Physics 598 SC1/SC2
Superconductivity, Ancient and Modern

Instructor: Anthony J. Leggett, 2113 ESB, 333-2077 (illinois email: aleggett)
Office hour: Monday 4:00-5:00pm

TA: Di Zhou (illinois email: dizhou2) 4105 ESB
Office hour: Wednesday 3:00pm

Class Times: Monday and Wednesday 1:00–2:20 pm

Place: 276 Loomis Lab.

1. Syllabus.

The course is modular, so that it is possible to take SC1 and SC2 individually if desired (but anyone wishing to take SC2 alone should consult the instructor).

SC1 covers the main experimental properties of the "classic" superconductors and their explanation in terms of the BCS theory. It assumes some background in quantum mechanics, statistical mechanics and solid-state physics, and preferably knowledge of the second-quantization formalism,* but no previous background in superconductivity.

SC2 covers those classes of superconductors discovered since 1975 which do not appear to fit into the BCS scheme (alkali fullerides, organics, heavy-fermions, ruthenates, ferropnictides, cuprates, FeAs compounds). It relies heavily on the theoretical considerations developed in SC1, but does not commit to any particular theory of (e.g.) cuprate superconductivity.

2. Schedule of lectures (provisional)

SC 1

Lecture	Date	Topic
1.	Wed. 26 Aug.	Brief history of superconductivity.
2.	Mon. 31 Aug.	Phenomenology of (classic) superconductivity
3.	Wed. 2 Sept.	Phenomenological theory of the EM properties of superconductors
4.	Wed 9 Sept.	Recap: normal metals and the electron-phonon interaction
5.	Mon. 14 Sept.	Fundamental ideas of BCS theory.
6.	Wed. 16 Sept.	Quantitative development of BCS theory.

* A self-contained introduction may be found (e.g.) in appendix 2A of AJLeggett, Quantum Liquids (OUP 2006).

7.	Mon. 21 Sept.	Thermodynamic and response properties of pure superconductors (non-EM).
8.	Wed. 23 Sept.	Microscopic properties of BCS superconductors (cont.).
9.	Mon. 28 Sept.	Dirty superconductors: thermodynamics and electrodynamics.
10.	Wed. 30 Sept.	Ginzburg-Landau theory: simple applications.
11.	Mon. 5 Oct.	The Bogoliubov-de Gennes and Andreev equations: Andreev reflection.
12.	Wed. 7 Oct.	Magnetic-impurity and other "pair-breaking" effects.
13.	Fri. 9 Oct (makeup)	The Josephson effect.
14.	Mon. 12 Oct.	The stability of supercurrents: fluctuation effects.
15.	Wed. 14 Oct.	Miscellaneous topics in BCS.

SC 2

Lecture	Date	Topic
1.	Mon 19 Oct.†	Non-BCS superconductivity: Diagnostics.
2.	Wed. 21 Oct.	Non-cuprate exotics I: BKBO, MgB2, alkali fullerides
3.	Mon. 26 Oct.	Non-cuprate exotics II: organics, heavy-fermions, ruthenates.
4.	Wed. 28 Oct.	The cuprate superconductors: generalities (composition, structure, phase diagrams. . .).
5.	Mon. 2 Nov.	Normal-state properties: Optimal doping: (+ overdoped regime).
6.	Wed. 4 Nov.	The phase diagram: the "pseudogap" regime, systematics of T_c.
7.	Mon. 9 Nov.	Superconducting-state properties: static and transport.
8.	Wed. 11 Nov.	Superconducting-state properties II: spectroscopic probes. Preliminary overview of the experimental situation.
9.	Mon. 16 Nov.	What do we know <u>for sure</u> about the cuprate superconductors?

† To be re-arranged

10.	Wed. 18 Nov.	What do we know for sure about the cuprate superconductors? II. Symmetry of the order parameter.
11.	Mon. 30 Nov.	Microscopic theories of cuprate superconductivity: a smorgasbord.
12.	Wed. 2 Dec.	Where is the energy saved?
13.	Mon. 7 Dec.	Non-cuprate exotics III: the FeAs superconductors.
14.	Wed. 9 Dec.	What are the most important questions concerning the cuprate superconductors?

3. Consultation

The instructor's consultation hour ("office hour") is 4:00–5:00 Monday, except when otherwise notified. If you wish to consult but cannot make this time, please send an e-mail. The TA's office hour is will be announced as soon as it is known.

4. Books

SC1: Two excellent books at roughly the level of the course are

P.G. de Gennes, *Superconductivity of Metals and Alloys*, Benjamin, NY 1966 (reprinted, Perseus Books, Reading, MA 1999).

M.W. Tinkham, *Introduction to Superconductivity*, 2nd ed., McGraw-Hill, New York 1996.

A discussion of BCS theory close to that of the lectures is given in ch. 5 of

A.J. Leggett, *Quantum Liquids: Bose Condensation and Cooper Pairing in Condensed Matter Systems*, Oxford University Press, Oxford 2006.

There are a number of books which treat much the same subject matter by more advanced formal techniques (Green's functions, etc.): e.g., J. R. Schrieffer, *Theory of Superconductivity*, revised printing, Perseus Books, Reading, MA 1999. A very useful collection of essays on specific topics in BCS superconductivity can be found in R. D. Parks, ed., *Superconductivity*, Marcel Dekker, New York 1969.

SC2: It is much more difficult to recommend books for this part of the course. For the (mostly relatively noncontroversial) non-cuprate exotics I list the following, for reference rather than cover-to-cover reading:

W. Andreoni, ed., *The Physics of Fullerene-Based and Fullerene-Related Materials*, Kluwer Academic, 2000.

T. Ishiguro et al., *Organic Superconductors*, Springer, Berlin 1994.

Y. Kuramoto and Y. Kitaoka, *Dynamics of Heavy Electrons*, Clarendon Press, Oxford 2000.

In the case of the cuprates a number of good reviews of experimental work up to 1996 may be found in

D. M. Ginsberg, ed., Physical Principles of High-Temperature Superconductors, vols. I–V, World Scientific, 1989–1996.

and I will give references to other review papers at the appropriate point in the course. Tinkham (1996) has a good chapter on the macroscopic electromagnetic properties of the cuprates. On the theory side, most books, such as P. W. Anderson, *The Theory of Superconductivity in the High-*T_c *Cuprates* (Princeton University Press, Princeton 1997) tend to be heavily invested in a particular theoretical scenario and to refer mostly to that part of the experimental data which fits that scenario. A review of current theoretical ideas similar to that of lecture 12 can be found in Leggett (2006), ch. 7, section 9.

5. Assessment

Assuming that departmental permission is granted, I intend to assess this course entirely on the basis of take-home problems. Normally, the problems will be distributed at a Wednesday lecture, starting Sept. 2, and solutions will be due by 9:00am on the Monday of the next-but-one week (i.e. 12 days later). Please note that in the grading of the problems no credit will be given for strings of algebra unaccompanied by adequate explanation of what you are doing, even if the final answer is correct.