Q 10: Cavity QED

Time: Monday 17:00–19:00 Location: HS 1199

Invited Talk Q 10.1 Mon 17:00 HS 1199

Correlated light-matter states from first principles and their use for chirality, and chemistry — •Christian Schäfer — Department of Physics, Chalmers University of Technology, 412 96 Göteborg, Sweden.

Confining optical or plasmonic modes results in a strong increase in light-matter coupling and leads to the creation of hybrid light-matter states, called polaritons. Control over the electromagnetic confinement allows, therefore, to non-intrusively control the correlated eigenstates. Here, we focus on two fascinating applications that emerge from this realization. First, breaking chiral symmetry with specifically designed electromagnetic environments paves the way for a new direction in chiral recognition [1,2]. Second, we refine our theoretical tool-box and investigate how vibrational strong coupling can control chemical reactivity [3-7]. We conclude with an outlook on active research addressing plasmonic catalysis and the quantization and treatment of macroscopic open quantum-systems.

[1] C. Schäfer, D. Baranov, J. Phys. Chem. Lett. 2023, 14, 15, 3777-3784. [2] D. Baranov, C. Schäfer, M. Gorkunov, ACS Photonics 2023, 10, 8, 2440-2455. [3] C. Schäfer, Phys. Chem. Lett. 2022, 13, 30, 6905-6911. [4] C. Schäfer, F. Buchholz, M. Penz, M. Ruggenthaler, and A. Rubio, PNAS 2021 Vol. 118 No. 41 e2110464118. [5] C. Schäfer, J. Flick, E. Ronca, P. Narang, and A. Rubio, Nature Communications, (2022) 13:7817. [6] C. Schäfer, J. Fojt, E. Lindgren, and P. Erhart, arXiv:2311.09739, (2023). [7] M. Castagnola, T. Haugland, E. Ronca, H. Koch, C. Schäfer, to be submitted (2023).

Q 10.2 Mon 17:30 HS 1199

Microcavity-mediated coupling of two molecules — •Jahangir Nobakht[1,2], André Pscherer[1,2], Jan Renger[1], Tobias Utikal[1], Stephan Götzinger[1,2], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, D-91058, Germany. — [2]Department of Physics, Friedrich-Alexander University, Erlangen, D-91058, Germany.

We have successfully established efficient coupling between two individual organic molecules by harnessing their strong coupling to a Fabry-Perot microcavity, thereby realizing the Tavis-Cummings model with dual emitters. This achievement is marked by the collective enhancement of the vacuum Rabi splitting, accompanied by the emergence of a distinctive dark middle peak. Our investigation further unveils the formation of subradiant/superradiant states within the dispersive regime of cavity quantum electrodynamics (QED), accompanied by a collectively enhanced Lamb shift in the superradiant state. Our work demonstrates the potential for achieving a high density of solid-state emitters with high individual cooperativity. This capability opens avenues for detecting rich, long range, coherent multi-photon intermolecular processes.

Q 10.3 Mon 17:45 HS 1199

Cavity Polaritons Formation at the Gap Edge of a Quantum Material — •Igor Gianardi[1], Michele Pini[1], and Francesco Piazza[1,2] — [1]Max-Planck-Institut für Physik komplexer Systeme, 01187 Dresden, Germany — [2]Institute of Physics, Universität Augsburg, 86159 Augsburg, Germany

Quantum nonlinear optics is a rapidly expanding field, which offers significant technological potential while engaging with intricate and novel many-body phenomena. This area of research delves into optical nonlinearities arising from the interactions between polaritons, hybrid quasi-particles which blend matter and light properties. The formation and interaction of polaritons, while having been extensively studied in various atomic platforms, remain largely unexplored in the realm of quantum materials, where the influence of strong electron correlations is particularly significant [1-3]. Our research concentrates on materials that exhibit an ordered gapped phase, introducing a novel type of polariton. This polariton is characterized by the hybridization of a cavity photon and a specific electronic interband excitation. As a paradigmatic example we consider CDW-insulators. Our findings reveal that polaritons located slightly below the energy gap display remarkably large dispersion while exhibiting zero absorption. The distinctive properties of these polaritons hint that their interactions will manifest highly pronounced nonlinearities.

[1] M. Kiffner et al., New J. Phys. 21, 073066 (2019)
[2] A. Allocca et al., Phys. Rev. B 99, 020504(R) (2019)
[3] L. B. Tan et al., Phys. Rev. X 10, 021011 (2020)

Q 10.4 Mon 18:00 HS 1199

Cavity-mediated collective emission from few emitters in a diamond membrane — •Kerim Köster[1], Maximilian Pallmann[1], Yuan Zhang[2], Julia Heupel[3], Timon Eichhorn[1], Cyril Popov[3], Klaus Mølmer[4], and David Hunger[1] — [1]Karlsruhe Institute of Technology, Germany — [2]Zhengzhou University, China — [3]University of Kassel, Germany — [4]University of Copenhagen, Denmark

When an ensemble of quantum emitters couples to a common radiation field, their polarizations can synchronize and a collective emission termed superfluorescence can occur. Entering this regime in a free-space setting requires a large number of emitters with a high spatial density as well as coherent optical transitions with small inhomogeneity. Here we show that by coupling nitrogen-vacancy (NV) centers in a diamond membrane to a high-finesse microcavity, also few, incoherent, inhomogeneous, and spatially separated emitters - as are typical for solid state systems - can enter the regime of collective emission. We observe a super-linear power dependence of the emission rate as a hallmark of collective emission. Furthermore, we find simultaneous photon bunching and antibunching on different timescales in the second-order auto-correlation function, revealing cavity-induced interference in the quantized emission from about fifteen emitters. We develop theoretical models and find that the population of collective states together with cavity enhancement and filtering can explain the observations. Such a system has prospects for the generation of multi-photon quantum states, and for the preparation of entanglement in few-emitter systems. Related publication: arXiv:2311.12723v1

Q 10.5 Mon 18:15 HS 1199

Ultrafast Excitation Exchange in a Maxwell-Fish-Eye Lens — •Oliver Diekmann, Dmitry O. Krimer, and Stefan Rotter — Institute for Theoretical Physics, TU Wien, Vienna A-1040, Austria

The strong coupling of quantum emitters to a cavity mode has been of paramount importance in the development of quantum optics. Recently, also the strong coupling to more than a single mode of an electromagnetic resonator has drawn considerable interest. We investigate how this multimode strong coupling regime can be harnessed to coherently control quantum systems. Specifically, we demonstrate that a Maxwell-Fish-Eye lens can be used to implement a pulsed excitation-exchange between two distant quantum emitters. This periodic exchange is mediated by single-photon pulses and can be extended to a photon-exchange between two atomic ensembles, for which the coupling strength is enhanced collectively.

Q 10.6 Mon 18:30 HS 1199

Jaynes-Cummings Model for Chiral Cavity Quantum Electrodynamics — •Lara Marie Tomasch, Stefan Yoshi Buhmann, and Fabian Spallek — Universität Kassel

We examine the effects of chirality on the interaction of a two-level quantum system with a single mode of the quantised electrcomagnetic field inside a cavity. Considering chiral standing waves inside a cavity and a chiral two-level molecule, we develop a generalised Jaynes-Cummings model and study its modified coupling constants and Rabi oscillations. Our results imply an increase of coupling for matching handedness of the field and molecule.

Q 10.7 Mon 18:45 HS 1199

Position-resolved pseudomode description of open cavities — •Lucas Weitzel, Andreas Buchleitner, and Dominik Lentrodt — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

A wide-spread quantum optical method to describe light matter interaction consists in reducing the involved degrees of freedom to the absolute minimum, such as those of a two-level atom (strongly) coupled to an isolated mode of a cavity. All other degrees of freedom are thus screened away as an “environment” which couples only weakly to the hybrid. Such separation is derived from first principles in many textbook scenarios, and allows an efficient description of the dynamics e.g. by Markovian Lindblad master equations. The system-environment separation becomes ever more difficult, though, as the number of strongly coupled degrees of freedom increases, e.g. for a two-level atom in a low-quality cavity where resonator modes may overlap or even drown in a continuum background. Given the mathematically well-controlled framework of Markovian Lindblad master equations, it is important to understand under which conditions the emerging dynamics can still be understood as resulting from an effective interaction of the atom with a set of broadened modes (pseudomodes), over a weakly coupled environment. To settle this question, we construct a fully analytical pseudomode representation of open cavities through "reverse-engeneering" from the position-resolved atomic dynamics within the cavity. We discuss the versatility of our method and potential applications to more complex atomic (or molecular) targets.