Warsaw University of Technology | Doctoral School No. 1

Course offered in the Doctoral School No. 1 – Spring semester of the 2021/2022 academic year

TITLE
Superconductivity and superfluidity
CONDUCTING UNIT
Doctoral School No. 1
SCIENTIFIC DISCIPLINE
Physical science
IMPLEMENTING UNIT
105000 - Faculty of Physics
SUMMARY DESCRIPTION
Superfluidity and superconductivity are generic quantum phenomena occurring in many physical systems including: quantum liquids He4 and He3, metals and compound materials, ultracold atomic gases, nuclear matter forming atomic nuclei and neutron stars. It is also predicted to appear in quark matter. The goal of this course is to explain a great variety of effects originating from superfluidity and superconductivity using quantum mechanics.
FULL DESCRIPTION
Lecture: 1. Discovery of superfluidity in He4. Phases: He4-I and He4-II and their properties. (2h) 2. First attempts to explain superfluidity: two fluid hydrodynamics of Tisza and Landau. First and second sounds. (2h) 3. Microscopic theory: Bose-Einstein condensation of weakly interacting gas. Critical temperature. Landau critical velocity. (3h) 4. Superfluid dynamics: Gross-Pitaevskii equation. Quantum vortices and solitons. (3h) 5. Experiments: Cooling of alkali atoms in traps. Bose-Einstein Condensation in ultracold atomic gas. (2h) 6. Discovery of superconductivity. Critical magnetic field. Meissner-Ochsenfeld effect. Type-I and type-II superconductors. (2h) 7. Phenomenological description: London equations, Ginzburg-Landau model. Magnetic flux quantization. (3h) Microscopic approach: Bardeen-Cooper-Schrieffer theory. Condensation energy. Energy gap. Quasiparticles and their dispersion relation. Critical temperature. (4h) 9. Nonuniform superconductors: Bogoliubov-de Gennes equation. Dirty superconductors. (3h)

10. Origin of superconductivity in metals. Superconductor-normal metal interface. Josephson junction. Superconductor-ferromagnet interface. (3h)
11. Manifestations of superconductivity in atomic nuclei and neutron stars. (2h)
12. Ultracold atoms: BCS regime and BEC regime. Unitary point. High-Tc superconductors. Exotic phases of superfluidity. (1h)

Tutorials:
1. Second quantization (2h)
2. Hydrodynamics: Potential flow, Circulation conservation, Euler equations (2h)
3. Vortex in superfluid. Healing length (2h)
4. Specific heat of superfluid Fermi gas (2h)
5. Uniform flow in BCS theory(2h)
6. Andreev approximation (2h). Application to Josephson junction
7. Vortex in superconductor. (2h)
8. Collapse of superconductivity under strong magnetic field (solid state), population-imbalance of particles (ultracold atomic gas), rotation (atomic nuclei). (1h)

LITERATURE

1. M. Tinkham, Introduction to superconductivity.

2. C.J. Pethick, H. Smith, Bose-Einstein Condensation in Dilute Gases.
3. N.B. Kopnin, Theory of Superconductivity.

4. N.B. Kopnin, Introduction to the Theory of Superconductivity and Superfluidity.

5. A. Leggett, Quantum Liquids: Bose Condensation and Cooper Pairing in Condensed-Matter Systems.

6. J.B. Ketterson, S.N. Song, Superconductivity.

LEARNING OUTCOMES

FT2_W01
FO2_W01
FT2_W03
FO2_W03
FT2_W04
FO2_W04
FT2_W10

ASSESSMENT METHODS AND CITERIA; COURSE COMPLETION FORM

The final grade is obtained after the oral exam. It reflects the degree of understanding of the material (presented during lecture and tutorials) achieved by a student.
The student's activity during tutorials is also taken into account.

LANGUAGE OF THE COURSE	ECTS CREDITS
English	3

TYPE OF CLASSES	NUMBER OF HOURS	COURSE INSTRUCTOR
Lectures	30	Piotr Magierski, prof. dr hab.
Tutorials	15	Piotr Magierski, prof. dr hab.