Q 19: Ultracold Atoms, Ions and Molecules III (with A)

Time: Tuesday 11:00–13:15 Location: f342

Q 19.1 Tue 11:00 f342

Towards an optical phase shift based on Rydberg blockade — •Daniel Tiarks, Steffen Schmidt, Stephan Dürr, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, 85748 Garching, Deutschland

Controlling the interaction between single photons is important for many quantum information technologies. Recently we demonstrated [1,2,3] that an opaque medium in which single photons are converted into stationary Rydberg excitations can be used to control the transmission of a subsequent light pulse by using electromagnetically induced transparency. Manipulation of coherent superpositions requires, however, non-dissipative interactions that only affect the phase of the light.

In this work we report on our recent progress towards realizing controlled phase shifts of single photons extending the work of [4,5]. We store photons in highly exited Rydberg states which change the refractive properties of the medium due to Rydberg blockade. A subsequent light pulse will thus experience a significant phase shift.

[1] S. Baur et al., PRL 112, 073901 (2014)
[2] D. Tiarks et al., PRL 113, 053602 (2014)
[3] H. Gorniaczyk et al., PRL 113, 053601 (2014)
[4] O. Firstenberg et al., Nature 502, 71 (2013)
[5] A. Feizpour et al., Nature Physics 11, 905 (2015)

Q 19.2 Tue 11:15 f342

Towards a single-photon source based on Rydberg FWM in thermal vapors — •Fabian Ripka, Yi-Hsin Chen, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart

Photonic quantum devices based on atomic vapors at room temperature combine the advantages of atomic vapors being intrinsicly reproducable as well as semiconductor-based concepts being scalable and integrable. One key device in the field of quantum information are on-demand single-photon sources. A promising candidate for realization relies on the combination of two atomic effects, namely four-wave mixing (FWM) and the Rydberg blockade effect.

Coherent dynamics to Rydberg states on ns timescales [1] and sufficient Rydberg interaction strengths [2] have already been demonstated in thermal vapors. These effects could also be observed in a pulsed FWM scheme [3]. Recently, we investigated a storage-retrieval scheme by means of two pulses. We could determine the collective lifetime of the Rydberg coherence to be 1.1ns, limited by motional dephasing. Additionally, this double-pulsed FWM scheme enables an enhanced generation efficiency of output photons up to tens of photons per pulse. The goal is then to reduce this number of photons by interaction-induced suppression of the Rydberg coherence, in order to obtain non-classical photon states and even single photons per FWM cycle.

[1] Huber et al., PRL 107, 243001 (2011)
[2] Baluktsian et al., PRL 110, 123001 (2013)
[3] Huber et al., PRA 90, 053806 (2014); Chen et al., accepted by Appl. Phys. B

Q 19.3 Tue 11:30 f342

Imaging of Rydberg atoms and light propagation through a non-linear non-local medium — •Vladislav Gavryusev, Miguel Ferreira-Cao, Adrien Signoles, Gerhard Zuern, Renato Ferracini, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Electronically highly excited (Rydberg) atoms constitute a system with long range interactions which allows to study many intriguing phenomena, ranging from quantum non-linear optics to dipole-mediated energy transport. To optically image Rydberg atoms we use the interaction enhanced imaging technique [1] which exploits interaction-induced shifts on highly polarizable excited states of probe atoms, that can be spatially resolved via an electromagnetically induced transparency resonance. The sensitivity is tunable up to few Rydberg excitations by using strong dipole-dipole interactions, induced via a Förster resonance or by direct dipolar coupling between the involved states. By monitoring the Rydberg distribution we observed the migration of Rydberg electronic excitations, driven by quantum-state changing interactions [2], and we are working towards controlling this dynamic. The strong interactions also affect the optical properties of the medium and can allow to explore a highly non-linear and non-local regime, where the response will depend both on local light intensity and atom density, leading to pattern formation and effective photon-photon interactions.

[1] G. Günter et al., Phys. Rev. Lett. 108, 013002 (2012)
[2] G. Günter et al., Science 342, 954 (2013)

Q 19.4 Tue 11:45 f342

Two-body interactions and decay of three-level Rydberg-dressed atoms — •Stephan Helmrich, Alda Arias, Nils Pehoviak, Emil Pavlov, Tobias Wintermantel, and Shannon M Whitlock — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

We theoretically analyse the interactions and decay rates for atoms dressed by multiple laser fields to strongly interacting Rydberg states using a quantum master-equation approach. In this framework a comparison of two-level and three-level Rydberg-dressing schemes is presented. We identify a resonant enhancement of the three-level dressed interaction strength which originates from cooperative multiphoton couplings. This feature can be effectively used for Rydberg dressing under electromagnetically-induced-transparency condition combined with small single-photon detunings. The cooperative enhancement in interaction is accompanied by low levels of distance-dependent dissipation. We will present first experimental studies of Rydberg dressing of ultracold potassium atoms with dressing times comparable to the timescales for atomic motion. In the future, near-resonant Rydberg dressing in three-level atomic systems may enable the realization of laser driven quantum fluids with long-range and anisotropic interactions and with controllable dissipation.

Q 19.5 Tue 12:00 f342

Dissipative Preparation of Entangled Many-Body States with Rydberg Atoms — •Maryam Roghani and Hendrik Weimer — Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

We study a one-dimensional atomic lattice gas where interactions are mediated by a weak admixture of a Rydberg state. This Rydberg dressing is combined with dissipative dynamics induced by optical pumping. We derive an effective quantum master equation for the ground state manifold and show that this driven dissipative dynamics can result in highly entangled stationary states. For a defined set of parameters, this non-trivial entangled many-body steady state is the ground state of a Hamiltonian which possesses a manifold of approximate Rokhsar-Kivelson points. This Rokhsar-Kivelson state is a coherent superposition of all possible configurations respecting the dipole blockade induced by the Rydberg dressing [1].

[1] I. Lesanovsky, Phys. Rev. Lett. 106,025301 (2011).

Q 19.6 Tue 12:15 f342

Dipolar photon- and excitation-transport in Rydberg-EIT media — •Daniel Viscor and Thomas Pohl — Max Planck Institut für Physik komplexer Systeme

We investigate the effects of excitation-exchange interactions on the propagation dynamics of quantum light through a strongly interacting Rydberg gas under conditions of electromagnetically induced transparency (EIT). Considering the most simple setting of a single Rydberg-polariton interacting with a stored collective Rydberg excitation, we show that long-range excitation-exchange between the two spin wave components gives rise to a photon propagation that differs fundamentally from the more common case of static van der Waals interactions. Using numerical simulations and analytical arguments, we characterise the resulting dissipative and dispersive optical response of the medium and discuss potential applications of the emerging new features.

Q 19.7 Tue 12:30 f342

Nonlinear Optics in a Rydberg-Excited Semiconductor Cavity — •Valentin Walther, Robert Johne, and Thomas Pohl — Max Planck Institute for the Physics of Complex Systems, Dresden

Recent experiments have demonstrated excitons with extraordinarily large binding energies in some two-dimensional semiconductors (TMDCs), whose Rydberg states give rise to giant interactions and, therefore, hold great promise for optical utility.

We evaluate the optical response under conditions of electromagnetically induced transparency (EIT), accounting for the full excited level structure and numerous decoherence mechanisms in a semiconductor. Strong exciton-exciton interactions result in enormous effective photon-photon potentials. Using experimental parameters, we show that the photonic nonlinearity exceeds that of traditional semiconductors by several orders of magnitude and we assess the material properties required for coherent optical applications.

Further, we investigate interesting optical effects in the transverse mode structure of a driven-dissipative cavity arising from the unusually large nonlinearity.

Q 19.8 Tue 12:45 f342

Multicritical behaviour in dissipative Ising models — •Vincent Overbeck[1], Mohammad Maghrebi[2], Alexey Gorshkov[2], and Hendrik Weimer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Deutschland — [2]Joint Quantum Institute, NIST/University of Maryland, College Park, MD, USA

Stationary states of dissipative quantum many-body systems are of great interest, having the possibility to undergo dissipative phase transitions that are fundamentally different from thermal equilibrium. We consider a dissipative extension of the Ising model, where the dissipation preserves the Z_2 symmetry. Using a variational approach [1,2], we find a second order and a first order phase transition line, which meet at a multicritical point that is not found in the equilibrium case. We make an analysis of the full phase diagram, discussing in detail the role of fluctuations in this model. Finally, we present a possible experimental realization based on Rydberg-dressed spin interactions.

[1] H. Weimer, Variational Principle for Steady States of Dissipative Quantum Many-Body Systems, Phys. Rev. Lett. **114**, 040402 (2015).

[2] H. Weimer, Variational analysis of driven-dissipative Rydberg gases, Phys. Rev. A **91**, 063401 (2015).

Q 19.9 Tue 13:00 f342

Effect of lattice geometry on bosonic quantum phases of Rydberg dressed lattice gases — •Andreas Geissler[1], Mathieu Barbier[1], Yongqiang Li[2], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Goethe Universität Frankfurt am Main, Germany — [2]Department of Physics, NUDT, China

Our recent reults [1] have shown the rich diversity of quantum phases which are induced by the strong correlations inherent to Rydberg dressed bosonic atoms trapped in optical lattices. While experimental feasibility of the dressing itself has just recently been demonstrated for the first time [2], a better understanding of the crystallisation is still required. We analyse Rydberg dressed lattice systems for various lattice geometries by further applying our real space dynamical mean-field theory (RB-DMFT) methods. These results serve as a benchmark of Gutzwiller type mean-field simulations where dissipative dynamics can be simulated within the Lindblad master equation approach. Within the latter approach we can observe crystallisation dynamics and the stability of crystalline structures. We additionally focus on quasiparticle excitations which we determine from linearised Gutzwiller equations.

[1] A. Geißler et al., arXiv:1509.06292, [physics.cond-mat]

[2] Y.-Y. Jau et al., Nat. Phys., nphys3487 (2015)