Energy, Specific heat

(c) Lattice Vibrations
- Phonons, velocity of sound
- Lattice Specific Heat
- Thermal Conductivity

(d) Electrical Conductivity
- Drude theory
- Specific Heat - linear term in metal
- Hall Effect
- Quantized Hall Effect

(e) Semiconductors
- Extrinsic, Intrinsic (Law of mass action)
- Electrons, holes, Hall effect
- p-n junction rectifier, p-n-p, n-p-n transistor
- Field effect transistor
- Metal Insulator transition with doing concentration

(f) Magnetism
- Net spin and/or orbit moments
- Phase transition to ordered state

(g) Superconductivity
- Zero resistance
- Meissner Effect
- Type I and type II superconductors
- Flux Quantization hc/(2e)

3. Important Model systems

(a) Harmonic oscillator chain, e.g., with nearest neighbor interactions

(b) Debye Model for phonons

(c) Free, Independent Electron Gas

(d) Nearly free electron approximation

(e) Tight binding approximation with short range matrix elements

(f) Effective mass approximation

(g) pn junctions in semiconductors; npn, pnp transistor

(h) Quantum wells in semiconductors – 2-d electron gas

(i) Integral Quantum Hall Effect

(j) Localized magnetic moments - Caused by Electron-Electron Interactions

- Hund's Rules
- Heisenberg model for interactions between neighboring moments
- Curie Law, Curie-Wiess mean field models

(k) Cooper Pair - BCS State

4. Key Experiments

(a) Elastic Bragg scattering to observe periodicity
X-rays, Neutrons

(b) Inelastic scattering to observe excitations
Photons, Neutrons

(c) Photoemission and electron bands

(d) Conductivity; Hall Effect

(e) Quantization in Magnetic Field

- de Hass van Alphen, etc. experiments
- Quantum Hall Effect
- Flux Quantization in macroscopic systems
Superconductors (-2e)

5. Important Orders of Magnitude

(a) Lengths - atomic dimensions, radii of donor, acceptor states in semiconductors, typical densities, values of r_s in metals, wavelength of visible light, x-rays

(b) Energies - phonons, electron band widths, band gaps, magnetic interactions ($\approx$ transition temp), Gaps in superconductors, Binding energies of typical solids, Binding energies of donors, acceptors in semiconductors, energies of visible light, x-rays

(c) Temperatures - transition temperatures for magnets, superconductors, Debye temperatures, Fermi temperatures in a typical metal

(d) Magnitudes of different types of magnetic susceptibilities

(e) Effective mass, dielectric constant in semiconductor like Si, or GaAs