Q 57: Quantum Effects: QED II

Time: Thursday 14:30–16:30 Location: f442

Group Report Q 57.1 Thu 14:30 f442

Interference and dynamics of light from a distance-controlled atom pair in an optical cavity — •Olivier Morin, Andreas Neuzner, Matthias Körber, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching

A single atom in a cavity is the most simple system of cavity QED. Reaching control over the internal and external degrees of freedom of the atom has enabled novel quantum physical applications. Similarly, research with atomic many-body systems has led to many new insights into complex quantum systems. However, only a few experiments have attempted to bridge the two areas of research.

We report recent results in this direction by extending our system from one to two atoms in regimes typically associated with super- and sub-radiance. As for the paradigmatic double-slit experiment, we observe the fundamental role of the relative phase between possible optical paths determined by the atoms' positions. This new degree of freedom introduce non-trivial effects based on the cavity-mediated long-range interaction between the atoms. A plethora of counter-intuitive phenomena in the intensity and the photon statistics of the light emitted from the atom-driven system is observed. The reported amount of control opens up a unique way to connect cavity QED and many-body physics.

Q 57.2 Thu 15:00 f442

Nonclassical light from an incoherently pumped quantum dot in a microcavity — •Lucas Teuber, Peter Grünwald, and Werner Vogel — Institut für Physik, Universität Rostock, D-18055 Rostock, Germany

Quantum dots in semiconductor microcavities have become one of the backbones of semiconductor quantum optics. However, technical and physical issues often limit the study of optical fields to incoherently excited systems. For incoherently driven two-level systems, we derive steady-state solutions for the correlation of intracavity field and the quantum dot by means of recurrence relations [1]. With these correlations, different nonclassicality criteria based on moments [2] are analyzed. Realistic cavity systems from previous experiments [3] show nonclassicality in terms of lower-order moments for moderate quantum-dot–cavity coupling. Our method also allows to compute the characteristic function [4] in order to prove that the intracavity field is always nonclassical.

[1] L. Teuber, P. Grünwald, and W. Vogel, Phys. Rev. A 92, 053857 (2015).
[2] E. Shchukin, Th. Richter, and W. Vogel, Phys. Rev. A 71, 011802(R) (2005).
[3] G. Khitrova, H. M. Gibbs, M. Kira, S. W. Koch, and A. Scherrer, Nature Phys. 2, 81 (2006).
[4] W. Vogel, Phys. Rev. Lett. 84, 1849 (2000).

Q 57.3 Thu 15:15 f442

Quantum decoherence of a single-ion qubit induced by single optical photons — Moonjoo Lee[1], Konstantin Friebe[1], Florian R. Ong[1], •Dario A. Fioretto[1], Bernardo Casabone[1], Klemens Schueppert[1], Rainer Blatt[1,2], and Tracy E. Northup[1] — [1]Institute of Experimental Physics, University of Innsbruck, Austria — [2]Institute of Quantum Optics and Quantum Information, Austria

Quantum measurement is based on the interaction between a quantum object and a meter entangled with the object. While the information stored in the object is being extracted by the interaction, the measurement leads to decoherence of the object due to the intrinsic quantum fluctuations of the meter. Here, we report the observation of measurement-induced dephasing of a single-ion qubit with single optical photons. We employ a single $^{40}Ca^{+}$ ion that is dispersively coupled to a high-finesse cavity. The cavity is driven by a weak laser field to populate the cavity with mean photon numbers up to five. Spectroscopy is performed on the 729 nm qubit transition to identify the shift and broadening of the atomic energy levels. The information stored in the qubit is extracted by photons escaping the cavity, which, in turn, leads to dephasing of the qubit owing to photon-number fluctuations. This measurement represents the first demonstration of such quantum decoherence effects in the optical domain. Furthermore, heterodyne measurements of the cavity output photons will make it possible to probe quantum trajectories of the qubit nondestructively.

Q 57.4 Thu 15:30 f442

Enhanced Nonlinearity in an Atom-Driven Cavity QED System — •Christoph Hamsen, Karl Nicolas Tolazzi, Haytham Chibani, Tatjana Wilk, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching

Optical nonlinearities at the single- to few-photon level are an essential ingredient to quantum optics and quantum information processing. An atom strongly coupled to the light field of an optical cavity provides such a nonlinearity. As described by the Jaynes-Cummings model, the system's eigenstates form an anharmonic ladder of doublets for each excitation number giving rise to nonlinearities strong enough to enable single- or multi-photon effects [1,2].

Here we investigate a system composed of a single ^{87}Rb atom strongly coupled to a cavity where the coherent drive resonantly excites the quantum emitter instead of the resonator. Compared to the cavity-driven case, we expect an enhanced nonlinearity since the transition elements from the first to higher manifolds are reduced. This in turn has distinct implications on the photon statistics of the cavity emission, as demonstrated experimentally: First, driving the emitter on the normal modes yields an improved photon-blockade effect. In contrast, resonant driving to the second manifold leads to a novel nonclassical photon-concatenation effect reflecting the internal dynamics of the system.

[1] K. M. Birnbaum et al., Nature **436**, 87 (2005).
[2] A. Kubanek et al., Phys. Rev. Lett. **101**, 203602(2008).

Q 57.5 Thu 15:45 f442

Injection locking of a self-sustained cQED oscillator — •Wolters Janik[1,2], Elisabeth Schlottmann[2], Steffen Holzinger[2], Benjamin Lingnau[3], Kathy Lüdge[3], Christian Schneider[4], Martin Kamp[4], Sven Höfling[4], and Stephan Reitzenstein[2] — [1]Universität Basel, Departement Physik, CH-4056 Basel — [2]Institut für Festkörperphysik, Quantum Devices Group, Technische Universität Berlin, Hardenbergstrasse 36, EW 5-3, 10623 Berlin, Germany — [3]Institut für Theoretische Physik, AG Nichtlineare Laserdynamik, Technische Universität Berlin, Hardenbergstrasse 36, EW 7-1, 10623 Berlin, Germany — [4]Technische Physik, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

We report on a comprehensive study of external control of a self-sustained cQED oscillator, namely a microscopic laser operating in the weak coupling regime with a few tens of photons in the cavity. Where perfect synchronization or chaotic dynamics are expected for its conventional macroscopic counterparts, stationary oscillation synchronized to the external signal and oscillation at the solitary frequency is observed to occur simultaneously. The experimental findings are quantitatively supported and explained by modeling the cQED oscillator under study. As indicated by the theoretical analysis, the observed partial injection is a phenomenon unique to cQED enhanced oscillators excited with a few tens of quanta. Our studies are a landmark for future experiments on external (quantum) control of optical, opto-mechanical or electronic oscillators exhibiting complex dynamics in the quantum regime.

Q 57.6 Thu 16:00 f442

Mean-field analysis of synchronization-induced cooling — •Simon B. Jäger[1], Minghui Xu[2], Stefan Schütz[1], Giovanna Morigi[1], and Murray Holland[2] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]JILA, National Institute of Standards and Technology and Department of Physics, University of Colorado, Boulder, Colorado 80309-0440, USA

We discuss the cavity cooling dynamics which accompanies synchronization of dipoles in a resonator. The atomic transitions are incoherently driven by an external pump and strongly coupled to a cavity. Friction forces and diffusion depend critically on the external parameters, and can lead to recoil temperatures in the synchronization regime. By means of a mean-field analysis we show that this is accompanied by an onset of correlations between internal and external degrees of freedom and determine the phase diagram for the stationary state as a function of the external pump strength and of the superradiant linewidth.

Q 57.7 Thu 16:15 f442

Thermodynamics and relaxation in a system of photon-mediated long-range interactions — •Stefan Schütz, Simon Balthasar Jäger, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany

We study the steady-state properties and relaxation dynamics of atoms in the quantum field of an optical cavity and which are driven by a laser. In a semiclassical limit we show that the steady state is a thermal distribution whose temperature is solely controlled by the detuning between laser and cavity. The laser intensity, on the other hand, determines the onset of selforganized Bragg gratings. We evaluate the free energy and demonstrate that the selforganization transition is a second-order phase transition described by Landau's model: the control field is the laser intensity and the order parameter is the cavity field amplitude. We then discuss the dynamics following a sudden quench across the phase transition, and report the observation of metastable spatial patterns, whose lifetime can be several resonator lifetimes. These metastable patterns are nonthermal and result from the interplay between the dispersive and the dissipative mechanical forces of the resonator.

[1] S. Schütz, H. Habibian, and G. Morigi, Phys. Rev. A **88**, 033427 (2013)

[2] S. Schütz, S. B. Jäger, and G. Morigi, arXiv 1508.06606v1, PRA in press.

[3] S. Schütz and G. Morigi, Phys. Rev. Lett. **113**, 203002 (2014)