

## Q 13: Cold Molecules I

Time: Monday 14:00–16:00

Location: V38.03

Q 13.1 Mon 14:00 V38.03

**Statistical multichannel quantum defect theory for resonant scattering of ultracold atoms and molecules** — ●MICHAEL MAYLE, BRANDON P. RUZIC, and JOHN L. BOHN — JILA, University of Colorado and NIST, Boulder, Colorado, USA

With the advent of state-resolved, ultracold samples of ground state molecules, novel opportunities arise to explore the physics of cold and ultracold molecular collisions. We revisit ultracold atom-molecule scattering by employing a multichannel quantum defect theory treatment that makes a clean distinction between the physics of the complex, which is pertinent when the colliding species are close together, and the physics of the long-range scattering, which is sensitive to such things as the hyperfine states of the atoms and molecule, the low collision energy, and any applied electromagnetic fields. This allows us to describe long-range interactions by means of a few quantum defect parameters while for the short-range part we apply the methods of random matrix theory. Uniting these two techniques, we can assess the influence of highly-resonant scattering in the threshold regime, and in particular its dependence on the hyperfine state selected for the collision.

Q 13.2 Mon 14:15 V38.03

**Low energy rare gas - alkali scattering experiments** — ●MATTHIAS STREBEL, BERNHARD RUFF, MARCEL MUDRICH, and FRANK STIENKEMEIER — Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, D-79104 Freiburg

In order to investigate reactive and non reactive collisions between atoms and molecules at very low scattering energies, a magneto-optical trap (MOT) for ultracold  $^7\text{Li}$  atoms is combined with a rotating nozzle setup for producing slow beams of cold molecules. Studying reactive scattering processes with collision energies down to 1 meV, we expect to get insight into the quantum mechanical nature of cold reactions.

First measurements of differential and integrated cross sections of elastic collisions with rare gases already show interesting features like rainbow scattering or glory undulations. The suitability of a MOT as a scattering target for low-energy collision experiments with regard to the particular kinematics resulting from a resting target and diagnostics such as fluorescence imaging as a measure for integral cross sections is discussed.

Q 13.3 Mon 14:30 V38.03

**Long-range interactions in cold atomic and molecular samples** — MAXENCE LEPERS<sup>1</sup>, ROMAIN VEXIAU<sup>1</sup>, MIREILLE AYMAR<sup>1</sup>, BÉATRICE BUSSEY-HONVAULT<sup>2</sup>, JEAN-FRANÇOIS WYART<sup>1</sup>, NADIA BOULOFA<sup>1</sup>, and ●OLIVIER DULIEU<sup>1</sup> — <sup>1</sup>laboratoire Aimé Cotton, CNRS, Université Paris-Sud, Orsay, France — <sup>2</sup>Laboratoire Interdisciplinaire Carnot de Bourgogne, Université de Bourgogne, Dijon, France

Long-range interactions play a crucial role in cold and ultracold physics and chemistry, for example on elastic, inelastic and reactive collisions between atoms and molecules. In this work, we have characterized the long-range interactions for a wide variety of systems being of strong experimental interest. We have calculated the asymptotic electrostatic interaction energy between alkali-metal atoms and diatomic molecules, between erbium atoms, and between oxygen atoms and molecules. In particular, we have focused our study on the Van der Waals contribution which requires a detailed knowledge of the energy spectrum of the two interacting partners. Improved values of dynamic polarizabilities based on accurate ab initio calculations as well as on up-to-date spectroscopic analysis have been determined.

We have obtained a huge dispersion in the Van der Waals coefficients, ranging from a few tens of atomic units for  $\text{O}+\text{O}_2$ , to a few  $10^5$  atomic units for polar diatomic molecules in their ground rovibrational level. In the atom-diatom case, we have shown that for sufficiently small distances the rotational levels of the diatomic molecule can be coupled due to the presence of the partner, leading to a complex pattern of potential energy curves, and possibly a complex collisional dynamics.

Q 13.4 Mon 14:45 V38.03

**The excited level of the  $2p\sigma_u$  electronic state in  $\text{H}_2^+$**  — ●TIM-OLIVER MÜLLER and HARALD FRIEDRICH — Technische Universität München

In Ref. [1] a new weakly bound vibrational level of the  $\text{H}_2^+$  molecular ion with a binding energy of only  $1.0851 \times 10^{-9}$  a.u.  $\approx 30$  neV is

predicted from three-body calculations. It is the (rotationless) excited vibrational level  $v = 1$  of the  $2p\sigma_u$  electronic state.

It is argued in [1] that calculations using the asymptotic expansion of the effective two-body potential for the ungerade state given by Landau [2] can reproduce neither the bound state energy of the  $v = 1$  state nor the scattering properties with sufficient accuracy.

We point out that the  $v = 1$  vibrational state can well be described as a bound state in the distant well of the enhanced p-H two-body potential [3] with a binding energy of  $0.9749 \times 10^{-9}$  a.u., very close to the exact result ( $\approx 10\%$ ). The exact scattering properties including the scattering length are also reproduced with good accuracy.

[1] Carbonell J., *et al.*, *Europhys. Lett.* **64**, 316, (2003)

[2] Landau L. D., and Lifschitz E. M., *Theoretische Physik 3, Quantenmechanik* (Akademie-Verlag, Berlin) 1965, p.305.

[3] Damburg R. J., and Propin R. Kh., *J. Phys. B* **1** 681 (1968).

Q 13.5 Mon 15:00 V38.03

**Two-Photon-Spectroscopy of YbRb-Towards paramagnetic molecules** — FRANK MÜNCHOW, ●CRISTIAN BRUNI, MAXIMILIAN MADALINSKI, and AXEL GÖRLITZ — Institut für Experimentalphysik, HHU Düsseldorf, 40225 Düsseldorf

Ultracold heteronuclear molecules offer fascinating perspectives ranging from ultracold chemistry to novel interactions in quantum gases. Here we report on the spectroscopic investigation of vibrational levels in the electronic ground state of the heteronuclear molecule  $^{176}\text{Yb}^{87}\text{Rb}$ . Using two-photon photoassociation spectroscopy in a laser-cooled mixture of  $^{176}\text{Yb}$  and  $^{87}\text{Rb}$  we are able to determine the binding energies of weakly-bound vibrational levels. By means of Autler-Townes spectroscopy we obtain transition rates between vibrational levels of different molecular states. This knowledge is a crucial step towards the realization of YbRb ground state molecules.

Q 13.6 Mon 15:15 V38.03

**Kalte Reaktionen von Kohlenwasserstoff-Ketten mit  $\text{H}_2$**  — ●ERIC ENDRES, THORSTEN BEST und ROLAND WESTER — Institut f. Ionenphysik und Angewandte Physik A-6020 Innsbruck

Die Entdeckung der ersten molekularen Anionen hat eine intensive Suche nach weiteren Anionen in verschiedenen astronomischen Objekten ausgelöst. Als erstes wurde  $\text{C}_6\text{H}^-$  im Labor und in dichten molekularen Wolken identifiziert [1]. Eine genaue Analyse dieses Moleküliöns ist somit von wesentlicher Bedeutung.

Experimente zum Photodetachment [2] und zu Reaktionen bei Raumtemperatur mit den atomaren Partnern H, N bzw. O [3] wurden bereits durchgeführt. Bei der Reaktion von negativ geladenen Kohlenwasserstoff-Ketten mit molekularem Wasserstoff liegen noch keine Resultate vor. Jedoch gibt es Hinweise, dass diese eher langsam ablaufen ( $k < 10^{-13} \text{cm}^3 \text{s}^{-1}$ ) [3]. Wegen der Häufigkeit von  $\text{H}_2$  im interstellaren Medium ist die genaue Kenntnis der Reaktionsrate der Reaktion dennoch bedeutsam.

Eine kryogene 22-Polige Radiofrequenz-Ionenfalle ermöglicht uns bei langen Speicherzeiten auch die Beobachtung selten ablaufender Reaktionen. Darüber hinaus ist die Temperatur der Falle zwischen 8K und 300K einstellbar, so dass eine mögliche Temperaturabhängigkeit der Reaktion, unter astrophysikalischen Bedingungen, gemessen werden kann [4]. Der aktuelle Stand der Messung wird berichtet.

[1] McCarthy et al. *Ap.J.* 652:L141 (2006); [2] Best et al. *Ap.J.* 742:63 (2011); [3] Eichelberger et al. *Ap.J.* 667:1283 (2007); [4] Otto et al. *Phys. Rev.Lett.* 101:063201 (2008)

Q 13.7 Mon 15:30 V38.03

**Position oscillations in ordinary space probed by asymmetries in doppler shifted Auger-ion coincidence spectra** — ●TORALF LISCHKE<sup>1</sup>, GREGOR HARTMANN<sup>1</sup>, ANDRE MEISSNER<sup>1</sup>, RAINER HENTGES<sup>1</sup>, BURKHARD LANGER<sup>2</sup>, UWE BECKER<sup>1,3</sup>, and OMAR AL-DOSSARY<sup>3</sup> — <sup>1</sup>Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — <sup>2</sup>Freie Universität Berlin, Berlin, Germany — <sup>3</sup>King Saud University, Rhiyad, Saudi Arabia

Inversion symmetry erases the distinction between left and right positions in ordinary space. Instead, coherent superpositions of both sites *gerade* and *ungerade* states are built, which are energetically non-degenerate. Superimposing these superpositions should give rise to reestablishment of the original position states which should, however,

oscillate with a frequency proportional to the energy difference between the original *gerade* and *ungerade* states. We show indirect evidence for this behavior in ordinary space analogous to the already observed behavior in flavor space. This behavior was an oscillation between the two strangeness components  $K$  and  $\bar{K}$  over time. We observe such an oscillation in ordinary space in an indirect way by probing the asymmetry between so called right and wrong Doppler shifted components of resonant Auger electrons following K-shell photo excitation of  $O_2$ . By selecting two types of resonant Auger transition with severely different Auger lifetimes we could make predictions on the expected asymmetry. The asymmetry values of approximately 0.3 and 0.0 for the two cases predicted by our model could be unexpectedly well verified.

Q 13.8 Mon 15:45 V38.03

**The effect of orientation in molecular double-slit experiments**  
— •GREGOR HARTMANN<sup>1</sup>, MARKUS BRAUNE<sup>2</sup>, ANDRE MEISSNER<sup>1</sup>, TORALF LISCHKE<sup>1</sup>, and UWE BECKER<sup>1</sup> — <sup>1</sup>Fritz-Haber-Institut der Max-Planck Gesellschaft, Faradayweg 4-6, 14195, Germany — <sup>2</sup>DESY, Notkestr. 85, 22607 Hamburg, Germany

Molecular double-slit experiments are a subject of high actual interest for the study of entanglement in ordinary space. The interference pattern observed on a screen in regular macroscopic double-slit experiments are exhibited as oscillations of the partial photoionization cross section of homonuclear diatomic molecules, the prototype of a molecular double-slit experiment. These oscillations were predicted already more than 40 years ago by Cohen and Fano and were experimentally verified by many groups since then. However, Cohen and Fano prediction was for randomly oriented molecules integrating over all possible directions of the molecular axis. Nowadays it is also possible to measure the photoionization properties of oriented molecules. The most fundamental system for such studies is molecular hydrogen. Here we present measurements of the same interference properties but performed on an oriented sample of  $H_2$  molecules. The experimental data cover an energy range from 20 to 500 eV electron kinetic energy. The results show a clear phase shift of  $\pi/2$  with respect to the random sample due to the differentiation of the integral axis orientation sample transforming a sin curve into a cos curve. This differentiation effect could be unambiguously proved for the first time.