Q 49: Quantum Effects: Cavity QED I

Time: Thursday 11:00–13:00 Location: B/gHS

Group Report Q 49.1 Thu 11:00 B/gHS

Cooperative Coupling and Cooling of Individual Atoms in an Optical Cavity — R. Reimann[1], W. Alt[1], T. Kampschulte[2], T. Macha[1], N. Thau[1], S. Yoon[1], •L. Ratschbacher[1], and D. Meschede[1] — [1]Institut für Angewandte Physik der Universität Bonn — [2]Departement Physik, Universität Basel

Optical cavities are excellent tools to strongly enhance the otherwise weak coupling of photons to individual trapped atoms. In the context of quantum communication they can act as efficient light-matter interfaces, which are essential elements for transferring quantum information between matter qubits and photonic qubits. The cooperative coupling of small ensembles of neutral atoms to photons can be used to increase the bandwidth of these interfaces.

Here, we investigate several of the challenges that arise for cooperative interaction: Residual atomic motion of trapped atoms complicates the ideal cavity QED situation of point-like, spatial fixed atoms with constant coupling strength. To reduce its detrimental effects, we have implemented a novel intra-cavity Raman sideband cooling scheme. The method is enhanced by a complete suppression of excitations on the two-photon carrier transition.

To study cooperative interaction effects we have implemented the controlled coupling of two atoms to the cavity mode. We observe constructive and destructive photon emission depending of the relative atomic positions. Our results are important for the realization of phase-sensitive cQED protocols, such as collective the photon storage in small atomic ensembles or the cavity mediated entanglement of two atoms.

Q 49.2 Thu 11:30 B/gHS

Atom-cavity physics with a Bose-Einstein condensate in an ultra-narrow band resonator — •Hans Kessler, Jens Klinder, and Andreas Hemmerich — ILP, Uni Hamburg

A Bose-Einstein condensate (BEC) is prepared inside an optical resonator with an ultra-narrow band width on the order of the single photon recoil energy. For transverse pumping with a traveling wave, matter wave superradiance is observed [1]: above a critical intensity superradiant light pulses are emitted into the cavity and the atoms are collectively scattered into coherent superpositions of discrete momentum states, which can be precisely controlled by adjusting the effective cavity-pump detuning δ_{eff}. For transverse pumping with a standing wave the physics encountered depends on the sign of δ_{eff}: at positive $\delta_{\mathrm{eff}} > 0$, matter wave superradiance is found, similarly as for traveling wave pumping. At negative $\delta_{\mathrm{eff}} < 0$, the Hepp-Lieb-Dicke phase transition is observed: a stationary intra-cavity field emerges, which confines the BEC in a self-organized lattice potential. Due to the narrow cavity bandwidth we operate in a regime where a sweep across the phase boundary on a ms time scale leads to significant hysteresis with an enclosed loop area showing power law scaling with respect to the transition time [2].

[1]H. Keßler et al., PRL 113, 070404 (2014)
[2]J. Klinder et al., arXiv:1409.1945v2

Q 49.3 Thu 11:45 B/gHS

All-optical control of photon statistics with a single atom in an optical cavity — •Haytham Chibani, Christoph Hamsen, Tatjana Wilk, and Gerhard Rempe — Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

The realization of controllable nonlinearities at the level of single quanta of matter and light is one of the main goals of quantum optics. Here, we show that non-classical states of light can be generated and optically controlled in an atom-cavity system via the fruitful combination of cavity quantum electrodynamics (QED) in the strong coupling regime with cavity electromagnetically induced transparency (EIT) as predicted by a recent theoretical study [1]. We report on a controlled transition from sub- to super-Poisson photon statistics in the light transmitted through a cavity containing a single atom. Moreover, we present transmission spectra showing for the first time both the EIT effect and the normal mode structure which is the signature of a strongly coupled cavity QED system.

[1] Souza et al. Phys. Rev. Lett. 111, 113602 (2013)

Q 49.4 Thu 12:00 B/gHS

High numerical aperture, ultralow mode volume and scannable Fabry Pérot cavity. — •Hrishikesh Kelkar[1], Daqing Wang[1,2], Björn Hoffman[1], Silke Christiansen[1,3], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nürnberg, 91058 Erlangen, Germany — [3]Helmholtz Center Berlin for Materials and Energy, 14109 Berlin, Germany

The interaction between a single emitter and vacuum radiation field can be enhanced by placing the emitter in an optical cavity. This enhancement scales proportionally with the cavity quality factor Q and inversely with the square root of the cavity mode volume. Previous Cavity QED studies have usually worked with high Qs and large or moderate mode volumes. We present the first tunable microcavity with a mode volume less than 0.5 μm^3 and a low Q of about 150. The cavity consists of a metal-coated curved micromirror fabricated by focused ion beam milling and a flat distributed Bragg reflector. In addition to the basic characterization of this cavity, we report on a strong modification of the cavity resonance by a nanoparticle and a counter-intuitive increase in Q. We also discuss our progress in operating the cavity at cryogenic temperatures, where we expect to modify the radiative decay channels of single emitters such as molecules and NV centers using a moderate Purcell factor of about 25.

Q 49.5 Thu 12:15 B/gHS

Ion trap cavity QED experiments at Sussex — •Hiroki Takahashi, Stephen Begley, Markus Vogt, Ezra Kassa, Jack Morphew, Sahar Hejazi, and Matthias Keller — University of Sussex, Department of Physics and Astronomy, Pevensey 2, Falmer, Brighton East Sussex, United Kingdom BN1 9QH

We are currently working on three distinct ion-cavity QED experiments. In one of them, a cavity collinear to the axis of a linear Paul trap is employed where a moderate ion-photon coupling is expected. The simultaneous couplings of multiple ions to the same cavity mode can be exploited, for example, for probabilistic generation of entanglement. A stronger coupling can be achieved by using a miniature fibre cavity. We have developed a novel endcap-type ion trap which tightly integrates a high finesse fibre cavity inside the electrodes [1]. With strong ion-photon coupling, a deterministic transfer of quantum states between ions and photons becomes possible. Finally, the third trap combines the benefits of the former two by employing a miniature linear trap with a fibre cavity collinear to the trap axis. This configuration allows us to strongly couple single ions in a linear string simultaneously to the cavity mode. This system can be used for ion-photon interface with collectively enhanced coupling and cavity cooling of molecular ions. We will present an overview of these three on-going experiments and their future prospects.

[1] H. Takahashi et al. , New. J. Phys. 15, 053011 (2013)

Q 49.6 Thu 12:30 B/gHS

Towards Strong Coupling of Single Ions to an Optical Cavity — •Ezra Kassa, Hiroki Takahashi, and Matthias Keller — University of Sussex, Department of Physics and Astronomy, Pevensey 2, Falmer, Brighton East Sussex, United Kingdom BN1 9QH

In our aim to pave the way towards cavity-QED based quantum network interfaces with trapped ions, we have developed a miniature endcap trap with a tightly integrated fibre cavity [1]. This allowed us to bring the cavity length to below 300 um. We have produced fibre cavities with finesses of up to 60,000 by CO2 laser machining [2]. We have successfully trapped single Ca+ ions in close vicinity of fibre ends and will couple them to the optical fiber cavity to implement a coherent ion-photon interface through strongly coupled cavity-QED.

[1] Takahashi et. al, An integrated fiber trap for single-ion photonics, New J. Phys. 15 053011 (2013)
[2] Takahashi et. al, Novel laser machining of optical fibers for long cavities with low birefringence, accepted by Optics Express

Q 49.7 Thu 12:45 B/gHS

Quantum nonlinear optics with an ion crystal in a cavity — •Robert Johne and Thomas Pohl — Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden, Germany

Ion crystals represent a versatile platform to engineer spin-spin interactions, which can be induced by an optical force and by common vibrational modes in the crystal [1]. Furthermore, ion-crystal cavity coupling has been realized [2]. Here, we theoretically investigate the combination of the spin-spin interaction with cavity quantum electrodynamics. Due to the spin-spin interaction in the ion crystal, the system provides a single photon nonlinearity and, at the same time, an enhanced collective light-matter coupling. The simulations show that the induced interaction blockade can be used as an efficient photon subtractor for weak probe fields. Furthermore, coherent driving allows for the generation of arbitrary Dicke states as well as their flying counterparts, n-photon Fock states, with high fidelity. The system represents a versatile platform for applications in quantum nonlinear optics.

[1] D. Porras and J. I. Cirac, Phys. Rev. Lett. 92, 207901 (2004)
[2] P. F. Herskind et al. Nature Physics 5, 494 (2009)