Q 15: Quantum gases (Bosons) II

Time: Tuesday 11:00–13:00 Location: e214

Group Report Q 15.1 Tue 11:00 e214

Bose-Einstein condensates in weak and strong disorder potentials — •Milan Radonjić and Axel Pelster — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

Here we consider different generalizations of a perturbative approach to the dirty boson problem, worked out by Huang and Meng within a Bogoliubov theory [1]. At first, we consider a time-dependent extension by considering how switching on and off a weak disorder potential affects the equilibration of an initially homogeneous BEC and the emergence of a disorder-induced condensate deformation. Afterwards, we work out an approach based on the cumulant expansion method [2] up to second order, that is non-perturbative with respect to disorder and also includes quantum fluctuations. We employ it to study static geometric properties of a harmonically trapped molecular BEC in laser speckle potential [3]. For weak disorder we find quantitative agreement with the Huang and Meng theory, while for strong disorder our theory perfectly reproduces the geometric mean of the experimentally measured transverse widths of the column density profiles. Finally, we compare the non-perturbative results of the second and the third order cumulant expansion approach for a homogeneous Bose gas in impurity disorder.

[1] K. Huang and H. F. Meng, Phys. Rev. Lett. **69**, 644 (1992)
[2] M. Radonjic et al., New J. Phys. **20**, 055014 (2018)
[3] B. Nagler, M. Radonjić, et al., arXiv:1911.02626

Q 15.2 Tue 11:30 e214

Atoms trapped by atoms — •Matthias Meister[1] and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, D-89069 Ulm, Germany — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt (DLR), D-89077 Ulm, Germany

In general, ultra-cold quantum gases are trapped by external magnetic or optical fields to prevent the atoms from expanding. However, in microgravity the different atom-atom interactions available in dual-species Bose-Einstein condensates (BECs) enable us to create a situation, where one atomic species is confined solely by the repulsive interaction with another species.

Our approach [1] is based on a dual-species mixture, where one species fully surrounds the other resulting in a shell-shaped ground state. By selectively trapping only the outer species and raising the inter-species interaction a potential wall forms preventing the inner species from escaping. We have thoroughly studied this process numerically and have analyzed the holding time of this newly formed atom trap as a function of the system parameters. In particular, the quality of the confinement depends on the geometry of the initial state, favoring isotropic setups.

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[1] M. Meister, PhD thesis, Universität Ulm, Ulm (2019)

Q 15.3 Tue 11:45 e214

Symmetry-induced many-body quantum interference in chaotic bosonic systems: An augmented Truncated Wigner approach — •Quirin Hummel[1], Peter Schlagheck[1], Denis Ullmo[2], Juan Diego Urbina[3], Klaus Richter[3], and Steven Tomsovic[4] — [1]Université de Liège (Belgium) — [2]Université Paris-Saclay (France) — [3]Universität Regensburg (Germany) — [4]Washington State University (USA)

Although highly successful, the truncated Wigner approximation (TWA) does not account for genuine many-body quantum interference between different solutions of the mean-field equations of a bosonic many-body (MB) system. This renders the TWA essentially classical, where a large number of particles formally takes the role of small $\hbar$. The failure to describe genuine interference phenomena can in principle be overcome by the MB version of the semiclassical van Vleck-Gutzwiller propagator. However, employing the later in its full glory generally eludes a formulation in terms of an initial value problem, one of the major strengths of TWA. Here we consider chaotic bosonic systems with discrete symmetries, where contructive interference leads to significant deviations from TWA [Schlagheck et al., *PRL* **123**, 215302 (2019)]. We show how there the two approaches can be reconciled, combining their strengths in an augmented TWA. We illustrate the validity of our method at pre- as well as post-Ehrenfest time scales in prototypical Bose-Hubbard systems, where it also reveals the existence of additional MB interference effects.

Q 15.4 Tue 12:00 e214

(Non)thermal states of ideal Bose gases contact with external reservoirs: The effect of finite reservoir coupling — •Alexander Schnell[1] and Juzar Thingna[2] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany — [2]IBS Center for Theoretical Physics of Complex Systems, Daejeon, South Korea

The standard framework in which systems in weak contact to external heat-reservoirs are investigated leads to a Lindblad master equation. The underlying assumptions are that the system–reservoir coupling is infinitely weak such that Born-, Markov- and rotating-wave approximation can be performed. For any finite system–reservoir coupling, however, the rotating-wave approximation cannot be performed. Using the standard Born- and Markov approximation one finds a different equation of motion, the Redfield quantum master equation. Contrary to common belief, it was shown that the steady state of this Redfield equation is incorrect already in the first order that goes beyond the Lindblad master equation. Still, there exists a procedure to extract the correct first order correction only from the Lindblad steady state and the Redfield rates [J. Chem. Phys. 136(19),194110 (2012)]. In general, an application of this procedure to quantum many-body systems is out of reach, since it requires knowledge of the full many-body eigenenergies and -states. An exception to this rule are ideal quantum gases. We apply this procedure to the noninteracting Bose gases, both for thermal states and nonequilibrium steady states, and discuss the impact of different bath models.

Q 15.5 Tue 12:15 e214

Non-equilibrium dissipative dynamics of interacting bosons in an optical lattice — •Jens Benary[1], Marvin Röhrle[1], Alexandre Gil Moreno[1], Christian Baals[1,2], Jian Jiang[1], and Herwig Ott[1] — [1]Department of Physics and OPTIMAS research center, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, 55128 Mainz, Germany

We experimentally investigate a driven-dissipative Josephson junction array, realized with a weakly interacting Bose-Einstein condensate loaded in a 1-D optical lattice. Engineered losses on one site act as a local dissipative process. The source of these losses is an electron beam, which we can also use to image the system (SEM) and monitor the losses. Tunneling from the neighboring sites makes up the driving force. Decreasing the tunnel coupling J makes the system cross from a superfluid state to a resistive state. For intermediate values of J, the system shows bistable behavior, with coexistence of a superfluid and an incoherent branch. Studying the individual realizations for single experimental runs we see a digital behavior in the filling of the lossy site, changing from the resistive to the superfluid state within a few tunneling times. We study the dynamics towards a steady state averaged over many experimental runs, finding a critical slowing down and intermediate filling levels of the lossy site, indicating the presence of a non-equilibrium first order quantum phase transition.

Q 15.6 Tue 12:30 e214

Inducing Resonances with Floquet Engineering of Ultracold Scattering — •Christoph Dauer, Axel Pelster, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

Magnetic Feshbach resonances are a powerful tool in order to control the scattering length in ultracold gas experiments [1], but are limited to given atomic species or applied magnetic field strengths. Recent studies showed that periodic driving can also induce scattering resonances, but are limited to the simplest inter-particle potentials [2-4]. In this work we consider a more realistic inter-atomic interaction by including an open and a closed channel, as they occur in the description of magnetic Feshbach resonances [5]. We allow for a time-periodic modulation of the inter-channel coupling or the detuning of the channel thresholds and report about the emergence of driving induced scattering resonances. A detailed investigation how resonance frequency and width depend on both driving frequency and strength is performed. With this we obtain predictions for a time-periodic modulation of the magnetic field near a magnetic Feshbach resonance, which are of experimental interest.

[1] C. Chin et al., Rev. Mod. Phys. **82**, 1225 (2010)
[2] D.H. Smith, Phys. Rev. Lett. **115**, 193002 (2015)
[3] A.G. Sykes et al., Phys. Rev. A **95**, 062705 (2017)
[4] S.A. Reyes et al., New J. Phys. **19**, 043029 (2017)
[5] R.A. Duine and H.T.C. Stoof, Phys. Rep. **396**, 115 (2004)

Q 15.7 Tue 12:45 e214

High fidelity two-qubit quantum gate with neutral atoms — •Hui Sun[1,2], Bing Yang[1,2], Hanyi Wang[1,2], Zhen-sheng Yuan[1,2], and Jian-wei Hui[1,2] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China

old neutral atoms hold great promise for constructing a quantum device that outperform the classical computer. However, the imperfections of gate operations hinder the implementation of fault-tolerant quantum computing, which requires the operation error to be lower than the threshold 10^{-2}. Here, we report on a high-fidelity two-qubit gate entangling 1250 pairs of neutral atoms in parallel with a operation error of $7(1) \times 10^{-3}$. By improving the precision of controlling the lattice potential, the gate operation driven by the second-order superexchange interaction achieve the same energy scale as the on-site interaction of the Hubbard model. The coherence time is prolonged and the decoherence of entanglement in optical lattice is mainly governed by the intrinsic light scattering. We calibrate the gate fidelity to be 99.3(1)% by measuring spin correlations of the quantum state after multiple gates performed on the atom pairs. Our experiment represents a benchmark towards fault-tolerant quantum computing with neutral atoms.