Q 2: Optomechanics

Time: Monday 11:00–12:45 Location: a310

Q 2.1 Mon 11:00 a310

Motional quantum ground state of a levitated nanoparticle from room temperature — •Uros Delic[1,2], Manuel Reisenbauer[1], Kahan Dare[1,2], David Grass[1], Vladan Vuletic[3], Nikolai Kiesel[1], and Markus Aspelmeyer[1,2] — [1]Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria — [2]Institute for Quantum Optics and Quantum Information (IQOQI) Vienna, Austrian Academy of Sciences, Boltzmanngasse 3, A-1090 Vienna, Austria — [3]Department of Physics and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

Optically levitated silica nanoparticles in ultra-high vacuum promise access to quantum behavior of massive objects in a room-temperature environment, with applications ranging from sensing to testing fundamental physics. We have recently developed a new experimental interface, which combines stable trapping potentials of optical tweezers with the cooling performance of optical cavities and demonstrated operation at desired experimental conditions. Furthermore, we implemented a new cooling method – cavity cooling by coherent scattering – which resolves typical technical issues of high phase noise at low motional frequencies and co-trapping by the cavity. We employ this method to demonstrate ground state cooling of the nanoparticle motion, a first step towards its full quantum control. In this talk I will compare its performance to standard (dispersive) optomechanical interaction and present our latest experimental results.

Q 2.2 Mon 11:15 a310

Levitated quantum electromechanics with charged nanoparticles — •Lukas Martinetz[1], Klaus Hornberger[1], and Benjamin A. Stickler[2] — [1]University of Duisburg-Essen, Faculty of Physics, 47048 Duisburg, Germany — [2]Imperial College London, Quantum Optics and Laser Science, London SW7 2AZ, United Kingdom

We propose an all-electrical platform for quantum experiments with charged nanoparticles of arbitrary shape and charge distribution. Each nanoparticle is levitated in a Paul trap, where its motion can be cooled resistively [1,2] and interfaced coherently with superconducting circuitry. We derive the effective potential of the ro-translational macromotion in the trap and develop a Raman-like pulsed interference protocol, which enables generating and observing spatial superpositions of the nanoparticles. This approach complements conventional optomechanical methods, providing a platform for generating entanglement between several nanoparticles and opening the door for networking levitated nanoparticles into hybrid quantum systems.

[1] Daniel Goldwater et al., Quantum Sci. Technol. 4, 024003 (2019)
[2] L. S. Brown et al., Rev. Mod. Phys. 58, 233 (1986)

Q 2.3 Mon 11:30 a310

Entangling optically levitated nanoparticles by coherent scattering — •Henning Rudolph[1], Klaus Hornberger[1], and Benjamin Stickler[1,2] — [1]Fakultät für Physik, Universität Duisburg-Essen — [2]QOLS, Imperial College London

Recently, coherent scattering of tweezer photons has been used to cool a levitated nanoparticle to the motional ground state [1]. We show how this technique can be extended to generate and verify translational entanglement between two nanoparticles, levitated in a common cavity and prepared in the ground state. Our method is based on the conditioned switching of the tweezer detuning from the blue to the red after detecting a Stokes photon. The arrival time distribution of the resulting anti-Stokes photon emission then reveals entanglement between the two particles provided its oscillation amplitude exceeds a time-dependent bound.

[1] U. Delić et al.: arXiv:1911.04406

Q 2.4 Mon 11:45 a310

Quantum States of Acoustic Modes in Optomechanical System — •Daniel Reiche[1,2], Kurt Busch[1,2], and Ryan O. Behunin[3] — [1]Humboldt-Universit\"at zu Berlin, Institut f\"ur Physik, AG Theoretische Optik \& Photonik, Newtonstr. 15, 12489 Berlin, Germany — [2]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2A, 12489 Berlin, Germany — [3]Department of Physics and Astronomy, Northern Arizona University, Flagstaff, AZ 86011, USA

Photons exchanging momentum with matter for the price of creating phonons is a remarkable feature of the interface between quantum electrodynamics and solid state physics. Under certain conditions, the decay length of the acoustic mode can become much larger than the physical dimensions of the material and the phonon exists over a surprisingly large period of time. This provides an intriguing playground for exploring and manipulating the phonon's quantum state.

In this context, we analyze the quantum properties of phonons excited in a medium due to the interaction with a coherent cavity field. For negligible dissipation, we solve the time evolution of an initially coherent state exactly and can demonstrate the existence of non-classicality.

Q 2.5 Mon 12:00 a310

Investigation of mechanical losses and photoelasticity in mechanical oscillators for applications in optomechanical devices — •Jan Meyer[1], Johannes Dickmann[2], Maik Bertke[3], Richard Norte[4], Peter Steeneken[5], Erwin Peiner[3], and Stefanie Kroker[1,2] — [1]LENA Laboratory for Emerging Nanometrology, TU Braunschweig, Pockelsstraße 14, 38106 Braunschweig, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [3]Institut für Halbleitertechnik, TU Braunschweig, Hans-Sommer-Str. 66, D-38106 Braunschweig, Germany — [4]Kavli Institute of Nanoscience, Delft University of Technology, Delft, 2628CJ, The Netherlands — [5]Solid State Physics Laboratory, Materials Science Centre, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands

The coupling of mechanical motion and optical fields is in many applications of interest like molecule detection, material investigation and sensing as well as in fundamental quantum experiments such as ground state cooling. The mechanical loss of oscillators and the photoelasticity of the involved materials are critical parameters for the coupling and thus for the design of optomechanical devices. The loss mechanisms in micro- and nanooscillators are still hardly known. In this contribution we demonstrate how temperature dependent measurements of first mechanical loss and second photoelasticity in mechanical oscillators perform. We present measurement results on silicon and diamond which are supported by finite element modelling and semi-analytical models.

Q 2.6 Mon 12:15 a310

Quantum tennis-racket dynamics of nanoscale rigid rotors — Yue Ma[1], Kiran Khosla[1], •Benjamin A. Stickler[1,2], and M. S. Kim[1] — [1]Imperial College London, London, United Kingdom — [2]University of Duisburg-Essen, Duisburg, Germany

We identify and discuss a quantum interference effect in the torque-free rotations of an asymmetric rigid body rapidly revolving around its mid-axis. The effect is based on the fact that the classical rotations around the mid-axis are unstable, leading to a pronounced quantum signature in the form of persistent periodic flipping between two opposite orientations. These quantum coherent oscillations persist much longer than their classical counterpart, even in the limit that millions of angular momentum states are occupied. We discuss how they can be observed with optically levitated nanoparticles.

Q 2.7 Mon 12:30 a310

Full time evolution of interacting harmonic oscillators in the ultra-strong coupling regime — •David Edward Bruschi[1] and Andreas Wolfgang Schell[2] — [1]Theoretical Physics, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Institute of Solid State Physics, Leibniz Universität Hannover, 30167 Hannover, Germany

In this work we study the time evolution of an ideal system composed of two coupled harmonic oscillators in the strong coupling regime. We solve the dynamics analytically by employing specifically developed tools to decouple the time-evolution operator induced by quadratic Hamiltonians. We use the solution to compute quantities of interest and compare them with the analogue classical solution. We also show that the full time evolution is equivalent to a specific series of beam-splitters and single mode squeezers. This allows for the system to be simulated with simple linear optics implementations. Applications to theory and experiments are also discussed.