Q 23: Cold Molecules (joint session MO/Q)

Time: Tuesday 11:00–13:15 Location: P 105

Invited Talk Q 23.1 Tue 11:00 P 105

Observation of diffraction oscillations and low-energy resonances in elastic collisions between He Rydberg atoms and HD molecules — •Arijit Das[1], Yufeng Wang[1], Karl Horn[1], Piotr Zuchowski[2], Julia Narevicius[1], and Edvardas Narevicius[1] — [1]Technische Universität Dortmund, Dortmund, Germany — [2]Nicolaus Copernicus University, Torun, Poland

Observation of shape and Feshbach resonances in low-energy ion-neutral collisions has been a long-standing goal, but such collisions at cold temperatures remain elusive because of the difficulty of controlling ion beams. While Feshbach resonances between ions and atoms have been observed using magnetically tunable interactions [1], Rydberg atoms offer a powerful platform for exploring quantum collision dynamics in ion-molecule systems. The Rydberg electron acts as a spectator, effectively shielding the ion core and enabling precise investigations of long-range interactions during ion core-molecule collisions.

In this work, we investigate elastic collisions between helium Rydberg atoms and HD molecules at cold temperatures using a merged-molecular-beam apparatus. Velocity-map images of scattered helium reveal pronounced diffraction oscillations linked to partial-wave contributions dominated by ion core-neutral interactions. By tuning the collision energy, we also observe a series of low-energy scattering resonances. These observations provide a new pathway for detecting low-energy ion-molecule resonances that have, until now, remained inaccessible.

(1) Weckesser, Pascal, et al. Nature, 600, 429-433 (2021).

Q 23.2 Tue 11:30 P 105

Surface collision and thermalisation of a laser-coolable molecule aluminium monofluoride — •Pulkit Kukreja, Lasse Rautenberg, Sebastian Kray, Gerard Meijer, and Sid Wright — Fritz-Haber-Institut der MPG, Faradayweg 4-6, 14195 Berlin

Until very recently, direct laser cooling of molecules has been restricted to reactive species with $^2\Sigma$ electronic ground states. These molecules are challenging to produce and have only been captured into a magneto-optical trap (MOT) from pulsed, cryogenically cooled molecular beam sources. These are rather complex, expensive, and difficult to operate reliably for long periods.

At the Fritz Haber Institute, we have now realised the first MOT of a spin-singlet molecule: aluminum monofluoride (AlF). AlF has high chemical stability compared to $^2\Sigma$ molecules, and can also be made efficiently at moderate temperatures ($\sim$ 900 K) in an oven. Remarkably, we observe that AlF can survive collisions with, and therefore thermalise to, room temperature vacuum walls of our experiments.

Here, we present the outcomes of single AlF-surface collisions on a camera via Doppler-sensitive laser-induced fluorescence. We observe that AlF undergoes trapping-desorption at surfaces, with complete rovibrational and translational thermalisation to the surface. The collision outcomes are highly surface-dependent, with polydimethylsiloxane (PDMS) coatings having a low sticking coefficient. Our results open a pathway to molecular MOTs loaded from compact and inexpensive beam sources and suggest that the technology employed in atomic vapour cells can be applied to a laser-coolable molecule.

Q 23.3 Tue 11:45 P 105

Decoding Feshbach resonances of Ne+HD+ reaction using ion-electron coincidence and merged beam techniques — •Yufeng Wang[1], Arijit Das[1], Baruch Margulis[2], Karl Horn[1,3], Meenu Upadhyay[4], Markus Meuwly[4], Christiane Koch[3], and Edvardas Narevicius[1] — [1]Technische Universität Dortmund — [2]National Institute of Standards and Technology — [3]Freie Universität Berlin — [4]University of Basel

Feshbach resonance in collisions is an interesting quantum effect. In AMO studies, Feshbach resonance is widely used to produce Feshbach molecules by tuning the magnetic field. In reaction dynamics studies, Feshbach resonances also play a critical role in influencing the scattering cross section. However, this important phenomenon remains unclear to us due to the difficulty of experimental measurement.

Here, we developed a new method to investigate the Feshbach resonance based on ion-electron coincidence measurements, starting with a cold collision that leads to Penning ionization.[1] This new method was applied to research on Feshbach resonances in the Ne and HD+ collision. Assisted by the merged-beam technique, we lowered the collision energy to 22 mK and realized a p-wave (l=1) scattering. Combined with the high-resolution velocity map imaging technique, more substructures were observed and assigned to the Feshbach resonances arising from different vibrational modes of Ne-HD+ by high-accuracy quantum calculations. This work deepens our understanding of the Feshbach resonances in scattering.

(1) Margulis, B. et al. Science 380,77-81(2023).

Q 23.4 Tue 12:00 P 105

Magneto-optical trapping of aluminum monofluoride — •Jionghao Cai[1], José Eduardo Padilla Castillo[1], Priyansh Agarwal[1], Pulkit Kukreja[1], Russell Thomas[1], Boris Sartakov[1], Stefan Truppe[2], Gerard Meijer[1], and Sidney Wright[1] — [1]Fritz-Haber-Institute, Berlin, Germany — [2]Imperial College London, London, UK

Ultracold polar molecules have aroused great interest for their applications in testing fundamental physics and chemistry. Whilst there has been considerable success in associating ultracold diatomic molecules from laser-cooled atoms, these species are weakly bound and scarce in nature. A complementary approach is to laser cool molecules directly. So far, all diatomic and polyatomic species loaded into a magneto-optical trap (MOT) are spin-doublet molecules, and therefore chemically reactive. Moreover, their electronic structure only supports simple optical cycling from the first rotationally excited ($N = 1$) level.

Recently, we demonstrated the first MOT of a molecule with a (spin-singlet) $X^1\Sigma^+$ electronic ground state, aluminum monofluoride (AlF). We can routinely trap 6×10^4 AlF molecules via the deep ultraviolet $A^1\Pi \leftarrow X^1\Sigma^+$ transition, and, different to spin-doublet molecules, can straightforwardly select different rotational levels in the MOT. In this talk, I will provide a status update for the AlF MOT experiments, investigations of potential loss channels in the cooling cycle, and prospects for further cooling and trapping.

Q 23.5 Tue 12:15 P 105

Colder collisions for cleaner tomography of Feshbach resonances between atoms and molecules — •Karl P. Horn[1,2], Arijit Das[1], Yufeng Wang[1], Julia Narevicius[1,4], Meenu Upadhyay[3], Baruch Margulis[4], Daniel M. Reich[2], Markus Meuwly[3], Christiane P. Koch[2], and Edvardas Narevicius[1,4] — [1]Technische Universität Dortmund — [2]Freie Universität Berlin — [3]University of Basel — [4]Weizmann Institute of Science

Fundamental quantum effects are investigated at the interface between theory and experiment. Foremost amongst these are Feshbach resonances - observed, for instance, in collisions between rare gas atoms and a dihydrogen molecule ions (and their isotopomers). By launching collisions using Penning ionisation, coincidence measurement can yield a tomographic picture between incoming and outgoing quantum states [1]. Ab initio calculations convoluted to match the experimental resolution demonstrate good agreement with these experiments.

Until now, resolving contributions to the spectra due to individual initial partial waves and Feshbach resonances has been beyond experimental limitations [2]. The latest experiments demonstrate sufficient resolution to resolve these features and thereby test the validity of high-quality potential energy surfaces. By utilising Feshbach resonances characteristic to individual electronic structure methods and basis sets, a systematic comparison can be made between experiment and different levels of theory.

(1) Baruch Margulis et al. Science 380,77-81(2023).
(2) Karl P. Horn et al. JPCL 16 (31), 7862-7867 (2025).

Q 23.6 Tue 12:30 P 105

Electric-field control of atom-molecule Feshbach resonances — •Mara Meyer zum Alten Borgloh, Jule Heier, Fritz von Gierke, Baraa Shammout, Eberhard Tiemann, Leon Karpa, and Silke Ospelkaus — Leibniz University Hannover

We present our latest results on collisions between $^{23}Na^{39}K$ molecules and ^{39}K atoms, where we successfully observe Feshbach resonances between these scattering partners. For the first time in comparable systems, we demonstrate the ability to control the position of these resonances using electric fields. This allows us to investigate the electric field dependence of bound trimer states and assign specific quantum numbers to these states.

Our observations highlight a significant influence of the potassium atom on the molecule, despite the weak binding of the trimer state, which can be attributed to hindered rotation. These findings represent a new step in controlling atom-molecule interactions in ultracold gases and offer valuable insights into the behavior of molecular systems under external fields.

Q 23.7 Tue 12:45 P 105

Theory and experiments towards laser cooling of NH — •Daniel Roesch — TU Dortmund, Germany

Laser cooling of atoms is a well-established technique to reach very low temperatures and to generate degenerate quantum gases. Due to their more complex internal structure, molecules are much harder to laser cool. However, laser cooling of CaF, SrF, YO, YbF, BaF, AlF and SrOH has already been demonstrated and many other molecules are currently under investigation. We are working on laser cooling of ^{15}NH. This is a challenging molecule for laser cooling. While its light mass and cooling transition in the UV give rise to large momentum transfer for each absorbed photon, a long lifetime of the excited state and resulting narrow transition are posing considerable challenges. I will present results of hyperfine state resolved laser-induced fluorescence experiments on the cooling transition $A^3\Pi_0 \leftarrow X^3\Sigma^-$ for ^{15}NH as well as high resolution THz spectroscopy probing the $X^3\Sigma^-, N = 1 \leftarrow X^3\Sigma^-, N = 0$ rotational transition in the ground state. In addition to the experimental spectroscopy results I will also present results from laser cooling simulations using the pyLCP python package and machine learning optimization of laser cooling parameters.

Q 23.8 Tue 13:00 P 105

Towards a Dipolar BCS-BEC Crossover — •Eugen Dizer[1], Arthur Christianen[2], Xin Chen[1], and Richard Schmidt[1] — [1]Institut für Theoretische Physik, Universität Heidelberg, 69120 Heidelberg, Germany — [2]Institute for Theoretical Physics, ETH Zürich, Zürich, Switzerland

Dipolar Fermi gases are expected to show exotic phases of matter, such as the supersolid and the Wigner crystal phase. Their anisotropic long-range interactions make them also highly relevant for the study of unconventional superconductivity. In this work, we focus on the case of highly population-imbalanced dipolar Fermi gases to explore their few- and many-body physics. We analyze the quantum scattering of a single impurity in a dipolar Fermi sea, highlighting key differences from conventional short-range interaction models. Additionally, we discuss implications for the polaron-to-molecule transition and Anderson's orthogonality catastrophe, introducing a new theoretical framework to address this problem. Our results provide insights into the interplay between s- and p-wave pairing, and the emergence of supersolid phases, in the dipolar BCS-BEC crossover. We propose an experimental protocol to test the predictions in this work using ultracold molecules.