In-Gas Cell Laser Spectroscopy of Neutron-Deficient Silver Isotopes

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IN-GAS CELL LASER IONIZATION

Basic Principles

In-gas cell laser spectroscopy has been developed at the Leuven Isotope Separator On-Line (LISOL) set-up. The radioactive isotopes of interest are produced using heavy- and light-ion induced reactions. The primary beam hits the target that is situated in a buffer gas cell filled with 100 to 500 mbar argon. The reaction products that recoil from the target are thermalised in the buffer gas, neutralized in the presence of the weak plasma created by the primary beam passing through the gas cell and transported together with the flowing gas towards a region for laser irradiation. Subsequently the ions are resonantly photoionized using a two-step laser-ionization scheme, extracted from the gas cell, injected into a radiofrequency sextupole ion guide, accelerated to 40 keV, analysed according to their A/Q value, and sent towards a detection station where their radioactive decay is observed [1,2]. By measuring the number of atoms arriving at the detection station as a function of the first step laser frequency, the atomic hyperfine structure of the atomic ground and/or excited state can be measured and charge radii, magnetic dipole and electrical quadrupole moments extracted provided the atomic physics is well understood. A review on laser spectroscopy measurements and other atomic physics techniques used to extract nuclear-physics properties can be found in [3].

Magnetic Moment of Neutron-Deficient Copper and Silver Isotopes

At LISOL, the magnetic moment for a number of neutron deficient copper isotopes, including ^{57}Cu (N=28), were determined using in-gas cell laser spectroscopy and

questioned the need for extra N=28 shell breaking beyond what was assumed in the current large-scale shell-model calculations [4].

In more recent experiments a study of the neutron deficient silver isotopes produced via ^{92}Mo(^{14}N,pxn)^{A}Ag and ^{64}Zn(^{36}Ar,pxn)^{A}Ag reactions was pursued and the magnetic moments of a number of them were obtained for the first time, including the semi-magic N=50 isotope ^{97}Ag. The analysis of the data is still ongoing, but the extracted g-factor indicate dominance of the proton $g_{9/2}$ orbital in the ground state of these neutron-deficient silver isotopes.

These experiments serve as a proof-of-principle of in-gas cell laser-spectroscopy measurements of reaction products from light- and heavy ion induced fusion evaporation reactions. In the next steps other isotopes around ^{100}Sn, including the indium isotopes, will be investigated, following the study of heavy isotopes starting with the neutron-deficient actinium isotopes.

Future Developments

Although the technique of in-gas cell laser spectroscopy is sensitive, measurements with production rates as low as a few ions per second have been performed, it suffers from a low-spectral resolution. This is mainly due to pressure broadening and, to a lesser extent, due to Doppler broadening. This results in a total resolution between 5 and 10 GHz. This limits the applicability of this technique to the heavy elements, where the hyperfine splitting and isotope shifts are large compared to the total spectroscopic resolution, or to specific elements like ,e.g., copper, silver and indium that have a large ground-state hyperfine splitting [2]. Ways to improve the spectroscopic resolution, the efficiency and the selectivity are under study. An interesting option is to perform laser-resonance ionization in the gas jet outside of the gas cell. By using a ‘de Laval’ nozzle as exit hole, a cold and homogeneous gas jet of over 5 cm long can be formed. By applying resonance laser ionization inside this jet (by counter propagating the laser beams) the atoms of interest are ionized and captured in the RF structure surrounding the jet. From there on the ions follow the same path towards the detection system as described above. By biasing the RF structure with a positive voltage relative to the gas cell, unwanted ions cannot escape from the gas cell and the selectivity increases by at least one-order-of-magnitude. Furthermore, the low-temperature and low-pressure jet decreases the spectroscopic resolution to about 200 MHz, again at least one-order-of-magnitude better compared to in-source spectroscopy. This technique, that has certain similarities with the so-called ‘Laser Ion Source Trap’ [5], is currently under investigation at LISOL and JYFL [6]

The final goal of the project is to couple the LISOL laser ion source at the focal plane of the Super Separator Spectrometer (S3) set-up of the SPIRAL-2 project at GANIL [7]. Superior heavy-ion beam intensities will be available to produce the most exotic nuclei including the so far poorly studied actinide isotopes. The reaction products will be separated from the primary beam using the S3 system and stopped in the buffer-gas cell system. Laser ionization inside the gas cell will be used to produce beams of refractory-type elements, not available at high-temperature target based ISOL systems. Laser spectroscopy measurements on nuclei around ^{100}Sn and in the

actinide region will be performed using the in-gas jet spectroscopy system described above.

OPTIONS FOR EURISOL

Laser Spectroscopy at EURISOL

Laser spectroscopy studies deliver charge radii, nuclear magnetic moments and quadrupole moments, and spins in a model independent way, provided the atomic physics is well understood [3]. A strong program for these studies at EURISOL, including the study of neutron-deficient isotopes, should be foreseen. As the production of isotopes from refractory type elements will be hampered at EURISOL when using the high-temperature target-ion source systems, it is essential that other efforts as the one mentioned above are pursued. In this way complementary information will be gathered.

Resonance Ionization Laser Ion Sources

Resonance Ionization Laser Ion Sources (RILIS) will inevitably have to be part of the EURISOL facility. The ionizing cavity used is the simplest and most ruggedized ion-source system available for producing RIB's. RILIS are essential to deliver pure (or purified) radioactive ion beams and have the potential to produce isomerically purified beams [8]. Both aspects deliver interesting cases for the study of neutron-deficient isotopes along the N=Z line as well as in the heavier mass region. For example, the isomers in the odd-odd N=Z nuclei in the region between Z=28 and Z=50 could be probed and e.g. be prepared for transfer reaction or Coulomb excitation studies. The same holds for studies of shape-coexistence in the lead region where for example Coulomb excitation and transfer reactions on very neutron-deficient mercury isotopes/isomers will unravel the underlying mechanism that creates shape coexistence. Interesting to note here is that one assumes that shape coexistence in the lead region is driven by a limited number of specific proton orbitals, however so far no undisputable experimental prove for this assumption has been delivered. Transfer reactions should clarify this situation and the use of isomeric beams can play herein an important role.

RIB to Access the Actinide Region

The high intensity RIB of EURISOL will also allow to enter into the parts of the actinide region that can not be reached with stable beams for, amongst others, laser spectroscopy studies. The general concept would be very similar to the laser spectroscopy studies planned for S3, except that the stable beams from SPIRAL-2 will be replaced by the intense RIB from EURISOL. This challenging idea needs further investigation to identify the regions in the chart of nuclei that can not be reached with stable beams or where the lower beam intensity of the RIB is fully compensated by the larger cross section using RIB compared to stable beams.

In-Gas Cell Laser Ionization at EURISOL

The use of a gas cell with a ^{238}U fission target close to the spallation neutron source of EURISOL might create the possibility to produce beams from refractory-type elements. The fission products will be thermalised in the gas cell and will be treated in the same way as described above to, either obtain intense neutron—rich beams of refractory type elements or to perform laser spectroscopy studies on these isotopes. This option is, however, extremely challenging as the gas cell has to be operated in a harsh environment whereby plasma effects, created by the fission products and their radioactivity, and other neutron-induced reactions, might hinder proper gas cell operation.

A final idea would be to use the gas cell for thermalization of reaction products produced in the fragmentation of the high-intensity radioactive ion beams with energies that allow fragmentation reactions. These conditions would be ideally suited for proper gas-cell operation.

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