A 11: Ultra-cold plasmas and Rydberg systems

Time: Tuesday 16:30–18:30 Location: S Fobau Physik

A 11.1 Tue 16:30 S Fobau Physik

On-demand single-photon source based on thermal Rubidium — •Florian Christaller, Fabian Ripka, Hao Zhang, Harald Kübler, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

Photonic quantum devices based on atomic vapors at room temperature are intrinsically reproducible as well as scalable and integrable. Besides quantum memories for single photons one key device in the field of quantum information processing are on-demand single-photon sources. A promising candidate for realization relies on the combination of four-wave mixing and the Rydberg blockade effect, as was demonstrated for ultracold atoms [1] and recently for room-temperature atoms in a micro-cell [2].

An important ingredient for strong cooperative interaction effects, like the Rydberg blockade, is the optical thickness in the micro-cell. The effect of light-induced atomic desorption (LIAD) [3] has demonstrated to be a suitable technique. With it, atoms absorbed at the glass surfaces of the micro-cell are desorbed optically by an intense ns-pulse of green light. By this, the optical thickness can be optically triggered from near zero to above one on the ns-timescale. Here we report on the latest LIAD measurements and on the status towards the high repetition rate single-photon generation at room-temperature.

[1] Dudin et al., Science 336, 6083 (2012)
[2] Ripka et al., Science 362, 6413 (2018)
[3] Atunov et al., Phys. Rev. A 67, 053401 (2003)

A 11.2 Tue 16:30 S Fobau Physik

A gas sensor based on Rydberg excitations — •Johannes Schmidt[1,2,5], Patrick Kaspar[1,5], Fabian Munkes[1,5], Denis Djekic[3,5], Patrick Schalberger[2,5], Holger Baur[2,5], Robert Löw[1,5], Tilman Pfau[1,5], Jens Anders[3,5], Norbert Frühauf[2,5], Edward Grant[4], and Harald Kübler[1,5] — [1]5th Institute of Physics — [2]Institute for Large Area Microelectronics — [3]Institute for Smart Sensors — [4]Department of Chemistry, UBC — [5]University of Stuttgart, Center for integrated quantum science and technology (IQST)

Sensitive and selective gas sensors become increasingly important for the analysis of the exhaled breath of mammals. Our scheme is based on the excitation of Rydberg states in the molecule of interest. Subsequent collisions with the background gas and predissociation will lead to ionization. The emerging charges can then be measured as a current. The occurrence of a current is an unequivocal indication of the presence of the molecule under consideration. We demonstrate technology readiness level 3 of our scheme at the example of the detection of 100 ppb Rb in a background gas of N_2 with a sensitivity of 10 ppb/$\sqrt{\mathrm{Hz}}$. We further experimentally verify the applicability in real life on the detection of nitric oxide in a gas mixture up to ambient pressure.

[1] J. Schmidt, et al., *SPIE* **10674** (2018)
[2] J. Schmidt, et al., *Appl. Phys. Lett.* **113**, 011113 (2018)

A 11.3 Tue 16:30 S Fobau Physik

Background gas induced line broadening in a rubidium vapor — •Fabian Munkes[1,4], Johannes Schmidt[1,2,4], Patrick Kaspar[1,4], Denis Djekic[3,4], Patrick Schalberger[2,4], Holger Baur[2,4], Robert Löw[1,4], Tilman Pfau[1,4], Jens Anders[3,4], Norbert Frühauf[2,4], and Harald Kübler[1,4] — [1]5th Institute of Physics — [2]Institute of Large Area Microelectronics — [3]Institute of Smart Sensors — [4]University of Stuttgart, Center for Integrated Quantum Science and Technology (IQST)

We investigate elastic and inelastic collisions of rubidium in a background gas of either nitrogen or argon. Rubidium is excited to different Rydberg S-states in an electrically contacted vapor cell [1,2]. This system implements a model for our future trace-gas sensor. The line broadening in various states is analyzed showing different behavior depending on the principal quantum number. While inelastic n- and l-changing collisions dominate for nitrogen, in contrary for argon elastic collisions prevail. A current signal in the nano-Ampere regime is generated by collisional ionization of the excited atoms for detection. For a more thorough understanding, the collisional ionization cross sections are calculated. The gained knowledge is employed to develope a trace-gas sensor based on Rydberg excitations in a thermal gas of nitric oxide [3], which is an important trace gas in medical and environmental applications.

[1] D. Barredo et al., *Phys. Rev. Lett.* **110**, 123002 (2013)
[2] J. Schmidt et al., *SPIE* **10674** (2018)
[3] J. Schmidt et al., *Appl. Phys. Lett.* **113**, 011113 (2018)

A 11.4 Tue 16:30 S Fobau Physik

Automated imaging optimization of an ion microscope for ultracold Rydberg experiments — •Phatthamon Kongkhambut, Thomas Schmid, Christian Veit, Nicolas Zuber, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

The experimental study of ion-atom scattering in the ultracold regime has so far remained elusive. We propose a novel method using Rydberg molecules to reach the quantum regime of ion-atom collisions [1] and present our new experimental setup which allows for the spatially resolved detection of the scattering process. The scattering process is initialized by the photoionization of a Rydberg molecule, providing well defined starting conditions for the collision. The scattered ions are imaged by an ion microscope and a delay line detector. Using automated feedback and optimization algorithms, we plan to tune the operation parameters of the ion microscope and minimize the aberrations. A magnification of more than 1000x can be realized with a field of view of 34 micrometers and depth of view of 25 micrometers. The expected resolution is below one micrometer.

[1] T. Schmid et al., Phys. Rev. Lett. **120**, 153401 (2018).

A 11.5 Tue 16:30 S Fobau Physik

Upgrading pairinteraction — •Johannes Block[1], Sebastian Weber[2], and Henri Menke[3] — [1]Institut für Physik, University of Rostock, Deutschland — [2]Institute for Theoretical Physics III, University of Stuttgart, Germany — [3]Department of Physics and MacDiarmid Institute for Advanced Materials and Nanotechnology, University of Otago, New Zealand

The open-source software pairinteraction [1,2] is a valuable tool to calculate interactions between Rydberg atoms. It has been used by the Rydberg community to determine two-body interactions between Rydberg atoms in a number of studies [3-5]. In order to increase the range of application, we introduced a Green tensor formalism [6] in the code. This allows for the simple implemantation of macroscopic bodies in proximity of the interacting atoms. We present sections of the improved code and first results that were produced with it.

[1] http://pairinteraction.github.io/
[2] Weber, S., Tresp, C., Menke, H., Urvoy, A., Firstenberg, O., Büchler, H. P., & Hofferberth, S. (2017), Journal of Physics B, 50(13), 133001.
[3] De Léséleuc, S., Barredo, D., Lienhard, V., Browaeys, A., & Lahaye, T. (2017), Physical Review Letters, 119(5), 053202.
[4] Kim, H., Park, Y., Kim, K., Sim, H. S., & Ahn, J. (2018), Physical Review Letters, 120(18), 180502.
[5] Ripka, F., Kübler, H., Löw, R., & Pfau, T. (2018), Science, 362(6413), 446-449.
[6] Block, J., & Scheel, S. (2017), Physical Review A, 96(6), 062509.

A 11.6 Tue 16:30 S Fobau Physik

Coupling Rydberg atoms and superconducting coplanar resonators — •Jens Grimmel, Conny Glaser, Manuel Kaiser, Lörinc Sárkány, Reinhold Kleiner, Dieter Kölle, and József Fortágh — CQ Center for Quantum Science, Physikalisches Institut, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen

The creation of hybrid systems consisting of Rydberg atoms and coplanar superconducting resonators has been proposed to enable efficient state transfer between solid state systems and ultracold atoms. Due to the large dipole moment of Rydberg atoms, the coupling strength to the cavity is expected to be much larger than for ground state atoms. At the same time, Rydberg states are strongly affected by any detrimental fields, such as the electric field of adsorbates on the chip-surface, which lead to spatially inhomogeneous energy shifts. We aim to transfer population between neighbouring Rydberg states using the microwave field of a driven coplanar waveguide resonator on a superconducting atom chip. The state transfer in the presence of adsorbate fields is detected via selective field ionisation. Ultimately, this method may aid in the observation of Rabi oscillations between neighbouring Rydberg states.

A 11.7 Tue 16:30 S Fobau Physik

Spectroscopy of Rydberg states in ultra cold ytterbium — •Christian Halter, Alexander Miethke, Eileen Trede, Stuti Gugnani, and Axel Görlitz — Heinrich-Heine-Universität, Düsseldorf, Deutschland

In recent years Rydberg atoms with their special features, like dipole-dipole interaction or van-der-Waals blockade, have become more and more important for quantum optics. Particularly ultra cold Rydberg atoms are of great interest for the investigation of long range interaction. A special feature of ytterbium is that due to its two valance electrons atoms in Rydberg state can be easily manipulated and imaged using optical fields. A first step towards studies of ultra cold ytterbium is to gain precise knowledge on the Rydberg states. Here we present a spectroscopy study of the Rydberg states of ultra cold ytterbium. For the detection of the Rydberg states we are using the induced loss of atoms in a MOT when atoms are excited to a Rydberg state. Using this method we could measure the energy and polarizability of several states in the region of a high principal quantum number n=70-90.

A 11.8 Tue 16:30 S Fobau Physik

Dissipative dynamics of strongly interacting driven Rydberg gases — •Carsten Lippe[1], Tanita Eichert[1], Jana Bender[1], Erik Bernhart[1], Oliver Thomas[1,2], Thomas Niederprüm[1], Fabian Letscher[1,2], Michael Fleischhauer[1], and Herwig Ott[1] — [1]Department of Physics and research center OPTIMAS, Technische Universität Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Gottlieb-Daimler-Strasse 47, 67663 Kaiserslautern, Germany

We investigate the dynamics of Rydberg blockade and facilitation by continuously driving open Rydberg many-body systems in different spatial configurations.

We discuss the facilitation dynamics of an off-resonantly driven 3-dimensional lattice gas in a Mott insulator state with single site occupancy in the regime of strong decoherence. Our experimental results give evidence for the formation of finite-sized Rydberg excitation clusters in the steady state. A scaling analysis with a numerical rate-equation model provides evidence against the existence of a global bistable phase because finite correlation lenghts of Rydberg excitations suggest that many small Rydberg clusters form.

Furthermore, we discuss the dynamics and steady states of a system of mesoscopic Rydberg blockaded clouds loaded into a 1-dimensional optical lattice with a lattice constant equal to the facilitation radius. Each cloud represents an effective two-level system with an asymmetric excitation and deexcitation rate, a so-called superatom. Thus, a chain of superatoms is a realization of a dissipative Ising-like spin model.

A 11.9 Tue 16:30 S Fobau Physik

Rydberg Dressed Quantum Many-Body Systems — •Lorenzo Festa, Nikolaus Lorenz, and Christian Gross — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

We are setting up a novel experiment for the study of quantum many-body systems with engineered long-range interactions. These interactions are induced by off-resonant laser coupling to Rydberg states, so called Rydberg dressing. A great potential of this dressing technique lies in the combination of Rydberg induced interactions and atomic motion in the quantum regime. This requires the long-range interaction between Rydberg atoms to be coherent on the timescale set by the atomic motion. By the choice of the laser parameters the extremely strong dipolar interactions can be balanced with the rate of dissipative light scattering. Studying two-dimensional Rydberg dressed system in an optical lattice will allow us to explore Hubbard models beyond onsite interactions and to realize quantum magnets with engineered inter-spin interactions.

A first intermediate goal of our experiment is to study tailored quantum magnets in microtrap arrays, where Potassium provides interesting prospects for deterministic array loading. The microtrap approach has been chosen in order to have a flexible and fast system for experiments that require high statistics. We are also developing the high power laser system for the ultraviolett light designed to maximize the coupling to Rydberg states.

Here we report on the status of the project and the progress done in the last year with the construction of the experimental apparatus.

A 11.10 Tue 16:30 S Fobau Physik

Dipole-Dipole blockade in strong fields close to the ionization limit — •Raphael Nold, Lea-Marina Steinert, Sonja Lorenz, Jens Grimmel, József Fórtagh, and Andreas Guenther — CQ center for quantum science, Physikalisches Institut, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen

We have developed a quantum gas microscope based on ionization of atoms and a high resolution ion optics. The system serves as a microscope for ultracold ground state and Rydberg atoms and achieves a magnification up to 1000 with a theoretical resolution limit below 100nm. In our experiments, we focus on the research towards strong correlations between Rydberg atoms in electric fields. We were able to use our high temporal resolution of the ion-microscope to measure the resonant energy transfer at Förster resonances via state selective field ionization. Additionally, we show a direct measurement of the excitation blockade for strongly Stark-shifted Rydberg states close to the classical ionization limit. We developed a detection scheme for controlled ionization in which we excite Rydberg atoms close to an avoided crossings between a weakly and a strongly ionizing state. This allows us to change the ionization rate over three orders of magnitude by applying small changes to the electric field. We investigate the dipole blockade by analyzing the spatial correlations of the excited Rydberg atoms for different values of the initial dipole moment and different dipole-diploe orientations.

A 11.11 Tue 16:30 S Fobau Physik

Interaction of Rydberg excitons with thin electron-hole plasmas in cuprous oxide (Cu_2O) — •Sjard Ole Krüger and Stefan Scheel — Institut für Physik, Universität Rostock, D-18059 Rostock, Germany

Wannier excitons are bound electron-hole states inside semiconductors showing striking similarities to hydrogen atoms. The observation of their Rydberg states and signs of a Rydberg blockade in Cu_2O [1] has sparked a lot of research into their properties. Not unlike their atomic counterparts, Rydberg-excitons are very sensitive to the existence of a plasma in their surrounding. It has been shown that plasma densities of less than one electron-hole pair per one hundred exciton volumes may suffice to ionise the Rydberg excitons [2]. Such electron-hole plasmas can be created by a variety of processes, like Auger-decay of ground-state excitons and direct or phonon-assisted excitations of unbound electron-hole pairs. It is therefore necessary to develop a good understanding of the plasma induced effects in order to distinguish them from the sought after exciton-exciton interactions such as the Rydberg blockade. In our poster, we investigate the ionisation of the Rydberg excitons in Cu_2O via the micro-fields induced by the plasma's free charges in a static Stark-interaction model.

[1] T. Kazimierczuk et *al.*, Nature **514**, 343 (2014).
[2] J. Heckötter et *al.*, Phys. Rev. Lett. **121**, 097401 (2018).

A 11.12 Tue 16:30 S Fobau Physik

A Rydberg atom coupled to a 2D lattice of ultracold ground state atoms — •Andrew Hunter, Matthew Eiles, Alexander Eisfeld, and Jan-Michael Rost — Max-Planck Institute for the Physics of Complex Systems

We investigate the spectrum of a Rydberg atom embedded in a two-dimensional lattice of ground state atoms. The strength of the interaction between the Rydberg electron and the neutral atoms is determined by the *s*-wave electron-atom scattering length. In the high lattice density regime, where many hundreds of atoms lie within the Rydberg wave function, we find that a class of perturbed states breaks away energetically from the others. These are circular states, highly localised in angular momentum. This is in stark contrast to the more familiar scenario of the "trilobite" molecule, where just one perturbing atom couples together many angular momenta and a single state, highly localised in space, splits away from the degenerate Rydberg manifold. We derive new scaling laws which stem from the planar structure of the perturbers, and with these we obtain a universal form of the energy spectrum in the high density limit. We also investigate the perturbed spectrum's dependence on the lattice properties.

A 11.13 Tue 16:30 S Fobau Physik

Using heteronuclear Rydberg dimers and trimers to probe ultracold mixtures — •Matthew Eiles — Max Planck Institut fur Physik komplexer Systeme

Long-range Rydberg molecules are composed of a Rydberg atom and a distant ground state atom tens of nanometers away. These unusual molecules have been studied extensively in the last decade as experimentalists searched for them in ultracold gases. They showed that these molecules can indeed be formed in the laboratory, and have confirmed all the original theoretical predictions. Interest in these molecules has hence shifted in two complementary directions: Can other similar bound systems akin to these fragile molecules be created, and, following more practical considerations, can these molecules be used to probe their environment? We have studied two extensions of the original Rydberg molecule concept: polyatomic molecules containing several ground state atoms, and heteronuclear molecules. Their vibrational energies and Franck-Condon factors are highly sensitive to the geometry of the ground state atoms and the properties of the constituent atomic species. Using these different types of Rydberg molecules we have found some promising avenues in which they can be used to probe their environment over large and controllable length scales [1].

[1] M. T. Eiles Phys. Rev. A 98, 042706 (2018).

A 11.14 Tue 16:30 S Fobau Physik

Optical activation of dipole-forbidden exciton transitions in cuprous oxide (Cu_2O) using orbital angular momentum light — •Annika Konzelmann and Harald Giessen — 4th Physics Institute, Center for Integrated Quantum Science and Technology IQST, and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Inspired from Rydberg atoms, we investigate the semiconductor equivalent of macroscopic quantum states in cuprous oxide, which have been discovered only recently. Cu_2O has a direct bandgap of 2.17 eV and is unique due to its large Rydberg energy of 90 meV and its large effective permittivity ϵ_1=9.8, resulting in the formation of excitons (electron-hole pairs), which are spatially extended over many thousands of lattice sites and spectroscopically well resolvable. Atomic transitions can be driven if the overlap of ground state of the crystal and excited exciton state contains the symmetry of the corresponding light excitation. We want to modify the selection rules by tuning the properties of the light, in particular, by adding angular momentum to the light. This is done by imposing a phase delay to the light beam by, e.g., using a spiral phase plate, resulting in a Laguerre-Gauss mode. We show theoretically (by symmetry considerations), that the transition selection rules can be modified, and that 1-photon-forbidden transition states become allowed states, as the spatial mode of the light is transferred to the exciton states due to phase (angular momentum) conservation.

A 11.15 Tue 16:30 S Fobau Physik

Tweezer Arrays for Rydberg States in Erbium for Quantum Simulation — •Arno Trautmann[1], Philipp Ilzhöfer[1], Benedict Hochreiter[1], Manfred J. Mark[1,2], and Francesca Ferlaino[1,2] — [1]Institute for Quantum Optics and Quantum Information Innsbruck, Austria — [2]University of Innsbruck, Austria

We present our design for a novel platform for quantum simulation based on erbium-Rydberg atoms in optical tweezers. Rydberg atoms are promising candidates for quantum simulation due to their extremely strong and long-range interactions, and have been applied already very successfully in alkali atoms. However, the simple electronic structure with only one valence electron limits the possible manipulation of Rydberg states, such as trapping, cooling or direct imaging. The extension to Rydberg states in multi-electron atoms is natural, and recently strontium and ytterbium have been studied. We plan to use erbium atoms, which have two valence electrons in their outer 6s shell and 12 electrons in an open, sub-merged, 4f shell. The properties of Rydberg states in such a complex system are not yet well understood and require intense spectroscopic effort. We here present our design for a new experiment dedicated to the study of these states in controllable arrays of optical tweezers.