A 6: Atomic Systems in External Fields I

Time: Monday 17:00–19:00 Location: HS 1098

A 6.1 Mon 17:00 HS 1098

Characterization of the Field Ionization Laser Ion Source and Trap FI-LIST — •Magdalena Kaja[1], Dominik Studer[2,3], Reinhard Heinke[4], Tom Kieck[2,3], and Klaus Wendt[1] — [1]Institute of Physics, Johannes Gutenberg University Mainz, Germany — [2]Jakob-Steffan-Strasse 3 — [3]Helmholtz Institute Mainz, Germany — [4]STI group, SY department, CERN, Switzerland

We present the development and initial application of the Field Ionization Laser Ion Source and Trap (FI-LIST) at the RISIKO mass separator at Mainz University. Derived from the well-established LIST and PI-LIST units previously developed at Mainz [1,2,3] and successfully implemented at CERN-ISOLDE [4,5,6], the FI-LIST is specifically tailored for field ionization of highly excited atoms within a well-controlled homogeneous electric field. To evaluate its potential for future applications in the field of rare radioactive species, e.g. actinides, we performed ionization potential (IP) measurements on ytterbium, a case where the IP is precisely known. Employing the saddle-point model, we determined the IP value with a relative precision of $3\cdot10^{-6}$, showing perfect agreement with the literature value and confirming the expectations of the device.

[1] K. Blaum, et. al., NIM B 204 (2003) 331-335
[2] K. Wendt, et. al., Nucl. Phys. A 746 (2004) 47-53,
[3] F. Schwellnus, et al., NIM B 266 (19) (2008) 4383-4386
[4]D. Fink, et. al., NIM B 344 (2015) 83-95
[5] D. A. Fink, Phys. Rev. X 5 (2015)
[6] R. Heinke, et. al., NIMB 541 (2023) 8-12

A 6.2 Mon 17:15 HS 1098

A universal method to polarize beams and samples — •Nicolas Faatz[1,2,3], Tarek El-Kordy[1,2,4], Christoph Hanhart[2,5], Chrysovalantis Kannis[6], Lukas Kunkel[1,2,3], Simon Pütz[1,2], Harsh Sharma[1,2,4], Vincent Verhoeven[1,2], Jan Wirtz[1,2,3], and Markus Büscher[6,7] — [1]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — [2]Institut für Kernphysik, Forschungszentrum Jülich, Jülich, Germany — [3]III. Physikalisches Institut B, RWTH Aachen University, Aachen, Germany — [4]FH Aachen, Campus Jülich, Jülich, Germany — [5]Institute for Advanced Simulation 4, Forschungszentrum Jülich, Jülich, Germany — [6]Institut für Laser- und Plasma-Physik, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany — [7]Peter-Grünberg-Institut 6, Forschungszentrum Jülich, Jülich, Germany

In various applications a high nuclear polarisation, ideally a total alignment of all spins, is favourable, e.g. for sources and targets for fundamental research. The hereby presented method provides an inexpensive, fast, versatile and effective solution to produce highly polarised materials in reasonable amounts based on radio-wave pumping of hyperfine states and quantum interference effects. This method is theoretically understood and was experimentally proven for beams of metastable hydrogen atoms in the keV energy range. Thus, this technique opens the door for new applications as polarised tracers or even low-field MRI with even better spatial resolution in medicine or the production of polarised fuel to increase the energy output.

A 6.3 Mon 17:30 HS 1098

A new polarization method and its applications — •Chrysovalantis Kannis[1], Ralf Engels[2,3], Tarek El-Kordy[2,3,4], Nicolas Faatz[2,3,5], Christoph Hanhart[2,6], Lukas Kunkel[2,3,5], Harsh Sharma[2,3,4], Jan Wirtz[2,3,5], and Markus Büscher[1,7] — [1]Institut für Laser- und Plasma-Physik, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany — [2]Institut für Kernphysik, Forschungszentrum Jülich, Jülich, Germany — [3]GSI, Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [4]FH Aachen, Campus Jülich, Jülich, Germany — [5]III. Physikalisches Institut B, RWTH Aachen University, Aachen, Germany — [6]Institute for Advanced Simulation 4, Forschungszentrum Jülich, Jülich, Germany — [7]Peter-Grünberg-Institut 6, Forschungszentrum Jülich, Jülich, Germany

Since the discovery of nuclear spin, scientific efforts have been focused on the production of non-equilibrium spin distributions, in which one of the possible spin projections prevails. Nuclear spin-polarization is advantageous for several fields of scientific (physics, chemistry, biology) and public (medicine) interest. Recently, our group developed a new polarization method based on radio-wave pumping at small magnetic fields that can be applied to particle beams and potentially to samples. Its advantages compared to conventional methods along with its limitations will be highlighted. Some exemplary applications are polarized sources and targets for the measurement of spin-dependent observables, polarized nuclear fusion, medical imaging diagnostics, etc.. Further developments and our future plans will be discussed.

A 6.4 Mon 17:45 HS 1098

Relativistic strong-field ionization including atomic polarization and Stark-shift — •Michael Klaiber[1], John S Briggs[2], Karen Z Hatsagortsyan[1], and Christoph H Keitel[1] — [1]Max Planck Institute for Nuclear Physics — [2]Universität Freiburg

Relativistic theory of strong-field ionization applicable across the regimes of the deep-tunneling up to the over-barrier ionization (OTBI) is developed, incorporating the effects of the polarization of the atomic bound state and the Stark-shift in an ultrastrong laser field. The theory addresses the order of magnitude discrepancy of the ionization yield at OTBI regime calculated via the numerical solution of the Klein-Gordon equation [1] and the recent experimental result [2] with respect to the state-of-the-art quasiclassical theory of Perelomov-Popov-Terent'ev for strong-field ionization or the relativistic R-matrix theory [3]. While the developed theory employs a simplified Keldysh-like approach describing the ionization as a quantum jump from the bound state to the continuum at a specific transition time, the improved performance is achieved by accounting for the bound state distortion in the laser field. In the nonrelativistic limit, the theory reproduces the well-known fitting formula to numerical calculations for the ionization rate of OTBI.

[1] B. Hafizi et al., Phys. Rev. Lett. 118, 133201 (2017)
[2] A. Yandow et al., arXiv:2306.09620
[3] M. Klaiber et al., Phys. Rev. A 107, 023107 (2023)

A 6.5 Mon 18:00 HS 1098

Dual-comb spectroscopy at high magnetic fields — •Razmik Aramyan[1,2], Oleg Tretiak[1,2], Sushree S. Sahoo[1,2], Arne Wickenbrock[1,2], and Dmitry Budker[1,2,3] — [1]Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany — [2]Helmholtz-Institut Mainz, GSI Helmholtzzentrum für Schwerionenforschung, 55128 Mainz, Germany — [3]Department of Physics, University of California, Berkeley, California 94720, USA

The invention of the frequency comb revolutionized metrology and became pivotal in various fields, including astronomy, optical communications, and more. Moreover, it found application in spectroscopy, serving as both a precise reference and the primary tool for sample interrogation. Dual-Comb Spectroscopy (DCS) further advanced this revolution, allowing rapid, high-resolution, and time-resolved analyses.

In various physics fields, atomic data play a pivotal role, especially in exploring 'new physics' beyond the standard model. They furnish essential information for understanding fundamental interactions and designing experiments to probe uncharted scientific fields. Our project aims to develop and use the DCS technique for broad-band spectroscopy of Rare-Earth Elements (REE) under a strong magnetic field (up to 100 T). The data will be used to train a neural network to predict atom-related information accurately. We will present the current state of DCS development and present initial results from our coherent data acquisition and analysis technique. Additionally, we will show the outcomes from various evaporation methods applied to REE, particularly in our first test case, samarium.

A 6.6 Mon 18:15 HS 1098

Structured-light-matter interaction in external fields — •Riaan Philipp Schmidt[1], Shreyas Ramakrishna[2], Anton Peshkov[1], Sonja Franke-Arnold[3], and Andrey Surzhykov[1] — [1]Physikalisch-Technische Bundesanstalt — [2]Helmholtz-Institut Jena — [3]School of Physics and Astronomy, University of Glasgow

During recent years, a number of studies has been performed to investigate the interaction of atomic media with structured light modes. These studies paved the way for the application of structured beams in optical traps and tweezers, classical and quantum communication, and atomic magnetometers. In particular, the latter are based on the analysis of absorption images of such beams in an atomic cloud [1]. In

this contribution, we perform a theoretical study for the coupling of atoms and structured light in external fields. In the framework of the density matrix approach and the Liouville-von Neumann equation, we show that experimental observables, i.e. intensity of the transmitted light, are very sensitive to the incident radiation and the external fields. To illustrate this sensitivity we performed detailed calculations for the $5s\,^2\mathrm{S}_{1/2} - 5p\,^2\mathrm{P}_{3/2}$ transition in a rubidium atom induced by various structured light modes. Based on the results of these calculations, we find that the transmission patterns allow for the detection of the alignment of an external magnetic field and the analysis of frequency detuning of the radiation from the atomic resonance. This opens up new opportunities for structured light in atomic magnetometers and polarization spectroscopy experiments.

[1] F. Castellucci et al., Phys. Rev. Lett. 127, 233202 (2021)

A 6.7 Mon 18:30 HS 1098

Ab Initio Dynamics of Orbital Angular Momentum Transfer to Atomistic Systems — •Esra Ilke Albar[1], Franco P. Bonafé[1], Valeriia Kosheleva[1], Heiko Appel[1], and Angel Rubio[1,2,3] — [1]Max Planck Institute for the Structure and Dynamics of Matter — [2]Center for Computational Quantum Physics (CCQ), The Flatiron Institute, 162 Fifth Avenue, New York, NY, 10010, USA — [3]Nano-Bio Spectroscopy Group, Departamento de Física de Materiales, Universidad del País Vasco, 20018, San Sebastian, Spain

Optical vortices are characterized by their orbital angular momentum (OAM) content. Due to their structured wavefront they can induce transitions beyond the dipole approximation. The study of their interaction with atomic and molecular systems in real time, therefore, demand novel computational tools that consider the spatial profile of the incoming fields.

We perform numerical simulations within the time-dependent density functional theory (TDDFT) using the Octopus code, coupling the time-dependent Kohn-Sham equations with Maxwell's equations, to describe self-consistent light and matter dynamics. We account for the spatial structure of optical vortices at different coupling levels beyond dipole using the multipolar expansion as well as the full minimal coupling Hamiltonian. We use atoms as a benchmark system and analyze the validity of the selection rules for different multipolar terms, considering incoming Bessel beams of different order and handedness. We also investigate the effect of other optical vortex parameters on the interaction such as the impact parameter and the envelope function.

A 6.8 Mon 18:45 HS 1098

Semiclassical spin self-organization in non-equilibrium generalized Dicke models — •Marc Nairn[1], Simon Jäger[2], Giovanna Morigi[3], Luigi Giannelli[4], and Beatriz Olmos-Sanchez[1] — [1]Institut für Theoretische Physik, Universität Tübingen, 72076 Tübingen, Germany — [2]Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau, 67663 Kaiserslautern, Germany — [3]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [4]Dipartimento di Fisica e Astronomia Ettore Majorana, Università di Catania, 95123 Catania, Italy

Cavity setups serve to probe all to all interactions in many-body spin systems and are intriguing platforms for quantum simulation of exotic states of matter. Motivated by recent experiments with BECs showing the self-organized phase in the non-equilibrium Dicke model, here we study a range of generalized Dicke models and establish the transition into an atomic self-organized state due to spin-motion correlations. We are able to faithfully replicate the dynamics of individual spins in a large atomic ensemble close to the semiclassical limit by taking advantage of the so called discrete Truncated Wigner Approximation (dTWA) and performing an extensive phase-space Monte Carlo sampling. We observe a transition to a spin self-ordered state when the coupling strength is increased beyond a critical value. At this point the atoms align themselves at the cavity field maxima and minima, resulting in an in-phase superradiant emission into the cavity mode. We show the system hosts a rich phase diagram, where the self-ordered state may be finely tuned by means of external lasers.