2007 Summer Course Outline: "Special Topics for Quantum Field Theory in Condensed Matter" at the National Taiwan University

INSTRUCTOR: Professor Nai-Chang Yeh, California Institute of Technology

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.
-- Phonons & electron-phonon interactions.

III. Conventional Superconductivity

-- Phenomenology of superconductivity: Landau-Ginzburg theory and London theory.
-- The Cooper instability and electron pairing.
-- Microscopic theory of superconductivity by Bardeen, Cooper and Schrieffer (BCS) and Gor'kov.
-- Theory of quasiparticle tunneling.

IV. 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*.

V. 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.
-- Attempts in 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.

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

-- Topological objects: solitons, vortices, and hedgehogs – field theory beyond Feynman diagrams.
-- Phenomenology of integer and fractional quantum Hall fluids.
-- Effective theory of the FQH liquids and topological orders.
-- Fractional statistics, anyons, and theory of braid & permutation groups.
-- Non-abelian FQH states and possible applications to quantum computation.

(*Topics to be covered contingent upon available time.)

Reference Books:

1. "*Quantum Theory of Many-Particle Systems*", A. L. Fetter and J. D. Walecka, Dover Publications, Inc. (2003).

2. "*Methods of Quantum Field Theory in Statistical Physics*", A. A. Abrikosov, L. P. Gorkov, and I. E. Dzyaloshinski, Dover Publications, Inc. (1975).

3. "*Quantum Field Theory in a Nutshell*", A. Zee, Princeton University Press (2003).

4. "*An Introduction to Quantum Field Theory*", M. E. Peskin and D. V. Schroeder, HarperCollins Publishers, (1995).

5. "*Quantum Field Theory of Many-Body Systems*", X.-G. Wen, Oxford University Press, (2004).

6. "*Fractional Statistics and Quantum Theory*", A. Khare, 2nd Edition, World Scientific.

7. "*Theory of Superconductivity*", J. R. Schrieffer, Cambridge University Press (1995).

8. "*Introduction to Superconductivity*", M. Tinkham, Dover Publications, Inc.

9. "*Superconductivity of Metals and Alloys*", P. de Gennes, Perseus Books (1999).