

An Introduction to Quantum Liquids (Option M1)

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Course webpage

<https://sites.google.com/site/roscilde/home/teaching/quantumliquids>

(M. Fruchart has collected his lecture notes in an electronic file - you can ask him directly via e-mail: michel.fruchart@ens-lyon.fr).

Course description

The course will be organized in 12 sessions of theory + 12 sessions of TD of 1hr 30min each. The course will be held in *English* (TDs will be in French).

This course is aimed at providing a broad introduction to the topic of quantum liquids, covering both traditional systems (superfluid Helium, electron liquid, superconductors) and more recent ones (e.g. trapped atomic Bose and Fermi gases). The central focus of the course is on the phenomena of *quantum degeneracy*, *macroscopic quantum coherence* and *condensation*, and on their various manifestations in quantum liquids.

The following is a (tentative) course plan:

1. Second quantisation of systems of identical bosons/fermions.
2. Bose statistics and Bose-Einstein condensation in ideal Bose gases;
3. General approach to Bose condensation: off-diagonal long-range order, macroscopic wavefunction;
4. Bogolyubov theory of weakly interacting Bose gases;
5. Gross-Pitaevskii equation: dynamics, vortex excitations;
6. Superfluid ^4He : phenomenology, hydrodynamics, Landau theory;
7. Superfluid ^4He : microscopic theories, elementary excitations;
8. Fermi-Dirac statistics and ideal Fermi gas;
9. Interacting Fermi liquid and Thomas-Fermi theory of screening;
10. Attractive interactions: physical origins and Cooper instability;
11. Bardeen-Cooper-Schrieffer (BCS) theory of superconductivity (I);
12. BCS theory (II); further topics in superconductivity: Josephson effect.

Pre-requisites: Mécanique quantique L3/M1, Physique Statistique L3, Matière Condensée M1.

Exam: written.

Bibliography

The bibliography on the various subjects addressed by the course is extremely vast, and we will provide here a (certainly incomplete) list of useful textbooks.

- A unifying view on quantum coherence in degenerate quantum liquids is provided in
 - A. J. Leggett, *Quantum Liquids*, Oxford (2006);
 - J. F. Annett, *Superconductivity, Superfluids and Condensates*, Oxford (2004).

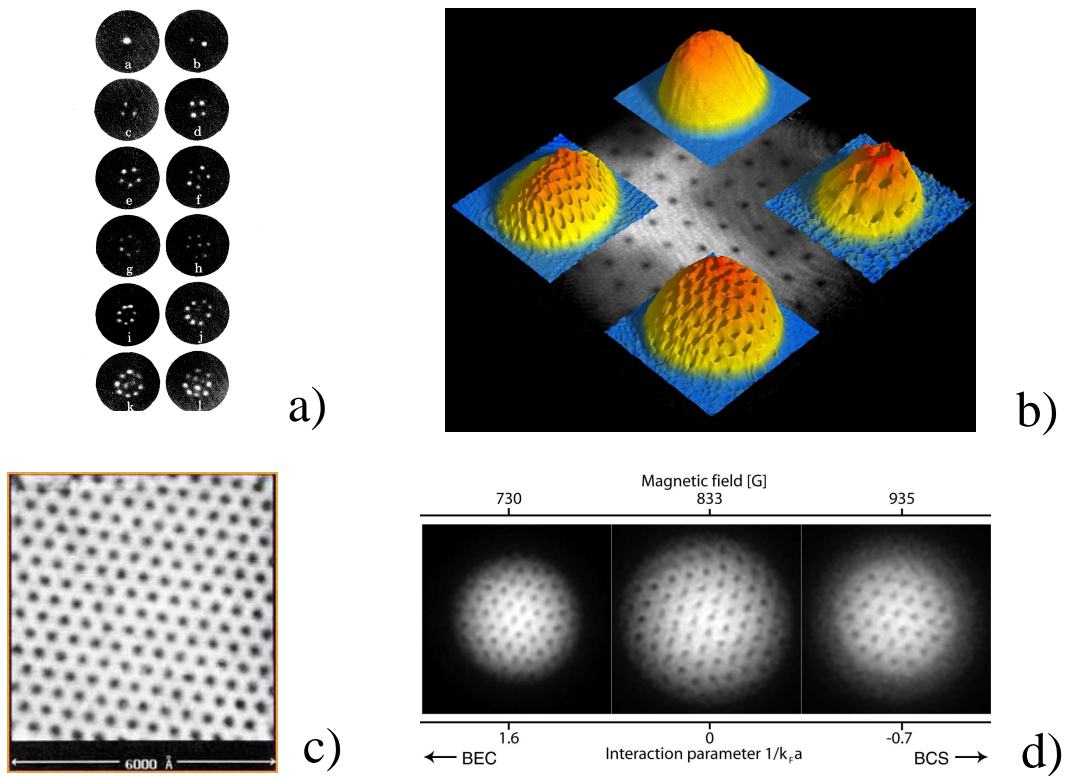


FIG. 1: Quantized vortices in quantum liquids. (a) Vortex arrays in rotating superfluid ^4He [E. J. Yarmchuk *et al.*, Phys. Rev. Lett. **43**, 214 (1979)]; (b) Vortex lattices in rotating Bose-condensed Rb (Ketterle's group @ MIT); (c) Vortex lattice in superconducting NbSe₂ in a 1T field, [H. F. Hess *et al.*, Phys. Rev. Lett. **62**, 214 (1989)]; (d) Vortex lattices in attractive ^6Li atoms across the BEC-to-BCS crossover (Ketterle's group @ MIT).

- On the general formalism of second quantisation and quantum many-body theory:

G. D. Mahan, *Many-Particle Physics*, Kluwer Academic (2000).

A. L. Fetter and J. D. Walecka, *Quantum Theory of Many-Particle Systems*, Dover (2003).

J. W. Negele and H. Orland, *Quantum Many-particle Systems*, Westview Press (1998).

A. A. Abrikosov, L. P. Gorkov, and I. E. Dzyaloshinski, *Methods of Quantum Field Theory in Statistical Physics*, Dover (1963).

R. P. Feynman, *Statistical Mechanics: A Set Of Lectures*, Westview Press (1998).

- On Bose-Condensation in weakly interacting gases and superfluid Helium:

C. J. Pethick and H. Smith, *Bose-Einstein Condensation in Dilute Gases*, Cambridge (2008).

L. Pitaevskii and S. Stringari, *Bose-Einstein Condensation*, Oxford (2003).

I. M. Khalatnikov, *An Introduction to the Theory of Superfluidity*, Westview Press (2000).

D. R. Tilley and J. Tilley, *Superfluidity and Superconductivity*, Taylor & Francis (2000).

P. Nozières and D. Pines, *The Theory of Quantum Liquids, Volume II: Superfluid Bose Liquids*, Westview Press (1994).

R. P. Feynman, *Statistical Mechanics: A Set Of Lectures*, Westview Press (1998).

- On interacting Fermi gases and superconductivity:

P. Nozières and D. Pines, *The Theory of Quantum Liquids, Volume I: Normal Fermi Liquids*, Westview Press (1999).

M. Tinkham, *Introduction to Superconductivity*, Dover (1996).

P. G. De Gennes, *Superconductivity Of Metals And Alloys*, Westview Press (1999).

J. R. Schrieffer, *Theory Of Superconductivity*, Perseus Books (1999).