Q 55: Quantum Effects

Time: Thursday 10:30–12:30 Location: K 1.013

Group Report Q 55.1 Thu 10:30 K 1.013

Strong Coupling between Photons of Two Light Fields mediated by one Atom — •Nicolas Tolazzi, Christoph Hamsen, Bo Wang, Jonas Neumaier, Gang Li, Alejandro González-Tudela, Tatjana Wilk, and Gerhard Rempe — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching

The key ingredient for many applications in quantum information processing is the controlled interaction between individual photons. In classical nonlinear optical media, typical interaction strengths are negligible at the level of individual quanta. However a significant interaction between single photons can be reached in single atom cavity quantum electrodynamics. Despite this paradigm's success in quantum nonlinear optics with multiple photons in one mode, engineering a system with direct nonlinear coupling between photons in two different modes is still an outstanding challenge. Here, we discuss how two optical cavity fields can be brought to interaction using a single four-level atom. While each field by itself is transmitted unaltered, already a single photon in one mode suppresses the transmission of photons in the other mode. As experimental proof we show strong anti correlations between the photons in the different light fields. Extending this system to the dispersive regime for one of the cavity modes would allow for sensing the exact number of photons in that mode without destroying them, leading to nondestructive counting of photons and heralded n-photon sources. We will present ideas, experimental results and perspectives towards the realization of such effects.

Q 55.2 Thu 11:00 K 1.013

Geometric phase in a quantum heat engine prototype — Sajal Kumar Giri and •Himangshu Prabal Goswami — Max-Planck-Institute for the Physics of Complex Systems, Dresden

We theoretically study a 4-level quantum system coupled to two thermal baths and a unimodal cavity which serves as a quantum heat engine prototype. By periodically modulating the temperature of the thermal baths in an adiabatic fashion, one can realize geometric or Pancharatnam-Berry phaselike (PBp) contributions identifiable from a full counting statistical method. Through the PBp contributions, the effect of quantum coherences in optimizing the total flux can be nullified. The PBp effects cause the universality in the expansion coefficient (1/2) and the universal bounds on the efficiency at maximum power as well as the Gallvotti-Cohen type of symmetry to be violated. We further observe a seeming inapplicability in the use of a standard large deviation technique to evaluate the cavity photon-flux probability distribution function.

Q 55.3 Thu 11:15 K 1.013

Multi-Photon correlations in an one-dimensional waveguide by light-matter interaction — •Kevin Kleinbeck, Jan Kumlin, and Hans Peter Büchler — University of Stuttgart, Institute for theoretical Physics 3, Stuttgart, Germany

We consider the scattering of photons at artificial atoms in one-dimensional, chiral waveguide systems and study the effective photon-photon interaction mediated by this medium. For the single atom system, we derive a generating functional for the outgoing wave function of any arbitrary multi-photon input state. Using this solution, we study the emergence of three-body correlations under the waveguide dynamics. We show, that even though the system only allows for two-body interactions, the three-body correlation function has contributions both from two-body and purely three-body effects.

In addition, we analytically prove the existence of universal many-body bound states in this model. We find numerical evidence that these bound state contributions become more important with increasing width of the initial wave function.

Q 55.4 Thu 11:30 K 1.013

Few-photon nonlinear optics using chirally-coupled two-level atoms — •Sahand Mahmoodian[1], Mantas Čepulkovskis[2], Sumanta Das[2], Peter Lodahl[2], Klemens Hammerer[1], and Anders Sørensen[2] — [1]Institute for Theoretical Physics, Institute for Gravitational Physics (Albert Einstein Institute), Leibniz University Hannover, Appelstraße 2, 30167 Hannover, Germany — [2]Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen, Denmark

Waveguide quantum electrodynamics studies the interaction between a quantum emitter coupled to a 1D photonic reservoir. It has been recently demonstrated that when quantum emitters couple to tightly-confined optical waveguide modes the light–matter interaction can become chiral leading to directional spontaneous emission and direction-dependent scattering of light. In this talk I discuss using a chain of N chirally-coupled two-level emitters driven by a resonant weak to mediate strong photon–photon interactions. By solving for the one- and two-photon dynamics analytically, we show that the physics of this system is governed by the interplay of nonlinear interactions and photon losses due to coupling to an external reservoir. For large optical depths the system evolves into a state that has a strongly bunched second-order correlation function and the output power exhibits a sub-exponential (inverse polynomial) scaling with N. By using an asymptotic expansion we describe these effects analytically. These dynamics can be demonstrated in state-of-the-art tapered fiber setups with trapped atoms.

Q 55.5 Thu 11:45 K 1.013

Localization control of few-photon states in parity-symmetric photonic molecules — •Christopher D B Bentley[1], Alan Celestino[1], Alejandro M Yacomotti[2], Ramy El-Ganainy[3], and Alexander Eisfeld[1] — [1]Max Planck Institute for the Physics of Complex Systems, Noethnitzer Strasse 38, 01187 Dresden, Germany — [2]Laboratoire de Photonique et de Nanostructures (CNRS UPR 20), Route de Nozay, Marcoussis 91460, France — [3]Department of Physics and Henes Center for Quantum Phenomena, Michigan Technological University, Houghton, MI 49931, USA

Spontaneous symmetry breaking (SSB) has been demonstrated approaching the quantum regime (with around 150 photons) using optically pumped, parity-symmetric photonic molecules [1]. The occurrence of SSB in the few-photon regime is a topic of active investigation. In this regime there are significant quantum fluctuations due to environmental couplings. We consider a system of two coupled, identical, optically-driven cavities, as in [1]. In this system, quantum fluctuations lead to transient population imbalance between the cavities, i.e. one cavity has higher population (mean photon number) than the other. No cavity is preferred: on average, there is no population imbalance. However, we demonstrate using feedback that one can control the population imbalance in this system without breaking the mirror-symmetry of the cavity driving. By time-dependent modulation of the amplitude of the mirror-symmetric driving, we select a cavity to have higher population on average.

[1] P. Hamel et al. 2015, Nature Photonics 9 (311)

Q 55.6 Thu 12:00 K 1.013

Linking ab-initio theory and phenomenological models of cavity QED — •Dominik Lentrodt, Kilian P. Heeg, Christoph H. Keitel, and Jörg Evers — MPI für Kernphysik, Heidelberg

Historically, there has been a gap in cavity QED between ab-initio theory and a class of phenomenological models based on the input-output formalism. These models have been important in understanding empirical results in the strong coupling regime of cavity QED, since they allow to reduce the dynamics of the atom-cavity system to an effective description in terms of few cavity modes. However despite their success, a derivation of the underlying Gardiner-Collett Hamiltonian from ab-initio quantisation has been elusive and its applicability in low-Q cavities has been debated [1].

Here we present a method to construct a family of Gardiner-Collett Hamiltonians from canonical quantisation of the dielectric Maxwell equations. We explicitly show the relation between classical scattering theory and the input-output formalism, revealing the necessity of a previously unknown background scattering factor. When an atom is added to the cavity, our formalism naturally yields an effective few-mode description of the system as a non-perturbative approximation scheme, in the same way as phenomenological models.

We expect our technique to find applications in the emerging field of x-ray cavity QED with Mössbauer nuclei, where low-Q cavities are in use and previously unknown phase shifts have been observed [2].

[1] S M Dutra & G Nienhuis (2000). Journal of Optics B, 2, 584. [2] Heeg, K. P. & Evers, J. (2015). Phys. Rev. A, 91, 063803.

Q 55.7 Thu 12:15 K 1.013

Generation of an X-ray echo from a nuclear resonance under magnetic field rotations — •Jonas Gunst[1], Chia-Jung Yeh[2], Wen-Te Liao[2], and Adriana Pálffy[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Department of Physics, National Central University, Taoyuan City, Taiwan

While Moore's law predicts the fast evolution of miniaturization, for future photonic devices the optical diffraction limit will emerge as bottleneck. Going to shorter wavelengths, e.g. x-ray photons, would drastically reduce this limitation and opens new possibilities for information science. However, versatile control of the basic properties of such photons is the key requirement for short wavelength photonic information carriers.

Nuclear forward scattering, as it occurs with ^{57}Fe Mössbauer nuclei, presents a great basis for exerting coherent control on x-ray photons. The nuclear response can be controlled by subjecting the sample to a hyperfine magnetic field and to fast rotations of the latter. Within such a setup the realizability of logical operations on polarization-encoded x-rays has already been demonstrated [1]. Inspired by the control of broadband quantum excitations using gradient photon echoes [2], we show here that such an echo can be generated in the x-ray regime by employing a setup consisting of multiple ^{57}Fe targets controlled via external magnetic field rotations.

[1] J. Gunst, C. H. Keitel and A. Pálffy, Sci. Rep. **6**, 25136 (2016).

[2] W. Liao, C. H. Keitel, and A. Pálffy, Phys. Rev. Lett. **113**, 123602 (2014).