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Crossed Beam Experiment for Multi-Electron Capture in Ion – Atom Collisions in the Energy Range of 10 – 100 eV/*q*

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Abstract

In order to study the charge transfer processes between highly charged ions and atoms or molecules in the collisional energy range of below 100eV/q, an experimental setup for the state selective differential cross section measurement of multi-electron capture processes was prepared. The apparatus is set at the 30° beam line of the RIKEN 14.5 GHz Caprice ECR ion source. Highly charged ions extracted from the ion source at 2keV/q into the beam line, are decelerated down to 10-100eV/q and then energy selected by a double hemispherical analyzer. A typical current of 300 pA was achieved for the energy selected 40eV/q Ar^{6+} beam with an energy width of 0.3 eV/q. The energy distribution of scattered ions for 36.6 eV/q (7.3 eV/u) Ar^{8+}-N_2 collisions at scattering angles from 0° to 10° has been measured.

1. Introduction

The study of multi-electron capture processes in slow collisions between highly charged ions and atoms or molecules has been the subject of considerable experimental and theoretical investigations. The knowledge of ion-atom and ion-molecule scattering such as cross sections provides important information for applications in astrophysics and fusion research. It is known that a quite large fraction of important astrophysical processes takes place at very slow collisions such as collisional energy lower than 10 eV/u. The interest in the very slow collisions in the ion-atom and ion-molecule scattering also arises from the fundamental aspect that the sensitivity of the angular differential cross sections to the shapes of active potential curves increases with decreasing the collisional energy. Since difficulties arise in producing the very slow and well collimated highly charged ion beam, experimental studies for very slow collisions between highly charged ions and atoms or molecules have been limited to ion trap and merged-beam techniques. However, it is difficult to derive the information on angular differential cross sections from these techniques. Recently, Cederquist *et al.* presented an experimental setup for studies of state-resolved angular distributions in very-slow collisions [1]. An another experimental setup has been presented by Yaltkaya *et al.* [2]. Both experimental techniques utilize a recoil ion source for producing the very slow ion beam for the angular differential cross sections measurements. The major advantage of using the recoil ion source is the narrow energy spread of the very slow ion beam. On the other hand, the intensity of the very slow ion beam is extremely small and species of the ions are limited. Here we present an experimental setup for state selective angular differential cross section measurements of multi-electron capture processes in very slow collisions between highly charged ions and atoms or molecules which utilizes the ion beam from the 14.5 GHz Caprice electron resonance (ECR) ion source at RIKEN. Using the direct ion beam from the ECR ion source has the advantage to achieve a high intensity beam, after the deceleration of the ion beam.

2. Experiment

The apparatus is set at the 30° beam line of the RIKEN 14.5 GHz Caprice ECR ion source [3]. The main components of the beam line are the 14.5 GHz Caprice ECR ion source, extraction lens, analyzing magnet, and switching magnet. The deceleration system was set between the switching magnet of the beam line and the collision chamber which contains the ion beam energy selector and the analyzer for the scattered ions. Highly charged ions produced in the ion source are extracted at a beam energy of 2 keV/q into the beam line and selected by m/q values by the analyzing magnet, where m is mass and q the charge of the ion. Since the beam energy depends on the potential of the plasma chamber of the ion source, the beam line is floating from the ground potential, so that a sufficient extraction potential can be applied. The ion beam is transported at 2 keV/q before the deceleration lens and decelerated down to the beam energy of 100eV/q by the deceleration lens and focused into the collision chamber. Figure 1 shows the schematic of the apparatus inside the collision chamber. The apparatus consists of the beam energy

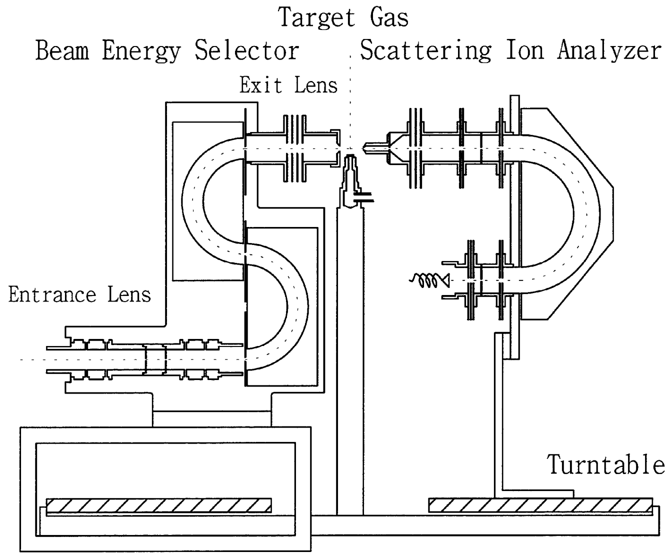

Fig. 1. Schematic view of the experimental apparatus installed in the collision chamber.

Table I. *Currents and energy widths of ion beams obtained in the present experimental setup*

Ion	Beam Energy (eV/q)	Before Deceleration (μA)	FC (pA)	Energy Width (eV/q)
Ar^{8+}	35	13	22	0.20
Ar^{6+}	50	9	300	0.27
Ar^{6+}	45	10	120	0.25
Ar^{4+}	60	3	135	0.66
He^{2+}	70	20	250	0.58
He^{+}	60	10	300	0.33
He^{+}	40	30	180	0.33
He^{+}	30	18	12	0.47
He^{+}	20	20	7	0.18

selector, an effusive target, and the scattering ion analyzer. The beam energy selector consists of entrance lenses, two sets of 40-mm radius hemispherical electrostatic analyzers, and an exit lens. The ion beam of 100eV/q is decelerated down to the pass energy of the analyzer by the entrance lens. Two collimators of 1 mm diameters are set at the entrance lens to limit the angular divergence. The energy selected ion beam is accelerated or decelerated to the desired energy and focused to the interaction region by the exit lens. A mesh was set at the exit lens for monitoring the ion beam current. The target gas is introduced by a multi capillary and intersects the ion beam at right angles. The size of the target beam at the intersection region is estimated as 1-mm diameter. Scattered ions are analyzed by a 50-mm radius hemispherical analyzer, which is set on the turntable. A Faraday Cup (FC) is set on the turntable and can monitor the beam current by rotating the turntable. The angular resolution of the scattering ion analyzer is estimated as 2°.

3. Results and discussion

Typical currents of the ion beam measured right after the m/q selection and in the FC set behind the intersection region in the collision chamber are shown in table I. The intensity of the very slow ion beam obtained in the present setup is a factor of 10^4 higher than that obtained with the setup using the recoil ion source [4]. The ion beam loses about half of its intensity during the transportation before the deceleration lens. The beam intensity is reduced by a factor of 10^3 by the deceleration and collimation before the focusing into the collision chamber. It seems that the space charge effect during transportation from the deceleration lens to the beam energy selector decreases the beam intensity. An over all energy resolution of about 1/180 of the beam energy is achieved in the present apparatus.

The energy distributions of scattered ion (Ar^{8+}, Ar^{7+}, and Ar^{6+}) for 36.6 eV/q (7.3 eV/u) Ar^{8+}-N_2 collisions at scattering angles from 0° to 10° are shown in the Fig. 2. The intense peak

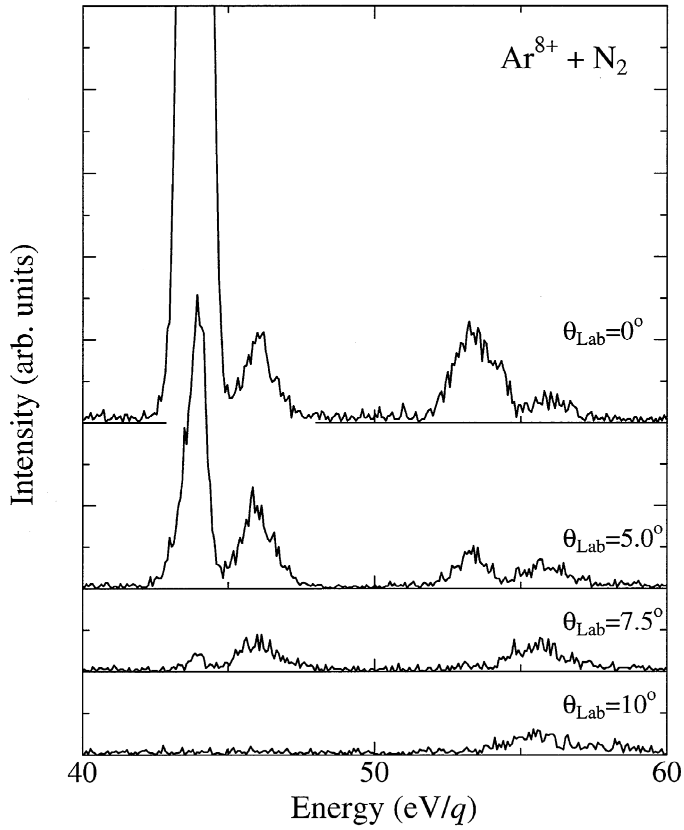

Fig. 2. Energy distributions of scattered ion (Ar^{8+}, Ar^{7+}, and Ar^{6+}) for 36.6 eV/q (7.3 eV/u) Ar^{8+}-N_2 collisions at scattering angles as indicated.

seen at 44 eV/q for $\theta = 0°$, originating from single electron capture, rapidly decreases with increasing scattering angle. The neighboring peak at 46 eV/q which is due to transfer ionization also decreases at larger angles. At 53 eV/q, a multi-component peak due to double electron capture processes is seen, the intensity of which decreases rather slowly. The peak at 56 eV/q does not decrease its intensity with increasing scattering angle as observed for the other peaks. These different scattering angle dependencies confirm the fact that single electron capture occurs mainly in glancing collisions, on the other hand multiple electron capture occurs in close collisions.

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