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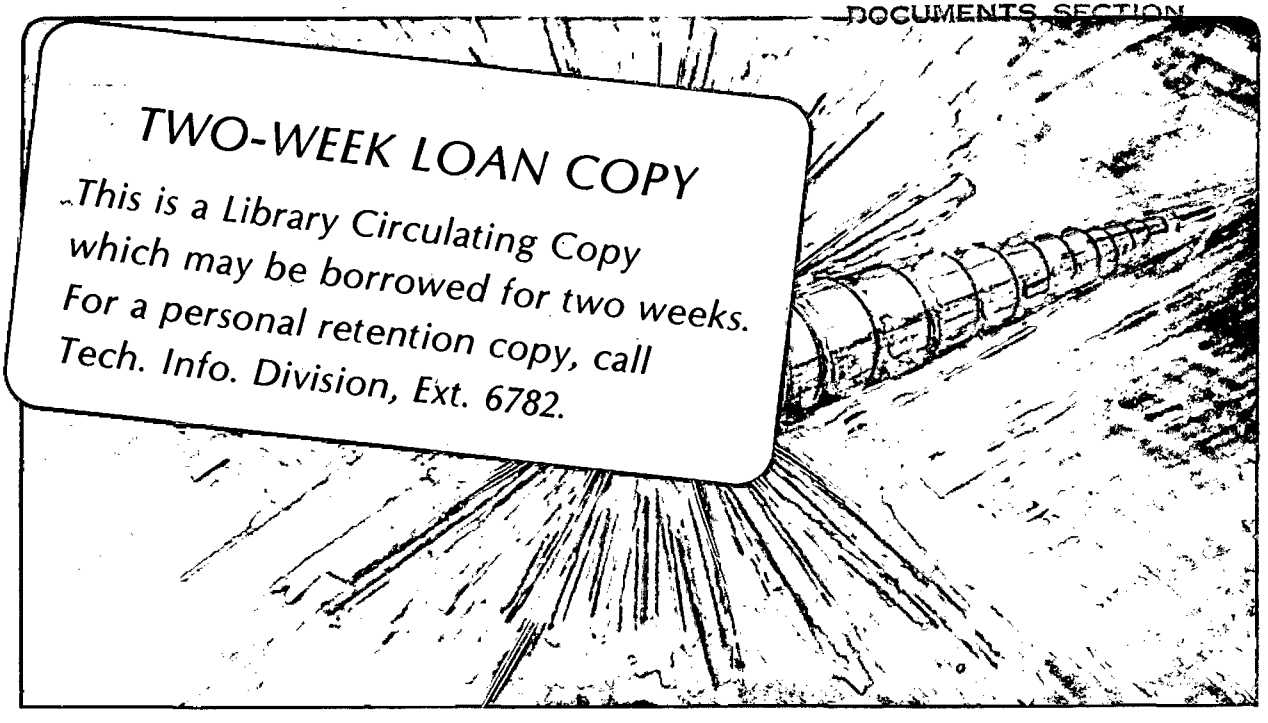

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DISCLAIMER

FLUOROCARBON STRIPPING OF LOW BETA HEAVY IONS*

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ABSTRACT

Equilibrium charge state distributions were measured for Kr, Xe, Ho and Pb ions at energies from 25 to 160 keV/amu passing through a high molecular weight fluorocarbon vapor, as well as air and carbon foil strippers. Measured charge state distributions are given which show that the fluorocarbon distributions are intermediate between those of air and foil strippers, becoming closer to foil values as velocity is decreased. At all energies substantial asymmetry in the fluorocarbon distributions towards higher charge states were observed. These favorable distributions, coupled with very high beam handling capability, low maintenance and indefinite lifetime clearly indicate the value of fluorocarbon stripping for many accelerator applications.

INTRODUCTION

Finding efficient ways of stripping heavy ions to the highest possible charge state is a continuing objective in heavy ion accelerator research. Since the dependence of accelerator design parameters on available ion charge states is critical, the development of higher charge state ion beams (through new ion sources or better strippers) considerably increases accelerator design flexibility and lowers machine costs. These thoughts have prompted recent research efforts in ECR and EBIS ion sources, which produce high charge states, but at relatively low intensities. If high intensities are mandatory, one must still rely on the combination of low charge state sources, preacceleration and stripping. Carbon foil strippers produce high charge states, but for high intensity beams the short foil lifetime, and heat dissipation problems are unwelcome complications. Gas strippers, on the other hand, are not as effective in producing high charge state ions.

These problems were recently faced in the design of the SuperHILAC Third Injector project, where the very high final beam currents desired completely preclude the use of carbon foils as well as gas strippers.

To understand the problem, it is instructive to look at the reasons that foils strip better than gases. One model for the production of higher charge states in foils (the density effect)[1] is that in a collision it is easier to strip electrons left in excited states from an earlier collision. Thus, if the time between collisions is shorter than the relaxation time of the atomic excited states, it is expected that more electrons will be lost. In a gas most of the ions have adequate time to return to their ground states between collisions, and so are harder to strip.

It was suggested by Wittkower and Ryding[2] that if a vapor of large fluorocarbon molecules were used for stripping, then multiple collisions would occur on the passage of an ion through a single molecule, thus potentially generating higher charge states. However, experiments at Daresbury[3] with Kr ions at 1.0 MeV/amu did not bear out the initial promise of the idea. It is possible, though, that the beam energy in this experiment was too high to see any effect. At higher energies electron loss cross sections are lower so the mean free path is longer; in the above experiment substantially longer than the molecular diameter. One should expect, then, to find an improvement in stripping performance either by going to heavier molecules (although path length improves roughly only as the cube root of the molecular weight), or at lower beam energies, where electron loss cross sections are larger.

EXPERIMENT

The energy range concentrated on in these experiments is from 30 to 150 keV/amu, with particular emphasis on 112 keV/amu, the injection energy of the SuperHILAC prestripper tank. Our apparatus, shown schematically in Figure 1, was located in the SuperHILAC experimental switchyard area. Two narrow slits serving as beam-definers were located upstream of the stripper cell. The cell, to be described below, was operated at a pressure of about 1 torr, this pressure having been determined experimentally to be adequate to ensure an equilibrium distribution of charge states in the emerging beam. Current in the 25° analyzing magnet was adjusted to bring the different charge states into the detector.

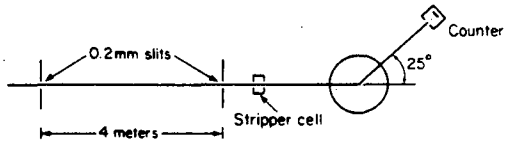

Fig. 1. Experimental setup. XBL 793-749

BEAM TRANSPORT

Ions used in these experiments were delivered from Adam, the 2.3 MV Dynamitron SuperHILAC injector. The standard PIG source was used for all ions; Kr and Xe being injected as gases, while Ho and Pb required the use of the sputter electrode. The charge state typically run in the SuperHILAC was selected, and the CW voltage and transport line were tuned for normal operation. For these experiments, though, the beam was drifted through both tanks of the SuperHILAC, with transmission being optimized by drift-tube quadrupole tuning. Since no acceleration was performed in the linac, the beam energy was determined only by the Cockroft-Walton voltage plus the source extractor voltage.

Making measurements at different energies was accomplished in a very simple manner by utilizing different charge state ions from the source. Since the entire beam transport system was set up for a given rigidity, the Cockroft-Walton voltage (beam energy) was adjusted to bring the rigidity of the new charge state to the tuned value. In this fashion, for example, holmium beams from 32 keV/amu (5+ charge state) to 133 keV/amu (10+ charge state) were studied, with only 5 minutes or less required to change energies. Since equilibrium charge distributions were being investigated, different incident charge states had no effect on the measurements.

STRIPPING CELL

The material selected for study was FOMBLIN Y-VAC 25/9 (marketed in the U.S. by Montedison USA, Inc.,

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1114 Avenue of the Americas, N.Y. 10036), a highly distilled perfluoropolyether with an average molecular weight of 3400. This material is marketed as a diffusion pump fluid, most suited for use in highly ionizing environments (electron microscopy, for example), since its molecules, in the presence of ionizing radiation tend to crack into lighter, more volatile fragments rather than polymerize into a heavy residue. Vapor pressure curves for Y-VAC 25/9 published by the manufacturer indicate that a temperature range of 170°C to 190°C will provide pressures of 1-10 torr, the desired operating range.

The cell shown in Figure 2 was designed to make best use of these properties. Liquid is held in a bath maintained at 180°C. Molecules evaporating from the surface travel through the ion beam and condense on the upper cooled dome of the cell, then flow back down the cell walls to the bath. The unidirectional flow of vapor is intended to reduce diffusion through the 1 cm beam port holes.

Under normal operating conditions the pressure in the surrounding beam-line vacuum box, which had no special provisions for extra pumping, remained in the microtorr range. After prolonged running (20 hours or so) a film of fluid was detected on the walls of the vacuum box, implying that some form of diffusion-baffling would be desirable. This diffusion did not degrade system performance, though, owing to the exceedingly low room temperature vapor pressure of the fluid.

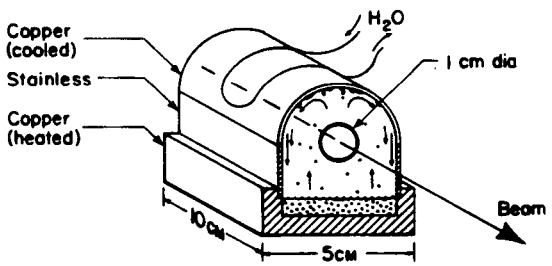

Fig. 2. Fluorocarbon vapor stripping cell. XBL 793-745

DETECTOR

The detector used, developed by M. I. Green[4] at LBL is insensitive to the charge state of the ion detected, and responds only to the number of particles. The beam enters through a narrow (1 mm) slit and directly behind the opening strikes a tungsten wire of slightly larger diameter than the slit. Secondary electrons ejected from the wire are accelerated onto the surface of a micro-channel plate which amplifies the signal according to the voltage applied across it. The great dynamic range inherent in channel plates provides detector sensitivity from single particle counts to the maximum intensity of SuperHILAC beams, limited only by cooling of the tungsten wire beam stopper. In addition, the absence of any entrance window means that there is no low energy cut-off to the detector range.

Signals from the detector are electronically processed, with the resulting analog output driving the vertical axis of a storage scope. A monitor of the analyzing magnet current was connected to the horizontal axis. Data were recorded from the scope face with Polaroid films. The measurement accuracies of about ± 10% coincided approximately with observed beam intensity variations over the period of any one run (no direct normalization of the data was performed).

RESULTS

Measurements were made for beams of ^{86}Kr (31 to 161 keV/amu), ^{136}Xe (25 to 122 keV/amu), ^{165}Ho (32 to 133 keV/amu) and ^{208}Pb (58 to 112 keV/amu). Stripping with FOMBLIN and carbon foils (8 μg/cm^2) was done for all beams. In addition, air stripping measurements were made for Ho and Pb ions by introducing a leak into an upstream section of beam pipe. The effective thickness of gas was about 3 μg/cm^2). Results for the four beams at energies around 110 keV/amu are shown in Figures 3-6. The vertical line in these figures indicates the lowest charge state which can be accepted by the SuperHILAC (determined by the highest allowed RF gradient in the first tank). The velocity dependence of the most probable charge state of Holmium for each stripper is shown in Figure 7. Complete tables of data are not included here, but are available separately[5].

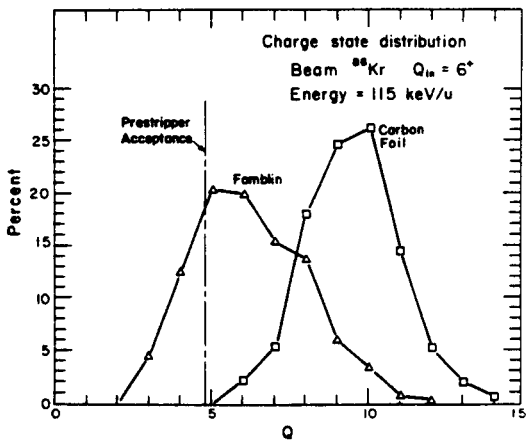

Fig. 3. Krypton charge state distributions.

XBL 789-2239

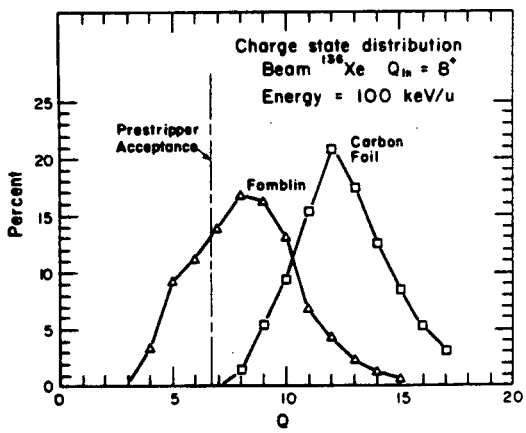

Fig. 4. Xenon charge state distributions. XBL 789-2240

It is readily seen that at these energies there is a substantial advantage to be gained by using the fluorocarbon stripper. Not only is the average charge state higher than for an air stripper, but also the distribution is skewed towards even higher charge states. In the case of Pb, this asymmetry brings the 10+ charge state (lowest accepted by the SuperHILAC) up to 11% of the total beam. Since any charge state higher than 10+ is in principle equally acceptable for acceleration in our linac, there is no great advantage to using a carbon

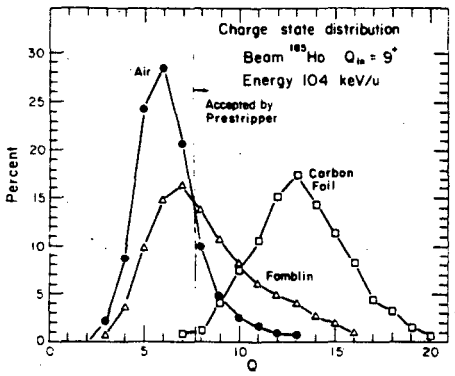

Fig. 5. Holmium charge state distributions.

XBL 789-1238

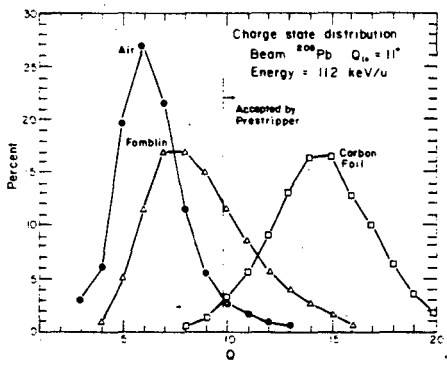

Fig. 6. Lead charge state distributions. XBL 789-2241

foil stripper, whose peak charge state (15+) has only 16% of the beam. When these numbers are coupled to the fact that there is effectively no limit to the beam current the fluorocarbon stripper can handle, the superiority of this stripper is clearly apparent for our application.

The velocity dependence shown in Figure 7 indicates that as one goes to higher energies the fluorocarbon looks more and more like an air stripper (in agreement with the Daresbury results), but that as the energy is decreased the charge state distributions come closer to those seen with foils. One can speculate that this behavior is explained by the changing ratio of the molecular diameter to the (strongly velocity-dependent) charge-changing mean free path of the ion through the molecule.

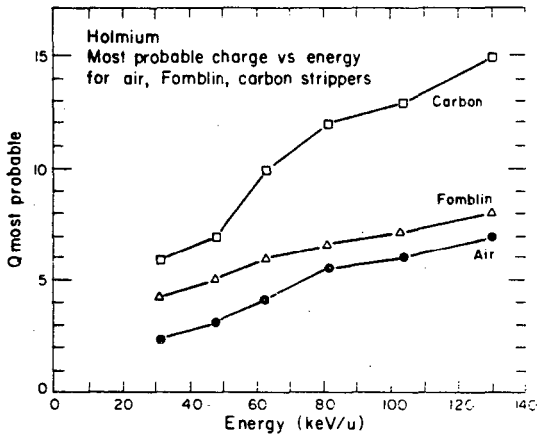

Fig. 7. Energy dependence of distribution peaks for Holmium beam. XBL 789-2237

One can further speculate that the great degree of asymmetry in the charge state distribution may be related in some way to different impact parameters (hence different path lengths through the molecule), higher charge states resulting from ions having gone through longer sections of the molecule.

SUMMARY

The very favorable charge state efficiency, coupled with the unlimited beam intensity handling capability, long lifetime and low maintenance clearly point to fluorocarbon vapor as the stripper of choice for the SuperHILAC Third Injector project. Applicability of this technique to other accelerator projects will depend on the energy and intensity of the beams to be stripped and on the degree to which diffusion of the fluorocarbon from the cell must be controlled.

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