Syllabus

Physics 861 (Fall, 2005) — **Solid State Physics**

Instructor: Victor Galitski
Office: 312D (Physics)
e-mail: vmg4e@virginia.edu
Phone: 434-924-6788

Office hours: Wednesday, 10:00-11:00am; Friday, 10:00-11:00am

Lectures: Tuesday, 11:00am-12:15pm and Thursday, 11:00am-12:15pm

Summary

The purpose of this course is to provide a framework for graduate students to understand at an advanced level some of the most important aspects of modern condensed matter physics. Modern theoretical methods will be introduced and used throughout the course. They will include the path integral formalism, the renormalization group, and diagrammatic techniques. Making use of these methods, we will study interacting fermion and boson systems, Fermi liquid theory, localization effects in disordered systems, and low-dimensional quantum magnets.

Reading

- *Main text:* G. D. Mahan, "Many-Particle Physics," Plenum (1990)
- L. D. Landau and E. M. Lifshitz, 'Statistical Physics, Part I" (Volume V of the "Course of Theoretical Physics" by Landau and Lifshitz), Butterworth-Heinemann (1980)
- A. A. Abrikosov, L. P. Gor'kov, and I. E. Dzyaloshinskii, "Quantum Field Theoretical Methods in Statistical Physics," Oxford (1965)
- A. L. Fetter and J. D. Walecka, "Quantum Theory of Many-Particle Systems," McGraw-Hill (1971)
- N. W. Ashcroft and N. D. Mermin, "Solid State Physics," Saunders College Publishing (1976)

Homework: There will be, on average, one homework assignment every week.

Exam: There will be a take-home mid-term exam and a take-home final exam or a term paper (at student's discretion).

Grading

Homework: 40%
Mid-term: 30%
Final exam or term paper: 30%

Outline

1. Non-interacting classical and quantum gases; Boltzmann, Fermi, and Bose distributions

   (a) Properties of a Fermi gas
   (b) Properties of a Bose gas; Bose condensation

2. Second quantization; Bogoliubov transformation.

   (a) Classical chain of oscillators; Acoustic and optical phonons
   (b) Quantum chain of oscillators
   (c) Quantum fermionic chain
   (d) One-dimensional spin systems; Jordan-Wigner transformation

3. Methods of quantum field theory in condensed matter physics; Schrödinger, Heisenberg, and interaction representations; S-matrix

   (a) Single-particle quantum mechanics: Perturbation theory for the scattering amplitude; A pictorial representation for the scattering amplitude (the simplest example of a diagrammatic technique)
   (b) Green functions in many-particle systems; Wick's theorem
   (c) Perturbation theory and Feynman's diagrammatic technique for interacting particles
   (d) Physical meaning of Green functions; Spectrum of quasiparticles
   (e) Two-particle Green's function; Self-energy function

4. Application of the Green's function formalism to Fermi systems

   (a) Friedel oscillations and the Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction between magnetic impurities in metals
   (b) Electron-phonon interaction; Polaron in the weak-coupling approximation; Self-energy and effective mass
   (c) Anderson orthogonality catastrophe
   (d) Peierls transition

5. Analytical properties of Green's functions

   (a) Retarded and advanced Green's functions; Spectral function
   (b) Generalized susceptibility; Kubo's formula for linear response quantities
   (c) Green functions at finite temperatures; Imaginary time and Matsubara frequencies; Feynman's rotation and analytical continuation

6. Landau Fermi-liquid theory (FLT) and its microscopic justification

   (a) Phenomenological FLT; Collective modes and instabilities

   (b) Microscopic justification of FLT
   (c) Interacting electrons in metals; Random phase approximation; Plasmons; The quasiparticle renormalization factor (Z-factor) and effective mass
   (d) Stoner instability

7. Path integral formalism and renormalization group (RG)
   (a) Three stages of RG transformation; Fixed points
   (b) An example of the RG in four dimensions
   (c) Grassmann variables; Path integral for fermions
   (d) Fermi liquid as a fixed point; Superconducting instability

8. Electrons in a random potential
   (a) Averaging Green's functions over disorder
   (b) Derivation of Boltzmann transport equation; Conductivity of a normal metal
   (c) Quantum diffusion; Weak localization
   (d) Dephasing mechanisms in electronic systems

9. Emergent phenomena in strongly correlated electron systems
   (a) Strongly interacting electrons on a lattice; Hubbard model and tJ-model
   (b) Artificial electrodynamics and fractionalization in quantum magnets
   (c) Spin liquids: Exotic states of matter in quantum magnets; Monopoles and confinement