Physica Scripta. T92, 339–340, 2001

Angular Resolved Energy Gain Spectroscopy to Study Double Electron-Capture Processes in Very Slow C^{4+}–He Collisions

Masamitsu Hoshino[1], Masashi Kitajima,[1] Yasuyuki Kanai,[2] Yoichi Nakai,[2] Hiroshi Tanaka,[1] and Yasunori Yamazaki[2]

[1] Department of Physics, Sophia University, Tokyo 102-8554, Japan
[2] Atomic Physics Laboratory, RIKEN Saitama 351-0198, Japan

Received July 31, 2000; accepted October 16, 2000

PACS ref: 34.50.-s

Abstract

Angular distribution of C^{2+} ions produced in $C^{4+}(1s^2) + He \rightarrow C^{2+}(1s^22s^2) + He^{2+}$ at collision energy of 270 and 470 eV are presented. Measurements have been carried out with an experimental setup for the state selective differential cross section measurements of electron capture processes which utilizes the 14.5 GHz Caprice Electron Cyclotron Resonance (ECR) ion source at RIKEN. It is found that results of calculations based on the potential, which was obtained from the previous experimental results at 1520 eV, do not reproduce the present experimental results at 270 and 470 eV.

1. Introduction

The study of multi-electron capture processes in highly charged ion (HCI)-atom collisions has been the subject of a number of experimental and theoretical investigations. Such informations are important for applications in many fields, e.g., astrophysics, fusion research, atmospheric science, and plasma diagnostics. Angular differential cross section measurements provide information on interaction potential curves, which are essential in the detailed understanding of HCI-atom interaction. Measurements at very slow collisions are of great interest because the angular differential cross sections are more sensitive to the shapes of interaction potential curves as the collision energy becomes lower. However, since difficulties arise in producing very slow and well-collimated HCI beams, experimental studies for very slow collisions between HCI and atoms have been limited.

Electron capture processes in C^{4+}–He collision system is one of the simple examples of HCI-atoms collision system, in which double-electron capture process occur. Previous total cross section measurements and theoretical calculations have shown that the double-electron capture process $C^{4+}(1s^2) + He \rightarrow C^{2+}(1s^22s^2) + He^{2+}$ is the most dominant process at sufficiently low energy [1,2]. However, angular differential cross section measurements for this system are scarce. The only available differential cross sections have been measured at collision energy of 1520 eV by Tunnell and Cocke reported in Barany *et al.* [3]. Barany *et al.* have also determined the potential curves of this system within the two-state curve crossing model [3]. Recently, Boyd *et al.* have improved the potential curves and reproduced much better differential cross sections [4]. Tan *et al.* have approached this system through a quantum two-channel molecular orbital close-coupling expansion method and well reproduced the experimental differential cross sections at 1520 eV [5]. All of these studies on $C^{4+}(1s^2) + He \rightarrow C^{2+}(1s^22s^2) + He^{2+}$ process have refered the differential cross section at 1520 eV of Tunnell and Cocke.

Recently, we have developed a crossed-beam experimental setup for angle resolved energy gain spectroscopy in very slow collisions [6]. Here we present angular distribution of C^{2+} ions produced in $C^{4+}(1s^2) + He \rightarrow C^{2+}(1s^22s^2) + He^{2+}$ at collision energies of 270 and 470 eV.

2. Experiment

The experiment was carried out utilizing the ion beam from the 14.5 GHz Caprice Electron Cyclotron Resonance ion source at RIKEN [6]. Briefly, HCI produced in the ion source are extracted at 2 keV/q and then decelerated to a beam energy of about 300 eV/q by a deceleration lens and introduced into the collision chamber which contains beam energy selector, an effusive target, and scattering ion analyzer. The energy of ions is selected by the energy selector and intersects with the target gas beam at right angle. Scattered ions are analyzed by an energy analyzer. The ion beam energy selector consists of entrance lenses, two sets of 40 mm radius hemispherical electrostatic analyzers, and an exit lens. The ion beam of 300eV/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 focused to the interaction region by an 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 is set on the turntable and can monitor the beam current by rotating the turntable. The typical current and energy resolution of the energy selected ion beam at 470 eV is 200 pA and 0.75 eV/q, respectively. The angular resolution of the scattering ion analyzer is estimated as 1° at 470 eV and 1.8° at 270 eV.

3. Results and discussion

Energy gain spectra obtained in the present measurement showed that $C^{4+}(1s^2) + He \rightarrow C^{2+}(1s^22s^2) + He^{2+}$ is the dominant process and the other processes are very weak. Figure 1 represents the angular distribution of C^{2+} ions produced in the $C^{4+}(1s^2) + He \rightarrow C^{2+}(1s^22s^2) + He^{2+}$ at collision energies of 270 and 470 eV. The angular distribution of C^{2+} shows a broad peak at 2.8° at 470 eV and 4.5° at 270 eV. The scattering intensity falls off toward 0° at both

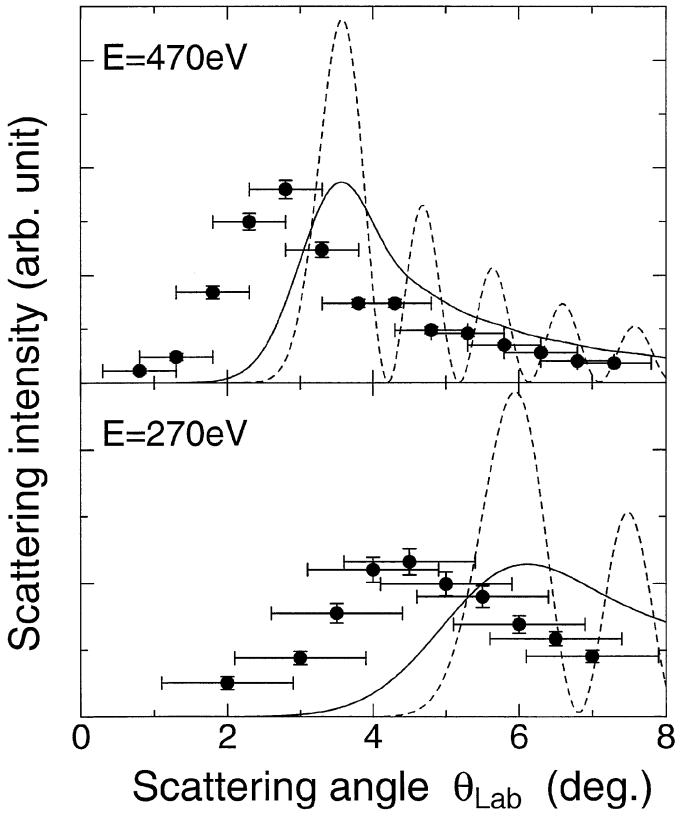

Fig. 1. Angular distribution of C^{2+} ions produced in $C^{4+}(1s^2)$ + He → $C^{2+}(1s^22s^2)$ + He^{2+} at collision energies of 270 and 470 eV (•). Calculated differential cross sections based on the potential curves of Boyd *et al.* [4] are shown together (– – –). Calculated differential cross sections convoluted with the experimental angular resolution spectra are also shown (——).

energies. We have calculated differential cross sections for $C^{4+}(1s^2)$ + He → $C^{2+}(1s^22s^2)$ + He^{2+} using the potential curves of Boyd *et al.* [4] at 470 and 270 eV. The calculated results of non-convoluted and convoluted curves are also shown in Fig. 1. Stueckelberg oscillations seen in the non-convoluted calculated results could not be resolved within the present experimental resolution. In Fig. 1, there is a clear difference of the peak positions between the experimental and calculated results. The peak positions of the calculated results are shifted to larger angles compared to the present experimental results. Smaller angle scatterings are due to scattering with large impact parameters in semiclassical picture, or large angular momenta in quantum-mechanical picture. The fact that scattering of the double electron capture process occur at smaller angles, the non-adiabatic transition for double electron capture occurs at larger internuclear distance than estimated in the model potentials of Boyd *et al.* [4]. Potential curves of Boyd *et al.* have been derived from the experimental results of Tunnell and Cocke at collision energy of 1520 eV. It is clear that the potential curves derived from experimental data at higher energies are not accurate enough. Measurements at very slow collisions are important to investigate the potential curves and interactions in the HCI-atom collisions.

First peaks are seen in both experimental and theoretical results, which shift to smaller angles with increasing collision energy. It should be noted that not enough is known about interaction potentials between HCI and atoms even in the case of extensively studied systems, such as the C^{4+}–He system. Experimental studies over a wide collision energy range, especially at very low energies, are needed to obtain further information on collisions between HCI and atoms or molecules.

References

1. Okuno, K. *et al.*, Phys. Rev. A **28**, 127 (1989).
2. Kimura, M. and Olson, R. E., J. Phys. B **17**, L713 (1984).
3. Barany, A. *et al.*, J. Phys. B **19**, L427 (1986).
4. Boyd, R., Ho, T.-S. and Rabitz, H., J. Chem. Phys. **106**, 6548 (1997).
5. Tan, J., Lin, C. D. and Kimura, M., J. Phys. B **20**, L91 (1987).
6. Kitajima, M. *et al.*, Physica Scripta **T80**, 377 (1999).