

## MO 17: Cold Molecules 3

Time: Thursday 11:00–13:00

Location: PH/HS1

**Invited Talk**

MO 17.1 Thu 11:00 PH/HS1  
**State-selective attachment of helium atoms to stored, cold molecular ions** — ●SANDRA BRÜNKEN, LARS KLUGE, ALEXANDER STOFFELS, OSKAR ASVANY, and STEPHAN SCHLEMMER — I. Physikalisches Institut, Universität zu Köln, Germany

Helium atoms attach to molecular cations via inversely temperature-dependent ternary association processes, forming weakly bound ( $< 3$  kcal/mol) He-M<sup>+</sup> complexes. We investigate the kinetics of this process by storing a few thousand mass-selected ions in a temperature-variable cryogenic rf 22-pole ion trap in the presence of a high number density of He and following the temporal evolution of He<sub>n</sub>-M<sup>+</sup> complexes ( $n < 6$ ). In this way the rate coefficients for ternary association and collision induced dissociation are obtained for a number of ions, e.g. H<sub>3</sub><sup>+</sup>, CH<sub>3</sub><sup>+</sup>, CD<sup>+</sup>, CF<sup>+</sup>, CO<sup>+</sup>, HCO<sup>+</sup>. The dependence of the ternary association rate coefficient on the vibrational and rotational excitation of the ions is observed. A detailed account of the underlying kinetics will be presented on the example of rotational excitation of CD<sup>+</sup>. This state-dependent complex formation rate is employed for sensitive action spectroscopy of the parent and complex ions [1,2]. Its apparent general applicability will be demonstrated with recent examples of high-resolution IR spectroscopy (LIICG - Laser Induced Inhibition of Complex Growth), and of purely rotational spectroscopy. In addition first results of IR pre-dissociation spectroscopy of stored He-M<sup>+</sup> complexes will be presented.

[1] Asvany et al., *Applied Physics B* **114**, 203 (2014); [2] Brünken et al., *ApJL* **783**, L4 (2014)

MO 17.2 Thu 11:30 PH/HS1  
**Cooperative effects of the hyperfine and Zeeman structure in the A – b state of Rb<sub>2</sub>** — ●MARKUS DEISS<sup>1</sup>, BJÖRN DREWS<sup>1</sup>, EBERHARD TIEMANN<sup>2</sup>, and JOHANNES HECKER DENSCHLAG<sup>1</sup> — <sup>1</sup>Institut für Quantenmaterie, Universität Ulm, 89069 Ulm, Germany — <sup>2</sup>Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany

We have studied the hyperfine and Zeeman structure of spin-orbit coupled A<sup>1</sup>Σ<sub>u</sub><sup>+</sup> – b<sup>3</sup>Π<sub>u</sub> states of Rb<sub>2</sub> molecules with small angular momentum ( $J = 1$ ). For this purpose, Feshbach molecules trapped in a 3D optical lattice are irradiated by cw-light of a diode laser. In a frequency scan, resonant excitation of an energy level of the A – b manifold causes molecular losses. We observe surprisingly large total hyperfine/Zeeaman splittings of up to 150 MHz at a magnetic field of 1000 G. Furthermore, we find that the hyperfine/Zeeaman structures of various vibrational states differ substantially. We explain the data as follows: The measured level structures arise in second order from hyperfine and Zeeman interactions which cooperatively mix the 0<sub>u</sub><sup>+</sup> and 0<sub>u</sub><sup>-</sup> components of the b<sup>3</sup>Π<sub>u</sub> state that are separated due to spin-orbit coupling. We can use our measurements to estimate the energy splitting between 0<sub>u</sub><sup>+</sup> and 0<sub>u</sub><sup>-</sup> for various vibrational levels.

MO 17.3 Thu 11:45 PH/HS1  
**Optimized Stark deflection and mixed-field orientation of OCS molecules** — ●JENS S. KIENITZ<sup>1,2</sup>, SEBASTIAN TRIPPEL<sup>1</sup>, KAROL DŁUGOLECKI<sup>1</sup>, ROSARIO GONZÁLEZ-FÉREZ<sup>2,3</sup>, and JOCHEN KÜPPER<sup>1,2,4</sup> — <sup>1</sup>Center for Free-Electron Laser Science, DESY — <sup>2</sup>Center for Ultrafast Imaging, University of Hamburg — <sup>3</sup>Instituto Carlos I, Universidad de Granada — <sup>4</sup>Department of Physics, University of Hamburg

We demonstrate the use of very strong static electric fields to improve the well-known techniques to state-select molecules in the electric deflector and to mixed-field orient them using laser pulses in combination with strong electric fields. These are important methods for molecular-frame imaging of molecular dynamics [1, 2]. For the state selection we developed a Stark deflector with a so-called b-type shape. Simulations of the new design predict a much stronger deflection and better state separation than previous Stark deflectors. In mixed-field orientation a strong static electrical field avoids nonadiabatic effects [3]. Therefore, we extended the idea of a two plate velocity map imaging spectrometer [4] to allow for strong electric fields up to 27 kV/cm. We will present its use in alignment and orientation experiments and disentangle the rotational motion of molecules in combined strong electric fields and laser pulses.

[1] Holmegaard et al., *Nat. Phys.* **6**, 428 (2010)

[2] Küpper et al., *Phys. Rev. Lett.* **112**, 083002 (2014)

[3] Nielsen et al., *Phys. Rev. Lett.* **108**, 193001 (2012)

[4] Papadakis and Kitsopoulos, *Rev. Sci. Instr.* **77**, 083101 (2006)

MO 17.4 Thu 12:00 PH/HS1  
**Toward Controlling Large Molecules** — ●NICOLE TESCHMIT<sup>1</sup>, DANIEL HORKE<sup>1</sup>, and JOCHEN KÜPPER<sup>1,2</sup> — <sup>1</sup>Center for Free-Electron Laser Science, DESY — <sup>2</sup>Department of Physics and Center for Ultrafast Imaging, University of Hamburg

The control of small gas-phase molecules has been experimentally demonstrated. This includes the separation of different conformers [1], the alignment and orientation of molecules in space [2], and the separation of different quantum states or clusters by using static and/or dynamic electric fields [3].

We are now working toward applying these techniques to larger molecules. This requires internally cold gas-phase molecules with high density, which will be produced with a new laser-desorption setup. By controlling large molecules structural and dynamic information can be gained from X-ray or electron diffractive imaging experiments, for example at free-electron lasers [4].

[1] Y.P. Chang et al, *Science* **342**, 98

[2] L. Holmegaard et al, *Nat. Phys.* **6**, 428

[3] D. A. Horke et al, *Angew. Chem. Int. Ed.* **53**, 1

[4] J. Küpper et al, *Phys. Rev. Lett.* **112**, 083002

MO 17.5 Thu 12:15 PH/HS1  
**Observation of molecular dimers in IR absorption Spectra of liquid hydrogen isotopologues** — ●ROBIN GROESSLE and SEBASTIAN MIRZ — Karlsruhe Institute of Technology (KIT), Institute of Technical Physics (ITEP), Tritium Laboratory Karlsruhe (TLK)

One of the main tasks of the Tritium Laboratory Karlsruhe (TLK) is the development of analytical methods for hydrogen isotopologues. A promising method for liquid hydrogen is IR absorption spectroscopy. For this a cryogenic sample cell, able to liquefy the hydrogen isotopologues, with an open beam path for IR light, has been developed and set up.

This talk will focus on the contribution of hydrogen dimers in the liquid phase to the IR spectra. The dimer model predicts non linear effects in the IR spectra. Thus the comparison of several spectra from different samples, including hydrogen, deuterium and mixtures enables a clear identification of dimers. In the case of pure H<sub>2</sub> a bunch of lines in between 8000 cm<sup>-1</sup> to 8800 cm<sup>-1</sup> and for D<sub>2</sub> between 5900 cm<sup>-1</sup> to 6500 cm<sup>-1</sup>, both corresponding to the 2nd vibrational branch of homomolecular dimers, are observed. A third spectrum of mixed H<sub>2</sub> and D<sub>2</sub> then shows in addition several lines in between, corresponding to hetroomolecular dimers. In addition these measurements have been repeated with varying compositions. And so the concentration dependence of the absorption intensity can be shown to follow predictions from this dimer model.

MO 17.6 Thu 12:30 PH/HS1  
**X-ray diffraction off isolated laser-aligned gas-phase molecules** — ●THOMAS KIERSPEL<sup>1,2</sup>, FENGLIN WANG<sup>1,3</sup>, and JOCHEN KÜPPER<sup>1,2,4</sup> — <sup>1</sup>Center for Free-Electron Laser Science, DESY, Hamburg, Germany — <sup>2</sup>The Hamburg Center for Ultrafast Imaging, University of Hamburg, Germany — <sup>3</sup>PULSE Institute, Stanford University, Stanford, California, USA — <sup>4</sup>Department of Physics, University of Hamburg, Germany

We report on x-ray diffraction off aligned isolated 2,5-diiodothiophene molecules. Using 0.13 nm (9.5 keV) radiation diffraction patterns were recorded at a degree of alignment of  $\langle \cos^2 \theta \rangle \approx 0.85$ . The short wavelength provides atomic resolution information of the molecular structure. The estimated 0.1 scattered photons/shot are mainly due to the two-center interference of the two iodines [1], with secondary signals due to the sulphur atom in the ring.

The main challenge of this experiment is the low signal-to-noise level. The experimental background is estimated to be more than 10 photons/shot, but should be largely discriminable due to photon energy differences. We discuss strategies on how to overcome the low signal-to-noise level and present resolutions by means of data analysis.

This work was carried out in a collaboration with spokespersons F. Wang, J. Küpper, P. Bucksbaum, and H. Chapman. The collaboration

consists of CFEL, PULSE, LCLS, European XFEL, Aarhus University, Kansas State University, Stanford University, and Uppsala University. LCLS is operated by Stanford University on behalf of the US DOE.

[1] Küpper et al., *Phys. Rev. Lett.* **122**, 083002 (2014)

MO 17.7 Thu 12:45 PH/HS1

**Precise study of deep two-body subradiance with ultracold Sr<sub>2</sub> molecules** — •WOJCIECH SKOMOROWSKI<sup>1,3</sup>, BART MCGUYER<sup>2</sup>, MICKEY McDONALD<sup>2</sup>, GEOFFREY IWATA<sup>2</sup>, MARCO TARALLO<sup>2</sup>, ROBERT MOSZYNSKI<sup>3</sup>, and TANYA ZELEVINSKY<sup>2</sup> — <sup>1</sup>Theoretische Physik, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — <sup>2</sup>Department of Physics, Columbia University, 538 West 120th Street, New York, NY 10027-5255, USA — <sup>3</sup>Department of Chemistry, University of Warsaw, Pasteura 1, 02-093 Warsaw, Poland

Weakly bound molecules have physical properties without atomic ana-

logues, even as the bond length approaches dissociation. For instance, the internal symmetries of homonuclear diatomic molecules result in the formation of two-body superradiant and subradiant excited states. While superradiance has been demonstrated in a variety of systems, subradiance is more elusive due to the inherently weak interaction with the environment. Here we directly probe deeply subradiant states in ultracold diatomic strontium molecules near the intercombination atomic line, and characterize their properties by *ab initio* model [1]. We find that two competing effects limit the lifetimes of the subradiant molecules, with different asymptotic behaviors. The first is radiative decay via magnetic-dipole and electric-quadrupole interactions. We prove that its rate grows quadratically with the bond length, confirming quantum mechanical predictions. The second is nonradiative decay through weak non-adiabatic predissociation, with a rate proportional to the vibrational spacing and sensitive to short-range physics.

[1] B. H. McGuyer et al., *Nat. Phys.* (2015), doi:10.1038/nphys3182.