RECOIL ION CHARGE STATE DISTRIBUTIONS IN LOW ENERGY Ar^{q+}-Ar COLLISIONS

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ABSTRACT

We have measured the recoil ion charge state distributions in Ar^{q+} - Ar ($8 \leq q \leq 16$) collisions at 2.3 qkeV and 0.18 qkeV by time of flight (TOF) spectroscopy. For $Ar^{8\text{-}16+}$, recoil ion charge states up to 6+ are clearly present, indicating that the 3p subshell in the target atom is being depleted, while for $Ar^{10\text{-}16+}$, there is evidence that target 3s electrons are also being removed. Comparison of the recoil ion charge state spectra at 2.3 and 0.18 qkeV shows that for a given projectile charge, there is very little dependence of the observed recoil target charge state distribution on projectile energy.

INTRODUCTION

It has been known for some time that in low energy, highly charged ion-multielectron atom collisions, the target atoms often have many electrons removed and they themselves become fairly highly ionized.[1] The appearance of several free electrons in the collisions has been attributed to processes not always specified, but referred to collectively as transfer ionization.[2] Transfer ionization is thought to be related in some way to the total potential energy (binding energy of missing electrons) brought into the collision by the highly charged projectile ion.

In order to investigate the process of electron removal from the target by the low energy, highly charged projectile in more detail, we have measured the ion charge state distribution of the recoil targets produced in Ar^{q+} on Ar ($8 \leq q \leq 16$) collisions at 2.3 qkeV and for selected charge states, at 0.18 qkeV. The objective was to obtain data, that together with other measurements, some of which are reported in these proceedings, will enable us to understand what is happening in these collisions.

EXPERIMENTAL METHOD

Ar^{q+} ($8 \leq q \leq 16$) ions were produced by the Cornell superconducting solenoid, cryogenic electron beam ion source CEBIS [3] and extracted at 2.3 kV. Magnetically selected charge states were crossed with a gas jet located between the first two plates of a 2.5 m long Wiley-McLaren type time of flight (TOF) spectrometer.[4] The incident ion beam was chopped by a several hundred nonosecond wide pulse and the recoil ions produced in the Ar^{q+} - Ar collisions swept out of the interaction region by a few volts/cm electric field and analyzed by TOF. To prevent the loss of ions in the almost 2.5 m long TOF drift region, a central guide wire, biased negatively at a few volts with respect to the drift tube guided the ions through the spectrometer.[5] The TOF spectrometer was electrically isolated from ground and could be floated at a high voltage. The spectrometer is shown in figure 1. An acce/decel lens in front of the interaction region (not shown) could speed up or slow down ions entering the spectrometer.

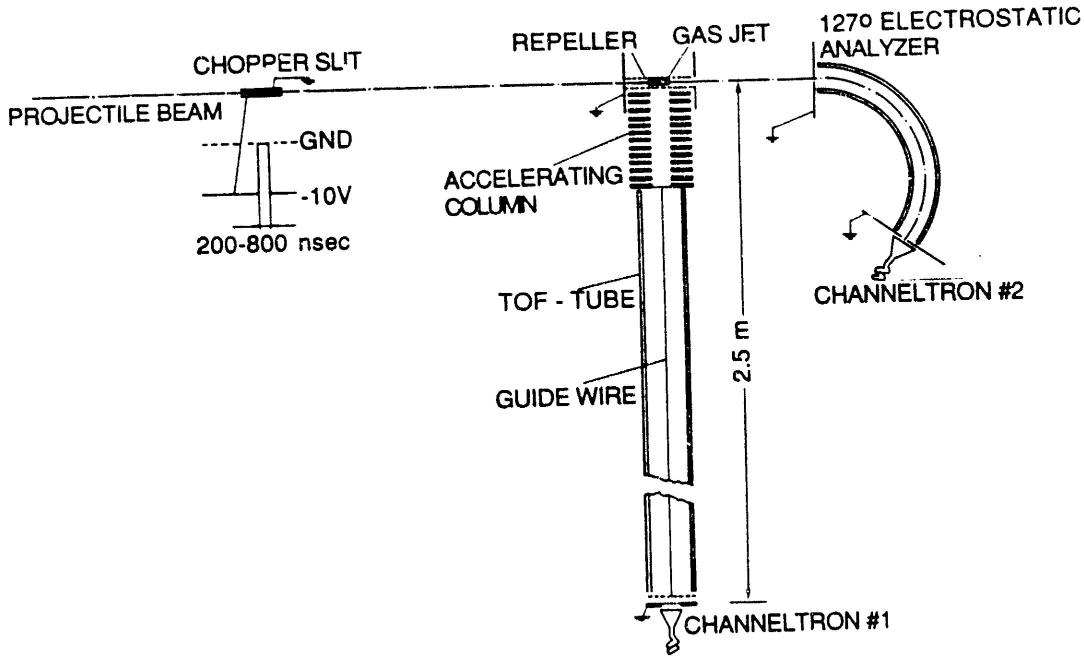

Figure 1. Experimental arrangement used to record recoil ion charge state distributions.

RESULTS

A typical recoil ion charge state distribution, measured under single collision conditions is shown in figure 2. For each spectrum, the charge state fraction was obtained by dividing the total number of counts under a given charge by the total number of counts under all peaks. For the higher recoil ion charges, the peaks were fitted by Gaussians of the same width. The fitted Gaussians then determined the areas under these peaks, figure 3.

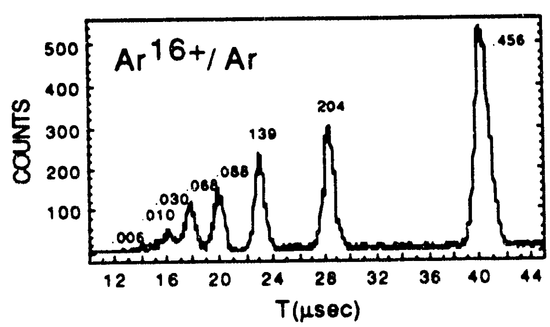

Figure 2. Typical recoil ion charge state distribution for a 36.8 keV Ar^{16+} projectile incident on Ar.

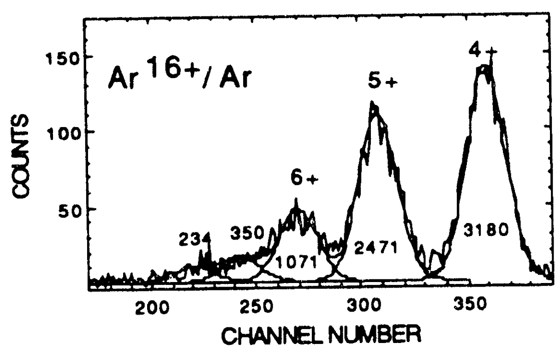

Figure 3. Constant width Gaussian fit to the higher charge states in the recoil ion charge state distribution.

Figure 4. shows a plot of the relative recoil ion charge state fractions as a function of the projectile charge q in 2.3 qkeV Ar^{q+} on Ar collisions. The data were extracted from the measured recoil ion charge state distributions.

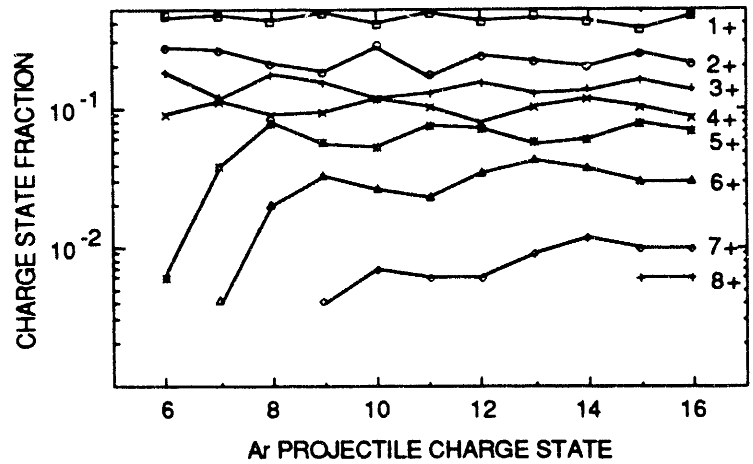

Figure 4. Relative recoil ion charge state fractions as a function of the projectile charge q in 2.3 qkeV Ar^{q+}on Ar collisions

We have also measured the recoil charge charge state distribution for selected charge states at lower collision energies. Figure 5 shows the distribution for Ar^{10+} on Ar at 2.3 and 0.18 qkeV. Distributions at lower energies are quite similar for the different projectile charge states incident on Ar.

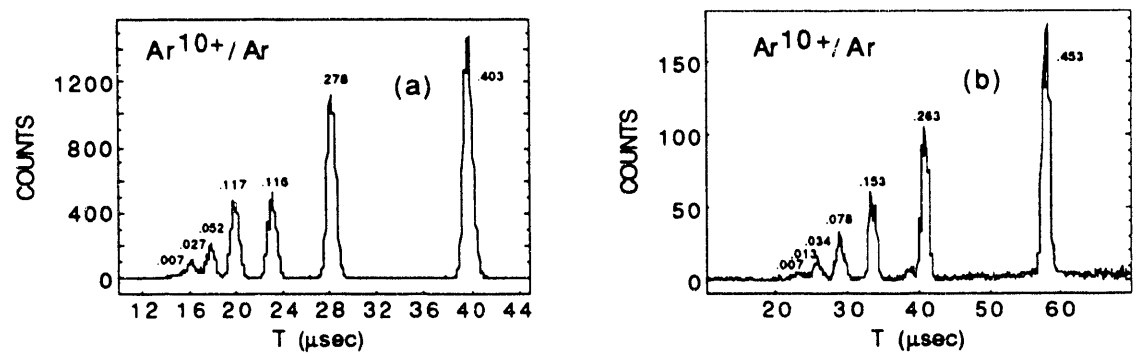

Figure 5 Recoil ion charge state distribution for Ar^{10+}on Ar at 23 keV, (a) and 1.8 keV, (b).

DISCUSSION

Total cross sections for Ar^{q+} on Ar, measured in a separate experiment for $8 \leq q \leq 16$ at 2.3 qkeV,[6] show that the highly charged projectiles mostly gain only one or two electrons. However, the recoil ions can end up in a fairly high charge state following such collisions. Thus, transfer ionization processes are very important in these collisions as has already been noted in earlier work using recoil ion sources to investigate Ar^{q+} on Ar for $q \leq 8$.[7] No satisfactory explanation of the transfer ionization process which can fully predict and reproduce the recoil ion charge state and the energy distribution of the accompanying electrons is available at present.

Our data show that for Ar $^{8-16+}$, recoil ion charge states up to 6 are clearly present, (figure 4), indicating that the 3p subshell in the target argon is being depleted, while for Ar^{10-16+} projectiles, charge states up to 8 are observed, giving some evidence that the target 3s subshell is also being depleted. From figure 4, the recoil ion charge states show little dependence on the projectile charge state, and hence the potential energy brought into the collision. This ranges from 568 eV for Ar^{8+} to 5,835 eV for Ar^{16+}.[8]

Of the various mechanisms proposed to explain transfer ionization [9,1], the most likely process at very low collision velocities involves a quasi-molecular state formed during the collision and populated by the 3p and 3s target argon electrons. Either this state decays non-radiatively during the collision, or it causes electrons to be stranded in an excited state of the projectile which decays non-radiatively shortly after the colliding partners have separated. In both cases electrons are removed from the target. At an internuclear separation around 10 a.u., corresponding to the measured cross sections for electron transfer in these collisions, it is unlikely that the vacancy in the projectile 2p and 2s subshells is filled by the target 3p and 3s electrons by interatomic Auger transitions as there is negligible overlap of all the pertinent wave functions at this separation. The same is true for any sequential process in which an electron goes over to an excited state of the projectile which in turn relaxes with energy transferred to another electron on the target.

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