Q 5: Laser Cooling and Trapping

Time: Monday 11:45–13:00 Location: P 11

Q 5.1 Mon 11:45 P 11

A tweezer system for trapping and addressing single atoms in an optical cavity — •Micha Kappel, Raphael Benz, Sebastián Alejandro Morales Ramirez, Daniel Reigel, Maurizio Trigilia, Luis Weiss, Vincent Beguin, Leon Layer, Violet Ruf, and Stephan Welte — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

A key building block for a quantum internet is a versatile multi-qubit quantum network node that can process and distribute quantum information. An array of neutral atoms, coupled to an optical cavity, is a promising hardware platform for implementing such a node. In this architecture, the cavity serves as the interface between the stationary atomic qubits and the flying photonic qubits. Leveraging optical tweezers, the atoms in the array are positioned and addressed within the cavity mode.

We present a setup featuring two acousto-optical deflectors that generates multiple optical tweezers for trapping and addressing arrays of ^{87}Rb atoms. Using this setup, we plan to trap atoms both within the cavity mode and next to it. This way, we can counteract the inevitable intra-cavity atom losses by reloading atoms from an atom reservoir outside the cavity. We discuss the experimental techniques and challenges associated with our optical setup, and describe the software developed for the project.

Q 5.2 Mon 12:00 P 11

Hybrid Trapping of Cold Atoms with Surface Forces and Blue-Detuned Evanescent Light on a Nanophotonic Waveguide — •Riccardo Pennetta, Antoine Glicenstein, Philipp Schneeweiss, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt Universitaet zu Berlin, 12489 Berlin, Germany

We demonstrate a novel hybrid nanophotonic trap for cold neutral atoms, leveraging surface forces for attraction and blue-detuned evanescent light for repulsion. We attribute the attractive potential to a combination of Casimir-Polder interactions and electrostatic charges distributed on the waveguide surface. Despite the trap's shallow depth, we efficiently load atoms into it via adiabatic transfer from a conventional two-color dipole trap. Remarkably, the hybrid trap supports a long atomic storage time of 140(9) ms and exhibits a Ramsey coherence time of 16.8(2) ms, the latter exceeding significantly previous reports for nanophotonic systems. Our results pave the way for further exploration of atom-surface interactions at the nanoscale and illustrate the potential of harnessing surface forces to enhance storage and coherence times for atoms coupled to nanophotonic waveguides. This advancement offers new opportunities for neutral-atom quantum technologies.

Q 5.3 Mon 12:15 P 11

Rotational cooling of trapped molecular ions — •Monika Leibscher, Alexander Blech, and Christiane P. Koch — Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, Germany

Polyatomic molecules are a promising new platform for fundamental physics and quantum information processing due to their rich internal structure. In particular, their rotational degrees of freedom span a large, well-isolated Hilbert space with strong anharmonicities, enabling precise control. Utilizing these features requires trapping and rotational cooling of molecules. We consider polar molecular ions which are co-trapped with atomic ions in a linear Paul trap. Dipole interaction couples molecular rotation to the collective vibration of the particles in the trap [1, 2]. We demonstrate that the complex rotational spectrum of asymmetric top molecules enables strong dipolar coupling that can be utilized for sympathetic sideband cooling of the rotational degrees of freedom [3]. Furthermore, by combining sideband cooling with coherent microwave control [4], we show that it is possible to tailor the rotational state distribution - either depleting arbitrary subspaces or cooling the entire manifold into a single rotational state.

[1] W. C. Campbell, E. R. Hudson, Phys. Rev. Lett. 125, 120501 (2020). [2] M. Leibscher, F. Schmidt-Kaler, Ch. P. Koch, arXiv:2504.00590 (2025). [3] M. Leibscher, Ch. P. Koch, arXiv:2506.20846 (2025). [4] M. Leibscher, E. Pozzoli, C. Perez, M. Schnell, M. Sigalotti, U. Boscain and Ch . P. Koch, Commun. Phys. 5, 110 (2022).

Q 5.4 Mon 12:30 P 11

Λ-enhanced gray-molasses loading and EIT cooling of neutral atoms in nanophotonic traps — Lukas Pache, Antoine Glicenstein, Arno Rauschenbeutel, •Philipp Schneeweiss, Jürgen Volz, and Riccardo Pennetta — Department of Physics, Humboldt-Universität zu Berlin, 12489 Berlin, Germany

Nanophotonic waveguides enable the observation of strong interactions between guided photons and ensembles of laser-cooled atoms. However, nanophotonic traps for cold atoms typically have mode volumes $\ll \lambda^3$, far smaller than for free-space optical tweezers. This makes efficient loading of these traps challenging, thereby limiting the total number of waveguide-coupled atoms. Here, we implement Λ-enhanced gray-molasses (GM) in a nanofiber-based cold-atom setup and observe a 7-fold increase in the trap loading efficiency. We operate in an unconventional regime for GM cooling, given that our optical traps have a depth of only 22 μK. Despite this, we load more than 2000 atoms, achieving optical depths exceeding 100. After loading, using the GM beams, we perform efficient EIT-assisted cooling that is found to increase the trap storage time to 400(9) ms. This is a 5-fold improvement over the passive storage time. Remarkably, EIT-cooling also works with a single nanofiber-guided beam, requiring only about 100 pW of optical power. Our results provide an effective method to boost both the loading rate and the storage time of nanophotonic atom traps. Since GM employs blue-detuned light, they also offer a pathway to surpass the collisional blockade in nanophotonic traps and explore collective radiative phenomena such as selective radiance.

Q 5.5 Mon 12:45 P 11

Grey molasses cooling with grating magneto-optical traps — •Kai-Christian Bruns, Julian Lemburg, Joseph Muchovo, Vivek Chandra, Sam Ondráček, Hendrik Heine, and Ernst M. Rasel — Leibniz Universität Hannover, Institut für Quantenoptik

In the field of quantum sensing, cold atomic clouds are utilized as test masses in high-precision matter wave interferometers. They can be created using grating atom chips, which simplify and miniaturize quantum sensors by enabling the trapping of atoms in a grating magneto-optical trap with a single incident beam. This enhances the scalability and portability of quantum sensing devices and holds promise for a wide array of applications, from fundamental research to practical implementations in earth observation.

In this talk, we show sub-Doppler cooling results on the D_2 line of ^{87}Rb utilizing gray molasses cooling. We manage to cool the atoms to (830±100)nK and increase the phase-space density by a facor of three compared to conventional molasses cooling. The cooling performance surpasses state of the art gray molasses cooling experiments with ordinary six beam MOTs.