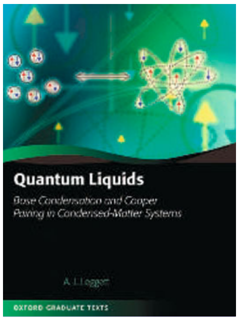
Quantum condensates



QUANTUM LIQUIDS: BOSE CONDENSATION AND COOPER PAIRING IN CONDENSED-MATTER SYSTEMS BY A. J. LEGGETT

Oxford Univ. Press: 2006. 408 pp. $64.50

A shoal of fish displays highly synchronized motion of a great number of fish, but it cannot compare with the perfect coherence of 10^{23} quantum particles at low temperatures. When a macroscopic system is cooled down the thermal motion of particles subsides, eventually revealing the quantum nature of matter. Without a doubt the most spectacular quantum phenomena in this respect are superconductivity and superfluidity. Here 'super' refers to the system's ability to sustain dissipationless flow of charged or neutral particles. Both superconductivity and superfluidity are the result of quantum condensation — that is, Bose–Einstein condensation (BEC) of bosons and pair formation of fermions, as described by the theory of Bardeen, Cooper and Schrieffer (BCS).

For a long time, conventional superconductors and the Bose liquid helium-4 were the only systems showing these exceptional properties. The discovery of superfluidity in helium-3 (a Fermi liquid) in 1971, of heavy-fermion superconductivity in 1979, of high-temperature superconductivity in the copper-oxide superconductors in 1986, of BEC in Bose alkali gases in 1995 and, most recently, of superfluidity in atomic Fermi gases has each time renewed and intensified the interest in these fascinating phenomena and their relationships. In particular, ultracold Fermi alkali gases now provide the opportunity to experimentally tune the crossover between BEC of tightly bound molecules of fermions and the BCS limit of overlapping Cooper pairs of fermions. This possibility, at last, enables researchers to test theories for the crossover — theories that were initiated by the author of this book in 1980. Indeed, A. J. Leggett is a pre-eminent expert in the field of quantum liquids and quantum condensation, having made pioneering contributions for more than 40 years. He was awarded the 2003 Nobel prize in physics for his ground-breaking explanations of the properties of superfluid helium-3.

In his book Leggett provides the first comprehensive, detailed overview of all the quantum condensates mentioned above. In the final chapter he discusses other topics of current research in this field, such as non-copper-oxide-based 'exotic' superconductors, liquid helium-3 in aerogel and supersolids. There are many features that make his book an extraordinarily valuable one. Outstanding merits include the author's attempt to provide physical ideas rather than equations and to derive standard results (such as the Ginzburg–Landau formulation of superconductivity theory) in a new way. He avoids advanced formal techniques altogether, choosing instead to present the more detailed theoretical derivations and discussions in the appendices. Leggett has at least one conviction that, as he writes himself, may not be shared by a large part of the relevant theoretical community. Namely, in his treatment of quantum condensation he neither finds it necessary nor desirable to make use of the concept of a spontaneously broken U(1) gauge symmetry. Instead he prefers to formulate the physics in terms of the one- or two-particle density matrix and he derives standard results within that framework.

On reading the book it becomes immediately clear that the author has thought deeply about every aspect of the subject. The formulations, side remarks and 321 footnotes give the book a very personal, almost conversational style. Remarkably, the BCS paper and some other 'famous' papers, although frequently mentioned in the book, do not appear in the reference list. Readers unfamiliar with the subject should therefore use other sources of the scientific literature in parallel.

All researchers in the field of quantum condensed systems, beginners and experts alike, will benefit from studying Leggett's highly original book. In view of the ongoing vigorous research in high-temperature superconductivity and, especially, cold alkali gases, it comes just at the right time.

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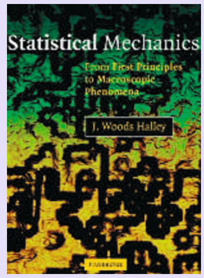

Statistical Mechanics: From First Principles to Macroscopic Phenomena by J. Woods Halley

Cambridge Univ. Press: 2007. 283 pp. $65.

Advances in quantum mechanical methods have improved the quantitative predictive power of statistical physics from first principles. The book emphasizes the link between complex systems and fundamental physical laws.

Fly me to the Moon: An Insider's guide to the New Science of Space Travel by Edward Belbruno

Princeton Univ. Press: 2007. 148 pp. $19.95.

Applying chaos to space travel sounds counter-intuitive, but it works; the subtle effect of fluctuations in the gravitational fields of planets helped rescue a stray satellite bound for the Moon.