Multiple Electron Stripping of 3.4A MeV Kr^{7+} and Xe^{11+} in Nitrogen

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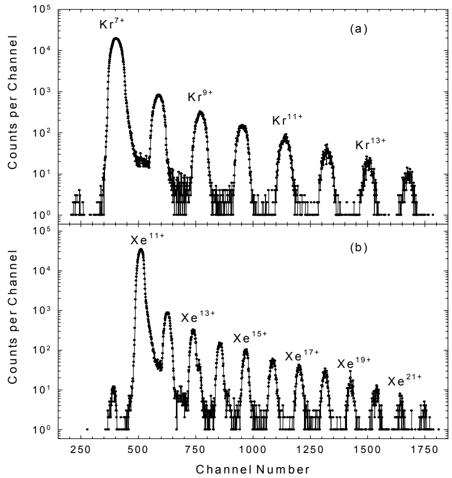
One of the approaches presently being explored as a route to practical fusion energy uses heavy ion beams focused upon an indirect drive target to produce x-rays, which then drive the compression of a deuterium-tritium pellet [1]. Some of the more prominent baseline designs currently being proposed for such reactors envision propagating a beam of singly-charged positive ions of a relatively heavy element, such as xenon or krypton, across a distance of several meters between the final focus magnet system and the target in the center of the target chamber. The target chamber gas density would probably be composed primarily of the vapor from a liquid wall such as FLIBE, a salt of fluorine, lithium, and berylium. The density of beryllium difluoride vapor in one such reference design, HYLIFE-II is 5 x 10^{13} cm^{-3} [2]. Ionization of this medium would supply space-charge-neutralizing electrons to compensate partially the space-charge force of the positive ion beam, which would otherwise cause the beam spot size to expand, decreasing the focusability. This medium would also remove additional electrons from the ion beam through impact ionization, thus raising the average charge state of the beam. This can increase the beam spot size, since the deflection of ions in the residual spac44e-charge fields is proportional to their charge state.

It is thus important in planning possible operating regimes for heavy-ion-driven fusion reactors to assess the rate at which the charge state of an incident beam evolves while passing through a background gas. It is important in particular, to assess whether multi-electron-loss events, events in which a beam ion loses more than one electron in a single ionization event, are major contributors to the charge state evolution and dispersion of the beam. The experiments described in this report were intended to appraise the magnitude of multi-electron loss events in regimes approaching, although not exactly duplicating, those anticipated for heavy ion fusion drivers. The gas used to simulate the medium in the fusion target chamber is molecular nitrogen, whose average atomic number is reasonably close to that of beryllium difluoride. Ideally, one would like to use beams of singly charged xenon and krypton at energies of 20A MeV. Such beams are not presently available from accelerators. The experiments reported here have instead used Kr^{7+} and Xe^{11+} at 3.4A MeV. If multi-electron loss events play a prominent role for these beams, in which the electron cloud is held more tightly than would be the case with the singly charged incident beam actually planned for a heavy ion driver, then it can be inferred that multi-electron loss events will also be significant for the actual driver beams. This information will be useful in the design of heavy ion fusion 4reactor options, since it will provide a guide to how much emphasis needs to be placed upon the implementation of approaches to improve the space-charge neutralization of the beam.

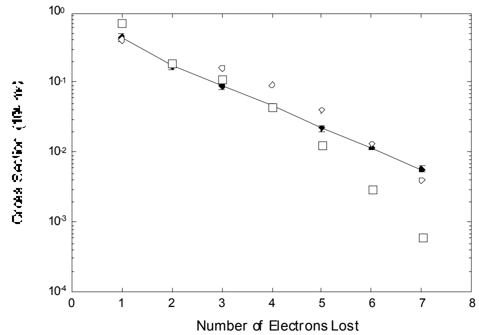
The charge state distributions for incident beams of 3.4A MeV Kr^{7+} and Xe^{11+} taken with gas cell pressures of 4 mTorr are shown in Fig. 1. It is clear from inspecting these plots that multiple electron loss collisions are important. In the case of Kr, 3.6 % of the initial beam is stripped of only one electron, and 1.3% is stripped of two electrons. For Xe, the



corresponding numbers are 2.6% and 0.8%. These high rates of two-electron loss relative to one-electron loss cannot be explained by multiple, single-electron-loss collisions.

Figure 1: Charge state distributions for incident 3.4A MeV Kr^{7+} (a) and Xe^{11+} (b) ions after passing through $7.6x10^{15}$ Torr-m of nitrogen.

Shown in Fig. 2 are the electron loss cross sections for Kr obtained using the data for pressures # 8 mTorr. The experimental cross sections are compared with the results of theoretical calculations based on (a) the classical model of Bohr [3], and (b) the plane wave Born approximation (PWBA) [4]. The predicted cross-sections reproduce the main trends in



behavior of the experimental results, but they differ from each other and from the experimental results by a factor of two or more.

These experiments have shown that, for

Figure 2: Comparison of the measured electron loss cross sections for 3.4A MeV Kr^{7+} ions in nitrogen (filled circles) with classical model (empty squares) and PWBA (empty circles) calculations.

beams with parameters approaching those likely to be used for heavy ion fusion drivers, multi-electron loss events are very important factors in the charge state evolution of the beam. This suggests that it will be important to develop an adequate means of space-charge neutralization. These measurements have also provided bench-marking validation of modeling techniques. Further refinements should enable accurate predictions of electron loss cross sections for heavy ion driver beams.

References

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