

Ph223bc "Advanced Condensed Matter Physics" (2007 -- 2008)

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SCHEDULE: Monday & Wednesday 10:30 – 12:00

LOCATION: Downs 103

INFORMATION: http://www.its.caltech.edu/~yehgroup/ph223bc_2007

Ph223bc

I. Introduction and Overview of Modern Condensed Matter Physics*

- Overview of Modern Condensed Matter Physics.
- Review of the second quantization techniques.
- Review of pictures of quantum dynamics and time-dependent perturbation theory.
- Low-energy excitations in condensed matter.

II. Quantum Field Theory for Many-Body Systems

- Review of the canonical & path-integral formalisms and Feynman diagrams.
- From relativistic to non-relativistic quantum field theory.
- Non-relativistic Green's function techniques.
- Interacting electrons: Hartree-Fock and random phase approximations.
- Linear response and correlation functions.
- Phonons.
- Electron-phonon interactions.

III. Fermi-Liquid Theory & Luttinger-Liquid Theory

- Overview of the Fermi liquid theory – phenomenology.
- Vertex contributions to the Fermi liquid theory – the quantum-field approach.
- Basic physical relations of the Fermi liquid theory and bosonic excitations.
- Kondo effect.
- Limitations of the Fermi liquid theory & Luttinger liquid theory.

* Part I will only be handed out as notes but not covered in lectures because most of the material has been covered in Ph223a this year. The purpose of this set of notes is for consistency in notation for later parts of the class notes.

IV. Interacting Bosons and Superfluidity

- Basic formalism for interacting bosons at $T = 0$.
- Perturbation theory and Feynman rules.
- Weakly interacting bosons.
- Field theory of interacting bosons at $T \neq 0$.
- Bosonic superfluid in liquid helium.

V. Conventional Superconductivity

- Phenomenology of superconductivity.
- The Cooper instability and electron pairing.
- Microscopic theory of superconductivity by Bardeen, Cooper and Schrieffer (BCS).
- Thermodynamic properties of superconductors.
- Theory of quasiparticle and Cooper pair tunneling.
- Heavy fermion superconductivity.

VI. Gauge Theory

- Gauge invariance.
- Magnetic monopole & Aharonov-Bohm effect.
- Symmetry, spontaneous symmetry breaking, and the Nambu-Goldstone bosons.
- Non-abelian gauge theory.
- Anderson-Higgs mechanism.

VII. High-Temperature Superconductivity

- An overview.
- Unconventional pairing symmetries in novel superconductors.
- Phenomenology: competing orders, quantum criticality and fluctuations, unconventional low-energy excitations, and pseudogap phenomena.
- Some attempts in developing the microscopic theory: t - J and Hubbard models; RVB and spin-liquid states; the $U(1)$, $SU(2)$ and Z_2 slave-boson gauge theories.
- Outlook.

VIII. Topological Field Theory & Fractional Quantum Hall (FQH) Effect

- Topological objects: solitons, vortices, and hedgehogs – field theory beyond Feynman diagrams.
- Fractional statistics and theory of braid & permutation groups.
- Phenomenology of integer and fractional quantum Hall fluids.
- Effective theory of the FQH liquids and topological orders.
- Edge excitations of the FQH liquids.[†]
- Basic properties of anyon models & possible applications to quantum computation.
- Candidate non-abelian anyons in FQH states & possible experimental verifications.[‡]

[†] Elective topic, depending on the availability of time.

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Reference Books:

1. “*Quantum Theory of Many-Particle Systems*”, A. L. Fetter and J. D. Walecka, Dover Publications, Inc. (2003). [ISBN: 0-486-42827-3]
2. “*Methods of Quantum Field Theory in Statistical Physics*”, A. A. Abrikosov, L. P. Gorkov, and I. E. Dzyaloshinski, Dover Publications, Inc. (1975). [ISBN: 0-486-63228-8]
3. “*Quantum Field Theory in a Nutshell*”, A. Zee, Princeton University Press (2003). [ISBN: 0-691-01019-6]
4. “*Quantum Field Theory*”, L. H. Ryder, Cambridge University Press (2003). [ISBN: 0-521-47814-6]
5. “*An Introduction to Quantum Field Theory*”, M. E. Peskin and D. V. Schroeder, Westview Press (1995). [ISBN: 0-201-50397-2]
6. “*Quantum Field Theory of Many-Body Systems*”, X.-G. Wen, Oxford University Press (2004). [ISBN: 0-19-853094-3]
7. “*Fractional Statistics and Quantum Theory*”, A. Khare, 2nd Edition, World Scientific (2005). [ISBN: 981-256-160-9]
8. “*Theory of Superconductivity*”, J. R. Schrieffer, Westview Press (1999). [ISBN: 0-7382-0120-0]
9. “*Introduction to Superconductivity*”, M. Tinkham, Dover Publications, Inc. [ISBN: 0-486-43503-2]
10. “*Superconductivity of Metals and Alloys*”, P. de Gennes, Perseus Books (1999).