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Editorial

Novel quantum phases and mesoscopic physics in quantum gases

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This volume of The European Physical Journal Special Topics is a collection of original papers presented either as posters or as oral contributions at the Sixth International Workshop "Theory of Quantum Gases and Quantum Coherence" and CNRS École Thématique "Physique Mésoscopique avec les gaz quantiques" held in Lyon (France) from the 5$^{\text{th}}$ to the 8$^{\text{th}}$ of June 2012. This event has involved mainly students and young researchers both as speakers and participants, each session being opened by an overview lecture given by senior researchers expert in the fields of quantum gases and condensed matter.

Since the observation of Bose-Einstein condensation (BEC) and of superfluidity in atomic Fermi gases, ultracold quantum gases have become a very versatile testing ground for quantum many-body theories. The amazing experimental possibilities which allow changing the dimensionality of the system, introduce disorder in a controlled way, and create a whole variety of strongly correlated states, have made the connection between the physics of ultracold quantum gases and condensed-matter physics stronger and stronger. This connection has been especially taken in consideration in the selection of contributions for the conference. In addition, attention has also been given to the recent activities devoted to the realization of BEC in condensed matter systems (e.g. polaritons and magnons), which create further links to the condensed matter community. The papers collected in this topical issue represent a cross section of the oral and poster contributions in the Workshop/École and contain original results on six relevant research directions in the field of condensed matter with ultracold gases.

A first important topic in condensed matter theory is the effect of dimensionality on correlated particles. In one dimension, a central concept is the Tomonaga-Luttinger liquid, in which the proper low energy excitations are not quasiparticles having the same quantum numbers as the non-interacting particles but renormalized masses and weak residual interactions, but collective charge and spin excitations propagating with different velocities (the so-called spin-charge separation phenomenon). Even at zero temperature, a Tomonaga-Luttinger liquid only exhibits quasi-long range order, with superfluid and density-wave correlations decaying as power laws with distance with non-universal exponents. Trapping in two-dimensional optical lattices, or on-chip trapping allows the realization of quasi-one dimensional atomic gases in which the Tomonaga-Luttinger liquid can be observed. Moreover, the application of a longitudinal periodic potential permits the observation of the Tomonaga-Luttinger liquid to Mott insulator transition. Atomic gases also offer the unique possibility to study the non-equilibrium dynamics of Tomonaga-Luttinger liquids. The physics of quasi-one dimensional atomic gases has thus been one of the main topics of the workshop, as shown by the contributions of Dalmonte et al., Jolicoeur, Nevado and Porras, Naddeo et al. and Langen et al.

A second important topic of condensed matter theory is Anderson localization. In the absence of interaction, it is well known that one and two dimensional systems have only localized states in the presence of disorder, while in three dimensions for weak disorder high energy extended states and low energy localized states are separated by a mobility edge, and for strong disorder all states are localized. In the absence of interaction, the resulting metal insulator transition is well understood thanks to analytical and numerical work. In condensed matter physics however, electron-electron and electron-phonon interaction make the picture more complicated. In experiments on ultracold gases, electron-phonon interactions are absent, and the particle-particle interaction can be tuned using Feshbach resonances. The observation of Anderson localization and of the Aubry-André transition in 2008 have led to a considerable activity in the field of disorder and cold atoms. Another route for studying the Anderson localization with cold atoms is by exploiting the relationship between a kicked rotor and the Prange model. The contributions of Alamir et al., Gaul and Müller, Jachymski and Idziaszek, Plisson et al., Piraud and Sanchez-Palencia, Seiringer et al., and Vermersch and Garreau cover that field.

A third important topic in condensed matter physics is the so-called "Dirac matter" in which the low-energy fermionic excitations are described by a two-dimensional analogue of the Dirac equation. In solid state physics, "Dirac matter" has been observed in graphene and in the "topological insulator" materials such as Bi_2Te_3, Bi_2Se_3. Atomic trapping allows the realization of lattices analogous to the one of graphene or topological insulators paving the way for the study of "Dirac matter" in ultracold gases. That topic is covered in the contributions of Tarruell et al. and Goldman et al.

A fourth important topic is the physics of strong interaction, in particular the BEC-BCS crossover, the unitary limit (where the scattering length diverges) and the polaron effect (where an impurity is moving in a bath of interacting particles). This theme is covered in the contributions of Enss, Bertaina and Casteels et al.

A fifth topic, which was the original motivation to study trapped atomic gases, is the hydrodynamics of interacting Bose gases. Questions such as the critical velocity, and the formation of vortices in a superfluid can be realistically considered within the Bogoliubov or the Gross-Pitaevskii formalism, in contrast with superfluid ^{4}He. Moreover, cold atoms allow the realization of spinorial Bose gases, in which a richer hydrodynamics can be expected. Also, BEC of magnons and polaritons offer new possibilites of probing the hydrodynamics of Bose gases. This topic is touched by the contributions of Chestnov et al., Rougerie and Szirmai.

A last topic is the interplay of coherent quantum transport and many body physics considered in mesoscopic physics. With cold atoms, such interplay can be observed in Bose-Josephson junctions, or in Bose-Hubbard lattices, allowing to characterize the entanglement and the decoherence of the eigenstates in these systems. Such a theme is covered in the contribution of Tarallo et al., Khripkov et al. and Mazzarella and Dell'Anna.

All the papers have been peer reviewed following the usual standards of The European Physical Journal Special Topics. We would like to thank the Chief Editors for giving us the possibility of publishing this topical issue, and all the staff and especially Agnès Henri. We would also like to thank the other organizer of the Conference, Frédérique Chévy, who has contributed to the success of the event.

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