Laboratory observation of forbidden x-ray transitions in solar wind charge exchange

Atomic Physics Laboratory B1378659 Naoki Numadate

1. Introduction

In 1990, the ROSAT satellite was launched and measured the soft x-ray background over the all sky. During the observation, it was discovered that the intensity of the soft x-ray background varies with short time within a few days in space where x-ray sources do not exist [1,2]. In 1996, the ROSAT satellite observed the soft x-ray emissions from the Hyakutake comet when it approached the earth [3]. After that, the x-ray emissions from various comets were observed and it was concluded that a part of the emissions is caused by the de-excitations in charge exchange processes between highly charged ions (HCIs) in solar wind and cometary neutrals [4]. Since then it has been recognized that the long-term enhancements of the soft x-ray background stem from the solar wind charge-exchange (SWCX) with neutrals within the heliosphere as well as cometary neutrals [5-7]. In order to quantitatively analyze the high-resolution x-ray spectra observed with the satellites in detail, the cross sections in SWCX processes, in particular x-ray emission cross sections, are needed. However, there are no sufficient cross section data so far.

In these contexts, some x-ray emission cross sections in the SWCX processes have been measured for the electric dipole allowed x-ray transitions [8,9]. However, the main emissions in SWCX are known to be the forbidden and inter-combination transitions in O^{6+} ($1s2s/1s2p - 1s^2$ transitions) [7], which have not been measured yet in a laboratory. Since the ion beam has a velocity of 200 - 900 km/s in order to reproduce the solar wind, it is impossible to observe the transitions with long lifetimes over microseconds by the beam-based experiments. Nonetheless, we have a chance to observe the forbidden transitions by trapping the metastable HCIs after the charge-exchange reactions of O^{7+} ($1s$) + He → O^{6+} ($1snl$) + He^+.

In this work, we report on the development of a Kingdon ion-trap system for trapping high energy HCI beams produced by an electron-cyclotron resonance ion source (ECRIS). As a performance test of the instrument, we measured trapping lifetimes of Ar^{q+} (q = 5, 6) under a constant number density of H_2. Some experimental problems and their solutions are discussed. Then, the charge-transfer cross sections of the Ar^{q+} - H_2 collision systems were measured at binary collision energies of a few eV [10]. The results are compared to previous data and the values estimated by some scaling formula. Finally we report on the status of the observation of the forbidden x-ray transitions from the metastable O^{6+} ($1snl$).

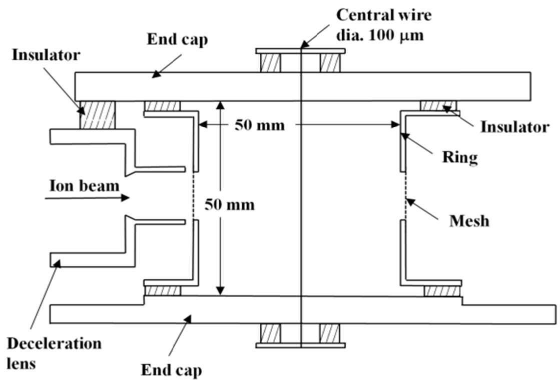

Figure.1 The side view of the Kingdon ion trap from the ion beam axis.

2. Experimental Setup

In this abstract, I describe the setup of trapping lifetime experiment. The highly charged ion beams were produced by ECRIS at an acceleration voltage of 6.0 or 8.0 kV. We selected the ions with a desired charge-state by an analyzing magnet. Then the ions were injected into a Kingdon ion trap for trapping experiments. The ion beam current was measured with a Faraday cup installed at the most downstream of the beam line before applying high voltage into the trap electrodes.

Figure.1 shows a schematic drawing of the Kingdon ion trap. It consists of a central wire electrode, a cylinder electrode and two end-cap electrodes. After pre-determined storage time, the trapped ions were ejected and a part of the ejected ions are detected by a micro channel plate (MCP). The output pulse signals from the MCP are counted by a fast multichannel scaler. In the earlier study using the Kingdon ion trap, D. A. Church *et al.* reported that no product ions with lower charge state were stored after the charge-exchange collisions between Ar^{q+} and Ar [11]. However, our study showed that the ions produced by the charge-exchange collisions between Ar^{q+} and H_2 were still trapped. Thus, we introduced the TOF measurement system in order to determine the trapping lifetime of HCIs. The data acquisitions were repeated 10^3 - 10^4 cycles depending on the ion beam current and storage time.

3. Results and Discussion

Figure.2 shows the decay of trapped Ar^{q+} (q = 5, 6) ions as a function of the storage time in H_2 gas at a pressure of 1.24×10^{-5} Pa. The decay rates of Ar^{5+} and Ar^{6+} were determined be 28(6) s^{-1}, 67(6) s^{-1}, respectively. In order to determine the charge-exchange cross sections from the decay rates, we need to know the average velocities of Ar^{q+} ions. For this purpose, we have performed extensive numerical simulations of ion trajectories trapped in the realistic Kingdon trap using the commercial software (SIMION8.0) and the average velocities of Ar^{5+} and Ar^{6+} were determined to be $1.8(0.3) \times 10^4$ m/s and $2.0(0.4) \times 10^4$ m/s, respectively. On the other hand, the number density of H_2 was determined by the ionization pressure gauge. Finally, the charge-exchange cross sections for the Ar^{5+}-H_2 and Ar^{6+}-H_2 systems were determined to be $5.2(2.6) \times 10^{-15}$ cm^{-3} and $1.1(0.5) \times 10^{-14}$ cm^{-3}, respectively. Note that the cross section of the Ar^{5+}-H_2 system at the low energy was determined for the first time. These cross section data are consistent with the values estimated by the scaling formula and previous experimental data [12,13].

As a first step of the x-ray observation from the metastable O^{6+}, we started the trapping experiment. Figure.3 shows a decay curve of the trapped O^{6+} ions as a function of the storage time in H_2 gas at the pressure of 4.4×10^{-7} Pa. The trapping lifetime of O^{6+} is determined to be 280(15) ms. Since the lifetime of the forbidden transition in O^{6+} ($1s2s$ - $1s^2$ transition) is approximately 1 ms [14], the trapping lifetime is long enough to measure the forbidden transition.

The details of the discussions and the progress of the x-ray observation will be presented at the oral presentation and the master thesis.

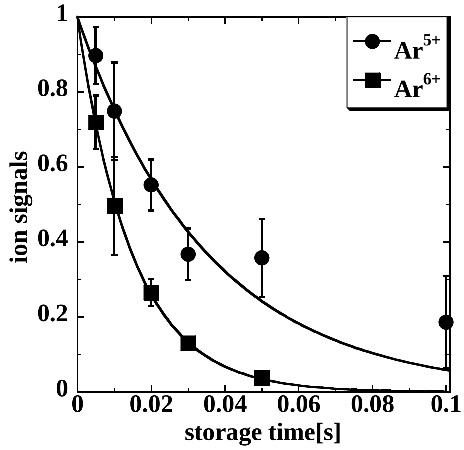

Figure.2 A plot of the extracted Ar^{5+} and Ar^{6+} as a function of storage time. The data are well fitted by single exponential function.

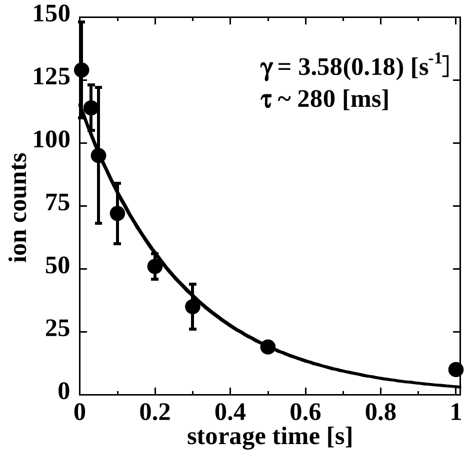

Figure.3 A plot of the extracted O^{6+} as a function of storage time. This data is well fitted by single exponential function.

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