

Ph223ab "Advanced Condensed Matter Physics" (2009 -- 2010)

INSTRUCTOR: Professor Nai-Chang Yeh
(Office: 128 Sloan Annex Phone: x-4313 E-mail: ncyeh@caltech.edu)

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

LOCATION: Downs 103

GTA: Huan Yang
(Office: 351 Cahill E-mail: huan.yang07@gmail.com)

INFORMATION: http://www.its.caltech.edu/~yehgroup/ph223ab_2009

I. Introduction & 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. 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 & 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. Introduction to Bose-Einstein Condensation in Cold Gases and Magnetic Insulators

- Introduction.
- Basic criteria of BEC in non-interacting Bose gas.
- Properties of the alkali atoms.
- Methods for trapping and cooling atoms.
- The ground state of trapped bosons.
- BEC in magnetic insulators.

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. 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.

X. High-Temperature Superconductivity in the Cuprates & Iron Pnictides

- 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 pnictides.*
- Outlook.

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

- 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 FQH liquids and topological orders.
- Edge excitations of the FQH liquids.
- Basic properties of anyon models.*
- Candidate non-abelian anyons in FQH states & possible experimental verifications.*

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. “*Fractional Statistics and Quantum Theory*”, A. Khare, 2nd Edition, World Scientific (2005). [ISBN: 981-256-160-9]
6. “*Theory of Superconductivity*”, J. R. Schrieffer, Westview Press (1999). [ISBN: 0-7382-0120-0]

* Elective topic, depending on the availability of time.