

## Ph223bc "Advanced Condensed Matter Physics" (2011 -- 2012)

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SCHEDULE: Tuesday & Thursday 9:00 – 10:30

LOCATION: Downs 107

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INFORMATION: <http://www.its.caltech.edu/~yehgroup/ph223bc> 2011

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### I. Introduction: Review of Second Quantization Techniques & Quantum Dynamics

- 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. Non-Relativistic Quantum Field Theory for Many-Body Systems

- Basic properties of Green functions.
- Temperature-dependent quantum field theory in the path integral formalism.
- The physical meaning of Green functions.
- Non-interacting Green functions at  $T = 0$  and  $T > 0$ .
- Interacting Green functions and Lehmann representation at  $T = 0$  and  $T > 0$ .
- Relating Green functions to physical observables.
- Wick's theorem.
- Application of Green functions to diagrammatic analysis and perturbation theory.

### III. Applications of Green Function Techniques to Interacting Electrons & Phonons

- Hartree-Fock approximation.
- Random phase approximation.
- Linear response theory & the Kubo formalism.
- Phonons.
- Electron-phonon interactions.

### IV. Fermi 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.
- Fermi-liquid theory with non-perturbative strong interactions: the Kondo effect.

#### **V. Breakdown of the Fermi Liquid Theory & the Luttinger Liquids**

- Limitations of Fermi liquid theory.
- The Tomonaga-Luttinger liquid theory.

#### **VI. 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.

#### **VII. 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.

#### **VIII. 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 superconductors.\*

#### **IX. High-Temperature Superconductivity in the Cuprates & Iron-Based Compounds**

- General properties of high-temperature superconducting cuprates.
- Microscopic models to high-temperature superconductivity from Hubbard and  $t$ - $J$  models.
- Recent development in phenomenology.
- A new class of high-temperature superconductors: the iron-based compounds.\*
- Outlook.\*

#### **X. Topological Field Theory**

- Topological objects: solitons, vortices, and hedgehogs – field theory beyond Feynman diagrams.
- Integer and fractional quantum Hall effects in two-dimensional electron gas.
- Braid groups, permutation groups, and fractional statistics.
- Effective theory of the fractional quantum Hall liquids and topological orders.
- Edge excitations of the fractional quantum Hall liquids.
- Quantum spin Hall effect and topological insulators.\*

\* Elective topics, depending on availability of time.

### **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 of Many-Body Systems*", X.-G. Wen, Oxford University Press (2004). [ISBN: 0-19-853094-3]
5. "*Quantum Theory of Solids*", C. Kittel, John Wiley & Sons, Inc. (1987). [ISBN: 0-471-62412-8 (pbk.)]
6. "*Fractional Statistics and Quantum Theory*", A. Khare, 2<sup>nd</sup> Edition, World Scientific (2005). [ISBN: 981-256-160-9]
7. "*Theory of Superconductivity*", J. R. Schrieffer, Westview Press (1999). [ISBN: 0-7382-0120-0]

