MO 10: Ultracold Molecules (joint session Q/MO)

Time: Wednesday 11:00–13:00 Location: HS 1015

Invited Talk MO 10.1 Wed 11:00 HS 1015

Ultracold interactions between ions and polar molecules — •Leon Karpa — Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, 30167 Hannover, Germany

Ultracold molecules stand out as a promising candidate in a broad spectrum of advanced applications including quantum chemistry, fundamental physics, quantum simulations and information science. Studies of neutral molecular quantum gases and ultracold ion-neutral interactions are two largely complementary interdisciplinary fields that nonetheless share the vision of understanding molecular systems of ever-increasing complexity, and ultimately controlling their properties. In my talk, I will discuss recent advances and challenges in these research domains and how methods from both fields can be used to combine atomic ions with quantum gases of polar molecules. The resulting complex yet precisely controllable system exhibits a hierarchy of tunable attractive and repulsive interactions of different scales, enabling a range of novel experiments and applications. This includes studies of dynamical properties of ultracold polar molecules, ion-molecule collisions in the quantum dominated regime, and the potential formation of ion-molecule many-body bound states.

MO 10.2 Wed 11:30 HS 1015

Developing a Hybrid Tweezer Array of Rydberg Atoms and Polar Molecules — •Kai Voges, Daniel Hoare, Yuchen Zhang, Qinshu Lyu, Jonas Rodewald, Ben Sauer, and Michael Tarbutt — Centre for Cold Matter, Imperial College London, UK

Hybrid tweezer arrays of atoms and molecules are a novel and versatile platform for quantum science and technology. The combination of Rydberg atoms with their large electric dipole moment and polar molecules with their rich level structure and long state coherence times makes this approach a promising candidate for quantum simulation [1] and computing [2,3].

In this talk, I present our efforts to build a hybrid tweezer array based on ultracold Rb atoms and directly laser-coolable CaF molecules. I discuss the advantages and challenges of using such a hybrid system and present our preparation procedures for the atoms and molecules. Furthermore, I show our efforts in trapping and imaging individual atoms and molecules and present our ideas for loading both species into separate tweezer arrays.

Our approach will make it possible to construct arbitrary patterns of atoms and molecules. Through the dynamic rearrangement of tweezers and the long-range interactions mediated by Rydberg atoms, this hybrid platform will be a compelling candidate for scalable quantum computing.

[1] J. Dobrzyniecki *et al.*, PRA **108**, 052618 (2023)
[2] C. Zhang *et al.*, PRX Quantum **3**, 030340 (2022)
[3] K. Wang *et al.*, PRX Quantum **3**, 030339 (2022)

MO 10.3 Wed 11:45 HS 1015

Quantum Dynamics of Two Composite Bosons on a One-Dimensional Lattice — •Caroline Stier, Andreas Buchleitner, and Gabriel Dufour — Physikalisches Institut der Albert-Ludwigs-Universität Freiburg

We study how the dynamics of two composite bosons on a one-dimensional lattice are affected by their constituents' quantum statistics as well as their initial state. We formulate an effective Hamiltonian assuming that the two composites – consisting either of two elementary fermions or two elementary bosons – are tightly bound objects. The contact interactions between the elementary constituents are chosen such that the resulting composite particles do not interact when they are located on the same site. However, due to the exchange of identical constituents, the composites experience an effective nearest-neighbor interaction if they are located on adjacent sites. We solve the Schrödinger equation analytically and perform numerical simulations of the dynamics from several initial configurations. In particular, we find that the composites can form a bound state whose group velocity depends strongly on the nature of their constituents.

MO 10.4 Wed 12:00 HS 1015

Non-abelian invariants in periodically-driven quantum rotors — •Volker Karle, Areg Ghazaryan, and Mikhail Lemeshko — Institute of Science and Technology Austria, Am Campus 1, 3400 Klosterneuburg

This presentation explores the role of topological invariants in the non-equilibrium dynamics of periodically-driven quantum rotors, inspired by experiments on closed-shell diatomic molecules driven by periodic, far-off-resonant laser pulses. This approach uncovers a complex phase space with both localized and delocalized Floquet states. We demonstrate that the localized states are topological in nature, originating from Dirac cones protected by reflection and time-reversal symmetry. These states can be modified through laser strength adjustments, making them observable in current experiments through molecular alignment and observation of rotational level populations. Notably, in scenarios involving higher-order quantum resonances leading to multiple Floquet bands, the topological charges become non-Abelian. This results in the remarkable finding that the exchange of Dirac cones across different bands is non-commutative, enabling non-Abelian braiding, paving the way for the study of controllable multi-band topological physics in gas-phase experiments with small molecules, as well as for classifying dynamical molecular states by their topological invariants.

MO 10.5 Wed 12:15 HS 1015

From rotational decay of diatomic molecules to quantum friction — •Nicolas Schüler, Omar Jesús Franca Santiago, and Stefan Yoshi Buhmann — Institute of Physics, University of Kassel, Germany

We study the rotational motion of diatomic molecules in free space and interacting with the quantum electromagnetic field [1]. Using macroscopic quantum electrodynamics [2], we obtain the rotation-dependent decay rates of the molecule. By analyzing the behavior of the resulting rates at zero and finite temperature, we find a connection between the decelerating rotational dynamics and quantum friction.

Invited Talk MO 10.6 Wed 12:30 HS 1015

Quantum Logic Spectroscopy of the Hydrogen Molecular Ion — David Holzapfel, Fabian Schmid, Nick Schwegler, Oliver Stadler, Martin Stadler, Jonathan Home, and •Daniel Kienzler — Otto-Stern-Weg 1, 8093 Zurich, Switzerland

I will present our latest results, implementing pure quantum state preparation, coherent manipulation, and non-destructive state readout of the hydrogen molecular ion H_2^+. The hydrogen molecular ion H_2^+ is the simplest stable molecule, and its structure can be calculated ab-initio to high precision. However, challenging properties such as high reactivity, low mass, and the absence of rovibrational dipole transitions have thus far strongly limited spectroscopic studies of H_2^+. We trap a single H_2^+ molecule together with a single beryllium ion using a cryogenic Paul trap apparatus, achieving trapping lifetimes of 11 h and ground-state cooling of the shared axial motion [1]. With this platform we have recently implemented *Quantum Logic Spectroscopy* of H_2^+. We utilize helium buffer-gas cooling to prepare the lowest rovibrational state of ortho-H_2^+ (rotation $L = 1$, vibration $\nu = 0$). We combine this with quantum-logic operations between the molecule and the beryllium ion for preparation of single hyperfine states and non-destructive readout, and demonstrate Rabi flopping on on several hyperfine transitions. Our results pave the way to high-precision spectroscopy studies of H_2^+ which will enable tests of theory, metrology of fundamental constants, and an optical molecular clock.

[1] N. Schwegler, D. Holzapfel, M. Stadler, A. Mitjans, I. Sergachev, J. P. Home, and D. Kienzler, Phys. Rev. Lett. 131, 133003 (2023)