Syllabus Course 682
Advanced topics in solid-state II:
Ultracold atoms
Spring 2023

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Course Description

We will go through the modern field of ultracold atoms. Starting from atomic properties we will discuss laser trapping and cooling, synthetic gauge fields, interatomic interactions and scattering lengths and its tunability via the Feshbach resonance, Bose-Einstein condenstates and superfluids in harmonic traps, rotating condensates and vortices, spinor bosons (including topological properties and artificial spin-orbit coupling), degenerate Fermi gases, optical lattices, and a collection of advanced topics. The course will use quantum mechanics with some second quantization when convenient.

Class meetings: Monday/Wednesday 2:00-3:20pm in Serin 287.

Course Requirements

- Homework 100%

Books

When appropriate we will supplement this with other texts that have some sections that I feel are more in depth.

- Main text: "Bose-Einstein Condensation in Dilute Gases" by Pethick and Smith (P&S).

- "Atomic Physics" by Foot
- "Fundamentals and New Frontiers of Bose-Einstein Condensation" by Ueda
- "Ultracold atomic physics" by Zhai

Course Content

1. Bose-Einstein condensation in a harmonic trap (week 1)
    - Chapter 2 P&S
2. Atomic Properties (Week 1 and 3)
    - Chapter 3 of P&S.
    - Atomic structure and "types" of ultracold atoms
    - Effects of magnetic and electric (static and oscillating) fields
3. Trapping and Cooling of Atoms (week 4 and 5)
    - Chapter 4 of P&S.
    - Magnetic traps
    - Interaction between atoms and laser light
    - Laser cooling, the magneto-optical trap, and additional cooling mechanisms
    - Synthetic gauge fields
4. Interactions between atoms (week 6 and 7)
    - Chapter 5 of P&S.
    - van der Waals interactions between atoms
    - Scattering theory and length
    - Feshbach resonance
5. Theory of the bosonic superfluid (week 8-10)
    - Chapters 6,7, and 8 of P&S.
    - Gross Pitaevskii equation and Thomas Fermi approximation
    - Condensates with dipolar interactions
    - excitations and collective modes
    - Solitons
    - Hartree-Fock and Popov approximations
6. Rotating condensates (week 11)

- vortices
- rotating traps
- vortex ararys

7. Spinor condensates (week 11 and 12)
    - Chapter 12 P&S
    - superfluidity and magnetism mean field theory
    - topological properties
    - synthetic spin-orbit coupling
8. Optical lattices (week 13 and 14)
    - Chapter 14 of P&S.
    - Formation of bands and non-linear effects
    - Hubbard models
9. Degenerate Fermi gases (week 14 and 15)
    - Chapter 16 P&S
    - Effects of a trap
    - Unitary limit
    - Superfluid ground state
    - BCS to BEC crossover