Q 11: QED and Cavity QED

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

Q 11.1 Mon 17:00 HS Botanik

To infinity and back - $1/N$ graph expansion of light-matter systems — •Andreas Schellenberger and Kai Phillip Schmidt — FAU Erlangen-Nürnberg, Erlangen, Deutschland

We present a method for performing a full graph expansion for light-matter systems, utilizing the linked-cluster theorem. This enables us to explore $1/N$ corrections to the thermodynamic limit $N \to \infty$, giving us access to the mesoscopic regime. This region is yet largely unexplored, as it is challenging to tackle with established solid-state methods. However, it hosts intriguing features, such as entanglement between light and matter that vanishes in the thermodynamic limit [1-3]. We calculate physical quantities of interest for paradigmatic light-matter systems like generalized Dicke models by accompanying the graph expansion by both exact diagonalization (NLCE [4]) and perturbation theory (pcst++ [5]), benchmarking our approach against other techniques.

[1] J. Vidal, S. Dusuel; EPL 74 817 (2006)
[2] K. Lenk, J. Li, P. Werner, M. Eckstein; arXiv:2205.05559 (2022)
[3] A. Kudos, D. Novokreschenov, I. Iorsh, I. Tokatly; arXiv:2304.00805 (2023)
[4] M. Rigol, T. Bryant, R. R. P. Singh; Phys. Rev. Lett. 97, 187202 (2006)
[5] L. Lenke, A. Schellenberger, K. P. Schmidt, Phys. Rev. A, 108 (2023)

Q 11.2 Mon 17:15 HS Botanik

Re-entrant phase transition in many-body Cavity QED — •Tom Schmit[1], Tobias Donner[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

We analyse theoretically self-organization of atoms that couple dispersively to an optical cavity and are subject to a transverse pump, in a configuration experimentally studied[1]. The transverse pump laser is blue-detuned w.r.t. the atomic transition, confining the atoms in the intensity minima of the generated optical lattice. The competition of pump and cavity field leads to self-organization of the atoms in an ordered pattern, giving rise to a re-entrant phase transition, such that by increasing the pump intensity above a critical value, one first observes a transition from disorder to self-organized and then, at larger values, again back to a disordered phase[1]. Our theoretical model, founded on a mean-field ansatz, provides a description of the stationary state's phase diagram in relation to pump intensity and detuning from the cavity frequency, aligning well with experimental observations. We show that stability of the ordered pattern is warranted when the scattered light interferes destructively with the pump at the atomic positions, effectively keeping the atoms in darkness. We discuss the connection between this phenomenon and *inverse melting*, observed in (classical) systems with repulsive and competing long-range interactions.

[1] P. Zupancic, et al., Phys. Rev. Lett. **123**, 233601 (2019).

Q 11.3 Mon 17:30 HS Botanik

Master Equation for Many-Body Cavity Quantum Electrodynamics — •Tom Schmit[1], Simon Jäger[2], Catalin-Mihai Halati[3], Tobias Donner[4], Corinna Kollath[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Physikalisches Institut, University of Bonn, Nußallee 12, 53115 Bonn, Germany — [3]Department of Quantum Matter Physics, University of Geneva, Quai Ernest-Ansermet 24, 1211 Geneva, Switzerland — [4]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, Otto-Stern-Weg 1, 8093 Zurich, Switzerland

Ensembles of atoms strongly coupled with the electric field of an optical cavity offer a formidable laboratory for studying the out-of-equilibrium dynamics of long-range interacting systems in the quantum regime. In this work, we derive a quantum master equation describing the optomechanical dynamics of the atomic ensemble, by eliminating the cavity degrees of freedom in perturbation theory. The master equation can capture the dynamics over a broad range of mechanical energies, from the thermal gas down to the ultra-cold, quantum degenerate regime. It can further systematically include the effect of external potentials, such as an optical lattice. We reproduce known limits and benchmark the master equation's prediction with exact diagonalization of the full quantum problem. Our model sets the basis for a systematic analysis of the dynamics of the characteristic timescale and correlations of quantum self-organization.

Q 11.4 Mon 17:45 HS Botanik

Three-Body Contributions to the Casimir Polder Force — •Emma Wünsche, Fabian Spallek, and Stefan Yoshi Buhmann — University Kassel, Germany

We study many-body contributions to the Casimir Polder (CP) force. Since for geometries of low symmetry or reduced symmetry no closed expressions for the CP potential are available, we employ a Born series for the Greens tensor and, relating the microscopic polarizability to the macroscopic permittivity, we derive a power series expansion of the CP potential in terms of the polarizabilities of the bodies' constituent atoms. The expansion can be interpreted as the sum of many-body Van-der-Waals contributions: the first term represents two-atom contributions, the second term three-atom interactions, and so on. For comparison, we reformulate existing results of macroscopic approaches for the CP potential and express them as a series in atomic polarizabilities. This allows us to validate the microscopic Van-der-Waals approach. We consider two different dielectric geometries: a small cylinder and an infinite half space, and find very good agreement for the two-atom contributions. While the three-atom contribution to the CP potential of an atom in front of an infinite plate can only be accessed numerically, for the cylinder-case, we find good agreement in the angular dependence of the three-atom contributions to the CP potential for the microscopic and macroscopic approaches.

Q 11.5 Mon 18:00 HS Botanik

Strong Chiral Coupling of a Molecule in a Two-Mode Cavity — •Lara Marie Tomasch, Fabian Spallek, and Stefan Yoshi Buhmann — Institut für Physik, Universität Kassel, Heinrich-Plett Str. 40, 34132 Kassel

We examine the effects of chirality on the interaction of a two-level quantum system with a single mode of the quantised electromagnetic field inside a cavity. We develop a generalised Jaynes-Cummings model and study the modified coupling constants, Rabi oscillations and eigenenergies of the system.

We generalise this system by having two chiral standing modes of opposite handedness present inside the cavity and determine their coupling to the chiral molecule. These two modes are in general detuned and may exhibit distinct coupling strengths as determined by the molecular dipole moments. We further examine the emergence of chiral-induced quantum phenomena and chiral forces acting on the molecule with potential applications in chiral sensing.

Q 11.6 Mon 18:15 HS Botanik

Quantum radiation and its correlations in tuneable dielectrics — •Sascha Lang[1,2,3], Stefan Yoshi Buhmann[1], Ralf Schützhold[2,4,3], and William G. Unruh[5] — [1]University of Kassel, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [3]Universität Duisburg-Essen, Germany — [4]Technische Universität Dresden, Germany — [5]University of British Columbia, Canada

Recent advances in THz nonlinear optics have revealed characteristic imprints of quantum vacuum fluctuations onto the two-point correlations of the electric field [1]. Media with explicitly time dependent properties even allow quantum vacuum fluctuations to be spontaneously promoted to real photon pairs—with distinctive signatures on the field correlations. Existing studies of such *quantum radiation phenomena* in dielectrics typically neglect dissipation and the associated quantum noise close to material resonances.

Based on established results for non-dispersive and lossless media [2], we are going to discuss the potential of correlation measurements for future quantum radiation experiments. Afterwards, we will present a model which includes dispersion and dissipation but still applies to tuneable media. Our formalism builds upon the famous Hopfield model and describes the medium via harmonic oscillators and a scalar environment field that may carry away energy and information [3].

[1] Settembrini, Lindel, Herter, Buhmann & Faist, Nat. Comm. **13**, 3383 (2022)
[2] Lang & Schützhold, Phys. Rev. D **100**, 065003 (2019)
[3] Lang, Schützhold & Unruh, Phys. Rev. D **102**, 125020 (2022)

Q 11.7 Mon 18:30 HS Botanik

Global pseudomode representation of cavity QED — •Lucas Weitzel, Andreas Buchleitner, and Dominik Lentrodt — Albert-Ludwigs Universität Freiburg

We construct an analytical and non-perturbative model for open cavities using discrete leaky modes – the so-called pseudomodes – by "reverse-engineering" the parameters in the model from the exact, position-resolved spectral density within the cavity. Furthermore, the approach generalizes the standard pseudomodes by incorporating an explicit mode expansion for the cavity electric field. The latter feature ultimately allows for a global – that is, at every position within the cavity – description of the dynamics of an emitter and extends the application of pseudomodes to more complex targets such as condensed matter or extended atomic systems and even to very leaky open cavities.

Q 11.8 Mon 18:45 HS Botanik

Quantum friction near chiral media — •Omar Jesus Franca Santiago[1], Stefan Yoshi Buhmann[1], Fabian Spallek[1], Steffen Giesen[2], Robert Berger[2], Kilian Singer[1], and Stefan Aull[1] — [1]Institute of Physics, Uni- versity of Kassel, Germany — [2]University of Marburg

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 a chiral medium. We use macroscopic quantum electrodynamics to obtain the Casimir–Polder frequency shift and decay rate. These results are a generalization of the respective quantities to matter with parity symmetry breaking. We illustrate our findings by examining the nonretarded and retarded limits for three examples: a perfectly conducting mirror, a perfectly reflecting chiral mirror and an isotropic chiral medium. We also discuss the importance of the symmetries in these examples in the framework of Curie's principle.

[1] Stefan Yoshi Buhmann, David T. Butcher and Stefan Scheel. New Journal of Physics 14, 083034 (2012).

[2] David T. Butcher, Stefan Yoshi Buhmann, Stefan Scheel, New Journal of Physics 14, 113013 (2012).

[3] O. J. Franca, Fabian Spallek, Steffen Giesen, Robert Berger, Kilian Singer, Stefan Aull, and Stefan Yoshi Buhmann. arXiv: 2412.18044 [quant-ph].