Bose-Einstein condensation, Superfluidity and Superconductivity

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Description

The course gives an unifying introduction to **macroscopic quantum phenomena**, i.e. phenomena where a very lage number of particles occupy the same "single-particle" quantum state.

In particular:

i) Bose-Einstein condensation in ultracold atomic gases.

ii) Laser light.

iii) Superfluidity in liquid helium 4 and ultracold gases.

iv) Superconductivity in metals and high-Tc materials.

In our lectures the unifying theoretical framework are the **coherent states** of **quantum field theory** at zero and finite temperature.

Symbolically, for bosons

$$\hat{\phi}(\mathbf{r},t) \to \phi(\mathbf{r},t) \ ,$$

while for fermions

$$\hat{\psi}_{\uparrow}(\mathbf{r},t)\hat{\psi}_{\downarrow}(\mathbf{r},t) \to \Delta(\mathbf{r},t) \ .$$

Syllabus

First part (12 hours)

1.1 Ideal bosons and Bose-Einstein condensation. Quantum fields. Coherent states and laser light properties.
1.2 Interacting bosons with broken symmetry. Macroscopic order parameter.
1.3 Gross-Pitaevskii equation of the bosonic condensate and quantum fluctuations. Experiments with alkali-metal atoms at ultralow temperatures.
1.4 Bogoliubov spectrum and sound velocity. Collisional vs collisionless dynamics. Experiments with bosonic ultracold atoms and Helium 4.
1.5 Solitons and quantized vortices. Theory vs experiments.
1.6 Topological phase transitions and the Berezinskii-Kosterlitz-Thouless phase transition in 2D systems.
1.7 Ultracold atoms in optical lattices: quantum phase transitions and device for quantum computers.

Syllabus

Second part (12 hours)

2.1 Ideal fermions and Fermi degeneracy.
2.2 Interacting fermions: Hartree-Fock, pairing, and coherent states.
2.3 Ginzburg-Landau functional for superconductors. Phenomenology of superconductivity.
2.4 BCS microscopic theory of superconductivity based on coherent states.
2.5 Macroscopic quantum tunneling and Josephson effect. Superconducting qubits for quantum computers.
2.6 BCS-BEC crossover in fermionic gases and superconductors.
2.7 Quantum fuctuations and pseudo-gap regime for fermionic ultracold atoms and high-Tc superconductors.

Further informations

Lecture period: between **November 2019** and **February 2020**.

Exam mode: seminar of the student about a specific topic of the course.

Some references

J. Annett, Superconductivity, Superfluids, and Condensates (Oxford Univ. Press, 2004).
L. Salasnich, Quantum Physics of Light and Matter (Springer, 2017).

Lecture notes

http://materia.dfa.unipd.it/salasnich/phd/