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Correlations and dynamics of tunnel-coupled one-dimensional Bose gases

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Abstract:

Understanding quantum many-body systems is of great importance for many branches of physics. While it is often easy to state the basic equations for the microscopic motion of countless particles, their exact solution is only possible in rare cases. To understand the properties of quantum many-body systems, one therefore needs effective theoretical descriptions as well as experimental model systems to test their predictions.

In this thesis, we present a series of experiments with ultracold Bose gases. Such gases represent a well-isolated, flexible and robust model system for quantum many-body physics. Numerous proven methods for manipulating and measuring such systems are available. In our particular case, we are working with ultracold one-dimensional Bose gases consisting of rubidium atoms.

We create two such ultracold gases in a double well potential. The atoms can tunnel from one well into the other, which leads, depending on the strength of the tunneling, to various degrees of phase locking between the two subsystems. Employing matter-wave interference, we can measure the spatially resolved phase difference between the two gases. This makes it possible to investigate spatial correlations of this phase difference.

By investigating whether correlation functions of higher order can be factorized into correlations of lower order, we can investigate the interaction properties of the system. For a non-interacting system, all correlation functions with orders greater than two factorize and one observes Gaussian fluctuations. In this thesis, we present the measurement of non-factorizing fourth-order correlation functions, leading to an experimental characterization of the interactions between the collective excitations of the quantum many-body system. The degree of non-factorizibility, i.e., the degree of non-Gaussianity of the phase fluctuations, depends on the tunneling strength, which is tuneable in the experiment.

Starting from such a non-Gaussian state, we are able to observe the dynamical evolution towards a state with factorizing correlation functions (Gaussian fluctuations). More precisely, we start in a double well with tunneling and then abruptly decouple the two subsystems. Subsequently, we observe how the initially non-Gaussian phase fluctuations become Gaussian. This represents the first experimental demonstration of `Gaussification' in quantum many-body systems. Investigating this type of dynamics is important to understand how Gaussian equilibrium states can be reached by quantum mechanical evolution.

Last but not least, we discuss the dynamical emergence of phase coherence in a double well potential with tunneling. We experimentally investigate the evolution starting from two different initial states.

In the first case, we split a cloud of atoms into two subsystems and trigger global oscillations in their relative phase. The oscillations subsequently damp and phase coherence sets in. In the second case, two independent subsystems are suddenly coupled by tunneling. Again, we see the emergence of phase coherence between the two subsystems.