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Performance of a high repetition pulse rate laser system for in-gas-jet laser ionization studies with the Leuven laser ion source @ LISOL

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ABSTRACT

The laser ionization efficiency of the Leuven gas cell-based laser ion source was investigated under on- and off-line conditions using two distinctly different laser setups: a low-repetition rate dye laser system and a high-repetition rate Ti:sapphire laser system. A systematic study of the ion signal dependence on repetition rate and laser pulse energy was performed in off-line tests using stable cobalt and copper isotopes. These studies also included in-gas-jet laser spectroscopy measurements on the hyperfine structure of ^{63}Cu. A final run under on-line conditions in which the radioactive isotope ^{59}Cu ($T_{1/2}$ = 81.5 s) was produced, showed a comparable yield of the two laser systems for in-gas-cell ionization. However, a significantly improved time overlap by using the high-repetition rate laser system for in-gas-jet ionization was demonstrated by an increase of the overall duty cycle, and at the same time, pointed to the need for a better shaped atomic jet to reach higher ionization efficiencies.

1. Introduction

The Leuven Isotope Separator On-Line (LISOL) facility at the Cyclotron Research Center (CRC) Louvain-la-Neuve [1] produces purified rare ion beams using resonant laser ionization of reaction products thermalized in a buffer-gas cell [2,3]. After almost two decades of operation, high-purity radioactive ion beams of more than 15 different elements have been obtained exploiting various production mechanisms including light- and heavy-fusion evaporation reactions [4,5], proton-induced fission [6], and the spontaneous fission of ^{252}Cf [7]. Thermalized ion beams of rare species are extracted from the Leuven gas cell in a supersonic jet, transported by a radiofrequency (RF) ion guide towards the mass separator, and finally sent to the detector station.

In addition to the routinely performed nuclear-decay-spectroscopy studies, the recent upgrade of the LISOL setup with a novel gas cell concept [8] has allowed in-source laser spectroscopy studies of neutron-deficient $^{57-59}$Cu [9,10] and $^{97-102}$Ag [11] isotopes. These measurements have become feasible owing to the enhanced selectivity of the apparatus, which has allowed in-gas-cell laser spectroscopy on exotic species with count rates as low as 6 ions/s for ^{57}Cu ($T_{1/2}$ = 200 ms) or 1 ion/s for ^{97}Ag, both representing interesting semi-magic nuclei (N = 28 and 50, respectively).

In laser-spectroscopy experiments spectral linewidths are required to be as close as possible to the intrinsic natural linewidths of the atomic transitions investigated. For in-gas-cell laser spectroscopy, however, the obtained linewidths result from the convolution of four components: the Doppler broadening caused by the atom velocity distribution, the pressure broadening (and additionally pressure shift) induced by collisions with the surrounding gas, the laser-power broadening, and the intrinsic bandwidth of the laser.

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Following the earlier results obtained at LISOL by gas-cell laser spectroscopy it becomes clear that the spectral resolution is mainly limited by the inherent pressure broadening. Hence, for the successful study of atomic properties of elements with particularly small hyperfine splitting and/or high sensitivity to atomic collisions, as observed in practice, e.g., on the tin isotopes around $A = 100$, a novel approach such as in-gas-jet laser spectroscopy would be the technique of choice. In this method, laser ionization takes place in the supersonic jet expanding out of the gas cell. The adiabatic expansion into a lower pressure regime results in an important reduction of the Doppler and pressure broadening up to the point where the laser bandwidth becomes the primary limitation for the final attainable resolution. The feasibility of in-gas-jet laser spectroscopy was demonstrated in previous experiments at LISOL [12]. In those measurements the advantages of this technique in view of the realization of spectroscopic studies and of the enhancement of the ion beam purity (LIST mode [13]) were evaluated and compared to the results obtained under equal conditions by in-gas-cell laser spectroscopy. The first results obtained in Ref. [12] proved that in-gas-jet laser spectroscopy can meet the requirements of superior selectivity and resolution.

To obtain optimum experimental conditions for the application of in-gas-jet spectroscopy the overlap efficiency between the laser light and the atoms in the gas jet must be maximized by the temporal and the geometrical overlap parameters. In Ref. [12] a maximum available pulse repetition rate of the LISOL laser system of 200 Hz prevented a complete evaluation of the in-gas-jet spectroscopy benefits. Since the atom's flow velocity in the gas jet is about 200 times higher than that inside the gas cell, a higher pulse repetition rate would be required for optimum temporal overlap between the lasers and the atoms in the jet.

In this paper, we report on the results obtained in new tests of In-Gas Laser Ionization and Spectroscopy (IGLIS) studies in the supersonic gas jet expanding out of the LISOL gas cell. A series of experiments were performed at LISOL in which the ionization efficiency using a high-repetition-rate all-solid-state laser system was investigated and directly compared to that of the LISOL low-repetition-rate dye laser system in off- and on-line conditions. Such a combination of a high-repetition rate laser system with a gas cell-based ion source is currently used also at the IGISOL facility in Jyväskylä [14,15].

The new possibilities for performing high-resolution laser spectroscopic studies of exotic nuclei using the in-gas-jet based technique arouse a great interest at other present and future on-line facilities, as e.g., IGISOL (JYFL), PALIS (RIKEN), KISS (KEK), and SPIRAL2 (GANIL).

2. Experiment

Here we shall describe briefly only the front end of the LISOL setup [16] as it is of central importance for the discussion of the reported measurements. A detailed description of the entire LISOL facility can be found elsewhere [2,17,18].

A primary high-energy projectile beam from a driver cyclotron enters the gas cell through a molybdenum window and impinges on a thin target inducing nuclear reactions. The reaction products are thermalized and neutralized in the buffer gas, typically argon at a pressure of a few hundred mbar, and are transported by the gas flow towards the ionization region. A dual-chamber gas cell-type [8] was employed in these measurements (see Fig. 1). The main characteristic of this gas cell with respect to previous models is the division of the cell in two volumes; one for production, thermalization and neutralization of species, and the other for ionization. This spatial separation between the two volumes increases the in-gas-cell ionization efficiency and allows for the application of DC fields in the ionization region, thus assuring the collection of ions surviving the process of neutralization.

The atoms of the element of interest can be laser ionized in the ionization chamber and subsequently extracted through the exit hole ($\phi = 1$ mm) or, alternatively, ionization can be carried out in the expanding free jet within the rods of an RF SextuPole Ion Guide (SPIG). Owing to geometrical constraints in the present setup the laser beams can only be sent along the extraction axis and through the exit hole to interact with the atoms either inside the cell or afterwards within the SPIG (see Fig. 1). By applying a positive bias between the gas cell and the SPIG rods ions from the gas cell can be

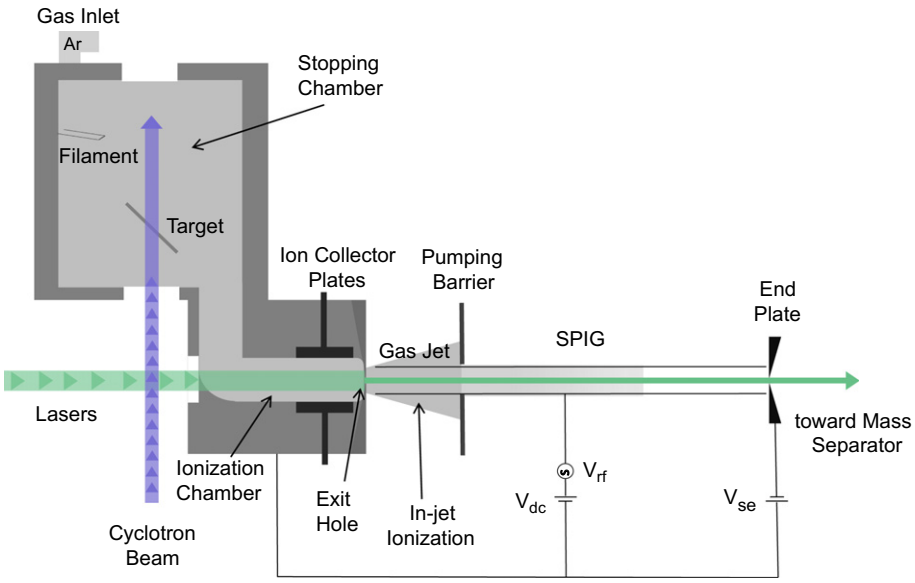

Fig. 1. Schematic layout of the laser ion source employed in these experiments. The dual chamber gas cell (separated stopping and ionization chambers) is depicted along with the primary projectile beam from the driver cyclotron and the laser beams path. Electrical connections, the expanding gas jet through the SPIG structure, and the region where in-gas-jet ionization takes place are also indicated. When V_{dc} is positive only ions produced inside the SPIG are extracted towards the mass separator. V_{se} is set for optimum extraction of the ions from the SPIG. A filament within the gas cell can be used to produce a stable atomic beam of the species of interest and perform reference measurements or off-line studies.