Q 29: Quantum Effects

Time: Wednesday 10:30–12:30 Location: S Gr. HS Maschb.

Invited Talk Q 29.1 Wed 10:30 S Gr. HS Maschb.
Nonlinear quantum transport of light in a cold atomic cloud
— Tobias Binninger, Vyacheslav Shatokhin, Andreas Buchleitner, and •Thomas Wellens — Physikalisches Institut, Albert-Ludwigs-Universität, Hermann-Herder-Str. 3, D-79104 Freiburg

The theory of multiple scattering in dilute media that consist of a disordered collection of discrete scatterers relies on the division of the total scattering process into single scattering events. In standard multiple scattering theory, these are assumed to be linear (scattered field proportional to incident field). For atomic scatterers with transition frequency close to the laser frequency, however, nonlinear multi-photon scattering processes are induced at high laser intensities. To account for the impact of these processes on the multiple scattering signal, we present an approach which combines tools of diagrammatic multiple scattering theory (ladder and crossed diagrams) with quantum-optical methods (optical Bloch equations). This approach allows us to evaluate how quantum-mechanical scattering processes influence, both, diffusive propagation of the average light intensity through a dilute cloud of cold atoms (with distances between the atoms much larger than the laser wavelength), as well as effects of coherent light propagation such as coherent backscattering.

[1] T. Binninger, V. Shatokhin, A. Buchleitner, and T. Wellens, arXiv:1811.08882 (2018)

Q 29.2 Wed 11:00 S Gr. HS Maschb.
Motional effects on cooperative behaviour in an atomic gas —
•Jemma Needham[1,2], Igor Lesanovsky[1,2], and Beatriz Olmos[1,2] — [1]Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, University of Nottingham, University Park, Nottingham, NG7 2RD, UK. — [2]School of Physics and Astronomy, University of Nottingham, University Park, Nottingham, NG7 2RD, UK.

We study the impact of residual motion of atoms in the onset of collective behaviour (such as the observation of super- and subradiant emission of photons) in a weakly driven dense atomic thermal cloud interacting with the radiation field. We systematically derive a quantum master equation that, under the Born and Markov approximations, describe the internal dynamics of such atomic systems. The first order effect of the atomic velocities of the atoms, such as the Doppler shift of the atomic frequencies, are incorporated in this equation from first principles. This allows us to simulate the dynamics of the laser excitation of a dense atomic gas and, in particular, investigate the existence of collective emission for different temperatures of the gas, and hence different atomic velocities. The results obtained here are of direct relevance to a number of experimental groups that study these collective phenomena both in dense and dilute gases [1-4].

[1] Bienaimé, T. et al. Phys. Rev. Lett. 2012, 108(12), 123602.
[2] Guerin, W. et al. Phys. Rev. Lett. 2016, 116(8), 083601.
[3] Pellegrino, J. et al. Phys. Rev. Lett. 2014, 113(13), 133602.
[4] Bromley, et al. Nat. Commun. 2016 7, 11039.

Q 29.3 Wed 11:15 S Gr. HS Maschb.
Rotational Alignment Decay and Decoherence of Molecular Superrotors —
•Benjamin A. Stickler[1], Farhad Taher Ghahramani[2], and Klaus Hornberger[1] — [1]University of Duisburg-Essen, Faculty of Physics, Duisburg, Germany — [2]School of Physics, Institute for Research in Fundamental Sciences (IPM), Tehran, Iran

We present the quantum master equation describing the coherent and incoherent dynamics of a rapidly rotating molecule in presence of a thermal background gas [1]. The master equation relates the rate of rotational alignment decay and decoherence to the microscopic scattering amplitudes, which we calculate for anisotropic van der Waals scattering. For large rotational energies, we find quantitative agreement of the resulting alignment decay rate with recent superrotor experiments [2].

[1] B. A. Stickler, F. Taher Ghahramani, and K. Hornberger, Phys. Rev. Lett. (in press) (2018).
[2] A. A. Milner, A. Korobenko, J. W. Hepburn, and V. Milner, Phys. Rev. Lett. 113, 043005 (2014).

Q 29.4 Wed 11:30 S Gr. HS Maschb.
Collective effects in resonance energy transfer phenomena —
•Severin Bang[1], Robert Bennett[1], and Stefan Yoshi Buhmann[1,2] — [1]Institute of Physics, University of Freiburg, Germany — [2]Freiburg Institute for Advanced Studies (FRIAS), Germany

Resonance energy transfer usually refers to a transfer between two partners. Superradiance is a collective decay effect, in which an ensemble of atoms emits radiation into its environment. In this talk, we explore the possibility of combining these two phenomena to potentially enhance the efficiency of energy transfer by introducing superradiant ensembles of donors and/or acceptors.

The process is described by quantum electrodynamics in terms of dipole moments coupled via an exchange of virtual photons, whose propagation is encoded in Green's tensors [1]. We focus on the possibility of enhancing the energy transfer rate and on its dependence on the spacial configurations of donors and acceptors.

[1] J. L. Hemmerich, R. Bennett, S. Y. Buhmann, Nature Commun. **9**, 2934 (2018).

Q 29.5 Wed 11:45 S Gr. HS Maschb.
Subradiant quantum state storage in a 1D atomic chain
— Jemma A. Needham[1,2], Igor Lesanovsky[1,2], and •Beatriz Olmos[1,2] — [1]School of Physics and Astronomy, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [2]Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

We investigate the potential of a 1D chain of atoms excited to low-lying states for the transport and storage of light. When the atoms are separated by a distance smaller or comparable to the wavelength of an atomic transition, the coupling of the atoms and the electromagnetic field leads to collective behaviour: excitations are exchanged between the atoms via virtual photons while the emission from the system happens at a much faster (superradiant) or much smaller (subradiant) rate than the one from an individual atom. We show here that a single excitation in a 1D chain can be created on one end of the chain such that it naturally gets stored in one of the subradiant states of the many-body system. By adiabatically tuning an external magnetic field we can manipulate the excitation's dynamics to an outstanding degree. We show that this allows one to store the light in a subradiant state for long times inside the chain's bulk and then release it. The experimental feasibility of this protocol is finally analyzed, and potential improvements are discussed.

Q 29.6 Wed 12:00 S Gr. HS Maschb.
Multilevel interference in superradiant emission —
•Aleksei Konovalov, Andreas Buchheit, and Giovanna Morigi — Saarland university, 66123 Saarbrucken, Germany

Quantum interference in the light emitted by multilevel systems causes frequency shifts in spectroscopic signals [1]. In order to be able to accurately describe these frequency shifts, multilevel-interference terms must be consistently included in the master equation of atoms forming an optically dense medium. We derive a master equation for dipole-dipole interactions using the coarse-graining procedure which consistently describes these dynamics. This master equation preserves the Lindblad form and includes terms beyond the rotating wave approximation. We then determine the resonance fluorescence and frequency shift of two atoms as a function of their distance taking into account their relevant level structures and discuss the relevance of multilevel interference in determining the spectroscopic properties.

[1] Andreas Alexander Buchheit and Giovanna Morigi, PHYSICAL REVIEW A 94, 042111 (2016)

Q 29.7 Wed 12:15 S Gr. HS Maschb.
Collective dipole-dipole interactions in planar cavities —
•Helge Dobbertin and Stefan Scheel — Institut für Physik, Universität Rostock, Albert-Einstein-Straße 23, 18059 Rostock, Germany

When densely spaced atoms are subject to near-resonant light, they couple via strong dipole-dipole interactions and react collectively. Recent experiments [1] observed the collective response of a thermal atomic vapour confined in a nano-cell. Here we calculate the corresponding transmission spectra from first principles by means of a microscopic coupled-dipole model at intermediate atomic densities. We incorporate the influence of the cavity environment on single-atom properties (Casimir–Polder and Purcell effects) and on atom-atom interactions. Our model shows the emergence of a macroscopic effective medium theory with refractive index n from the microscopic level. Furthermore, we study the resulting line broadening and line shift including a geometry-dependent shift, called 'collective Lamb shift', which we show to be an entirely classical effect [2]. Our approach may be used to identify and study new vapour-cell based structures with collectively enhanced light-matter interaction.

[1] T. Peyrot *et al.*, Phys. Rev. Lett. **120**, 243401 (2018).
[2] J. Javanainen *et al.*, Phys. Rev. A **96**, 033835 (2017).