Superconductivity, Superfluidity and Magnetism (M1)

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24 hours of lectures (in English) + 24 hours of TD

Web-page: https://sites.google.com/site/roscilde/home/teaching/superconductivity-superfluidity-magnetism-m1

Course description

This course is aimed at exploring some of the most striking manifestations of quantum mechanics at the macroscopic scale, through the phenomena of Bose-Einstein condensation, superfluidity and superconductivity, all related by the overarching concept of macroscopic phase coherence/rigidity. Magnetism nicely fits within this picture as a fundamental phenomenon in quantum condensed matter, and offering the simplest paradigm of *spontaneous symmetry breaking*, on which the description of condensation and superconductivity is based.

Tentative course scheme:
Second quantization: bosons and fermions, Fock space, creation/annihilation operators, one-body and two-body operators.
Magnetism and the paradigm of *symmetry breaking*: physical origin of magnetic moments in solids, paramagnetism of insulators and Pauli paramagnetism of metals. Heisenberg model of ferro/anti-ferromagnetism. Mean-field theory of the magnetic transition. Spin-wave theory and low-temperature thermodynamics.
Bose-Einstein condensation: Bose-Einstein statistics, Bose condensation of an ideal Bose gas. Generalized Bose-Einstein condensation and off-diagonal long-range order. Bogolyubov theory of the weakly interacting Bose gas. Gross-Pitaevskii equation, vortex excitations, Josephson effect in condensates.
Superfluidity: Superfluid He-4: phenomenology, Landau theory, elementary excitations.
Superconductivity: Fermi liquids, electron-electron and electron-phonon interactions, attractive interactions and Cooper instability. Bardeen-Cooper-Schrieffer theory of superconductivity. Non-uniform superconductors and Ginzburg-Landau theory. Electrodynamics of superconductors, London equations and Meissner effect. Josephson effect in superconducting junctions.

TD sessions

Your active participation to the TD sessions can gain you some **TD-points,** which will count towards the final grade.

The TD teachers will declare for the every TD sessions the questions that will be discussed in the following meeting. To gain TD-points, you have to send an e-mail to your teacher (see addresses above), including a scan/picture of your written solutions to some (or all) of the proposed questions. Your written solutions must be sent by 10 pm (22h) on the Sunday before the TD (Monday 3:45 pm, 15h45). By sending an e-mail, you automatically engage yourself to discuss at the blackboard the questions for which you sent the solution. During the TD session the teacher will then extract at random one of the volunteers for each question.

In the TD sessions your group will discuss in total N (with N~100) questions out of the ~ 10 TD sheets that you will find on the course webpage. **Volunteering for one question (by sending your written solution) will grant you 5/N TD-points, independently of whether you have the correct answer or not.** In total you can gain up to 5 points on the final grade by preparing in advance for the TD and volunteering via e-mail.

Your written solutions will not be graded — the fact of sending them is simply a warranty for the teachers that you have indeed worked on them.

Requirements

Mandatory: Mécanique Quantique (L3), Introduction à la Physique Statistique (L3). Recommended (not mandatory): Condensed Matter (M1)

Exam mode

A written **midterm exam** (2h, all documents allowed) will be organized on Monday, Feb. 28th. Participation to it is on a **voluntary basis**. It will be graded on a 20-point scale, and its note will be averaged with the note on the final exam only if the average is higher than the note of the final exam itself.

The **final exam** will consist of a **written report on a research article** that will be assigned towards the end of the class. Each student will be assigned at *random* to a *team* of two/three people, who will be asked to write a report of 10 pages maximum (title page and bibliography included) on an article that will be assigned, also at random, by the teaching staff.

The report should explain the article to an audience of students who have attended the class; and it should identify all the possible points of contact between the content of the article and the material presented in class and in the TDs — in other words, **it should explain the article in light of what has been taught in the lectures and TD sessions.** The mark to the report will be given based on the quality of the presentation and, most importantly, on the links established between the article and the content of the class/TD.

The report will have to be sent via e-mail in .pdf format before a deadline to be communicated later (typically midnight of the last day - Sunday - of the exam week).

Depending on the availability of the students, we may envision to have **short oral presentations** of the research articles as well. The presentations will be given on a voluntary basis, and they will be held in front of the rest of the students attending the class. The oral presentation will be given a mark to be averaged with that of the written report *only if* the average mark is higher compared to that of the report.

Bibliography

The literature on superconductivity, superfluidity and magnetism is really vast! You can find below a few representative examples of potentially useful books:

1) **Condensation, superconductivity and superfluidity in a unified view**

A. J. Leggett, *Quantum Liquids,* Oxford (2006);
J. F. Annett, *Superconductivity, Superfluids and Condensates*, Oxford (2004).

2) **Condensation and superfluidity**

C. J. Pethick and H. Smith, *Bose-Einstein Condensation in Dilute Gases*, Cambridge (2008).
L. Pitaevskii and S. Stringari, *Bose-Einstein Condensation and Superfluidity,* Oxford (2016).
R. P. Feynman, *Statistical Mechanics: A Set Of Lectures*, Westview Press (1998).
B. V. Svistunov, E. S. Babaev, N. V. Prokof'ev, *Superfluid States of Matter,* CRC Press (2015).
P. Nozières and D. Pines, *The Theory of Quantum Liquids, Volume II: Superfluid Bose Liquids*, Westview Press (1994).

3) **Superconductivity**

M. Tinkham, *Introduction to Superconductivity*, Dover (1996).
P. G. De Gennes, *Superconductivity Of Metals And Alloys*, Westview Press (1999).
H. Alloul, Introduction to the Physics of Electrons in Solids, Springer (2007).

4) **Magnetism**

S. Blundell, *Magnetism in Condensed Matter*, Oxford (2001).
D. C. Mattis, *Theory of Magnetism Made Simple*, World Scientific (2006).
L. P. Lévy, *Magnetism and Superconductivity*, Springer (2000).