Contribution ID: **94** Type: **Oral**

General hydrodynamic approach for a cold Bose gas

Tuesday, 24 September 2024 15:30 (20 minutes)

The aim of this paper is to derive the hydrodynamics for a cold Bose gas from the microscopic platform based on the many-body Schr¨odinger equation and general assumptions of the hydrodynamic approach (HA) applicable to any dimension. We develop a general HA for a cold spatially inhomogeneous Bose gas assuming two different temporal and spatial scales and obtain the energy as a functional of both fast inner quantum mode and slow macroscopic mode. The equations governing the fast and slow modes are obtained from this functional by their independent variations. The fast mode is the wave function in the stationary state at local density which can be ground, excited with a nonzero atom momenta, or a superposition of more than one states. The energy eigenvalue (or expectation value) of this local wave function universally enters the hydrodynamic equation for the slow mode in the form of the local chemical potential which incorporates the inner local momentum. For zero inner momenta and particular choices of this eigenvalue as a function of gas density, this equation reduces to the known equations based on the local density approximation. If however the inner momenta are nonzero, the equation includes the interaction between these momenta and the slow mode velocity. Relation between this general HA and the standard local density approximation is elaborated. Two effects of the local momenta and their density dependence on the soliton solutions are demonstrated.
(To appear in the Physical Review A, arXiv:2408.12363v1).

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Session Classification: Afternoon Session 1

Track Classification: CONDENSED MATTER PHYSICS