Q 16: Quantum Effects I

Time: Tuesday 10:30–13:00 Location: Q-H13

Q 16.1 Tue 10:30 Q-H13

A Quantum Klystron - Controlling Quantum Systems with Modulated Electron Beams — •Dennis Rätzel[1], Daniel Hartley[2], Osip Schwartz[3], and Philipp Haslinger[2] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin, Germany — [2]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria — [3]Dept. of Physics of Complex Systems, Weizmann Institute of Science, Rehovot, Israel

Coherent control of quantum transitions - indispensable in quantum technology - generally relies on the interaction of quantum systems with electromagnetic radiation. Here, we theoretically demonstrate that the non-radiative electromagnetic near-field of a temporally modulated free-space electron beam can be utilized for coherent control of quantum systems. We show that such manipulation can be performed with only classical control over the electron beam itself, and is readily realizable with current technology. This approach may provide a pathway towards spectrally selective quantum control with nano-scale spatial resolution, harnessing the small de Broglie wavelength of electrons.

Q 16.2 Tue 10:45 Q-H13

Quantum friction near nonreciprocal media — •Omar Jesús Franca Santiago and Stefan Yoshi Buhmann — Institute of Physics, University of Kassel, Germany

We investigate how the quantum friction experienced by a polarisable charged particle moving with constant velocity parallel to a planar interface is modified when the latter consists of nonreciprocal media, with special focus on topological insulators. We use macroscopic quantum electrodynamics to obtain the Casimir–Polder frequency shift, decay rate and force for the atom. These results are a generalization of the respective quantities to matter with time-reversal symmetry breaking which violates the Lorentz reciprocity principle.

Q 16.3 Tue 11:00 Q-H13

Quantum pulses in non-Markovian waveguide QED — •Kisa Barkemeyer, Andreas Knorr, and Alexander Carmele — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin

Waveguide quantum electrodynamics (QED) systems, where emitters interact with the electromagnetic field confined to a one-dimensional geometry, are a promising platform for the implementation of quantum networks. If memory effects cannot be neglected, non-Markovian approaches have to be employed. In this regime, coherent time-delayed feedback allows controlling the system dynamics while preserving quantum coherence, and characteristic features such as the formation of bound states in the continuum can be observed.

In this talk, we discuss the strongly entangled system-reservoir state in waveguide QED systems with coherent time-delayed feedback. Thereby, we focus on the role of quantum pulses to describe the transmission of quantum information in a fully quantized manner. We employ different methods, an approach based on the time evolution with matrix product states [1,2] and a Heisenberg-picture approach [3], which complement each other and allow an in-depth study of various aspects of non-Markovian waveguide QED with multiphoton pulses.

[1] K. Barkemeyer, A. Knorr, and A. Carmele, *Phys. Rev. A* **103**, 033704 (2021).

[2] S. Arranz Regidor, G. Crowder, H. Carmichael, and S. Hughes, *Phys. Rev. Research* **3**, 023030 (2021).

[3] K. Barkemeyer, A. Knorr, and A. Carmele, arXiv:2111.02816.

Q 16.4 Tue 11:15 Q-H13

Ginzburg effect in a dielectric medium with dispersion and dissipation — •Sascha Lang[1,2], Roland Sauerbrey[1,3,4], Ralf Schützhold[1,5,2], and William G. Unruh[6,7] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Fakultät für Physik, Universität Duisburg-Essen, Duisburg, Germany — [3]Institut für Angewandte Physik, Technische Universität Dresden, Dresden, Germany — [4]Center for Advanced Systems Understanding (CASUS), Görlitz, Germany — [5]Institut für Theoretische Physik, Technische Universität Dresden, Dresden, Germany — [6]Department of Physics and Astronomy, University of British Columbia, Vancouver, Canada — [7]Institute for Quantum Science and Engineering, Texas A&M University, College Station, Texas, United States

As a quantum analog of Cherenkov radiation, an inertial photon detector moving through a medium with constant refractive index n may perceive the electromagnetic quantum fluctuations as real photons if its velocity v exceeds the medium speed of light c/n. For dispersive Hopfield type media, we find this Ginzburg effect to extend to much lower v because the phase velocity of light is very small near the medium resonance. In this regime, however, dissipation effects become important. Via an extended Hopfield model, we present a consistent treatment of quantum fluctuations in dispersive and dissipative media and derive the Ginzburg effect in such systems. Finally, we propose an experimental test.

Q 16.5 Tue 11:30 Q-H13

Resonances and radiation features of a quantum free-electron laser — •Peter Kling[1], Enno Giese[2], C. Moritz Carmesin[3], Roland Sauerbrey[4], and Wolfgang P. Schleich[3,1] — [1]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Ulm — [2]Institut für Angewandte Physik, Technische Universität Darmstadt — [3]Institut für Quantenphysik, Universität Ulm — [4]Helmholtz-Zentrum Dresden-Rossendorf e.V.

In the quantum regime of a free-electron laser (FEL) the quantum mechanical recoil, an electron experiences during the scattering from photons, dominates the dynamics of the electron-light system. Energy-momentum conservation combined with the discreteness of the recoil lead to narrow resonances for the electron momentum. We investigate the time scales of the dynamics as well as the features of the emitted radiation from such a Quantum FEL for different resonant momenta.

Q 16.6 Tue 11:45 Q-H13

Observation of coherent coupling between super- and subradiant states of an ensemble of cold atoms collectively coupled to a single propagating optical mode — •Riccardo Pennetta, Daniel Lechner, Martin Blaha, Arno Rauschenbeutel, Philipp Schneeweiss, and Jürgen Volz — Department of Physics, Humboldt Universität zu Berlin, 12489 Berlin, Germany

We discuss the evolution of the quantum state of an ensemble of atoms that are coupled via a single propagating optical mode. We theoretically show that the quantum state of N atoms, which are initially prepared in the timed Dicke state, evolves through all the N-1 states that are subradiant with respect to the propagating mode. We predict this process to occur for any atom number and any atom-light coupling strength. These findings are supported by measurements performed with cold cesium atoms coupled to the evanescent field of an optical nanofiber. We experimentally observe the evolution of the state of the ensemble passing through the first two subradiant states, leading to sudden, temporary switch-offs of the optical power emitted into the nanofiber. Our results contribute to the fundamental understanding of collective atom-light interaction and apply to all physical systems, whose description involves timed Dicke states.

Q 16.7 Tue 12:00 Q-H13

Investigating the Casimir-Polder force in nonplanar geometries — •Bettina Beverungen[1], Kurt Busch[1,2], and Francesco Intravaia[1] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Newtonstr. 15, 12489 Berlin, Germany — [2]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2A, 12489 Berlin, Germany

Quantum and thermal fluctuations of the electromagnetic field are responsible for many nontrivial effects such as dispersion forces. One example is the Casimir-Polder force, which describes the interaction between an atom and a macroscopic, electrically neutral object. At short distances, the quantum effects dominate and can be highly relevant to many nanotechnological applications. Since the interaction depends on the system's geometry, this constitutes one possible avenue to influence its behavior.

We focus our investigation on this aspect, using a Green tensor based formalism. The Green tensor characterizes the system's electromagnetic response and encodes the geometry as well as the material properties of the macroscopic object. This information allows us to identify the system's intrinsic characteristics such as relevant length scales and link them to the behavior of the interaction. We perform semi-analytical calculations for different geometries and interpret them in light of the physical system's properties. Furthermore, we perform analytical calculations of various asymptotic limiting cases in order to validate our results. At the same time, this can offer a deeper insight into the underlying physics.

Q 16.8 Tue 12:15 Q-H13

Probing the Quantum Vacuum in Space and Time — •Frieder Lindel[1], Robert Bennett[2], Francesca Fabiana Settembrini[3], Alexa Marina Herter[3], Jérôme Faist[3], and Stefan Yoshi Buhmann[4] — [1]Instiute of Mathematics and Physics, University of Freiburg, Germany — [2]School of Physics and Astronomy, University of Glasgow, United Kingdom — [3]Institute of Quantum Electronics, ETH Zürich, Switzerland — [4]Institute of Physics, University of Kassel, Germany

When quantising the electromagnetic radiation field, one of the most fascinating consequences is the existence of fluctuations associated with the ground state. These vacuum fluctuations manifest themselves indirectly through their influence on matter where they may be regarded as responsible for fundamental processes such as spontaneous emission or the Lamb shift. More recently, an alternative route to observing the quantum vacuum has been developed in electro-optic sampling experiments [1,2].

In my talk, I will show how vacuum correlations between individually chosen space-time regions can be accessed in electro-optics sampling experiments. I will argue that this makes it possible to observe retardation effects, cavity-induced changes and correlations between causally separated regions of the quantum vacuum.

[1] C. Riek et al., Science 350, 420 (2015)
[2] I.-C. Benea-Chelmus et al., Nature 568, 7751 (2019)

Q 16.9 Tue 12:30 Q-H13

A Photon Pair Source from a Single Atom — •Luke Masters, Martin Cordier, Xinxin Hu, Gabriele Maron, Lucas Pache, Maximilian Schemmer, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt Universität zu Berlin, 10099 Berlin, Germany

Photon emission from a single quantum emitter can be described as an interference phenomena between coherent and incoherently scattered light. In this picture, perfect photon anti-bunching in the light scattered by an atom arises from the complete destructive interference of the two-photon components of these two light fields.

The coherent and incoherently scattered light have distinct spectral properties, making it possible to separate them from each other by applying selective spectral filtering. In turn, this will modify the photon statistics of the emitted light, and can transform the perfect anti-bunching into strong photon-bunching.

In our experiment, we employ narrow-band spectral filtering to isolate the incoherent two-photon wavefunction from the fluorescence of a single, laser cooled Rb^{85} atom confined in an optical dipole trap. Without filtering, the measured second order correlation function shows a strong photon anti-bunching of $g^{(2)}(0) \approx 0$, while a photon bunching of $g^{(2)}(0) \gg 1$ is measured when filtering is applied. This is in agreement with our expectation that the incoherently scattered part consists purely of energy-time-entangled photon pairs.

Q 16.10 Tue 12:45 Q-H13

Multi-mode quantum optics in lossy resonators — •Dominik Lentrodt[1,2], Oliver Diekmann[2], Christoph H. Keitel[2], Stefan Rotter[3], and Jörg Evers[2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [3]Institute for Theoretical Physics, Vienna University of Technology (TU Wien), 1040 Vienna, Austria

Few-mode models — such as the Jaynes-Cummings model and its generalizations — have been an indispensable tool in studying the quantum dynamics of light-matter interactions in optical resonators. Recently, novel regimes featuring strong coupling in combination with large losses have attracted attention in various experimental platforms. In this context, central assumptions of these canonical quantum optical models have to be revisited. In this talk, I will discuss extensions of Jaynes-Cummings-type few-mode models and an associated class of loss-induced multi-mode effects. Besides recent theoretical progress [1-4], I will discuss implications for experiments in x-ray cavity QED with Mössbauer nuclei [5] — an emerging platform at the high-energy frontier of quantum optics, featuring lossy resonators doped with ultra-narrow emitters.

[1] Lentrodt & Evers, *PRX* **10**, 011008 (2020), [2] Medina et al. *PRL* **126**, 093601 (2021), [3] Lentrodt et al. *arXiv:2107.11775 [quant-ph]*, [4] Franke et al. *PRL* **122**, 213901 (2019), [5] Lentrodt et al. *PRResearch* **2**, 023396 (2020)