Physics 642

# Quantum Field Theory for Condensed Matter Physics

Tuesday and Thursday, 9:50 to 11:05AM (Room P608).

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**Course Description: Many systems in nature are far too complex to analyze directly. Solving for the atomic scale behavior is simply not feasible. Despite this fact, such systems often exhibit emergent simple and striking behaviors that become more transparent after taking the continuum limit. The resulting field theory can be solved by using the same methods that were originally developed for describing fundamental fields, such as the electromagnetic field. The formalism of quantum field theory then serves the double purpose of providing a quantum mechanical description of fundamental physical fields, as well as explaining emergent behaviors of complex systems by retaining a minimum number of relevant degrees of freedom. The concepts and methods of quantum field theory have penetrated many fields of science, including high-energy physics, statistical mechanics and condensed matter physics. This course will cover the basic concepts and methods of quantum field theory with applications to condensed matter physics. Note that field theory is a very mathematical subject and sometimes requires mathematical sophistication and rigor that goes beyond the level of a typical Physics course. For this reason, it is very important to be familiarized with some basic mathematical concepts, such as functional analysis. While we will devote three lectures to second quantization, this course assumes that the students are already familiarized with this notion. The same is true for the path integral formulation of quantum mechanics for a single particle.**

1. *From particles to fields.* Classical harmonic chain. Lagrangian formulation and equations of motion. Hamiltonian formulation. Functional analysis and variational principle. Quantum fields. Symmetry transformations and Noether's theorem.

2. *Second quantization.* Foundations of second quantization. Representation of operators. Tight-binding and the Mott transition. Quantum magnetism: the ferromagnetic and the anitferromagnetic chains. Bogoliubov theory of weakly interacting Bose gas.

3. *Functional path integral.* Construction of the path integral. Path integral and statistical mechanics. Saddle point and stationary phase analysis. Coherent states. Many-body coherent

state path integral. Partition function of non-interacting gas.

4. *Perturbation theory.* Asymptotic expansions. $\phi^4$-theory. $n$-point correlation functions. Perturbation theory at low orders. Application to interacting fermionic gas. Infinite-order expansions. Self-energy operator and Dyson equation. Large-$N$ expansion. Bethe-Salpeter equations.
5. *Broken symmetry and collective phenomena.* Mean field theory. Plasma theory of non-interacting gas. Bose-Einstein condensation and superfluidity. Spontaneous symmetry breaking and Goldstone modes. Superconductivity. Ginzburg-Landau theory. Meissner effect and the Anderson-Higgs mechanism.

**Credit Hours:** 3

**Main text:** Alexander Altland and Ben Simons, Condensed Matter Field Theory, second edition (Cambridge, 2010).