Extraction of thermalized projectile fragments from a large volume gas cell

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ABSTRACT

Experiments to determine the stopping and extraction efficiency of energetic (90 MeV/u) ^{76}Ga fragments in a 1.2 m long gas cell filled with helium at 123 mbar are reported. The thermalized ions were transported by DC and RF fields as well as gas flow, then jetted through a supersonic nozzle into a RF quadrupole ion-guide and accelerated into an electrostatic beam line. The ions were collected in either a Faraday cup or a silicon beta-detector immediately after acceleration or after magnetic analysis. The range distributions of the ions and extraction efficiency of the system were measured for different implantation rates and compared with the theoretically calculated values. The singly charged ^{76}Ga ions were observed as $[^{76}\text{Ga}(\text{H}_2\text{O})_n]^+$ molecular ions with $n=0$, 1, and 2. The stopping efficiency and the extraction efficiency were obtained from the measured distributions and compared to previous results from other devices.

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1. Introduction

Beam thermalization is a necessary process for the production of low-energy ion beams from high-energy projectile fragments. A number of systems have been developed to thermalize much lower energy recoils from nuclear reactions in gas beginning with the long-running IGISOL facility in Finland [1] and including the LISOL system in Belgium [2], the ShipTrap system at GSI in Germany [3], and the CPT and new CaRIBU system at Argonne National Lab (ANL) in the US [4,5]. The collection efficiency of devices for near-Coulomb barrier energies can be large, but the total efficiencies drop for energetic heavy ions due to large energy straggling. In addition, the ShipTrap system does not have to deal with high ionization rates. The present devices for thermalization of fast ions are located at RIKEN [6], GSI [7,8], and the National Superconducting Cyclotron Laboratory (NSCL) [9,10]. These devices generally use a linear gas-filled cylindrical chamber into which the beam enters along the central axis and the thermalized ions are extracted on-axis at the far end of the cylinder. These devices also use electrodes in the gas to rapidly separate the more mobile electrons from the ionized buffer-gas atoms and the incident ions. A positive space charge builds up in the center of the chamber that tends to push the thermalized ions towards the walls and less-so towards the exit [11–13]. A new generation of devices have been designed with large internal volumes and RF ion-guiding structures along the walls of the chamber to attempt to mitigate these effects [5].

Recently, the NSCL upgraded its beam thermalization area with the installation of new high-resolution beam lines and a new large-volume RF-based gas catcher constructed by ANL. The high-energy projectile fragment beams ($\sim$100 MeV/u) from the A1900 separator [14] are dispersed in momentum and then passed through solid degraders and a monochromatic wedge to remove nearly all their kinetic energy and to reduce the beam's energy spread, respectively, immediately before entering the 1.2 m long gas catcher. Upon entering the chamber, the ions are thermalized through collisions with ultra-pure helium buffer gas. The high ionization potential of the helium gas forces most of the ions to remain ionized in the 1+ or 2+ charge state. The gas flow inside the chamber is relatively slow; therefore, a static drift field on the order of tens of V/cm is used to sweep the positive ions towards the collection area where gas flow becomes strong enough to push the ions through the extraction orifice. A RF potential is applied to closely spaced electrodes along the wall of the gas cell and along a RF cone that focuses the ions on the nozzle. Note that each incident projectile fragment will create 10^5 to 10^6 ion pairs in

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the helium gas during the slowing down process [15]. The RF potential repels the heavier ions from the electrodes along chamber walls directing them out of the cell while the very light He_2^+ and any He^+ ions are unimpeded and lost on the walls. The collection of the helium ions on the walls reduces both the space charge and the probability that they will charge-exchange with any impurities in the gas. The thermalized projectile fragments are jetted out into a new RFQ ion-guide [16] that maintains the ions on a central trajectory as they pass through three stages of differential pumping before acceleration to 30 keV/q and magnetic analysis. Several experiments were carried out to commission the new projectile fragment thermalization system using the ANL gas cell. Here we report the first results for the range distributions observed by the ionization of the buffer gas, the extraction of radioactivity as a function of degrader thickness, and the mass analysis of the extracted activities.

2. Description of experiment

A primary ^{82}Se beam at 140 MeV/u was used with a 415 mg/cm^2 beryllium target and a 299 mg/cm^2 aluminum achromatic wedge located in the A1900 fragment separator [14] to produce a 75% pure 90 MeV/u ^{76}Ga^{31} ($B\rho = 3.4331$ Tm) secondary beam. The primary beam current was frequently monitored by inserting a Faraday cup into the beam's path at the target position. A narrow momentum spread of $\Delta P/P = 0.5\%$ was used in the present work for the full acceptance of the separator. The only contaminant ion in the secondary beam was ^{74}Zn^{30+}. A schematic diagram of the experimental setup is shown in Fig. 1. Most of the kinetic energy was removed from the high-energy secondary beam with a degrader system that included a 1503(5) μm thick Al plate and a silicon dioxide (glass) monoenergetic wedge that was 1050(50) μm thick in the middle with a 5(0.9) mrad wedging angle. The calculated effective thickness of the aluminum degrader plate (final degrader) was varied by remotely adjusting its angle in the beam's path. The relatively small momentum spread of the secondary beam (0.5% $\Delta P/P$) was reduced as the dispersed beam passed through the glass wedge. The slowed fragments passed through a 37(2) μm Al window with a Titanium alloy support grid and into highly purified helium gas at less than 1 MeV/u. The support grid had an 85% transmission efficiency. High purity helium gas (99.999%) was passed through a Monotorr purifier and a gas regulator system that held the pressure inside the chamber at 123 mbar. The gas filled chamber and all the materials inside were constructed and assembled to ultra-high vacuum standards. The chamber does, however, contain Indium seals and could not be baked prior to the experimental work. As shown below, the helium gas was found to contain a high level of water vapor.

A drift field of 7.5 V/cm was applied with a bias of approximately 900 V between the entrance window (anode) of the gas catcher and the exit nozzle (cathode). Separate RF potentials were applied to the body and cone electrodes in the cell at 3.514 MHz (90 W) and 3.180 (50 W), respectively. The electrode structures are described in Ref. [17]. The range distribution of the secondary beam was obtained by measuring (1) the total negative ion current on the window and (2) the total positive ion current on a Faraday cup after the ion-extraction system as a function of the effective thickness of the final degrader. The measured currents for an incident beam intensity of $\sim 7.6 \times 10^5$ pps agree within the uncertainty of the measurement and show the typical Bragg curve shape. A systematic shift in the value of the angle (thickness) between the two measurements was observed due to a mechanical lash. The total beta-decay activity (see below), also shown in Fig. 2, peaks near the midpoint of the falling curve as expected. The optimal angle for degrading the incident ions with the final degrader was determined to be $34°(\sim 1876$ μm) from the maximum yield of radioactivity.

The thermalized projectile fragments were guided by the static DC and RF potentials applied to the gas cell's electrode structure towards the exit nozzle. The time needed for a typical atomic ion
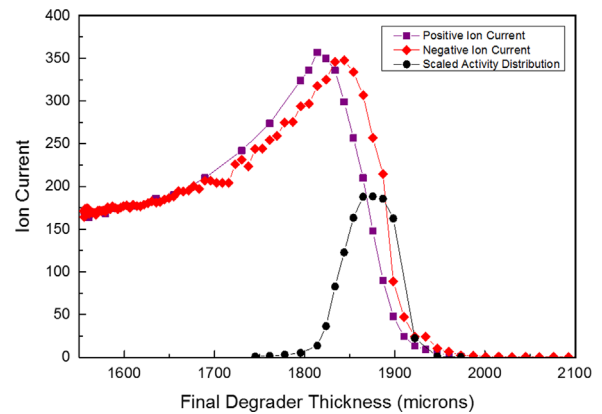
Fig. 2. Measured distributions of the positive (squares, arbitrary scale) and negative (diamonds, nA) ion currents as a function of degrader thickness. The total scaled activity distribution measured with the first silicon detector (circles) is shown for reference.
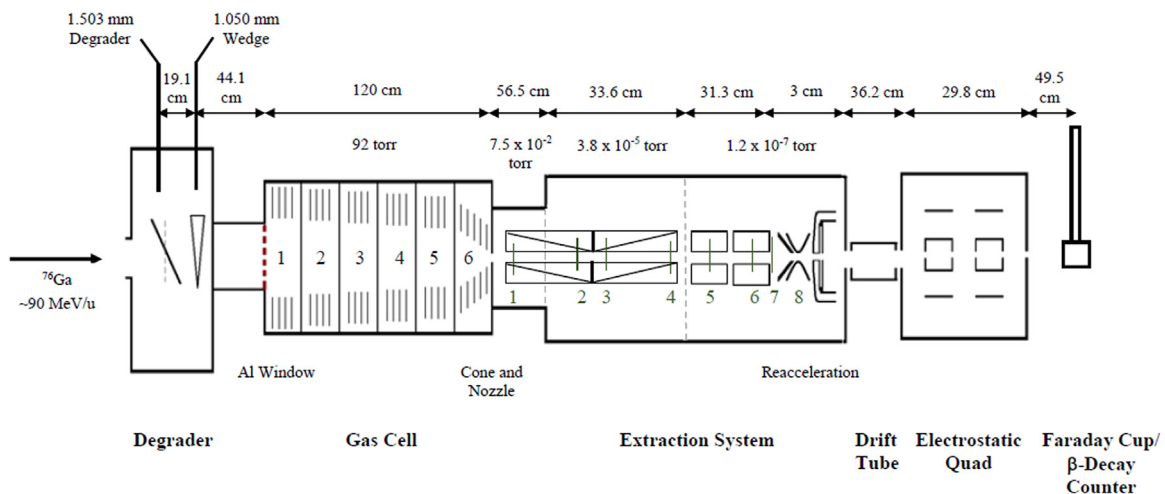
Fig. 1. Schematic layout of the experimental equipment, not to scale. The distances between components are given in cm.