Syllabus

Physics 625 (Spring, 2018) — Non-relativistic Quantum Mechanics

Lectures: Monday, Wednesday; 12:30 p.m. – 1:45 p.m., room PHYS 1219
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Office hours: Tuesday; 3:00 p.m. – 4:00 p.m.,

Summary

The purpose of this course is to provide a graduate-level introduction to quantum many-body physics and condensed matter physics. This will include an introduction to second quantization, Green’s function formalism, Feynman diagrammatic technique, Kubo linear response theory, Fermi liquid theory, Bardeen-Cooper-Schrieffer theory of superconductivity, topological quantum matter, theory of phonons in solids, theory of disordered quantum systems (in particular, localization), and (time permitting) path integral formalism.

Reading


Homework: There will be, on average, one homework assignment every two weeks.

Exam: There will be (possibly) a mid-term exam and a take-home final exam.

Grading

Homework: 50%
Exam(s): 50%
Outline

1. Second quantization; Bogoliubov transformation
   (a) Classical chain of oscillators; Acoustic and optical phonons
   (b) Quantum chain of oscillators
   (c) Quantum fermionic chain
   (d) One-dimensional quantum spin systems; Non-local Jordan-Wigner transformation. New emergent degrees of freedom in many-particle systems
   (e) Bogoliubov mean-field theory of a Bose-Einstein condensate

2. Topological quantum matter
   (a) Introduction to topological classification of band structures; bulk-boundary correspondence
   (b) Berry phase in quantum mechanics
   (c) Topology in 1D: Su-Schrieffer-Heeger model, Kitaev-Majorana chain, Haldane spin chain
   (d) Jackiw-Rebbi modes on domain walls/solitons
   (e) Topology in 2D: Chern insulators and integer quantum Hall effect
   (f) Topology in 2D: Haldane model and Kan-Mele model of a time-reversal invariant topological insulators
   (g) Topology in 3D: weak and strong topological insulators, Fu-Kane method
   (h) Topology in time: Thouless pump and Floquet topological insulators
   (i) Introduction to intrinsic topological order: toric code model and string nets.

3. Elements of single particle-quantum mechanics (warm-up/reminder before Feynman diagrams)
   (a) Green’s function of the Schrödinger equation
   (b) Simplest example of the diagrammatic technique: a pictorial representation of the scattering amplitude in single-particle quantum mechanics
   (c) Schrödinger, Heisenberg, and interaction representations; S-matrix

4. Methods of quantum field theory in condensed matter physics;
   (a) Green functions in many-particle systems; Perturbation theory and Feynman’s diagrammatic technique for interacting particles
   (b) Physical meaning of Green functions; Spectrum of quasiparticles
   (c) Two-particle Green’s function; Self-energy function

5. Application of the Green’s function formalism to electronic systems
   (a) Friedel oscillations and the Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction between magnetic impurities in metals
6. Generalized susceptibility; Kubo’s formula for linear response quantities

7. Fermi liquid theory and elements of superconductivity
   (a) Landau Fermi liquid theory; Phenomenology and microscopic justification
   (b) Collective modes: Zero sound and plasmons in an electron gas
   (c) Instabilities in a Fermi liquid
   (d) Superconducting instability and Cooper pairs
   (e) BCS wave-function

8. Electrons in a random potential
   (a) Averaging Green’s functions over disorder
   (b) Boltzmann transport equation; Conductivity of a normal metal
   (c) Quantum diffusion; Weak localization
   (d) Dephasing mechanisms in electronic systems