Q 54: Quantum Optics and Quantum Information with Rigid Rotors (joint session MO/Q/QI)

Time: Thursday 14:30–16:30 Location: F102

Q 54.1 Thu 14:30 F102

Cooling and control of the translational and rotational motion of a nano rotor — •Peter Barker[1], Antonio Pontin[1], Marko Toros[2], Hayden Fu[1], Tania Monteiro[1], Jonathan Gosling[1], and Markus Rademacher[1] — [1]University College London, UK — [2]University of Glasgow, Glasgow, UK

There has been significant interest in controlling the motional degrees of isolated, single nanoparticles, trapped within optical fields in high vacuum. They are seen as ideal candidates for exploring the limits of quantum mechanics in a new mass regime while they are also massive enough to be considered for future laboratory tests of the quantum nature of gravity. In this talk I will report on the control and cooling of all translational and rotational degrees of freedom of a nanoparticle trapped in an optical tweezer using cooling via coherent elliptic scattering where translational temperatures in the 100 μK range were reached, while temperatures as low as 5\,mK were attained in the librational degrees of freedom. I will also outline nanoparticle characterisation techniques based on the control and measurement of the librational and translational motion. This work opens up future applications in quantum science and the characterisation of single isolated nanoparticles free of interference from a substrate.

Q 54.2 Thu 14:45 F102

Polarization control of optically levitated nanoparticles — •Yanhui Hu, James Sabin, Mudassar Rashid, and James Millen — Department of Physics, King's College London, Strand, London

The optical control of anisotropic particles opens up applications in torque sensing and the study of rotational quantum mechanics. The angular modes of a levitated particle are markedly different from the linear modes, and new tools are required to achieve full control. In the Levitated Nanophysics Group at King's College London we work with nanofabricated silicon nanorods, which allow enhanced control over all degrees-of-freedom. We control the rotation of the nanorods through a recently discovered method for generating transverse optical vortices, which can be used to exert a large torque on an array of levitated nanoparticles. We also present a method to simultaneously cool all of the linear and angular modes of levitated, anisotropic particles, without the necessity for a delicate optical cavity.

Q 54.3 Thu 15:00 F102

Surface-induced decoherence and heating of charged rigid rotors — •Lukas Martinetz, Klaus Hornberger, and Benjamin A. Stickler — University of Duisburg-Essen

Levitating charged particles in ultrahigh vacuum provides a preeminent platform for quantum information processing, for quantum-enhanced force and torque sensing, for probing physics beyond the standard model, and for high-mass tests of the quantum superposition principle. Existing setups, ranging from single atomic ions to ion chains and crystals to charged molecules and nanoparticles, are crucially impacted by fluctuating electric fields emanating from nearby electrodes used to control the motion. In this article, we provide a theoretical toolbox for describing the rotational and translational quantum dynamics of charged nano- to microscale objects near metallic and dielectric surfaces, as characterized by macroscopic dielectric response functions. The resulting quantum master equations describe the coherent surface-particle interaction due to image charges and Casimir-Polder potentials as well as surface-induced decoherence and heating with the experimentally observed frequency and distance scaling. We explicitly evaluate the master equations for relevant setups, thereby providing the framework for describing and mitigating surface-induced decoherence as required in future quantum technological applications.

Q 54.4 Thu 15:15 F102

Decoherence-Free Rotational Degrees of Freedom for Quantum Applications — •Julen S. Pedernales, Francesco Cosco, and Martin B. Plenio — Institut für Theoretische Physik und IQST, Albert-Einstein-Allee 11, Universität Ulm, D-89081 Ulm, Germany

I will describe the use of spherical t-designs for the systematic construction of solids whose rotational degrees of freedom can be made robust to decoherence due to external fluctuating fields while simultaneously retaining their sensitivity to signals of interest. Specifically, the ratio of the signal phase accumulation rate from a nearby source to the decoherence rate caused by fluctuating fields from more distant sources can be incremented to any desired level by using increasingly complex shapes. This allows for the generation of long-lived macroscopic quantum superpositions of rotational degrees of freedom and the robust generation of entanglement between two or more such solids with applications in robust quantum sensing and precision metrology as well as quantum registers.

[1] J. S. Pedernales, F. Cosco, and M. B. Plenio, Phys. Rev. Lett. 125, 090501 (2020).

Q 54.5 Thu 15:30 F102

Group report: Precision spectroscopy and quantum information with trapped molecules — •Brandon Furey, Stefan Walser, Zhenlin Wu, Guanqun Mu, Rene Nardi, and Philipp Schindler — Institut für Experimentalphysik, Universität Innsbruck, Österreich

The quantum molecules group at the University of Innsbruck utilizes a range of innovative advances in molecular spectroscopy and quantum logic spectroscopy (QLS) to study molecular rovibrational structure and explore quantum information processing with trapped molecules. The efforts of our group are divided into three projects. The first is pump-probe recoil spectroscopy, where we measure the rovibrational population dynamics excited by a pump pulse by mapping them to the electronic state of an atomic ion via QLS. The second project investigates state-dependent force spectroscopy, where an optical tweezer generates a state-dependent force on a trapped molecule. Our third project is demonstrating superpositions of rotational states in a diatomic molecular ion built using stimulated Raman transitions driven by two beams from an optical frequency comb. This could pave the way for using quantum error correction to realize the use of trapped molecules for quantum information or memory. We are interested in creating the rotational superposition states that form the codewords of a truncated $Z_3 \subset Z_6$ linear rotor code. In order to demonstrate ultrafast light-matter interaction in our system, we have measured the photodissociation spectrum of $CaOH^+$ using an optical parametric amplifier.

Q 54.6 Thu 15:45 F102

From the rotation of a planar rigid rotor in electric fields to the semifinite-gap structure of an optical superlattice — •Marjan Mirahmadi[1], Bretislav Friedrich[1], Burkhard Schmidt[2], and Jesús Pérez-Ríos[1,3,4] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — [2]Weierstraß-Institut, Berlin, Germany — [3]Department of Physics, Stony Brook University, NY , USA — [4]Institute for Advanced Computational Science, Stony Brook University, NY, USA

We show that two seemingly unrelated problems − the trapping of an atom in a one-dimensional optical superlattice (OSL) formed by the interference of optical lattices whose spatial periods differ by a factor of two, and the libration of a polar polarizable planar rotor (PR) in combined electric and optical fields − have isomorphic Hamiltonians. It is possible to establish a map between the translations of atoms in the former system and the rotations of the rotor due to the coupling of its permanent and induced electric dipole moments to the external fields. The latter system belongs to the class of conditionally quasi-exactly solvable problems in quantum mechanics and exhibits intriguing spectral properties. We make use of our findings to explain the *semifinite-gap* band structure of the OSL. This band structure follows from the eigenenergies obtained as solutions of the Whittaker-Hill equation and their genuine and avoided crossings. Furthermore, the mapping makes it possible to establish correspondence between concepts, such as localization on the one hand and orientation/alignment on the other.

Q 54.7 Thu 16:00 F102

Experimental advances in the quest for perfect enantiomer-specific state control of cold molecules — •Juhyeon Lee[1], Johannes Bischoff[1], Alicia. O. Hernandez-Castillo[2], Boris Sartakov[1], Gerard Meijer[1], and Sandra Eibenberger-Arias[1] — [1]Fritz Haber Institute of the Max Planck Society, Berlin, Germany — [2]Harvey Mudd College, Claremont, California, USA

Enantiomer-specific state transfer (ESST) was recently developed us-

ing tailored microwave fields [1]. This technique enables the population or depopulation of a rotational state of a chosen enantiomer, providing a way of quantum-controlled chiral separation. Recently, we have explored spectroscopic schemes to overcome previous limitations in the transfer efficiency of ESST: thermal population of the rotational levels and M_J degeneracy [2]. We improved the transfer efficiency up to 50%, and quantitatively studied ESST for the first time [3]. The experimental ESST efficiency was $\sim 20\%$ lower than theoretically expected. We attribute this partially to imperfections in the microwave polarizations and their respective orthogonality. We show a method to experimentally determine the polarization of microwave fields in-situ by quantitative analysis of molecular Rabi oscillations.

[1] S. Eibenberger, et al., Phys. Rev. Lett. 118, 123002 (2017)
[2] M. Leibscher, et al., Commun. Phys. 5, 1 (2022).
[3] J. H. Lee, et al., Phys. Rev. Lett. 128, 173001 (2022)

Q 54.8 Thu 16:15 F102

Photoelectron circular dichroism in rotationally excited mixtures — •Alexander Blech[1], Loren Greenman[2], Reinhard Dörner[3], and Christiane P. Koch[1] — [1]Fachbereich Physik, Freie Universität Berlin, Berlin, Germany — [2]Department of Physics, Kansas State University, Manhattan, KS, USA — [3]Institut für Kernphysik, Goethe-Universität, Frankfurt am Main, Germany

Gas phase experiments with chiral molecules may be carried out with randomly oriented molecules because there exist enantiomer-sensitive observables that survive orientational averaging. The strength of these observables is directly related to the enantiomeric excess and vanishes in the limit of a racemic mixture. Here we turn the perspective around and investigate whether it is possible to detect chiral signatures from racemic, but rotationally excited mixtures. We focus on photoelectron circular dichroism (PECD), which is the forward-backward asymmetry in the photoelectron angular distributions of chiral molecules upon ionization with circularly polarized light. Based on an analysis of the electric dipole response in rotationally excited molecular ensembles, we show that PECD can be observed in racemic mixtures by breaking the isotropy of the orientational distribution.