# Q 45: Quantum Effects (QED) II

Time: Thursday 11:00–13:00 Location: f442

Q 45.1 Thu 11:00 f442

**Quantum friction and internal atomic dynamics** — •Nico Strauss and Stefan Yoshi Buhmann — Albert-Ludwigs-Universität Freiburg

The Casimir-Polder force between atoms is of quantum mechanical origin and forms the basis of quantum friction, which is predicted to occur when two objects move at distance on the order of a few tens of nanometers relative to each other. In this presentation, we consider the effects of this force on the energy levels of atoms and their velocity dependence as well as that of the resulting transition frequencies [1]. We investigated how this frequency dependence can be observed in the experiments of M. Ducloy and M. Fichet [2] by measuring the changes in the reflection coefficients of a modulated laser beam incident on the boundary between a dielectric and a gas moving atoms.

[1] J. Klatt, R. Bennett and S. Y. Buhmann, Phys. Rev. A 94, 063803 (2016).

[2] M. Ducloy and M. Fichet, J. Phys. II, 1529 (1991).

Q 45.2 Thu 11:15 f442

**Theory of quantum vacuum detection** — •Frieder Lindel[1], Robert Bennett[1,2], and Stefan Yoshi Buhmann[1,2] — [1]Institute of Physics, University of Freiburg — [2]Freiburg Institute for Advanced Studies (FRIAS), 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 important processes, e.g. spontaneous emission, the Lamb shift, and the Casimir force. More recently, an alternative route to observing the quantum vacuum has been developed in electro-optic sampling experiments: they are based on the output statistics of ultrashort laser pulses sent through nonlinear crystals whose optical properties are influenced by the vacuum fluctuations [1,2].

In my talk, I will report on the development of a theoretical framework based on macroscopic quantum electrodynamics which is capable of describing the output statistics of electro-optic sampling experiments accounting for absorption, dispersion and general optical environments. It is in good agreement with available experimental data and recovers previous theoretical findings in certain limits. Furthermore, I will discuss how it can be exploited in order to serve as a convenient tool for detailed studies of the full polaritonic QED ground state in general environments.

[1] C. Riek et al., Science 350, 420 (2015)

[2] I.-C. Benea-Chelmus et al., Nature 568, 7751 (2019)

Q 45.3 Thu 11:30 f442

**On the Heisenberg limit for detecting vacuum birefringence** — •Naser Ahmadiniaz[1] and Ralf Schutzhold[1,2] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Institut fur Theoretische Physik, Technische Universitat Dresden, Dresden, Germany

Quantum electrodynamics predicts the vacuum to behave as a nonlinear medium, including effects such as birefringence.

However, for experimentally available field strengths, this vacuum polarizability is extremely small and thus very hard to measure.

In analogy to the Heisenberg limit in quantum metrology, we study the minimum requirements for such a detection in a given strong field (the pump field).

Using a laser pulse as the probe field, we find that its energy must exceed a certain threshold depending on the interaction time.

However, a detection at that threshold, i.e., the Heisenberg limit, requires highly non-linear measurement schemes – while for ordinary linear-optics schemes, the required energy (shot noise limit) is much larger.

Finally, we discuss several experimental scenarios in this respect.

Q 45.4 Thu 11:45 f442

**Many-body photon bound state propagation in waveguide QED** — Sahand Mahmoodian[1], •Giuseppe Calajó[2], Darrick Chang[2], Klemens Hammerer[1], and Anders Sørensen[3] — [1]Institute for Theoretical Physics, Leibniz University Hannover, Germany — [2]ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, Spain — [3]Niels Bohr Institute, University of Copenhagen, Denmark

Generating many-body states of light is an outstanding challenge in quantum optics. One of the main obstacles in the pursuit of this goal has been developing a system with a sufficiently strong nonlinear response. In this talk, we show that two-level atoms chirally coupled to a waveguide provide an ideal platform to observe quantum many-body states of photons. By computing the propagation of light through this system, we show that of central importance are the class of photon bound states with a well-defined photon number $n$, which propagate with a photon-number-dependent group-delay scaling as $1/n^2$. This leads to input coherent pulses of light becoming spatially separated after interacting with sufficiently many atoms. We also show that, in the classical limit, the photon bound states map onto the soliton solutions of self-induced transparency. Our many-body theory is able to capture the entire spectrum of behaviour from few-photon quantum propagation, genuine many-body photon dynamics, and finally, the quantum-to-classical transition. This physics can be potentially demonstrated in state-of-the art circuit QED and nanophotonic experiments.

Q 45.5 Thu 12:00 f442

**Enhanced coherent atom-photon interaction in a hollow-core light cage** — •Esteban Gómez-López[1], Flavie Davidson-Marquis[1], Bumjoon Jang[2], Tim Kroh[1], Chris Müller[1], Mario Ziegler[2], Julian Gargiulo[3], Stefan A. Maier[3], Harald Kübler[4], Markus A. Schmidt[2,5], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin — [2]Leibniz Institute of Photonic Technology, Jena — [3]Ludwig-Maximilians-Universität München — [4]University of Stuttgart — [5]Otto Schott Institute of Material Research, Jena

Quantum memories and repeaters are needed to overcome the unavoidable losses in the channels of quantum networks [1]. For this, atomic vapor cells provide a relatively easy to handle platform [2]. In this work we show for the first time coherent interaction between Cs atoms and light in a hollow-core light cage [3]. The tight confinement of the light in the cage placed inside a warm vapor cell leads to a significantly enhanced interaction strength compared to a freely propagating beam. Measurements of Electromagnetically Induced Transparency (EIT) transmission profiles show a clear deviation from the weak probe approximation predictions. We discuss these deviations and show generalized theoretical simulations, which provide a better fit to the measured spectra. The experiments set the base for delaying light pulses using EIT in a chip-integrated, easy-to-fill, device, and to the implementation of a compact quantum memory using the EIT-storage scheme. [1] Phys. Rev. Lett. 81, 5932 (1998). [2] Phys. Rev. Lett. 107, 053603 (2011). [3] ACS Photonics 6, 649 (2019).

Q 45.6 Thu 12:15 f442

**Photon dynamics in a one-dimensional waveguide coupled to a chain of atoms** — •Jan Kumlin and Hans Peter Büchler — Institute for Theoretical Physics III, University of Stuttgart, 70550 Stuttgart, Germany

In this talk, we discuss the photon dynamics inside a one-dimensional waveguide that is coupled to a chain of two-level atoms. It is possible to realise a chiral system where time-reversal symmetry is broken by selectively coupling only to the forward propagating modes of the waveguide.

By integrating out the photonic degrees of freedom, we derive an effective master equation for the atomic degrees of freedom. The system's dynamics can then be described by dissipative terms characterising the collective emission of photons and coherent interaction due to the exchange of virtual photons. In the chiral system, the character of this interaction is fundamentally different compared to a non-chiral system and we discuss the dynamics for both cases.

Introducing an additional classical light field to couple to a third level for each atom, we also show an alternative derivation of electromagnetically induced transparency and slow light in a perfectly chiral waveguide. Furthermore, we discuss the effects when the chirality is broken and backscattering is taken into account.

Q 45.7 Thu 12:30 f442

**Tailoring a Single Photon with an Atomic Frequency Comb** — •Tom Schmit, Luigi Giannelli, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

Quantum memories are storage units for flying qubits such as single photons [1] and they are one of the key ingredients for building a quantum network [2]. Memories based on solid-state media, such as rare-ion doped crystals, are promising due to their coherence properties. Among the protocols that have been developed for solid-state memories is the *Atomic Frequency Comb* (AFC) protocol [3]. Here, a given absorption line of the medium is spectrally shaped such that it consists of a series of narrow peaks. In this work we theoretically explore the perspectives of an AFC to tailor the temporal and spectral shape of the photon that is retrieved from the memory. We determine the shape of the comb that is required for generating a target photon of arbitrary shape and discuss some specific examples.

[1] N. Sangouard and H. Zbinden, Jour. of Mod. Opt., **59:17**, 1458-1464 (2012).
[2] H. J. Kimble, Nature **453**, 1023 (2008).
[3] M. Afzelius, C. Simon, H. de Riedmatten, and N. Gisin, Phys. Rev. A, **79**, 052329 (2009).

Q 45.8 Thu 12:45 f442

**Control of directionality in photon storage** — •Martin Korzeczek and Daniel Braun — University Tübingen - Institute for Theoretical Physics, Tübingen, Germany

When storing light pulses in atomic clouds, emission directionality is usually determined fully by the signal and control pulse directionality. Making use of the fact that the spin wave encodes the pulse directionalities in complex phases in Hilbert space, we propose a method of manipulating these phases and achieving arbitrary emission directions. Using a fully 3d numerical model and Gaussian pulses, we analyse the scaling of storage efficiency and its dependence on pulse directionality and cloud parameters. Additionally to determining the emission directionality, the phases in Hilbert space play a role in the degradation of the spin wave. Controlling them opens up the possibility of avoiding this source of state degradation, which adds to the methods for improving storage time.