Q 66: Precision Spectroscopy of Atoms and Ions V / Ultra-cold Plasmas and Rydberg Systems II (joint session A/Q)

Time: Friday 14:30–16:30 Location: HS 1098

Q 66.1 Fri 14:30 HS 1098

Laser Spectroscopy of Californium-253,254 — •Sebastian Berndt for the Fermium-Collaboration — Johannes Gutenberg Universität Mainz, 55099 Mainz, Germany

Laser resonance ionization spectroscopy (RIS) is an efficient and element-sensitive technique to study the atomic and nuclear structure of transuranium elements. We present recent activities at the RISIKO mass separator at Johannes Gutenberg University Mainz (JGU) regarding laser spectroscopy of the exotic isotopes ^{253,254}Cf. Here, theoretical predictions point to a relevant role of ^{254}Cf in kilonova events associated with r-process nucleosynthesis in the cosmos. For this study, targets of $^{244-248}$Cm were neutron-irradiated at the High Flux Isotope Reactor, Oak Ridge National Laboratory (ORNL) to breed ^{253,254}Es, which was chemically separated at ORNL's Radiochemical Engineering Development Center. This sample was shipped to JGU via Florida State University and then sent to Institut Laue-Langevin for a second irradiation with thermal neutrons to produce ^{255}Es (39.8 d). As the sample also contained about 10^9 atoms of ^{252}Cf, this was in addition transmuted to ^{253,254}Cf. The hyperfine structure of the 420 nm ground state transition in ^{253}Cf as well as the isotope shift of ^{254}Cf in the 417 nm and 420 nm ground-state transitions were investigated with high resolution RIS, giving access to the nuclear ground-state properties.

Q 66.2 Fri 14:45 HS 1098

Laser-induced population transfer in $^{25}Mg^+$ at the CRYRING@ESR storage ring — •Konstantin Mohr for the STOA-Collaboration — Institut für Kernphysik, TU Darmstadt, Germany

At the magnetic storage ring CRYRING@ESR located at the GSI facility for heavy ion research the laser spectroscopy experiment is performed on $^{25}Mg^+$ to investigate the interplay between internal and external degrees of freedom, i.e. quantum states and particle momenta.

Particular interest is devoted to the question whether it is possible to achieve and maintain a nuclear polarization of $^{25}Mg^+$ by optical pumping within the magnetic manifold of the hyperfine structure. This was studied with an electron-cooled coasting ion beam as well as in bunched beam operation at energies of about 155keV/u. In bunched-beam operation, it turned out that both the laser-induced spontaneous force and the varying velocity of the ions due to synchrotron oscillations need to be considered in order to explain the subtleties of the resonance shape.

We present our recent results and discuss the dynamic behavior of both modes of operation.

We acknowledge support from the BMBF under contract numbers 05P21RDFA1 and 05P19PMFA1, and from the DFG–Project-Id 279384907–SFB 1245.

Q 66.3 Fri 15:00 HS 1098

Stopping mass-selected alkaline-earth metal monofluoride beams via formation of unusually stable anions — •Konstantin Gaul[1], Ronald F. Garcia Ruiz[2], and Robert Berger[1] — [1]Fachbereich Chemie, Philipps-Universität Marburg,Hans-Meerweinstraße 4, 35032 Marburg, Germany — [2]Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Direct laser-coolability and a comparatively simple electronic structure render alkaline-earth metal monofluoride molecules (MF), versatile laboratories for precision tests of fundamental physics. In this theoretical work, prospects for efficient stopping and cooling of hot beams of mass-selected MF molecules via their anions are explored. With sophisticated quantum chemical methods it is shown that these molecular anions posses an unusually strong chemical bond and have favourable photo-electron detachment energies. For RaF^- a vibronic structure with favorable properties for efficient pre-cooling is identified. This study indicates even chances for direct laser-cooling of the anion.

Q 66.4 Fri 15:15 HS 1098

Precise Temperature Characterization of Project 8's Atomic Hydrogen Source — •Brunilda Muçogllava and Martin Fertl for the Project 8-Collaboration — Johannes Gutenberg Universität Mainz

In order to achieve a neutrino mass sensitivity of 40 meV, the Project 8 experiment aims to use the Cyclotron Radiation Emission Spectroscopy technique to analyze the atomic tritium beta decay spectrum. Due to the radioactive nature of tritium, initial measurements have been carried out using a Hydrogen Atom Beam Source (HABS) at the Mainz atomic test stand. Molecular hydrogen is introduced into the HABS setup, flowing through a 1 mm diameter tungsten capillary which is radiatively heated to ~2300 K by a tungsten filament. This causes the molecules to thermally dissociate in a temperature-dependent way. Accurate capillary temperature measurements with low uncertainty at these high temperatures are required to characterize the source accurately and understand the dissociation efficiency from molecular to atomic hydrogen. This talk will present infrared spectroscopy measurement results of the capillary, addressing challenges arising from uncertain emissivity values, ultra-high vacuum conditions, and device-dependent absolute calibration.

Q 66.5 Fri 15:30 HS 1098

Quantum Gate Optimization for Rydberg Architectures in the Weak-Coupling Limit — •Nicolas Heimann[1,2,3], Lukas Broers[1,2], Nejira Pintul[1,2], Tobias Petersen[1,2], Koen Sponselee[1,2], Alexander Ilin[1,2,3], Christoph Becker[1,2], and Ludwig Mathey[1,2,3] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

We demonstrate machine learning assisted design of a two-qubit gate in a Rydberg tweezer system. Two low-energy hyperfine states in each of the atoms represent the logical qubit and a Rydberg state acts as an auxiliary state to induce qubit interaction. Utilizing a hybrid quantum-classical optimizer, we generate optimal pulse sequences that implement a CNOT gate with high fidelity, for experimentally realistic parameters and protocols, as well as realistic limitations. We show that local control of single qubit operations is sufficient for performing quantum computation on a large array of atoms. We generate optimized strategies that are robust for both the strong-coupling, blockade regime of the Rydberg states, but also for the weak-coupling limit. Thus, we show that Rydberg-based quantum information processing in the weak-coupling limit is a desirable approach, being robust and optimal, with current technology.

Q 66.6 Fri 15:45 HS 1098

FRESNEL: Engineering a Neutral Atom Quantum Computer — •Guillaume Villaret for the FRESNEL-Collaboration — Pasqal SAS, 7 Rue Léonard de Vinci, 91300 Massy, France

Based on the work from the group of A. Browaeys and T. Lahaye at Institut d'Optique, quantum startup PASQAL developed and produced a first generation of commercial QPUs called FRESNEL. These devices allow analogical computations on arrays of up to 100 Rydberg atoms. Interfaced through a cloud access, these QPUs already proved their reliability. They allowed quantum software engineers to propose and demonstrate applications for solving hard combinatorial optimisation problems, non-linear differential equations and classifying sets of graphs using machine learning. Some of these QPUs are currently under construction in two HPC centers in Jülich, Germany and in Bruyères-le-Châtel, France. This represents a big step forward in term of reliability for neutral atoms QPUs, and more generally for cold atoms technologies which require a high level of engineering. We will give an overview of the technical building blocks of the FRESNEL products, discuss its capabilities for analog-based quantum computing in the NISQ era, and present the latest results.

Q 66.7 Fri 16:00 HS 1098

NON-ADIABATIC COUPLINGS AS A STABILIZATION MECHANISM IN LONG-RANGE RYDBERG MOLECULES — AILEEN DURST, •MILENA SIMIĆ, NEETHU ABRAHAM, and MATTHEW EILES — Max-Planck-Institut for The Physics of Complex Systems, Dresden, Germany

The electronic potential curves of long-range Rydberg molecules composed of a Rydberg atom and a ground-state atom possess several

distinctive features, including oscillations as a function of internuclear distance and, for an alkaline ground state atom, a steep drop when the electron-atom scattering interaction becomes resonant. This latter feature is accompanied by a narrow avoided crossing between potential energy curves, which implies that non-adiabatic couplings could become significant very close to the position of this rapid change in the potential curve. When these couplings are sufficiently strong, they can stabilize the molecule by shielding the vibrational states from the steep drop and possible decay. To demonstrate the importance of the non-adiabatic couplings in a rubidium Rydberg molecule, we compare the binding energies and lifetimes of the vibrational states obtained in the Born Oppenheimer approximation with those including beyond-Born Oppenheimer effects.

Q 66.8 Fri 16:15 HS 1098

Quantum Optimization of Two-Qubit Gate of Neutral Rydberg Atoms — •Aslam Parvej[1,2], Nicolas Heimann[1,2], Lukas Broers[1,2], and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Germany

The fundamental cause of error for the high-fidelity gates in the quantum computing architectures of neutral atoms in optical tweezer arrays is the unwanted entanglement of motional excitations in the tweezer traps. We study the machine learning aided neutral Rydberg atoms in the weakly-interacting regime of two Rydberg atoms, with van der Walls interaction to implement a high-fidelity two-qubit controlled-Z gate while returning to the system to its motional ground states and generates an optimized pulse using hybrid quantum-classical optimizer. In the set up, the Rydberg state is coupled with logical qubit via global Rabi pulse and the motional degrees of freedom inside optical tweezers is coupled with each Rydberg atom.