Characterization of ion-stopping and extraction from a high pressure gas cell

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The ability to stop very energetic exotic ions and extract them from a gas catcher at the end of a fragment separator is a key component of the design of RIA. When the radioactive ions come to rest in ultra pure helium gas a fraction remain in the 1^+ charge-state. The radioactive ions can be extracted by drifting the ions to a supersonic nozzle in tens of milliseconds, that is, before they beta decay. The least proven aspects of this concept are the efficiency of stopping ions from a large acceptance fragment separator and the efficiency for extraction of 1^+ ions. Wada recently reviewed the general features of ion collection and gave an overview of the status of various experiments on this topic [1].

Collection studies with the rare beams from the NSCL allow a fully realistic test and demonstration of the technique under conditions similar to those expected at RIA. We have carried out a series of measurements of the range distributions and range compression of rare ions and subsequently we began a series of studies of the extraction efficiency of rare ions from a gas cell operating at 1 bar. The group at Argonne National Lab is studying the properties of a lower pressure cell (P ~ 200 mbar) that incorporates a radiofrequency ion-funnel to guide the ions to the nozzle. The stopping power of helium, or any gas for that matter, is low and a useful gas cell for ions from a fragment separator should have a “thickness” on the order of 1 bar-m. The NSCL system was developed to operate at high-pressures. An overview of our results is given below. The construction is complete and after a variety of preliminary measurements, our extraction tests are just now entering the quantitative phase. The initial results are intriguing and indicate that the system is operational.

The NSCL gas cell is designed to stop and collect the high-energy rare isotopes produced by the A1900 fragment separator. The gas cell was designed so that the standard beam line magnets can be tuned to provide a horizontal dispersion on a “monoenergetic degrader” to compensate for the momentum distribution of projectile fragments [2]. The beamline connecting the gas cell to the A1900 fragment separator was completed at the end of 2001. A degrader system can position very flat borosilicate glass plates (~2 microns variation in thicknesses of millimeters) in the path of the beam at the dispersive image along with several wedges. Numerous runs have been performed to measure the range distribution of different primary beams and secondary ions. As one example, ^{32}P secondary beams at 113 MeV/A were degraded so that they stopped in the gas or in a silicon detector stack in the gas. The data for ion transmission through the gas are shown in figure 1. The data were obtained under four conditions, with a “homogeneous” or flat degrader, with a shaped “monoenergetic” wedge, each with and without gas in the cell.

The fraction of ions that can are stopped in the gas is obtained by the difference in the fitted curves. Values of the ranges are in excellent agreement (an error of <0.5%) with the most recent range-energy calculations using the ATIMA code [3]. Similar results for range compression of somewhat higher energy fragments at GSI have been recently reported by Scheidenberger [4]. A manuscript describing our first results has been submitted for publication [5].

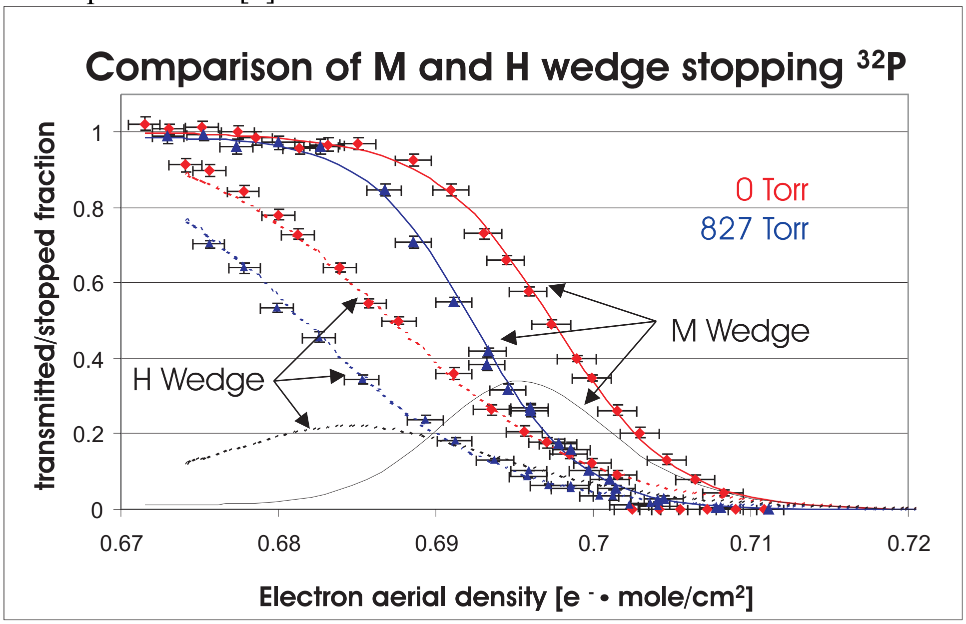

Figure 1. A comparison of the normalized transmission of ^{32}P ions at 3.359 Tm ($\Delta p/p$=2%) through the NSCL gas cell for pressures of 0 and 827 torr as a function of total degrader thickness. The thickness dimension incorporates the different elements present in the degraders and wedge. The curves represent functions fitted to the data. The results from the monoenergetic (M) shaped wedge and those from a homogeneous (H) or flat degrader show that the stopped fraction (the difference between the number of transmitted ions with and without gas) is improved by this technique.

The entire gas cell system is designed to implant ions in helium gas at pressures of one or more atmospheres and then extract the ions from the gas. The overall device consists of four differentially pumped chambers: a high pressure gas volume (~1atm x 0.5m) with a guide electric field and a small supersonic exit nozzle, an expansion chamber with an rf-quadrupole ion guide and skimmer, an intermediate pressure chamber traversed by a second rf-quadrupole, a second aperture and finally a third ion guide in a high vacuum chamber. All of the collection and guiding electrodes have been constructed and tested but in this report we will focus on the gas cell. A schematic diagram of the gas cell is shown in figure 2. As indicated by the measurements above, the ions come to rest in a distance in the gas on the order of 16 cm (110 microns of glass, FWHM) and are drifted to the nozzle by a static electric field on the order of 2kV/m. A spherically symmetric field is created in the region close to the nozzle. An important ingredient of this system is the nozzle itself is a semiconductor (silicon at present) so that a gradient can be established along the throat.

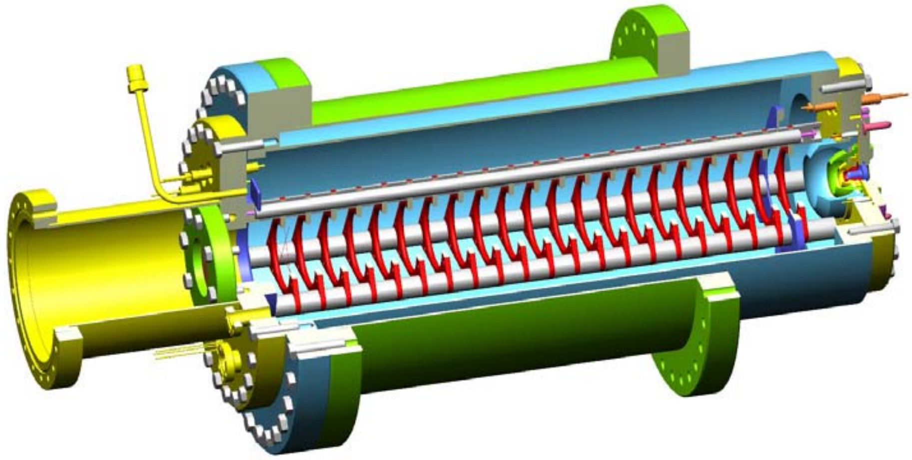

Figure 2. A rendering of the NSCL gas cell that emphasizes the drift electrodes and the extraction electrodes is shown. The ions enter from the left and pass through a rigid beryllium window and come to rest over distances on the order of 10-20 cm, depending on the ion, gas pressure, and other variables of the ion production and transport.

The electrode construction was complete early in 2003 and we began a period of extensive testing and measurement with radioactive beams as a function of momentum and momentum-width. Studies were performed with several radioactive ions and some

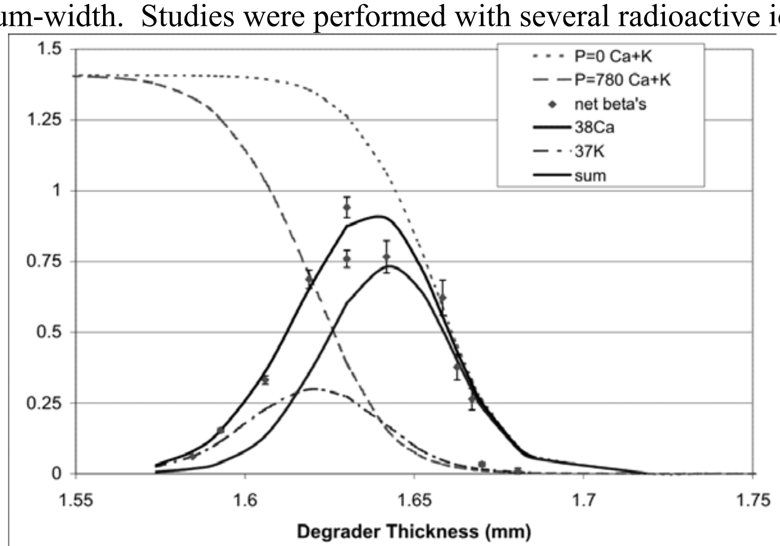

Figure 3. The stopping profiles for a combination of ^{38}Ca and ^{37}K ions are shown as a function of glass degrader thickness with and without helium gas. The very preliminary measured net counting rate observed in a plastic scintillator placed downstream from the nozzle is shown by the points has been scaled to the stopping curve.

of the first results for the extraction of radioactive ions from the NSCL gas cell are presented in the figure 3. The net activity on a collection electrode after the gas cell nozzle is shown as a function of degrader thickness and compared to the measured stopping curves. The collector was biased to +350 and –350 volts to obtain this net difference. The cyclotron beam was also cycled on and off with a three second period and the data only collected during the time that the beam was off. The factor needed to scale the counting rate to the stopping curve gives an extraction efficiency of approximately one percent. These initial results are extremely encouraging as they were obtained without optimizing the drift fields. A large number of important studies of ion extraction remain to be done, for example, optimization of the drift fields, then measuring the dependence of the extraction efficiency on gas pressure, ion-type, and ion intensity. The present designs for the fragment separator that will feed the RIA gas cell have anticipated some additional range-selectivity in the gas cell. The range selection process implies that a number of fragments besides the one of interest will be traversing and ionizing the gas volume. Thus, any limitations from ionization of the buffer gas on the collection process will have some implication for the separator design.

Along a parallel path, we are part of the collaboration to measure the stopping of high-energy uranium ions at GSI, a RIA R&D task led by Guy Savard at ANL. We supplied all the mechanical and electrical components for an rf-quadrupole to go in the chamber after the nozzle. This gas cell was recently completed and tested at ANL. We expect to take part in the experimental measurements at GSI may take place at the end of 2003.

We are in the position to do detailed comparisons of our data on range compression and ion extraction from the gas cell. The simulation program for the range work was developed at the NSCL and it was recently modified to include all the necessary ingredients to accurately estimate the fragment separator efficiency and range compression. The code can also make a reliable estimate of the stopping efficiency for ions in a given gas volume. Thus, a very important feature of this work is that the simulations will be tested against the measured fragment production and range compression data. The effects of ion extraction efficiency can also be tested against detailed simulations of the gas cell including space charge effects using the measured range distributions of the ions.

References

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