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Ultracool dynamics far from equilibrium

Ultracold atomic quantum gases belong to the most exciting challenges of modern physics. At temperatures below one Microkelvin, gases of bosonic atoms, i.e., such with an integer angular momentum quantum number, can contain a "Bose-Einstein condensate" in which essentially all atoms are in the same state. Today, the theory of ultracold atomic gases is characterized by (semi-)classical field equations. Outstanding attraction possess the Gross-Pitaevskii and Hartree-Fock(-Bogoliubov) theories as well as their perturbative extensions, cf. e.g. [1,2]. These "mean-field" approximations are in general reliable for dilute gases, i.e., they presuppose that the gas atoms sufficiently rarely collide with each other. This is often equivalent to the condition that the gas is not too far from thermal equilibrium. The further the gas is driven or initially assumed to be away from equilibrium and the stronger the interactions between the atoms are, the shorter is the time over which semiclassical methods apply. Over longer times, collisions as well as classical and quantum fluctuations become important and require beyond-mean-field approaches. For weakly interacting systems, much is known through extensive work on perturbative kinetic theories which allow to describe the quantum relaxation evolution of systems not too far from equilibrium, over intermediate time scales. For larger gas densities or strong interactions, however, only a few ansaetze exist to describe the dynamical evolution. In the lecture, an introduction to functional integral techniques will be given which are based on the two-particle-irreducible effective action [3] for the description of non-equilibrium atomic quantum gases. The approach allows a non-perturbative expansion in terms of the inverse of the number of field components [4,5]. It gives thermalization of an ultracold Bose gas to an equilibrium Bose-Einstein distribution as well as the characteristics of the intermediate dissipative dynamics [6,7]. With these methods, the consequences of complex multiple-scattering processes can be taken into account in an efficient way and quantum fluctuations be distinguished from classical ones [8,7]. The technique goes far beyond the quantum extension of the Boltzmann equation and therefore also beyond standard mean-field theory. Making these methods accessible to experimental precision verification has important potential impact on other areas like heavy-ion collisions or cosmology, where non-equilibrium methods are needed and much more difficult to be checked experimentally.

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