Syllabus for PHY676, Condensed Matter Physics, Spring 2005

17th January 2005

Condensed matter physics

Condensed matter physics is a huge subject with many topics and techniques. By numbers of practitioners, it is the largest part of the physics community. The broad range of techniques and concepts it uses have also found applications in fields such as particle physics and cosmology.

Condensed matter physics includes describing the macroscopic behaviors of material objects: transport properties, such as conduction of heat and electricity, and responses to external perturbations, such as mechanical stiffness and magnetic susceptibility. Condensed matter physicists study color and fracture in materials, soap froths, the nature of superconductivity, the electrical conductivity of carbon nanotubes, and the distribution of proteins on the surface of bacteria. Theoretical techniques used in this discipline include field theory in many forms, scaling and the renormalization group, simple equations based on physical arguments, very extensive simulations, and rather qualitative arguments. The goal is to use symmetries, conservation laws, and the study of how effects depend on scale to build effective descriptions of large systems. A huge number of phases and transitions between them have been predicted, explained, and measured. Experimental equipment is typically smaller scale than that of particle or astrophysics, as the energy and length scales are more compatible with the human scale: the variety of experiments that can and have been executed is enormous.

Course goals

My goal for this course is to help you acquire some background in condensed matter physics. It will not be possible to touch upon every topic in condensed matter physics. We will focus on a selected subset of particular systems. We will also work on general tools (concepts and mathematics) that can be used on topics beyond those that we will have time to discuss.

I will assume a standard undergraduate background in statistical mechanics and quantum mechanics. An introductory undergraduate solid state physics course and graduate statistical mechanics would be of extra help to your understanding, but is certainly not required or assumed.

Course content

The current plan is to work through the following concepts, but as this is the first time I have offered this course and given varying interests, I may change direction:

1. What is condensed matter physics? An introduction to the guiding principles of microscopic descriptions, macroscopic effective models, conservation laws, order and symmetry.

2. Structure of matter

    a) Structure factor and its measurement; liquids

    b) Crystalline symmetries and reciprocal lattice

    c) Liquid crystals; quasicrystals

3. Phases and phase transitions - structure, magnetism

    a) Brief review of thermodynamics

    b) Mean field theory

    c) Describing long wavelength behavior: scaling, introduction to renormalization

    d) Applications to xy-model

4. Electronic transport

    a) Simple models of conduction

    b) Brief introduction to band theory and its justification

    c) Anderson localization and interacting electrons

    d) Brief treatment of special topics: quantum hall effect, quantum dots, etc.

5. Quantum phases

    a) Bose-Einstein condensates

    b) Superfluids

    c) Superconductors

Resources

I recommend that you purchase a copy of Chaikin and Lubensky's *Principles of Condensed Matter Physics*, as you will be reading from that book. Problems that I assign will follow up on that reading. This book has NOT been ordered for the bookstore. It is a great book for study and advanced reference; everyone should have a copy.

I have placed the following books, which will be the source for some of the lectures, on two-hour reserve in the library:

- Charles Kittel, *Introduction to Solid State Physics*
- Nigel Goldenfeld, *Lectures on Phase Transitions and the Renormalization Group*

I will occasionally hand out copies of further readings, such as assigned for the first class.

Graded work

You are expected to complete homework assignments each week.

I will assign three or four *short* (about 4 pp.) papers for you to complete, during the semester. This will give you a chance to practice exploring the literature, applying your knowledge from class, and summarizing your understanding in written form.

You grade will directly be affected, but not to a large extent, by your involvement in and contributions to the class. This includes asking questions during lectures or using e-mail to ask about the course content or making suggestions on topics.

Your course grade will reflect how well you have learned the material, based upon my assessment of your homework, papers, and class contributions. There will be no midterm or final exams (the short papers will help me understand how well you are learning the material).

HOMEWORK POLICY: Working through problems is the only way to learn material well. I expect you to invest your own effort into solving a homework problem. However, you may *consult* with other sources, including your classmates, after you think you have understood what the problem is asking and you have tried to attack the problem by yourself. If you do consult other sources, including written materials, on-line sources, or other people, I expect you to give credit for your sources: you must list your sources and describe how they helped you find your answe (e.g., "I spoke with S. and we jointly came up with the idea of integrating Eq. 8 by parts" or "This derivation is in parallel with the derivation presented in the book ..."). I cannot emphasize enough how important this is: ethical conduct and giving proper credit to your sources is crucial in science, where every person uses ideas generated by others.

Contact information and office hours

My office is Room 213, Physics Building. I will be available immediately after class and Thursdays at 3 pm to discuss the course. My office number is x3-2408. My home number is 423-0321 (before 9 pm, please). My e-mail is aam@syr.edu.